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Control of Enterprise Interfaces for Supply Chain Enterprise Modeling

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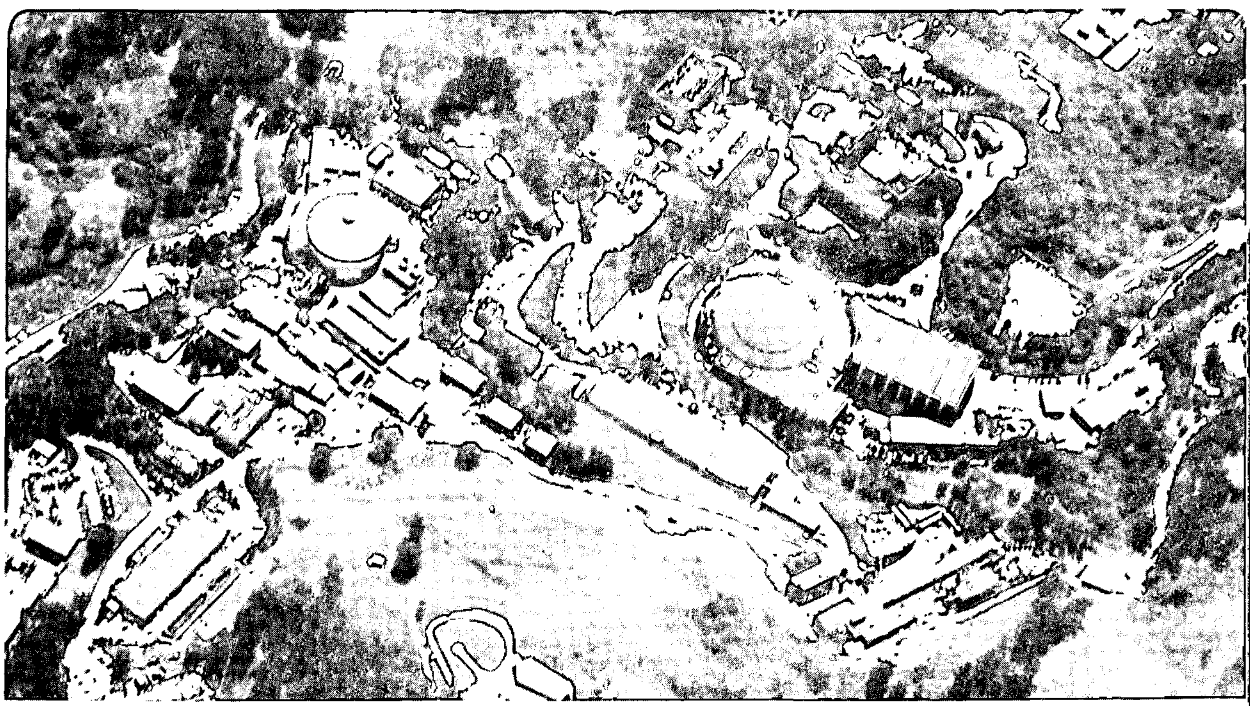

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I. Introduction

There is a current trend for manufacturing enterprises in a supply chain of a particular industry to join forces in an attempt to promote efficiencies and improve competitive position. Such alliances occur in the context of specific legal and business agreements such that each enterprise retains a majority of its business and manufacturing information as private and shares other information with its trading partners. Shared information may include enterprise demand projections, capacities, finished goods inventories, and aggregate production schedules. Evidence of the trend toward information sharing includes the recent emphases on vendor-managed inventories, quick response, and Electronic Data Interchange (EDI) standards.

The increased competition brought on by the global marketplace is driving industries to consider the advantages of trading partner agreements. Aggregate-level forecasts, supply-chain production smoothing, and aggregate-level inventory policies can reduce holding costs, record-keeping overhead, and lead time in product development. The goal of this research is to orchestrate information exchange among trading partners to allow for aggregate-level analysis to enhance supply chain efficiency. The notion of Enterprise Interface Control (EIC) is introduced as a means of accomplishing this end.

II. Inter-Enterprise Models

The focus of the partnerships are to enable the organizations that comprise the business links in the production system to make tradeoffs between time and cost in order to provide a competitive but quick response to consumer demand. Due to inherent uncertainty in consumer demand, these tradeoffs are, by definition, made with incomplete information and can incur significant risk to the organization.

Partnerships can provide a first step in reducing the effect of incomplete information. However, many believe that partnerships are only the beginning of the knowledge sharing needed to optimize the production system and that the sharing must extend to all organizations involved in the production system. However, understanding the production system and the critical knowledge that must be shared to optimize the time to market and increase responsiveness to product change is the challenge that is facing many industrial systems today. There is a need to provide new models to better describe and study the effects of decision making in such a knowledge sharing environment.

A software framework for industrial systems modeling and simulation is under development for evaluating the time/cost tradeoffs that face the business decision makers. 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 it is rendered useless. A crucial design issue encountered in the 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.

The purpose of the framework is to study the tradeoff between the value of information and cost of generating information. This will enable decision makers to focus their resources on areas that will generate the maximum improvements for the integrated system. With the framework in place, further analysis and optimization of the information content and its sensitivity to disturbances in the production system will enable an industry system to tune itself for optimal performance.

III. Supply Chain Analysis

1. Difficulties

Computer-aided manufacturing analysis at the inter-enterprise level suffers from some of the same problems as analysis at the enterprise level. In fact, the effect on analyses can be magnified in some cases. In particular, it has been difficult, if not impossible to adequately characterize the effect of interactions among subsystems in a manufacturing enterprise. For example, many machine scheduling techniques assume constant demand. How can one model the effect on a manufacturing cell production schedule of a delay in the transport of raw materials to the cell? How is such a delay reflected in updated shipping schedules? At the inter-enterprise level, what is the effect of shipment delays from one enterprise to the next one in the supply chain? How do changes in consumer demand for retail products affect inventories and capacities at earlier sectors in the chain?

Much research is underway to provide a better understanding of manufacturing system interactions (e.g., enterprise modeling [Fox, 1992], chaos theory [Kempf and Beaumariage, 1994], negotiation among agents [Claassen and Interrante, 1994], etc.). Such an understanding is necessary but not sufficient for accomplishing the goal of improving aggregate-level supply chain analysis.

Consider a manufacturing model which is a distributed agent architecture. Such an arrangement is a common one for manufacturing analysis. Each agent contains its own local goals, knowledge, and means of communication. Typically much thought is given to the design of each agent. The agents are combined in a system with a view of accomplishing one or more global objectives (e.g., meet the master production schedule). In a system of agents, each with local goals, the attempt on the part of each agent to satisfy local goals does not necessarily insure the satisfaction of global goals for the agent system. Additional agent system design activities typically occur at this point with the aim of achieving the desired satisfaction of global goals. For example, a series of constraints and an associated algorithm may be used to determine how to allocate a limited resource among competing agents.

The problem in such a case is that the focus of the agent system development is on the components (agents) rather than on the explicit definition of what can and cannot occur among the components (agents). Collective system behavior is as much a result of the component interactions as it is the makeup of each component. Therefore, we advocate explicit definition of the connections among components in the same way that the components are explicitly defined. Furthermore, such definition should be other than a static rendering of who sends what kinds of messages to whom. It is desired to go beyond understanding effects and propagation of effects in the supply chain to the control of such effects by orchestrating information exchange such that aggregate-level production smoothing is accomplished.

2. Existing Approaches

It is useful to examine several existing approaches to the modeling of manufacturing systems to determine how the modeling of component interactions is handled.

a. Discrete-Event Simulation

Discrete-event simulation has been applied to characterize the effects of changes in the system of enterprises. System state is captured as a collection of well-defined state variables and values. Dynamic change occurs via events, which may alter the values of state variables. Data is stored regarding a set of defined measures of performance during the execution of simulation replications. In a process-centered model, execution of the model occurs as entities (e.g., parts) move through the system (e.g., plant or supply chain) in well-defined paths [Law and Kelton, 1991]. Additional logic may be applied to accomplish complex information flow which does not necessarily follow material flow in the system. Information flow follows predefined paths which may contain conditional branching, goto's, or aggregation via merging, etc.

b. Expert Systems

Expert systems have been developed which contain a large rule set to handle the modeling of manufacturing systems. Boundaries and interfaces among enterprises are defined by the collective behavior of a number of rules. Such rules may or may not be partitioned into a group. If the rules exist as a single large, flat group it may be extremely difficult to understand the effect on system behavior of the addition or removal of one or more rules to the set. One way to alleviate this problem is to tie the rules to a more structured model of the manufacturing system. Interactions may then be defined by the model connections and the rules which are either triggered by or which alter the connections.

c. Object-Oriented Models

Object-oriented models have been developed to represent entities in a manufacturing system. Associated methods propagate changes through the modeled enterprise system. This architecture may suffer from the same difficulties as those associated with expert systems based on an accompanying model.

The disadvantage of each of the approaches mentioned above is that it is difficult to gain an understanding of and to control states and constraints in inter- enterprise interactions. A notion of what is allowed to occur and what is not allowed in the dynamics of the system is implicit and buried in the rules, simulation elements, and/or methods of the model. It is more desirable to explicitly render such information - to provide an architecture which embodies this valuable information in a more structured form. Achievement of this goal moves the analysis of manufacturing enterprise dynamics from a black box approach to a white box one.

d. Discrete Control Theory

Discrete control theory has been applied to manufacturing systems with this goal in view. Discrete-event systems are dynamic systems which change state abruptly in accordance with the occurrence of physical events [Ramadge and Wonham, 1989]. Finite-state automata have been developed for small-scale manufacturing scenarios such that allowable sequences of events can be explicitly defined [Brandin, Wonham, and Benhabib, 1991].

The advantage of discrete control theory is that feedback control can be accomplished and enterprise interactions can be explicitly defined. This approach is infeasible for large systems because the number of possible states is exponential in the number of constituent processes [Ramadge and Wonham, 1989].

IV. Enterprise Interface Control (EIC)

1. Motivation

Figure 1 [Parr, 1995] depicts a typical supply chain for textile manufacturing, with four sectors and two companies per sector. This figure shows material flow through the system. Figure 2 [Parr, 1995] depicts information flow for the same system. Note the complexities involved in information flow for this simple model as compared to the material flow connections. In addition to the many connections among enterprises, the large databases and high state of flux in inter-enterprise manufacturing analysis lead to a very large number of possible states of the system. An alternate approach to discrete-event control is proposed for providing a white-box view of interactions among enterprises which explicitly defines allowable communication patterns (as opposed to states) for the supply chain enterprise system. Rather than defining allowable sequences of states, the allowable data transfers are defined, providing a much higher-level mode of tying dynamic behavior to system state.

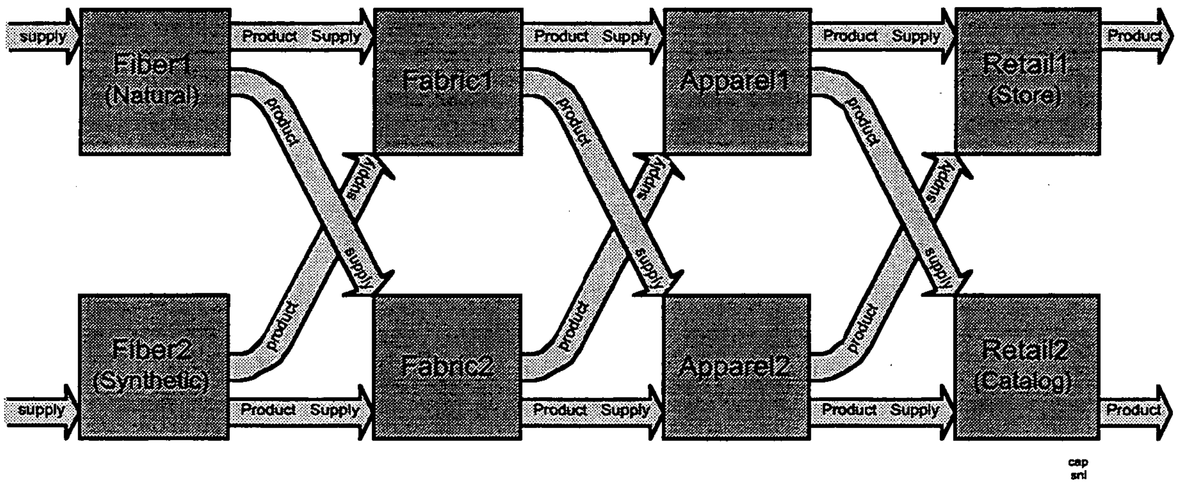

Figure 1: Supply Chain Material Flow

2. Description

Enterprise Interface Control (EIC) defines the allowable pattern of communication links and the information which can traverse each link. The communication definition is both explicit and flexible in the dynamic operation of the supply chain. The drivers for such explicit definition include the following:

1. legal considerations (e.g., anti-trust laws)
2. business agreements (e.g., trading partner agreements)
3. physical constraints (e.g., location of material in transit)

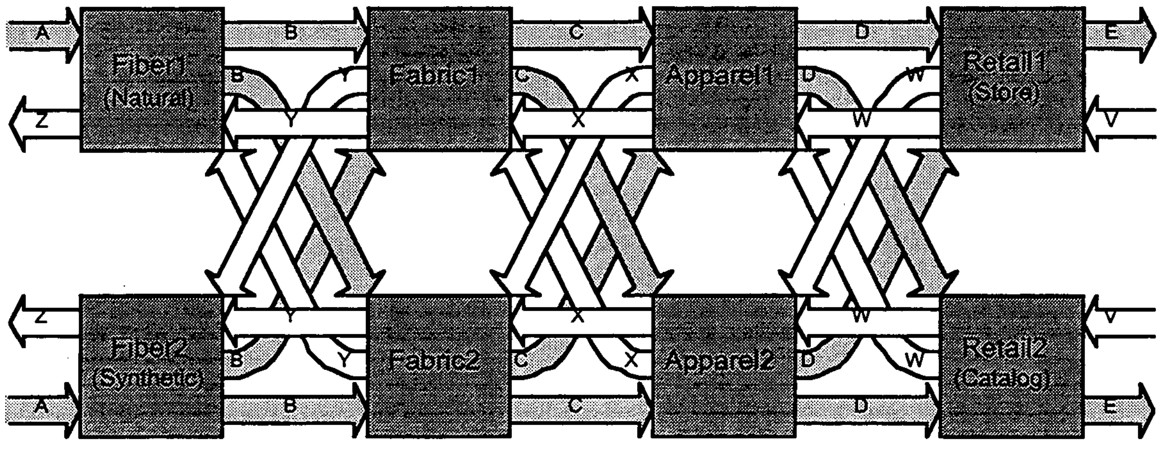

Figure 2: Supply Chain Information Flow

4. system architecture/timing constraints (e.g., many messages on a single processor)
5. enterprise preferences (e.g., most useful form/type of data)
6. current problem-solving focus (e.g., selective attention capability)

At any given time, the pattern and content of information exchange among supply partners allows and/or inhibits the aggregate-level analyses which can be performed. Such behavior is desirable in order to minimize the amount of data which must be passed over the network connecting the enterprise partners. Thus, manufacturing planning, scheduling, and contingency handling efforts can be orchestrated across the entire supply chain.

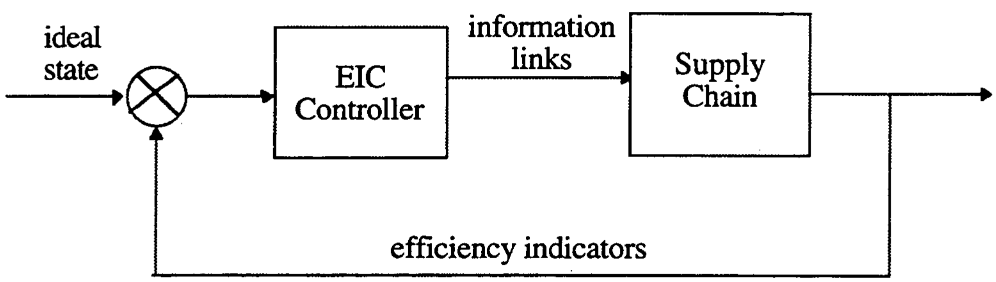

Figure 3: Enterprise Interface Controller

The notion of a closed-loop control system that maintains the state of the entire supply chain is shown in Figure 3. Efficiency indicators, denoted in the feedback loop, for supply chain dynamics include the following:

1. inventory stockouts
2. inventory levels
3. forecast error
4. ability to meet last-minute orders.

The efficiency indicators are compared to desired levels that are agreed upon by all members of the specific supply chain. The EIC then determines the appropriate communication links and information exchanges necessary for the particular analysis at hand. Typical control-related adjustments would be to expedite production of a particular product, alter the information content of particular links during an aggregate-level production scheduling analysis, or reorganize the particular patterns/contents of links for each of the types of aggregate analyses (e.g., production scheduling, forecasting, etc.).

The proposed controller design is heavily dependent on the supply chain dynamics. The dynamics will define the structure for the controller and the sensitivity of the control parameters. The framework under construction for analyzing the suppy chain dynamics is composed of three layers: the business model, the business decision model and the production process model. The three layers form a representation of an industrial system that can be modified according to a specific case of interest.

For the business model, we model business functions, compose them into organizational entities and customize the entity for a specific role in a supply chain. With this approach we can study the interactions between business functions, such as the impact of sales forecast bias on production planning. Using a standard information modeling process, we have identified relevant information in the business functions and their inter-relationships.

Business decisions are explicitly partitioned from standard business functions, such as purchasing. Replenishment policies, transport route and carrier selections, and performance measures are examples of business decisions that are modeled. This partitioning allows us to study the interactions of business decisions, such as the effect of changing the measurement of sales performance to integrate planning deficiencies that result from poor sales forecasting.

Key attributes of the production process steps include time and cost elements. The production process model includes transportation and inspections. A simulation that captures the representation and provides the capability to modify the business structure of the system will drive the controller design and provide a mechanism for measuring system performance.

3. Architectures

The problem remains that the number of system states is too great to allow system state to be a feasible trigger for communication pattern change. Two other possible triggers exist:

1. state classes
2. analysis "phases".

Supply chain states can be grouped into classes for the purposes of identifying how communication links should change. Analysis "phases" include the following:

1. forecasting
2. production scheduling
3. capacity planning (capital planning)
4. adjustment to handle contingencies.

At a high level, the orchestration of supply-chain level production includes at least these phases of analysis, and precedence relationships exist among the phases.

One possible architecture has a many-to-one relationship between state classes and analysis phase. Any number of state classes trigger a particular analysis phase, which determines the particular communication pattern and link contents for the supply chain. Alternatively, a one-to-many relationship may exist between a state class and a number of possible analysis phases. Such an arrangement may be useful if it is desired to improve the orchestration of supply-chain analysis by, e.g., tracking data dependencies via a reason maintenance system. The effect of a chain of analyses in time can be measured and backtracking can be used to determine a better approach to orchestration by trying out different choices at particular decision points. Backtracking can also be used to reconcile proactive and reactive analysis by allowing plans to be changed to, e.g., accommodate the need for extra capacity.

V. Conclusion

Provision of Enterprise Interface Control capability will enable better inter-enterprise modeling by fitting aggregate manufacturing analysis capability within the realm of real-world business contingencies and constraints. Interactions among supply-chain enterprises are both more definable and more flexible with such an approach.

Currently a large prototype system is under development which will serve as a testbed for one or more of the suggested architectures. The system includes a variety of manufacturing databases for eight enterprises in a supply chain. Future efforts will be aimed at the definition of state classes, analysis phases, corresponding communication links/patterns, and the theoretical development necessary to accomplish Enterprise Interface Control.

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