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ANALYSIS AND ENHANCEMENT OF PLANNING AND SCHEDULING APPLICATIONS IN A DISTRIBUTED SIMULATION TESTBED

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ABSTRACT

Planning and scheduling applications and operations simulation models jointly represent the manufacturing activities of an enterprise. This paper relates to a framework that enables integration of both into a unified model and allows improvement of their performance with discrete event simulation (DES) technology. The High Level Architecture, which is the IEEE standard for interoperability of simulations, forms the backbone of this framework in which business applications can be re-used with operations simulation models to generate an integrated simulation model. This enables a company to optimise not only operational processes such as shop floor or warehouse operations but also business processes such as planning, order management and scheduling through simulation using the same software infrastructure. A case study to demonstrate the feasibility of this framework is included and ongoing work on implementation of this framework in an industrial environment is presented.

1 INTRODUCTION AND MOTIVATION

The most important competitive advantage for a corporation today is the speed, cost and efficiency at which changes are executed. On many occasions, improvements in operations and business are often discarded at the design table as their implementation involves high cost or the advantage might be lost by the time the changes are made. Further, the effects of business changes on operations and vice-versa are investigated by either employing external consultants or by assigning internal resources but seldom involve proper validation of the findings through techniques like simulation.

To tackle this challenge, we have developed a novel framework for business process optimisation that provides opportunities to improve business processes and resulting applications by testing them in a simulation environment and also overcomes some of the major limitations of today's simulation approaches. This framework is described in more detail in Lendermann et al. (2003a). Such high-fidelity simulation environments in which demand change scenarios, capable-to-promise procedures, and new scheduling approaches can be studied are needed. These testbeds allow experimentation and performance improvements that otherwise would not be possible, reduce the risk of transition, and ultimately enable faster deployment and technology adoption.

In this paper, we illustrate how this framework can be used through a case study consisting of a manufacturing operations simulation model and two business applications. We also present ongoing work on implementation of this framework in an industrial environment. In Section 2 we discuss some challenges faced in applying discrete event simulation (DES) in a demand-driven environment. Section 3 describes the framework in brief and presents some technical issues associated in its realisation. We present a manufacturing case study in Section 4. Finally, Section 5 describes the ongoing work in implementation of the framework in a company engaged in semiconductor backend manufacturing.

2 CHALLENGES FOR APPLYING DISCRETE EVENT SIMULATION IN A DEMAND-DRIVEN ENVIRONMENT

DES has been established as a powerful technology to tackle a wide range of strategic, tactical and operational challenges in manufacturing, logistics, and supply chain management. In today's fast changing business environment, simulation technology needs to be highly flexible and scalable. It must be able to address the entire cycle from simulation modeling, model validation, configuration of simulation runs, data input, execution of simulation, output data analysis, optimization, and implementation of optimized business execution models to model maintenance. The ever-reducing time window to perform the above activities also poses significant challenges to the technology.

In most of the conventional approaches, simulation models typically represent the operational execution on the shopfloor or in a warehouse, and simulations are driven by simulated release of materials into the system. Such input releases, however, are difficult to generate in today's pull-environments that are driven by customer demand scenarios with high variability and frequent phase-in of new products. In such an environment, input releases are the result of a complex translation from customer demand into material quantities to be released into and moved within the system at pre-specified times. Also, the uncertainties in the execution of the production steps causes the schedules to change and demand rescheduling from time to time based on the latest state of the system. Various techniques to handle such cases are provided in literature. (Yeung, Wong and Ma 1998; Guide and Srivastava 2000; Loh and Saad 2003) Consequently, in a demand-driven business world, simulation models can be made much more realistic if the process of translating demand into input release (i.e. planning and order management processes) and the complex interdependencies between the business processes and the operational execution are fully incorporated into the model.

Today, simulation models address this issue to a limited extent since often they can generally incorporate a relatively crude abstraction of the associated planning processes only. A more straightforward way of translating customer demand into feasible input release rates is to integrate the underlying planning and customer order management system with the simulation (Lendermann, Gan and McGinnis 2001).

3 OVERVIEW AND TECHNICAL FEASIBILITY OF THE FRAMEWORK

3.1 Limitations of Using Business Applications for Business Re-Engineering

Business applications such as Enterprise Resource Planning (ERP) and Advanced Planning and Scheduling (APS) systems are tools to run a business rather than to re-engineer and optimize it. They are also not able to address all aspects of the complex interdependencies between operational execution and variability on the shopfloor. A conventional solution to overcome this problem is to translate the processes of the business application into a simulation model, using a commercial simulation tool. However, this leads to a cumbersome translation of one computer representation of the business model into another. It is possible to analyse different business scenarios and optimise the underlying models based on the results using such an approach, but implementation of suggested changes in the corresponding business applications would remain cumbersome.

An alternative would be to use the business application within the simulation model. This poses a problem as most business applications by nature are designed to run in real time whereas the simulation progresses based on the simulation clock. A novel approach to overcome this problem would be to make the business application compliant with DES.

A replicated copy of the application can then be used within the simulation model. Thus, ultimately the same piece of software can be used to run the business in the real world and to represent the business operations in the simulation world for re-engineering and optimization of the overall business.

3.2 A Framework to Achieve Integration by Leveraging Distributed Simulation Technology

The High Level Architecture (HLA) has become the standard architecture for simulation reuse and interoperability (Kuhl, Weatherly and Dahmann 1999). Distributed simulation technology based on HLA allows smaller models of entities to connect with each other in a virtual environment and perform a simulation. The entities are known as federates and the virtual model they create by connecting to each other is called a federation. Federates are able to communicate and synchronize using services provided by the Run-Time Infrastructure (RTI). Application of distributed simulation technology for supply chain management has been pioneered for example by the Production and Logistics Planning Group at Singapore Institute of Manufacturing Technology (SIMTech) in collaboration with Nanyang Technological University (Gan et al. 2000) and Georgia Institute of Technology, (Lendermann et al. 2003b) and also by the Manufacturing Engineering Laboratory of National Institute of Standard and Technology. (McLean and Riddick 2000). Currently, the HLA is emerging as a standard (IEEE standard 1516) for Plug & Play of simulation-based decision support components for manufacturing and logistics systems.

A DES-compliant application can thus be wrapped with a federate and integrated into a distributed simulation. This federate is known as an 'application proxy' federate as it represents the application in the integrated simulation model (Figure 1). Synchronization of real time and simulation time can be achieved by using the time management services of the RTI. A few pre-requisites are needed for such integration:

- All the relevant manufacturing, logistics and decision-making events not triggered by the application itself need to be emulated.
- The application has to be made DES-compliant (i.e. it can be synchronized with the simulation model).

- The capability to configure various scenarios on the fly and perform multiple simulations to analyse the performance of the business operations and changes made in it has to be created.

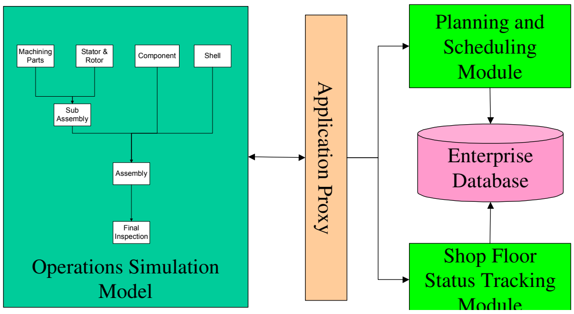

Figure 1: Overall Architecture of the Simulation Testbed

Details on achieving the above mentioned prerequisites can be found in Lendermann et al. (2003a).

For overall performance optimisation all processes that are related to operational execution have to be included into simulation such as:

- Process customer order (very critical in an environment where the available-to-promise procedure stretches across several IT systems),
- (Re-)generate execution plan/schedule,
- Execute production.
- Examples of business process changes that one might want to simulate, assess and implement with such a technology are:
- Change elements and/or sequence of queries in available-to-promise process,
- Change scheduling rules in production management/control,
- Temporarily change resource structure,
- Outsource parts of the performance process.

4 MANUFACTURING CASE STUDY

For the purpose of proof-of-concept we developed a simulation model based on the assembly process of a refrigerator compressor manufacturer. This model was then used to analyze demand scenarios and scheduling policies.

4.1 Integrated Simulation Model

The integrated simulation consists of a manufacturing operations model, an application proxy, a scheduling module, and a tracking module (Figure 1). Each of the components is explained in the following sub-sections.

4.1.1 Manufacturing Operations Simulation Model

The process flow of the manufacturer is also shown in Figure 1 and is encapsulated in the model. The production capacity is dimensioned in such a way that the plant is capable of producing a quantity of about 400 compressors per hour, of a single product type and without setup time. This throughput estimate is used to design the types of loading condition for the experiments to be conducted.

The number of machines in each work center family is variable. All machines have their own queues and each lot has a pre-assigned route to follow. A lot completed by a machine is directly sent to the queue of the next machine in the lot's route. Work centers such as Sub-Assembly and Assembly are driven by the output from Machining Parts, Stator & Rotor, Shell and Component. Sub-Assembly or the Assembly parts are produced when the required quantities of each subpart (based on the BOM) are available. Setup times are not imposed here. For multiple-product scenarios, setup times are imposed for the four work center families Machining Parts, Stator & Rotor, Shell and Component whenever there is a switch in part type to be processed.

The above model is developed based on HLA standards. Each machine line is modeled as a federate. The operations simulation model thus contains a total of 13 federates (see Table 1).

Table 1: Machine Groups Modeled as Federates

Family	Machining Parts	Components	Shell	Stator & Rotor	Sub-assembly	Assembly	Final Inspection
Number	2	3	3	2	1	1	1

4.1.2 Application Proxy

The application proxy connects the scheduling and the tracking modules with the operations simulation. The application proxy triggers the module based on the needs in the simulation and passes the output from the modules back in to the simulation. Being a federate itself, the application proxy can seamlessly integrate with the operations model and thus assure that time synchronization is enforced on the applications.

4.1.3 Scheduling Module

The scheduling module is developed as a stand-alone tool for optimal work allocation based on order data in the database. Scheduling policies are pre-defined and configured when the module is invoked. Upon invocation, the scheduling module retrieves data from a centrally managed database (SQL 2000) to perform scheduling. The data includes static as well as dynamic product and resource information. Product information comprises the details of orders to be scheduled, routings and BOM. Resource information consists of resource family, process information, setup details, and shop floor status.

The actual scheduling process is initiated by creating an empty time line for each resource in the system. The time line holds vital scheduling information such as job identity, start and end times that are related to the current and planned activities (or operations) of the resource. Examples of activities are load, setup, process, unload, down, etc. These activities do not overlap each other on the time lines. The dynamic status of the shop floor is used to populate the current activities on the time lines. Planned activities are inserted into the time lines during the scheduling process.

There are two pre-defined scheduling policies in the module-product-based and order-based. The former groups the same product types together to minimize setup (i.e. sort by product type and then due date) while the latter ranks the products based on the due date (i.e. sort by due date and then product type) to achieve better on-time delivery. After sorting, the products are scheduled one by one following the rank, from the highest to the lowest priority, into the time lines. In our implementation, one or more products form a single customer order, and all the products of an order have the same due date.

As each product is made up of many levels of subassemblies and parts and each part consist of many operation steps, the parts' operations have to be scheduled before the actual product's operations. To schedule a product, the BOM of the product is examined to identify all parts that are required to make the product, and these parts are ranked based on levels. The lowest level parts are scheduled first, followed by higher-level parts.

Each operation in the routing of the part is inserted into the time line of the resource that gave the earliest possible start time from among the group of eligible resources. Other activities such as setup and load are checked and incorporated before the operation is inserted into the time line. Setup of a succeeding operation in a route can begin before the preceding operation is completed, as parts are not required to be present during setup.

When all orders are scheduled into the time lines, a schedule for the orders is generated and written to a database. This schedule is used and executed by shop floor.

Based on the need in the simulation, the application proxy triggers the scheduling module and passes the relevant configuration information to it. It then captures the schedule from the module, converts it into input releases of parts and passes it into the simulation maintaining the time sequence of events. The information passed to the different machines includes the entire path that is to be followed to produce a particular product under a particular order. Figure 2 provides an overview of the scheduling process.

4.1.4 Tracking Module

The tracking module is essentially a shop floor status tracking system user by operators of the various machines. The information entered into the tracking system includes the completion of regular jobs and the work-in-progress (WIP) reported at the end of a day. The tracking module records all this information into the main database.

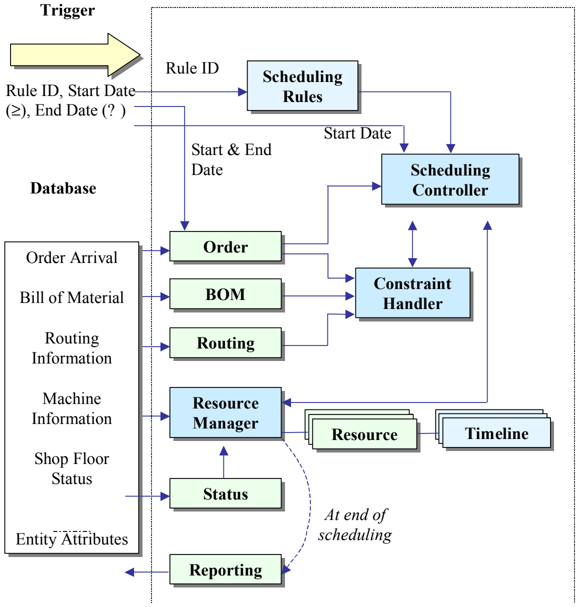

Figure 2: Scheduling Process

In the integrated model, the application proxy receives task completion information from the operations simulation and in turn triggers the tracking module and passes the information to it. The application proxy thus, in this case, mimics the worker on the shop floor.

4.1.5 Data Flow and Control of the Simulation Model

The simulation is bootstrapped and eventually controlled by the application proxy. The data flow from a database centric view is shown in Figure 3. The execution module in the figure represents the operations model and the application proxy.

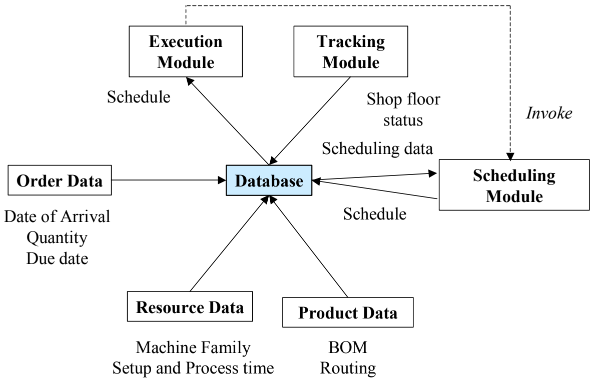

Figure 3: Database-Centric View of the System

4.2 Scenarios Analyzed

Two order profiles were used for simulating the order arrival. Orders consisted of multiple products (X, Y, Z, with same BOM structure) and quantities. One profile (A) comprises orders with similar amount of quantities of each product. The other profile (B) exhibits large differences in amounts of different products in the same order (Table 2a and 2b).

Table 2a: Profile A with Balanced Order Quantities

Order Number	Units of X	Units of Y	Units of Z
10001	200	230	-
10002	80	-	70
10003	150	130	140
10004	-	500	450
10005	300	-	-

Table 2b: Profile B with Skewed Order Quantities

Order Number	Units of X	Units of Y	Units of Z
10001	100	330	-
10002	30	-	120
10003	400	10	10
10004	20	400	530
10005	180	120	-

The scheduling module sequenced the lots for the four parts (Machining Parts, Stator & Rotor, Components and Shell) according to policies described in Section 4.1.3. The two predefined scheduling policies combined with the two different profiles generated four scenarios to be studied (Table 3). The choice of right policy for a particular order profile is not intuitive and cannot be accurately analyzed using a spreadsheet simulation.

Table 3: Scenarios Analyzed

	Scheduling Policy	Order Profile
Scenario 1	Product-based	Balanced Quantities
Scenario 2	Order-based	Balanced Quantities
Scenario 3	Product-based	Skewed Quantities
Scenario 4	Order-based	Skewed Quantities

The plant operated for 24 hours a day with no planned and unplanned downtime such as shift breaks, preventive maintenance and machine breakdown. The plant was capable of producing a maximum of 9600 units per day and 67200 units per week. Since plant was loaded with 3 different product types, additional setup times reduced the efficiency of the plant. Assuming the plant only operated at 80% efficiency as a result of this, we generated order arrivals averaging at 7600 units per week. This was to ensure that the plant was not overloaded with the number of backorders growing with time.

The total number of days simulated were 180. The total number of orders for each scenario was 1500 and the data analyzed represents the central 50% of the orders.

4.3 Experimental Results

Five runs were performed for each scenario. The total amount ordered in a particular order number was the same across the two order profiles. The lead-times of those orders could thus be compared with each other. The difference between the lead-times of corresponding orders and scenarios were plotted. The results are shown in Figure 4.

It was concluded that the order-based scheduling policy is more effective than the product-based scheduling policy, irrespective on the order profile the manufacturing operations was exposed to.

The integrated simulation was executed on a cluster of 10 computers (Pentium 4, 2 GHz, 256MB RAM). It took approximately 2 hours to complete. Some scenarios were run on a 4-processor server (Pentium 2 Xeon, 800MHz, 2GB RAM) and the simulation took around 5-6 hours to complete.

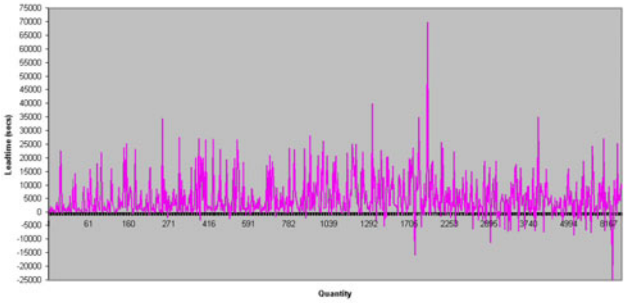

Figure 4a: Leadtime Difference Between Scenarios 1 and 2

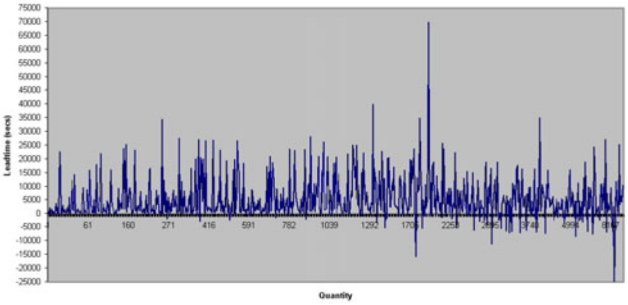

Figure 4b: Leadtime Difference Between Scenarios 3 and 4

5 APPLICATION OF THE FRAMEWORK IN AN INDUSTRIAL ENVIRONMENT

Ongoing work aims to apply the described framework in an industrial context. The industrial company is one of the world's leading manufacturers of integrated circuits, covering the entire range from commodity and application-specific standard products to customer-specific products.

Presently, capacity planning is done in weekly buckets, and incoming customer orders are checked "capable-to-promise" against these weekly buckets. Consequently, delivery of an order to a customer on a specific date can be ensured only if they are planned for in the previous planning week already. As a result, the overall leadtime (from customer order processing to final delivery) presently stretches to more than six weeks. This includes 5 days processing time for customer orders plus 28 days order fulfilment leadtime OFLT (7+7 days planning & preparation time + 14 days manufacturing cycle time) plus 3 days for shipment to distribution centre (DC) plus 2 days for shipment from DC to customer plus 6 days because of weekly planning buckets.

To stay at the competitive edge, significant reduction of this overall leadtime is considered indispensable. An important contribution to such leadtime reduction can be made through moving from weekly to daily planning buckets. This is to be accomplished in parallel to the implementation of a new scheduling system (NSS) for assembly and test operations.

At the same time, high variability on the shopfloor has significant impact on the schedule adherence. In this setting, the establishment of an appropriate balance between the variability of the production lines and the flexibility/sophistication of the scheduling process is considered essential.

At present the company uses two different scheduling systems – Scheduling System for Assembly (SSA) and Scheduling System for Test (SST), for the assembly and test operations respectively. The company has existing simulation models in WITNESS which model the assembly and the test processes separately. These models are presently used on an operational level to study operational scenarios in individual processes.

The intended study thus has three stages. First stage is the formation of two integrated simulation models which links SSA and SST to the corresponding simulation models. The two resulting simulation models are then further integrated to provide the simulation model for the entire company. Integration of the simulation model components and the scheduling system is accomplished through the Runtime-Infrastructure of the High-Level Architecture (HLA-RTI). The integration involves development of the middleware incorporated in the application proxy that is capable of synchronising the time progress of simulation model components, transforming simulation software internal representation (events or objects/entities) to RTI messages for sending and introducing RTI messages to simulation software internal representation upon receiving them. A federation object model (FOM), including events and objects/entities supported by the simulation software, is defined as a baseline for the simulation.

The scheduling system is also integrated into the simulation testbed through the HLA-RTI middleware. The status of the simulation testbed (WIP) is extracted on a regular basis (depending on the scheduling frequency) and sent as input to the scheduling system through the middleware. The output schedule for the assembly operations produced by the scheduling system is fed back into the simulation testbed.

The second stage involves conducting studies on this model for the new scheduling policy of moving from weekly planning buckets to daily planning buckets. After accomplishing this it is possible to simulate the execution of the Assembly and Test operations for several week on a rolling horizon basis, based on schedules generated by SSA and SST every week (always taking account the latest WIP status from the shopfloor and new demand information) and also observe deviations from the schedule that are caused by additional variability. Analysis of the interdependency between the granularity of planning buckets and operational performance and optimization of the interface to the planning level is performed here. Interdependencies between lot sizing heuristics and operational performance are also studied.

The third stage involves replacing SSA and SST in the simulation model with a configured copy of NSS which can handle both the assembly and test facility. The new system will be studied for effectiveness as well as be tweaked based on the simulation studies performed. The version of NSS for final deployment would be based on the configuration of the system used in the simulation.

6 CONCLUSIONS

In the above work we presented a framework for analysis and enhancement of business applications in a simulation test-bed. The prototype exhibited this on a rather small scale. We performed simulation studies and used the scheduling and tracking applications as part of the integrated simulation model. Such a technique can be leveraged heavily by applications that can be reconfigured in very short durations using very small amount of resources. Examples of such applications are framework-based applications (Lendermann et al. 2003a) and applications based on business model management (Terai et al. 2002).

We also outlined ongoing work to create a more complex case study by using commercial business applications. This is the first step to industrial adoption. Simulation needs to be fully integrated into the decision-making process of an enterprise and the above-mentioned framework is one of the steps towards that. Details of this work will be made available in future publications.

Another issue that will come up with such integration is the need for high computation resources. We are presently working on execution of such integrated simulation systems on a grid platform.

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