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Quality Through Integration of Production and Shop Floor Management by Discrete Event Simulation

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Abstract: *With the intention to integrate strategic and tactical decision making and develop the capability of plans and schedules reconfiguration and synchronization in a very short cycle time many firms have proceeded to the adoption of ERP and Advanced Planning and Scheduling (APS) technologies. The final goal is a purposeful scheduling system that guide in the right direction the current, high priority needs of the shop floor while remaining consistent with long-term production plans. The difference, and the power, of Discrete-Event Simulation (DES) is its ability to mimic dynamic manufacturing systems, consisting of complex structures, and many heterogeneous interacting components. This paper describes such an integrated system (ERP/APS/DES) and draw attention to the essential role of simulation based scheduling within it.*

Keywords: *simulation, shop floor management, production*

1. INTRODUCTION

The acceleration of supply chain pace in which customer orders are initiated and finished products are delivered is one of the basic problems manufacturers must compete with and conquer. Lessons learned recent years point out that the most universal challenge is in handling supply, operational and demand exceptions what leads to the apparently impossible mission of planning for the unplanned. The speed at which business system identify these exceptions and react in order to reduce its negative impact on overall system performance primarily depends on responsiveness of enterprise information system and its capability of handling the above three factors. The contemporary solution is integration of strategic and tactical decision making and, on production level, developing the capability for synchronization, modification and fine-tuning of production plans and schedules as quick as possible. Today, business systems try to achieve this goal through implementation of modern information technologies, specifically, through integration of Enterprise Resource Planning (ERP), Advanced Planning and Scheduling (APS) and Discrete Event Simulation (DES) software systems. Although an ideal ERP system should support the majority, if not all, of an enterprise's business processes, in the production area and, more specifically, in the production planning and scheduling field, there was a lack of satisfactory support. Since 2000 many well known vendors of ERP systems such as SAP, Oracle, Baan, PeopleSoft and others have included in its commercial solutions, up to this moment relatively independent APS systems with scheduling and certain, limited simulation capabilities and have recorded consistent growth in revenues. Simulation's scheduling role in such a system is key due in large part to its ability to faithfully replicate the real production ambiance and quickly react on unpredictable exceptions in the field. Its value is further enhanced when this solution is fully integrated with advanced planning function.

Despite this fact, even now are evident problems in successful implementation and utilization of this scheduling, simulation supported solutions in everyday production practice. The main reason, what this paper suggests, is that in the domain of production scheduling it is not possible to design generic model (simulation software) capable to encompass all possible production system types and, in as much detail as it is necessary, all the subtleties of the concrete manufacturing environment. This is reason why above simulation solutions suffer the loss of its prediction power that is crucial for handling exceptions.

In this framework the paper propose methodological design approach for Discrete Event Simulation solution. This approach gives verbal and mathematical problem description, builds ontology of problem domain, uses Extended Petri Nets and event graphs as activity cycle diagrams as modeling tools, in order to obtain faithful model which easily can be replicated in object oriented class and object hierarchy.

2. MERGING ERP, APS AND DES

Enterprise Resource Planning (ERP) systems are software solutions that provide seamless integration of all enterprise's business processes and information flows in the company attempting to synergise the resources of an organization. A typical ERP system is single software package that use multiple components of computer software and hardware to achieve mentioned integration. A distinctive constituents of most ERP systems is the use of a unified database, common data-processing and communications protocols to process and store data for the various system modules. ERP system combines all business applications together into a single, integrated software program that runs off a single database so that the various departments can more easily share information and communicate with each other.

Ideally, ERP delivers a single database that contains all data for the software modules or business application, which would include: Manufacturing (*Engineering, Bills of Material, Scheduling, Capacity, Workflow Management, Quality Control, Cost Management, Manufacturing Process, Manufacturing Projects, Manufacturing Flow*), Supply Chain Management (*Inventory, Order Entry, Purchasing, Product Configurator, Supply Chain Planning, Supplier Scheduling, Inspection of goods, Claim Processing, Commission Calculation*), Financials (*General Ledger, Cash Management, Accounts Payable, Accounts Receivable, Fixed Assets*), Projects (*Costing, Billing, Time and Expense, Activity Management*), Human Resources (*Human Resources, Payroll, Training, Time & Attendance, Benefits*), Customer Resources and Marketing (*Sales and Marketing, Commissions, Service, Customer Contact and Call Center support)* etc.

Planning and scheduling are closely related and are best done using the same or closely related tools like APS. Scheduling determines what is actually implemented in the process, while planning explores what is possible. Plans have little value if they are inaccurate and cannot be implemented because they do not consider important process requirements. As such a contemporary APS system should support both planning and scheduling. With this in mind an APS system can be defined as computer software with ability to rapidly and simultaneously plan and schedule customer demand while considering material and capacity constraints as well as to reconfigure synchronized plans and schedules in a very short cycle time. The potential to increase business performance such as on-time delivery, shorter cycle times, reduction in inventories and increased throughput with APS is enormous.

The available data suggests that the estimated improvement attributable to effective planning and scheduling is 5% to 15% as measured by a decrease in process costs (such as waste, changeover, inventory reduction) and/or increase in process throughput. In order to achieve this performance an APS system must be used in an effective business process whereby the data used is reasonably accurate and schedules and plans must be executed with reasonable precision. To achieve consistent results the planning and scheduling process must be repeated when business conditions change significantly. Simulation's scheduling role in such a APS system is key due in large part to its ability to faithfully replicate the real production ambiance and quickly react on unpredictable exceptions in the field. Its value is further enhanced when this solution is fully integrated with advanced planning function.

Despite this fact, even now are evident problems in successful implementation and utilization of this scheduling, simulation supported solutions in everyday production practice. The main reason, what this paper suggests, is that in the domain of production scheduling it is not possible to design generic model (simulation software) capable to encompass all possible production system types and, in as much detail as it is necessary, all the subtleties of the concrete manufacturing environment. This is reason why above simulation solutions suffer the loss of its prediction power that is crucial for handling exceptions.

Simulation software systems attempt to model or replicate complexity of real systems what result in complexity at analytical, design and technological level of software creation. This is reason why effective modeling is one of the most important and difficult steps in the development of reliable simulation software systems.

3. PLANNING AND SCHEDULING IN ERP/APS ENVIRONMENT

The computerized process of planning and scheduling in manufacturing have evolved from simplistic Material Requirements Planning systems to today's sophisticated Advanced Planning and Scheduling systems. While planning is concerned with the long-range determination of what needs to be manufactured, typically over a relatively long time period, scheduling is the task of deciding how that manufacturing is to be accomplished, usually over a relatively short time period. Simulation is well suited to the scheduling task since it can handle as much detail as is necessary to capture the subtleties of the manufacturing process. It is desirable for a simulation-based scheduling function to be integrated with an Enterprise Resource Planning system, which maintains the system data suitable for driving a simulation of the current system load and thereby producing a feasible schedule.

Modern Enterprise Resource Planning (ERP) systems contain all the data necessary for detailed production planning and scheduling. This includes product information, such as bills of material and routing of parts through the manufacturing process. It includes system information such as equipment, manpower, and shift schedules. It also includes status in formation such as the current order book, work in process, inventory levels, and released purchase orders. This is what is needed for an Advanced Planning and Scheduling (PS) function to determine how to efficiently plan a plant's operations and to replan quickly and accurately based on changing requirements.

The traditional Material Requirements Planning (MRP) computerized process in an ERP system concerns itself with determining the quantity of products to be made in a specified period of time. Initial informations are demand for final products in that period, the component products which compose that demand, and the lead time required to produce each component and final product. A major defect in such an approach, of course, is that limits on manufacturing capacity are not considered. Actual lead times usually vary considerably from the fixed lead times assumed by MRP when a system is highly utilized and dynamic. In order to determine whether or not an infinite capacity plan such as produced by MRP is actually feasible, simulation can be used to determine whether the start times generated by the plan will actually allow the manufacturing orders to be completed by their due dates. While simulation is capable of producing a highly realistic manufacturing schedule, the task of "correcting" the infeasibilities of an MRP plan in capacity-constrained environments is quite discouraging. Through the years the authors have been involved in many successful applications of such, but the data requirements to maintain a realistic model consistent with the plan and the business process expertise needed to effectively execute it have made these successes costly and difficult to perpetuate. What is needed is a better starting point from which to schedule - which leads to APS systems.

An APS system uses variants of the planning and scheduling approaches described above in an integrated way. A planner module which pays some attention to capacity constraints produces a "schedulable" plan. This plan then feeds a scheduler module, which produces a detailed list of operations showing how capacity will be used and returns this information to the planning function for use in the next planning period.

The data regarding current and planned operations can also be used to provide realistic estimates of the ability to meet a new customer order request. Function of an APS system is to coordinate material and capacity planning in order to fulfill the demands being placed on the manufacturing system. The role of planning in APS is to determine what demands on the production system will be met over a given planning horizon. The input to the planning process includes information on manufacturing capacity and demand data. Demands may be of several types: customer orders, forecasts, transfer orders (i.e., orders from other plants), released jobs, or replenishments of safety stock. Manufacturing system data includes bills of material, workcenter availability, part routings through workcenters, and inventory (both on-hand and scheduled for delivery). The output from the planning process is a feasible plan, which provides release and completion times for every demand. Like MRP before it, APS takes into account the availability of materials. Unlike MRP, it also takes into account the capacity of workcenters to process the material and satisfy demands. This planning process is order-centric, focusing on the demand for end items and determining how much demand can be met in a given time period. Exactly how that demand will be met, in terms of specific assignments of jobs to workcenters and their sequencing, is left to the scheduling function. It is in fact often desirable for a plan to be somewhat tentative, since it covers a planning horizon subject to disruptions. Forecasts may not be accurate. Deliveries may be delayed. Equipment may fail. Unexpected rush orders may be received.

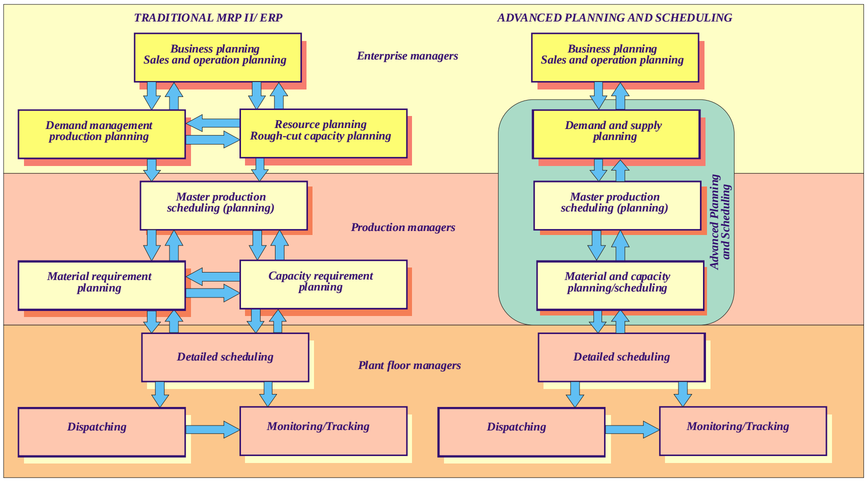

Figure 1. Traditional MRP and Advanced Planning and Scheduling

Therefore planning is not expected to be highly detailed. Individual machines may be aggregated into a workcenter with no determination of which will be used by a specific order. Setup times may be averaged since sequencing at this time is premature. Buffer times may be defined, especially prior to processing on bottleneck machines, to allow for possible disruptions. The end result is a “schedulable” plan. The result is an accurate representation of what to expect on the shop floor in the immediate future. While the planner module typically considers demand on the system over a few weeks or months, the scheduler module will typically work with a much shorter time frame such as a shift, a day, or a week.

The usefulness of a detailed schedule degenerates quickly as time passes, since disruptions on the shop floor or changes to the order mix may require significant adjustments. For this reason a simulation used for generating a schedule is usually deterministic. If a random event occurs (i.e., machine failure, arrival of a rush order, or a missed delivery date by a supplier) then a new schedule can quickly be generated and its impact evaluated. Which specific machine will it be allocated at a given operation? How long will it have to wait for other orders at the same machine? What will the setup time be? Answers to these questions cannot be planned ahead of time, but rather unfold dynamically as orders move through the system over time. The answer proposed in this paper is design of discrete event simulation software that fully replicate dynamic shop floor environment.

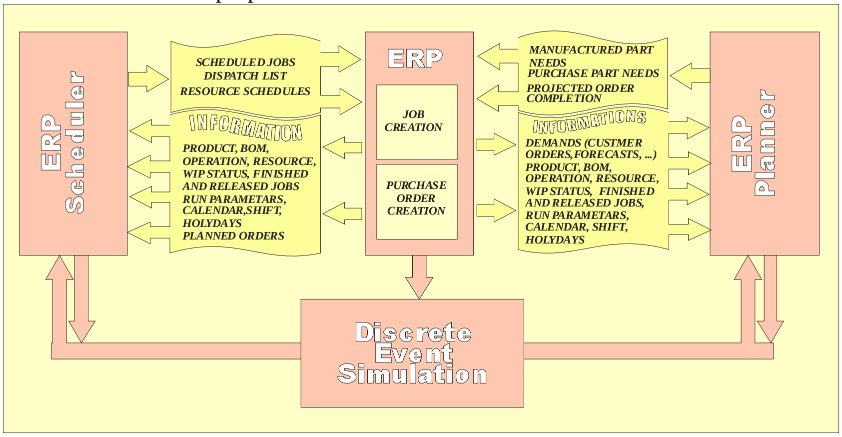

Figure 2. Closing the Planner/Scheduler Loop with simulation

4. DESIGN METHODOLOGY

Simulation software systems attempt to model or replicate complexity of real systems what result in complexity at analytical, design and technological level of software creation. This is reason why effective modeling is one of the most important and difficult steps in the development of reliable simulation software systems. At this point, the paper highlights inevitability of knowledge transfer between three knowledge domains. First domain is knowledge about the business processes, second knowledge about software development and implementation and third from academic community research (Operational Research and Management Science) about problem domain. Integration and overlapping of mentioned specialized fields of knowledge for the solution of the common task result in useful and functional simulation model.In this framework the paper propose methodological design approach for Discrete Event Simulation solution (*Figure 3.*).

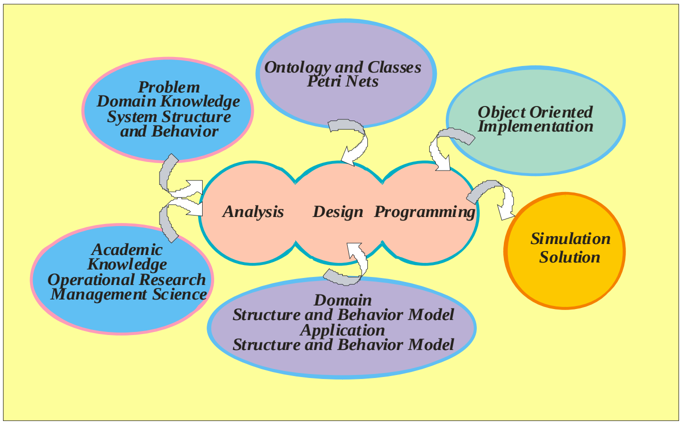

Figure 3. Proposed methodology

This approach gives verbal and mathematical problem description, builds ontology of problem domain, uses Extended Petri Nets and event graphs as activity cycle

diagrams as modeling tools, in order to obtain faithful model which easily can be replicated in object oriented class and object hierarchy.
Some of the basic ontology concepts of the proposed methodology are:
Order (*Order_code, Product_code, Quantity, Due_date, Order_status*),
Product (*Product_code, Routing_code*),
Activity (*Activity_code, Product_code, Activity_duration, Start_time, End_time, Workcenter_code, Activity_range, Activity_status*),
Routing (*Routing_code, Activity_code, Activity_range*),
Work center (*Workcenter_code, Activity_code, Setup_time, Workcenter_ capacity, Workcenter_ status*)

This approach uses Extended Petri Nets (EPN) like graphical and mathematical modeling tools that can be used to perform static and dynamic modeling of existing manufacturing systems. Manufacturing systems are characterized as being concurrent, asynchronous, distributed, parallel, non-deterministic, and stochastic and can be effectively modeled and analyzed by using Petri Nets.

A place—denoted by a circle—represents a condition such as input data, input signal, resource, condition, or buffer. A transition—denoted by a solid bar— represents an event such as a computation step, task, or activity. Arcs are utilized to connect places and transitions in a Petri Net. Arcs are directed (depicted by arrows) and are either drawn from a place to a transition or from a transition to a place. Arcs in a Petri Net have multiplicity. The fourth element called the token and denoted by a solid circle provides the dynamic simulation capabilities to Petri Nets. Tokens are initialized

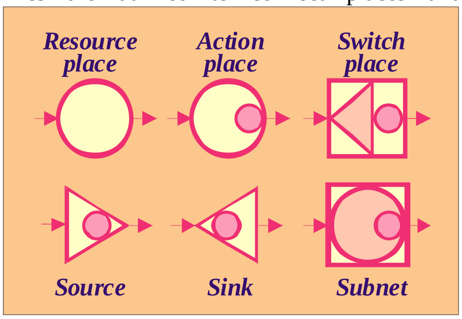

Figure 4: EPN symbols

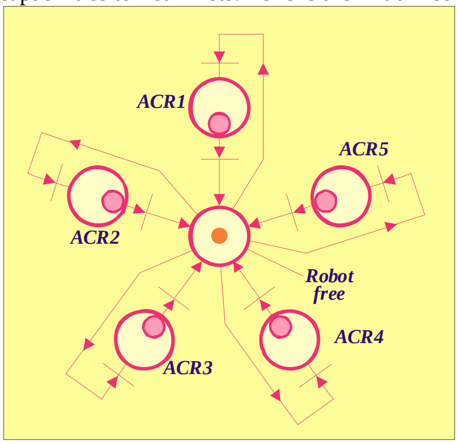

Figure 5: AC diagrams

at a place and a place may contain zero or more tokens. With the use of tokens the modeler can provide the necessary dynamic links between the places (conditions) and transitions (tasks or events) in a Petri Net. The concept of transition “firing” allows a Petri Net to simulate the dynamic behavior of a system. In their original form transition firing in Petri Nets was instantaneous. but, time is incorporated into Extended Petri Nets. This results in a timed transition that will have the ability to model tasks or activities.

Ontology concepts are the base for object oriented class and object hierarchy design and EPN approach helps modeling of manufacturing system and software system dynamics. Realized simulation tool has a number of unique characteristics such as interactive Gantt chart display, specialized reports, integration with external data sources, specialized scheduling rules, concurrent graphical animation etc. The quality of the generated schedule is largely determined by the scheduling rules that are specified for selecting resources and operations. A complete set of rules must be incorporated into the simulation tool to support a specific range of given manufacturing identity. Figures 6 and 7 presents screens of simulation solutions developed for different manufacturing environments.

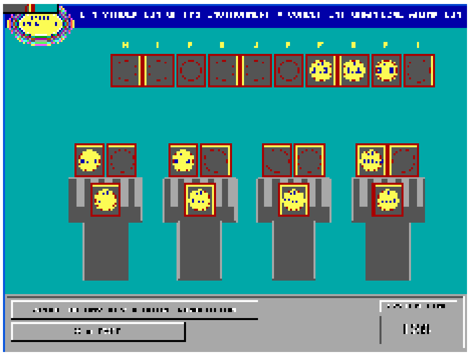

Figure 6. Concurrent graphical animation

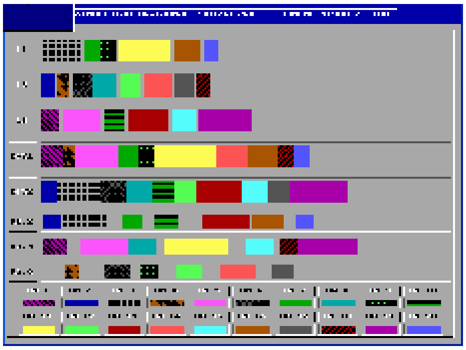

Figure 7. Gantt chart

5. CONCLUSIONS

A dynamic simulation-based approach to production planning and scheduling has distinct advantages over commonly used static approaches. The most vital of these is the direct and dynamic link to the shop floor. Simulation has the ability to accurately model detailed system operating rules and evaluate them over time what is invaluable in ensuring that a plan or schedule is feasible on the shop floor level.
Sudden changes in employee availability, machine breakdown, extra orders, order expediting requirements, etc. can be reacted to quickly using simulation to generate a new and efficient schedule within minutes. It is difficult to assess the feasibility of schedules generated by static methods other than by actually executing it in real time on the shop floor. This limits the opportunity to anticipate inefficient or unfeasible plans in advance. Solutions can be fully customized according to the current planning and scheduling rules and incorporated in modern ERP/APS environmet. Integration of planning and scheduling with simulation bridge the gap between tactical and strategic management information systems resulting in a more coordinated production planning and execution.

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