Simulation Modeling for Information Management in a Supply Chain

Track: Enterprise Resource Planning

Abstract

The complexity of problems and issues companies face requires unique decision-making alternatives to be developed and analyzed for problem solving. The reliance on simulation as a problem-solving tool has increased considerably. One such problem is that of a supply chain where autonomous entities collaborate to define common goals and objectives and achieve these through cooperation. The supply chain problem can be modeled in unique ways to represent many structures that it may assume. In this paper, a simulation technique utilizing a generic activity for information management is described. It is based on standard-activity form of enterprise, which recognizes that activities across supply chain members have commonality.

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Introduction

The concept of supply chain (SC) is about managing coordinated information and material flows, plant operations, and logistics (Lee and Billington, 1993). The fundamental premise of this philosophy is synchronization among multiple entities represented in it. That is, improved co-ordination *within* and *between* various SC members. Co-ordination is achieved within the framework of commitments made by Members to each other. Increased co-ordination can lead to reduction in lead times and costs, alignment of interdependent decision-making processes, and improvement in the overall performance of each Member, as well as the supply network (Group) (Chandra, 1997).

One of the structure that a SC adapts is a virtual enterprise (VE) form as depicted in *Figure 1*. It is a temporal co-operation of independent units (members) which provide a service on the basis of shared products, technologies (and processes), and resources for changing market needs built on a common business understanding. VE components are technology and associated resources available to a unit(s), belonging to a VE at various time intervals. One of the phases of VE creation is its configuration (Smirnov, 1999; Smirnov and Chandra, 1999; Wang and Majety, 2000), wherein product, process and resource components of units are aligned to common objectives of the VE at a given time interval. The interconnections among members of such a network can become complex as it configures to meet changes in the market. This paper describes a simulation technique that utilizes the concept of a generic activity for information management in complex SC structures. It is based on standard-activity form of enterprise, which recognizes that activities across supply chain members have commonality in functions, strategies and policies adapted, and information used in decision-making. An automobile industry SC example has been used for illustrative purposes.

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Problem Description

As depicted in *Figure 1*, a SC consists of several tiers (or echelons) of its members. A possible SC configuration may have the same member belonging to several echelons simultaneously. Further, the SC may be configured to meet the needs of its production environment, which may follow a parallel, sequential, distributed production system structure.

In order to improve efficiency in a SC, it is necessary to coordinate behavior of all its members under various production configurations, which require different strategies and policies for SC decisions at macro and micro levels as well as at different tiers and SC members.

This requires that interconnection among decisions at various levels of its structure must be analyzed. That means that successive SC functioning requires high-level information management within it. This study is devoted to use of simulation as a way to model SC and its information interchange. This will help to better understand SC member information needs required from other members (Bhaskaran, 1998; Ingalls, 1998; Petrovic et. al. 1998). Obviously, it not possible and even feasible, to exchange all information between members of the SC. The goal of the study is to apply simulation method to ascertain which information is most important and relevant for SC coordination in a specific problem domain.

A technique for simulation and information sharing among SC members and some experimental results from a software prototype implemented using this technique are presented in the rest of the paper.

Generic Simulation Architecture

The objective in proposing generic simulation architecture (GSA) is to create a domain independent simulation model that is capable of representing various application scenarios with minimum of changes. Configuration management offers a mechanism to design structures of supply chain networks to support its dynamic environment by considering its integrated product-process-resource framework. The simulation and information technique for SC configuration presented in this paper is built on the generic activity form of simulation modeling architecture as proposed in Chandra et al., 2000a. A simulation prototype described in Chandra et al., 2000b were built according to the generic activity simulation architecture. Some of the basic features of this architecture and the software prototype are described below.

The basic unit of the modeling is the **Generic Activity** (GA) (Chandra et al. 2000a). GA's behavior depends on several parameters namely, control parameter (defines some control function for the GA), resources available to activity (play role of some internal constraints on GA), environment (also is a set of constraints, but external) and objective function (for example, throughput maximization, or cost minimization, etc.). Products come into the GA through input; get processed inside GA and then leave it through output. For a manufacturing environment GA's can be categorized into four types: Inbound Logistics (responsible for queuing of incoming products or materials), Processing (responsible for processing itself), Outbound Logistics (performs outbound queuing) and Control (controls actions of the other three GAs). Each GA can be both one-resource and multi-resource activity.

The next level is the aggregation of GAs or **Generic Process** (GP). It combines four GAs of different types described above according to their functions. Any production system can be modeled utilizing GP's and their Aggregations. Each aggregation may consist of any number of GP's, connected both in parallel and sequentially. For each aggregation, the new Control GA can be added, what allows performing complex control related to the aggregation. The structure of a GA and their aggregations is depicted in *Figure 2*.

Experimentation with the Generic Simulation Architecture

The complexity of the SC structures described above makes it difficult to understand its internal and external interactions in its business environment. The difficulty is primarily encountered due to the breadth (tiers or echelons) and depth (product, process and resource variety), of integration involved in the SC, utilizing the above GA concept. An exhaustive analysis of these interactions is, therefore, necessary in order to understand information management in a SC structure. To achieve this task, experimentation must be performed in order to make inference on behaviours of SC configurations, as a result of sharing information among SC members.

In this section, an automotive SC example is described for preliminary experimentation. Various mass-customisation approaches have been combined with different SC structures, strategies and policies in order to measure SC system robustness and effectiveness to information representing alternative decisions. Through this experimentation, it is hoped to make inferences on the performance of various SC configurations under specific market conditions and availability of information.

Simulation Software Prototype

For implementation of the GSA approach, a software prototype was developed. *Figure 3* depicts the structure of an experimentation algorithm. Main stages of its implementation are described below.

1) *Collection of data about the object to be modelled.* This stage is aimed at gathering necessary information about the object to be modelled. This can be a factory, an enterprise or a supply network. At this stage, the level of abstraction is chosen as well. The correct choice of the latter defines precision of the modelling activity and model complexity.
2) *Experimental planning.* At this stage, goals of the experiment and requirements for expected result, as well as strategies of changing model parameters are selected.
3) *Simulation model building*. This is achieved via interactive procedures, which are supported by the developed software. The development of the software is based on pre-defined macro-level enterprise models and model libraries.
4) *Model parameter definition.* At this stage, parameters that fit the problem and the modelling environment are defined. For example, some of the parameters for a supply chain reengineering problem are as follows:
    - Process: Lot Size, and Lot Processing Time
    - Queueing: Type of Queue, Product Priorities
    - Controlling: Safety Stock, Estimated Lead Time, Costs
5) *Inventory replenishment schedules.* A time series of demand forecast of product(s) under

evaluation is used to generate inventory replenishment schedules for various echelons in the SC.

6) *Simulation.* A simulation environment to design, model, and analyse various problem solving alternatives.
7) *Simulation result analysis.* Results of running simulation experiment are analysed to study model behaviour under changing environment. If the results of analysis are not acceptable, some model parameters are changed according to the plan of experiment, in order to achieve better results.
8) *Results and Recommendations.* This stage provides analysis of experimental results, and offers recommendations and conclusions for the decision-maker

Automotive Supply Chain Case Study

The product (a *car*) consists of four major parts -- Body, Interior, Under Carriage and Power Train. Each of these consists of several components, depicted in *Figure 4* and described as follows:

1. *Body*: 14 Pre-formed Tubes, 5 Exterior Sheets
2. *Interior*: Dashboard, 2 Front Seats, Rear Seat
3. *Under Carriage*: Wheels, Front and Rear Axles, 2 Front and 2 Rear Shock Absorbers
4. *Power Train*: Engine, Transmission, Cardan Shaft

Some of the components can be of different types, depending on the final configuration of the car. A large number of configurations can be built for this simple example. However, for illustrative purposes, simulation analysis presented in this paper is based on product configurations for 3 components.

In order to produce and assemble car products for the configurations identified above, following SC production networks depicted in *Figure 5* were built:

- One-Stage Distributed Production Model
- Parallel Distributed Production Model
- Sequential Distributed Production Model

These networks are characterised by the production schemes represented in them. For example, in a "One-Stage Distributed Production Model" goods are produced in a single stage, whereby all product components are assembled as one large unit, even though individual components may have been produced at different locations.

The 3 component configuration example presented in this paper is implemented using a sequential model of a distributed 3-echelon SC production network.

Experimental Results and Analysis

The following example demonstrates how simulation can be used for measuring the Bullwhip Effect (forecast noise amplification) on SC echelons. The objective of study through this experimentation was to analyze the impact of Bullwhip Effect in an environment where demand information is, (a) not shared, and (b) fully shared, from one SC echelon to the next.

A discrete event simulation of the 3-echelon SC described in the previous section was performed.

Results of simulation analysis are presented as follows:

- *Figure 6* plots Order quantities from Consumers to Car Assembler, from Car Assembler to Body Assembler, and from Body Assembler to Power Train Assembler, in the system; where information about demand is not transferred through echelons, and
- *Figure 7* plots Order quantities from Consumers to Car Assembler, from Car Assembler to Body Assembler, and from Body Assembler to Power Train Assembler, in the system; where information about demand is fully transferred through echelons.

As is evident from this simple example, transferring of demand information, enables considerably reducing system costs for inventory holding, and avoiding stock-outs in the SC network. For example, with demand information sharing, ordering is highly synchronized between Body Assembler and Power Train Assembler as depicted in *Figure 7*. This is in sharp contrast to ordering pattern depicted in identical interaction in *Figure 6*, where ordering is biased towards initial planning periods leading to carrying high stock levels, thereby incurring high holding costs.

This example can be expanded to investigate impact of other factors, such as capacity and inventory levels due to implementation of different strategies and policies related to information management in the SC.

Conclusion

Simulation, when used as a decision support system, can be a useful technique for testing different information management strategies within a SC. Generic simulation modeling technique for a SC, described in this paper, offers a flexible and domain independent approach for experimentation with complex SC configurations. With such an approach, it is feasible to represent information management decisions, such as *fully*, *partially*, and *no* sharing of information for various SC production configurations. These decisions are required from temporal (time) and spatial (location) perspectives, in evaluating alternatives for manufacturing several products represented in the SC.

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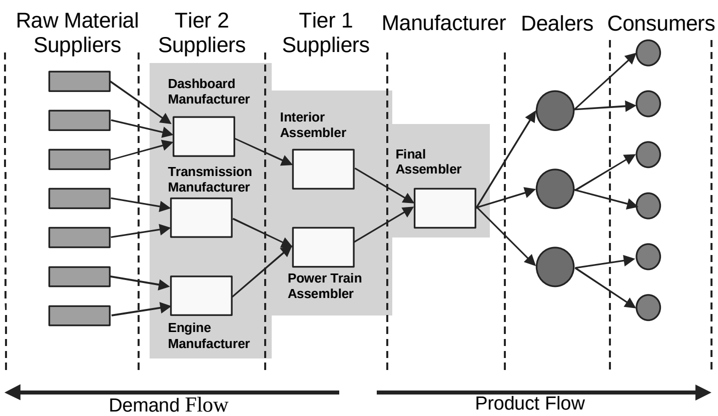


Figure 1. A generic supply chain scheme

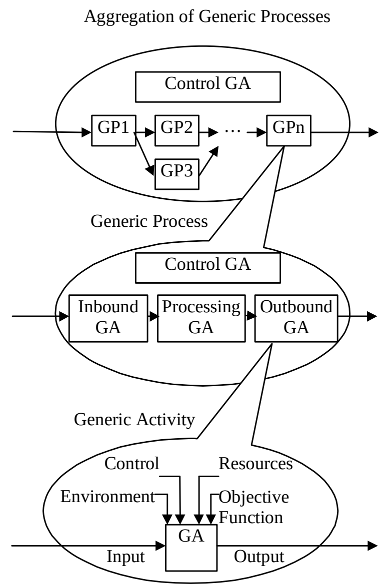


Fig. 2. Macro-level Enterprise Modelling

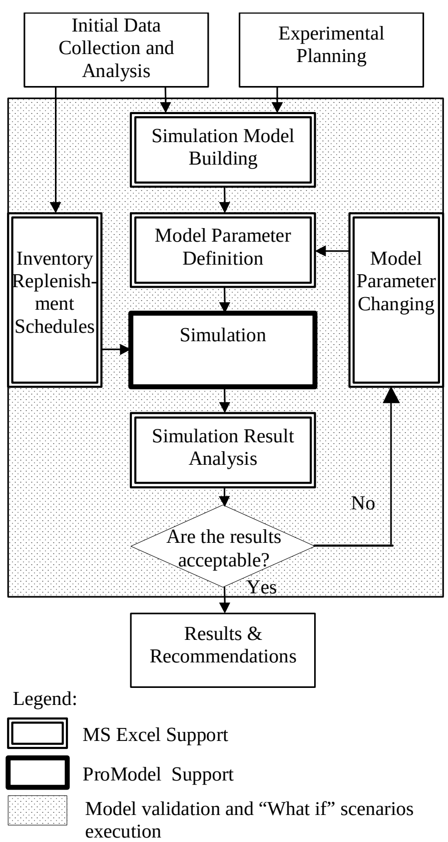


Fig. 3. Algorithm for proposed approach

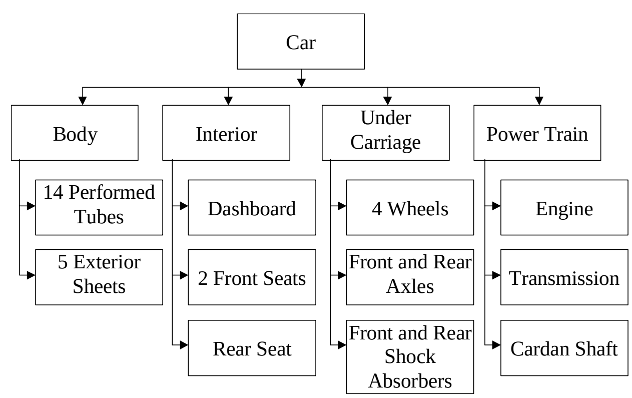


Figure 4. A generic automotive supply chain example: Product structure

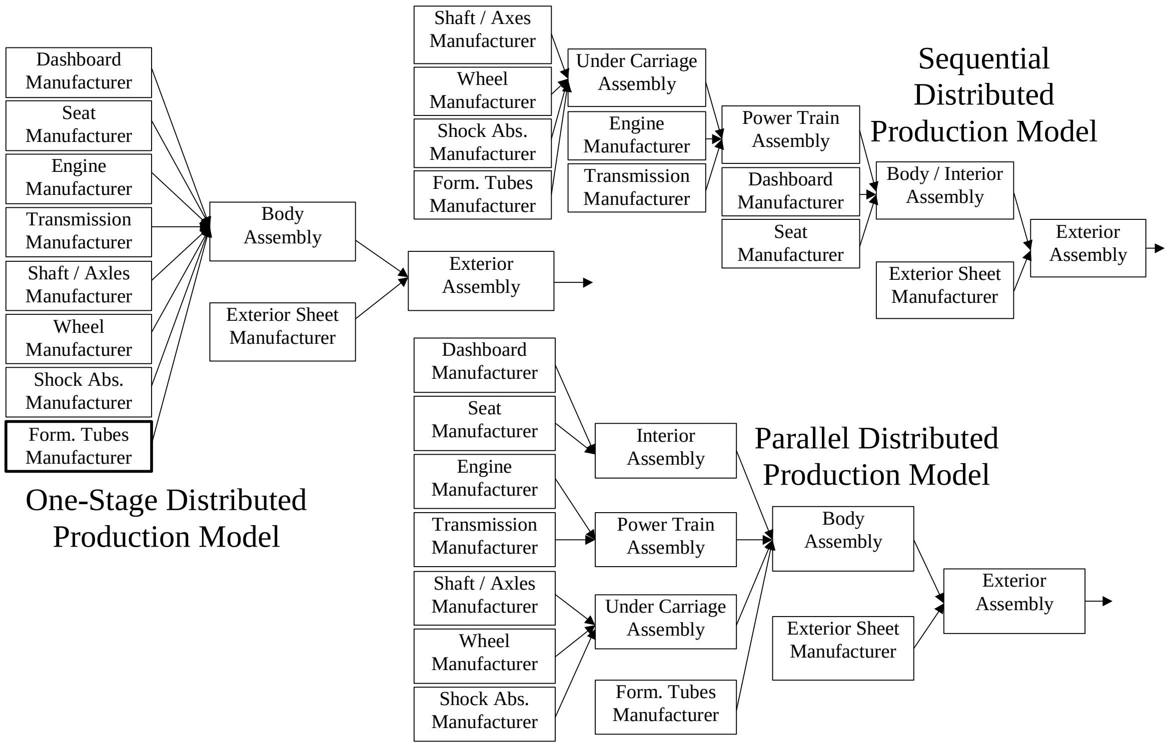
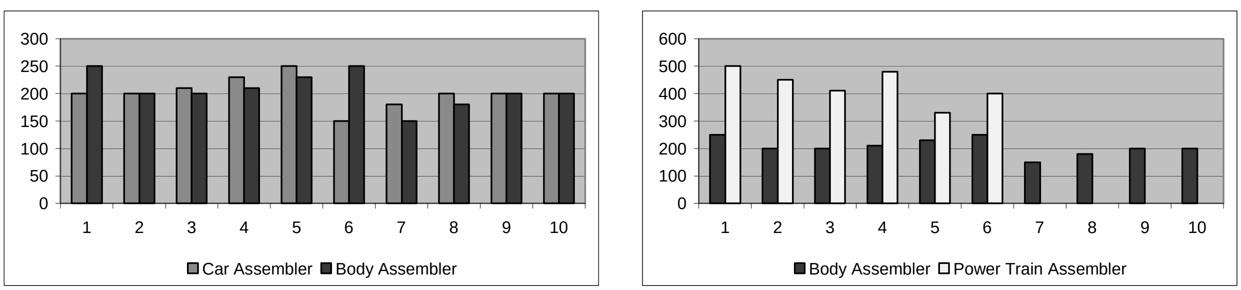


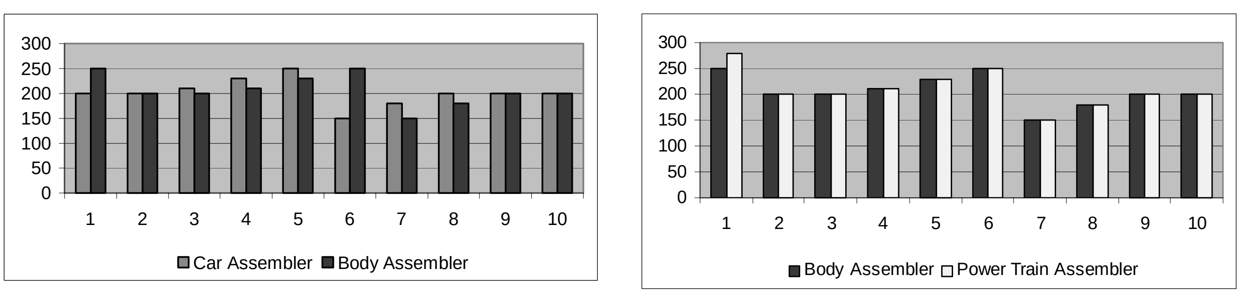
Figure 5. A generic automotive supply chain example: SC configurations



View a: Order Quantities between Consumers and Car Assemblers and between Car Assembler and Body Assembler

View b Order Quantities between Car Assemblers and Body Assembler, and between Body Assembler and Power Train Assembler

Figure 6. Orders between SC members in the system without information sharing



View a: Order Quantities between Consumers and Car Assemblers and between Car Assembler and Body Assembler

View b Order Quantities between Car Assemblers and Body Assembler, and between Body Assembler and Power Train Assembler

Figure 7. Orders between SC members in the system with information sharing