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A Framework for Industrial Systems Modeling and Simulation

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Abstract

This paper describes the development of a software framework for industrial systems modeling and simulation. The framework provides a mechanism for investigating changes to industrial systems in a manner which minimizes the effort and computational power needed to develop focused simulations. The architecture and it's component parts are described.

1. Introduction

To successfully compete in a global market, manufacturing production systems are being forced to reduce time to market and to provide improved responsiveness to changes in market conditions. The organizations that comprise the business links in the production system must constantly make tradeoffs between time and cost in order to achieve a competitive but quick response to consumer demand. Due to the inherent uncertainty of consumer demand, these tradeoffs are, by definition, made with incomplete information and can incur significant financial and competitive risk to the organization.

Partnerships between organizations are a mechanism for increasing the information in the decision making process by combining information from the two partners. Partnerships are inherently difficult to implement due to trust issues. A mechanism for investigating and validating the mutual benefit to partnering would be useful in designing and implementing partnerships.

Partnerships and knowledge sharing between organizations may be only the beginning of the knowledge sharing needed to optimize the production system. It is possible that information sharing extended to all entities involved in the production system without respect to their business partner would markedly improve the system. Understanding the production system, and the critical information that should be shared to optimize the time to market and increase responsiveness to product change is the challenge that faces many industrial systems today.

This paper describes the initial development of a software framework for industrial systems modeling and simulation. We describe the architecture and it's component parts. Our effort to build an object-oriented simulation builder that allows the user to select and assemble a focused industry simulation that captures their particular environment is described. Our experience to date with this architecture and the results of our initial studies on the dynamics of a supply chain are discussed.

The goal of these efforts is to provide a mechanism for evaluating business structure and business process changes in an industrial system. Examples include: examining the effect of increased availability of information throughout the system through, or the impact of a strategic business decision to invest in new plant facilities and its effect on the distribution network.

2. Framework

Industrial systems analysis involves the time consuming process of capturing an understanding of an industry system at a level of detail that will capture the dynamics of time and cost but not yield an unwieldy model so large and complex that will be rendered useless and static. In addition, a crucial design issue encountered in this process is choosing a representation to capture the knowledge that will not limit the final use of the knowledge. This means that a flexible framework must be designed that can handle many different types of information.

Modeling the entire production system as a whole would be an enormous effort and require large amounts of compute resources for simulation. Our solution is to design a framework to enable the development of focused simulations of the production system. A framework defines the overall architecture of the system and focuses on design reuse as well as code reuse [Gamma94]. Our framework partitions the system into layers which allow developers to concentrate on specific issues. By carefully choosing the partitioning a complex system can be successfully modeled and simulated.

Frameworks are built by analyzing a number of specific problems or areas within a system, identifying reusable components, and then building those components [Johnston91]. Preliminary analyses of specific problems and an analysis of a specific industrial system have led to the decomposition of our system into three layers; production processes, business processes, and business decisions. The division of the industrial system into these layers allows us to successfully model and build focused simulations for specific analyses. These simulations may span one or more system sectors.

2.1 Production Process Layer

The production process layer models the physical activities that must occur to transform raw material to finished product. This layer is composed of the physical processes and physical entities that exist in the system.

The physical processes model the activities in the system that incur time and cost. Shipping and inspection are examples of physical processes. The physical entities model the real world things that participate in the processes and the real world locations of the processes. Product is a model of the real world product e.g. a widget. Store or facility are also examples of a physical entity. The attributes of a store would include its location, which affect the time and cost of transportation to and from the store. The production process model includes transportation, inspections and manufacturing processes. Figure 1 shows the division between physical processes and physical entities.

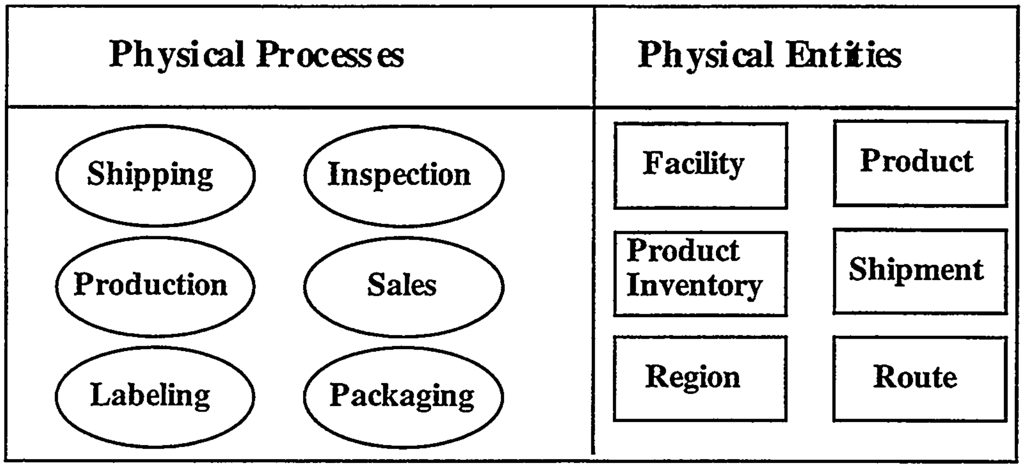

Fig. 1 The fundamental process layer is divided into the physical processes and physical entities. Both the physical processes and the physical entities are modeled as objects.

Example Objects in the Production Process Layer

Physical Entities

Facility

All the physical entities where product is stored, manufactured or displayed are modeled as a facility object. Plants, distribution centers, warehouses and stores are modeled as facility objects. A facility object has attributes such as: the product inventory that is stored or manufactured there, and facilities' location.

Product Inventory

A product in a facility is modeled as product inventory. The attributes of the product inventory vary depending on the type of the facility. For example, at a store product inventory has a minimum order size associated with it. At a plant, where the product is manufactured, there may be a minimum lot size instead of an order size. A product inventory has a list of associated financial attributes. These include the fractional holding cost, the profit margin, the unit transit cost and the order processing cost. A product inventory' total quantity is separated into allocated and unallocated quantities. At a warehouse, the inventory available for incoming orders is designated as unallocated inventory.

Shipment

The shipment object is used to model the shipment that is created in response to a sales order at a suppliers' facility. The shipment object will be associated with the order that caused the shipment to be created.

Route

A shipment can travel through a number of facilities on its way to reaching its final destination. At each facility a physical process may be carried out on the shipment. For example, there may be a retailer specific labeling process applied to a shipment at a warehouse facility. The route object models the real world route a shipment may actually take on its way to its destination. A route has information about the facilities that the shipment will visit and is associated with the operations that will be performed on the shipment.

Physical Processes

These objects model the physical activities that take place during the process of replenishment. The common abstraction among these objects is that they all require time and have and associated cost.

Ordering

Ordering models the activity associated with sending an order from the customer firm to the supplier firm. Ordering requires a period of time, at the end of which the supplier firm has received the sales order. The duration is dependent upon the ordering mechanism i.e. EDI, mail, fax etc.

Shipment Generation

Shipment generation models the activities that are performed in response to receiving a sales order. The steps performed to generate a shipment are:

1. A search for an appropriate facility where there is adequate unallocated product inventory.
2. The activity of defining the route the shipment must follow on its way to its final destination.
3. The activity of creating of the shipment. This involves marking the appropriate quantity of product inventory at the facility as allocated quantity.

At the end of a shipment generation, an appropriate facility has been identified and quantity for the order has been allocated.

Operation

Ticketing, packaging, labeling and other such operations are abstracted as operation objects. The operation object models the activity associated with performing an operation on a shipment. The operation could be anything from packing a case of product to putting the labels on the case. At the end of an operation the shipment has a completed operation at a facility and is ready to be transported to the next facility on its route.

Transport

The transport object models the transport of a shipment from one facility to another. The duration of a transport is dependent on the mode of transport selected at that particular stage. There is also an associated cost of transport. Thus, a faster mode of transportation might reduce time and increase cost associated with the transport object.

Production

If a firm is capable of manufacturing a product, it replenishes a product inventory through production tasks. The production task object models the activity associated with manufacturing a product at a plant. The production object involves a duration. At the end of the production task there is a quantity of product that is added to the product inventory at the plant where the product is manufactured.

3. Business Process Layer

The business layer models business functions, composed into organizational entities and customized for a specific role in the supply chain. With this approach we can study the interactions between business functions, such as the impact of sales forecast bias on production planning. The business layer is divided into business processes and business entities. A business entity models tangible things within the system such as a firms, purchase orders or sales orders.

The business processes model the business functions that are necessary to operate a business within the system. Inventory management and purchasing are examples of these functions. The business entities can be seen as participating in or containing the business functions. For example, a firm is an organizational entity composed of a particular set of business functions, while an order is a business entity that participates in the business functions. Figure 2 shows the division between the business processes and business entities.

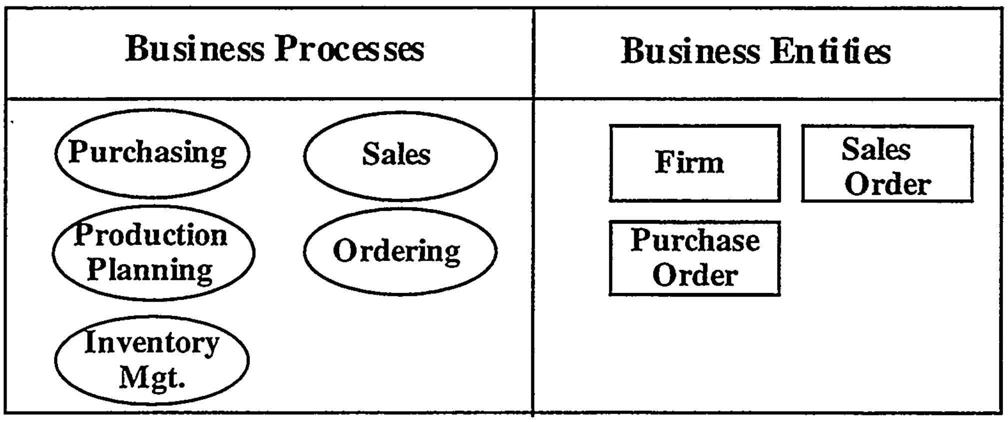

Fig. 2 The business process layer is divided into the business processes and business entities. Both the business processes and the business entities are modeled as objects.

<u>Example Objects in the Business Process Layer</u>

Business Entities

<u>Firm</u>

The firm represents an organizational business entity composed of business functions. It could have a physical structure consisting of facilities and fundamental production processes located at these facilities. Firms may be composed of an arbitrary set of business functions. For example, a converter firm may be composed of just sales and purchasing and not own any facilities.

<u>Purchase Order and Sales Order</u>

A purchase order is an object that models the real world order. When a product inventory needs replenishment a purchase order is created along with the corresponding sales order.

Inventory Management

The inventory management activity is responsible for querying a product inventory for its replenishment policy and then using a specified policy to determine whether replenishment is needed for that product inventory. If replenishment is needed, the inventory management reports back to its associated object (firm) with the quantity required for replenishment.

Purchasing

The purchasing is an abstraction for the time taken by the activity required for generating a purchase order. All that is considered is that a certain amount of time is taken to find an appropriate supplier firm and generate a purchase order.

3.1 Business Decision Layer

Business decisions, our major focus area for innovation, are explicitly partitioned from the standard business functions, which are modeled in the business process layer. Partitioning the business decision in this manner allows us to study the interactions between business processes.

Replenishment policies, transport route and carrier selections, and performance measures are examples of business decisions that are modeled in the business decision layer. The replenishment policy determines when a particular product in a facility is replenished and the quantity of replenishment. Transport route and carrier selections consider the tradeoff between reduced transport time and higher costs. The effect of changing the measurement of sales performance to integrate planning deficiencies resulting from poor sales forecasting on the entire system may be easily investigated in this way.

4. Simulation Builder

The simulation capability allows us to study the tradeoff between various business decisions in terms of time and cost and end-value to the consumer. With this data, one can extend the tradeoff analysis to evaluate the value of information with respect to the cost of generating information. This enables organizational decision makers to focus their resources on areas that will generate the maximum improvement for the integrated system.

Mapping the representation provided by the framework into a focused simulation that can be managed by an individual and run on a workstation class machine, requires a new approach to simulation building. Our efforts do not focus on building traditional numerically intensive simulations focused on bottlenecks, queue times and resource utilization. Instead the work concentrates on providing the ability to build a simulation model to study the effect of changing business structures and decisions.

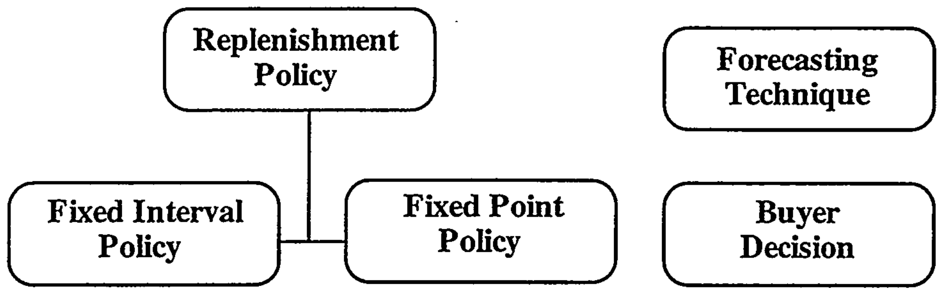

Fig. 3 The decision layer encapsulates the objects used to make business decisions.

Our approach is to develop a simulation builder . A simulation builder allows the selection and modification of specific parts of the model. Only the pieces required for the specified industrial system are included. The simulation builder be able to select which pieces are required and know how to map them together into a comprehensive simulation.

An analysis of the requirements for a simulation builder identified four domains (Fig. 4). A domain is defined as an area of development which is complete in and of itself and which can be analyzed independent of other domains. The complete development of the builder involves analyzing and designing the software required for each domain and building the connections between the domains.

This approach allows concurrent development of all domains. This aids in creating a more open and flexible design by reducing unnecessary dependencies between domains [Shlaer/Mellor 92]. An object in the application domain will not be affected by its graphical representation.

5. Experience

We have built a significant part of the framework and have initiated several investigations both to validate the usefulness of the framework and to validate the methodology of the simulation builder.

5.1 Supply Chain Dynamics

We have incorporated forecasting and various inventory replenishment policies into the business decision model and have developed a first prototype simulation to analyze how forecast errors affect inventory levels in the integrated system. The purpose of this analysis was to investigate the impact of forecast error on lost sales. The intent was to evaluate the trade off between investing time and money to improve or purchase forecasting capabilities and shortening the lead time of the supply chain by specifying faster, but more expensive, transport methods [Macfarlane/Nachnani 95]. A companion analysis evaluated the trade

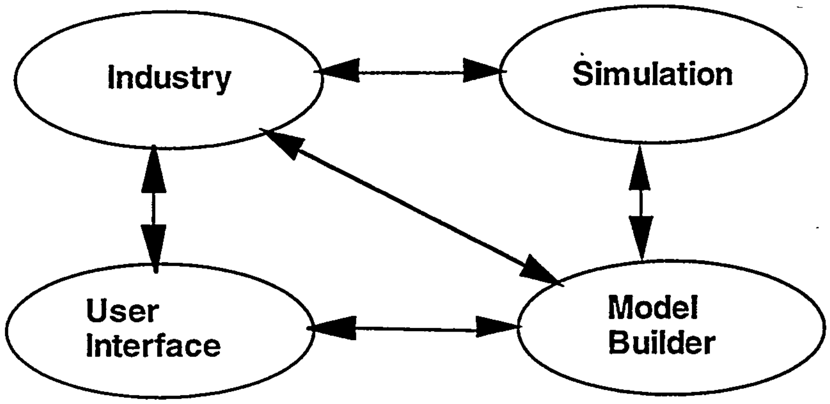

Fig. 4 The analysis of the simulation builder is broken into four domains. Such a breakdown allows a concurrent analysis of the four domains.

off between the purchase of a forecasting package or reduction in the minimum production lot size to observe the effect on holding costs.

The preliminary results of these analyses show that reducing lost sales by reducing transportation time, or reducing holding costs by lowering minimum production lot size may be more cost effective than investing in efforts to reduce forecast error. Real world data from a pipeline is needed to validate the dynamics. Collecting this data is currently being addressed.

5.2 Direct Shipment

Direct shipment of goods from manufacturers to consumers is also being investigated to determine the product characteristics that make direct shipment a feasible solution for fast consumer response. The goal of this study was to investigate whether direct shipment is more profitable than traditional shipping channels, i.e., from a manufacturer distribution center to the retail distribution center (DC), from the DC to the store, then to the retail shelf [Macfarlane/Tsai 95]. We compared the costs involved in this distribution method and the costs of direct shipment to determine under what conditions and what product characteristics each method is preferable. This analysis was designed to validate the framework and the simulation builder concept.

Preliminary results show that direct shipment is a better strategy for:

- high value products;
- slow-moving items; and
- fast-moving items that are often out of stock.

6. Future Work

In addition to continued development of the software framework, we plan to investigate the effect of changing performance measures on control points within the supply chain. For example, changing the performance measure of the buyer in the last link of the industry system by including measures beyond their specific product gross margins. By incorporating performance measures of product assortments, corporate gross margins, corporate inventory levels, or partnership performance into the end buyer performance, the pipeline may be controlled more effectively.

Another area of investigation includes the impact pipeline profit sharing upon product sale, whereby each member of the pipeline is paid for goods only after the final sale of the product to the consumer.

7. Summary

The major focus of our effort is to understand and characterize the dynamics of an industrial system and investigate better ways of controlling the performance of the system in terms of global marketshare. Specifically, the impact of increased levels of information aggregation in the system is a near term area of investigation.

We have demonstrated the feasibility of a framework approach to the analysis of industrial systems by analyzing the dynamics of two business decisions. We have shown that our approach to the framework and simulation builder will allow us to generate focused simulations based on the models built using our framework in a timely and efficient manner.

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