# Hybrid Modeling Approach for Supply-Chain Simulation

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**Abstract.** This paper proposes a novel simulation-modeling framework that combines discrete-event simulations with system-dynamics simulations. The former represents both operational processes inside of a supply-chain, and the later represents management environment outside of a supply-chain. Further, the paper also discusses modeling capabilities of the proposed framework for supply-chain systems in real world by using several example simulation models.

## 1 Introduction

Supply chain management is one of the hottest topics in production planning and control areas. The primary goal of supply chains is to provide manufactured products to end-customers. Supply chain planning is, in a sense, restructuring a business system for supply chain members to collaborate with each other by exchanging information.

A supply-chain is a network of autonomous and semiautonomous business units collectively responsible for procurement, manufacturing, distribution activities associated with one or more families of products. Individual process in the chain can be affected by technology, marketing, and transportation. Such enterprise environment can also influence system performance of supply-chain. Supply chain managers, in both planning phases and operational phases, face various kinds of problems, such as capacity planning, production planning, inventory planning and others. Systematic approaches are needed to support planning and control of such supply chain systems.

Simulation is an effective tool to optimize designs and operations of manufacturing and logistics systems. Steady-state simulation can provide major system performance evaluation indexes, such as resource utilization, queuing length, and throughput. Terminated simulation also provides predictions of potential status

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by “what-if scenario”, for examples, “What is the system throughput, if another machinery resources are added?”, ”What happens in picking server, if its queuing constraints are added?”, and etc. [1].

Performances of supply-chain systems often depend on external factors such as marketability, traffic congestions, and other management environments. When simulation practitioners analyze supply-chain performance, these external factors are usually condensed into several parameters, which are independent on individual supply-chain components. For an example, an average demand volume is a very important simulation parameter. In this case, simulation practitioner condenses every marketing phenomenon into several numeric variables, probability distribution functions, and its statistical parameters such as means and variances. Once these variables are defined at simulation start time, they are kept as the constant values during simulation execution.

Consideration of external environment enables more realistic and detail simulations to system planner. Integration of discrete-based process simulation into external management environment will provide more realistic and detail simulation outputs. System dynamics model is applicable to represent such management environment, and it enables practitioners to analyze strategic scenarios as well as simulation of policies and operations.

This paper proposes a novel simulation-modeling framework that combines discrete-event simulations with system-dynamics simulations. The former represents both operational processes inside of a supply-chain, and the later represents management environment outside of a supply-chain. Further, the paper also discusses modeling capabilities of the proposed framework for supply-chain systems in real world by using several example simulation models.

## 2 Hybrid modeling for supply-chain simulation

### 2.1 Discrete-based simulation of supply-chain operations

#### (1) Feature-elements models and modeling hierarchy

“Feature-elements model” defines the following members as elements of the top layer of the models. These models represent business processes of each member.

- Supplier: It provides materials, parts, or products in the chain.
- Source: It starts the material-flows in the chain. Parts and material suppliers, which material-flows start in the chain.
- Storage: It stores materials, parts, or products.
- Consumer: It sends purchase orders to the chain, and it acquires products.
- Deliverer: It transports products, parts, and/or materials between chain members.
- Planner: An organization that controls material-flows and information-flows in the chain.

The discrete-event simulator is composed of four-layered simulation models: “Feature Element Model”, “Function Element Model”, “Implementation Model”, and “Execution modules”. These represent supply chain members, major activities of business process activities in supply-chain systems, fundamental elements of discrete event simulation, and simulation programming codes using commercial simulation software, respectively.

**(2) Control models**

The major characteristic of this approach is an introduction of two types of common control method in supply chain systems: These are "stock-driven" control and "schedule-driven" control [2][3]. These are based on material management policies in discrete manufacturing systems [4].

- Schedule-driven control: It uses a production schedule, the so-called "Master Production Schedule" (MPS), which the supply chain planner generates.
- Stock-driven control: A stock-driven supplier autonomously replenishes material inventories based on parameters of input material stock volume.

Control models mainly represents business activities in a headquarters of the prime contractor controlling other supply-chain members. This model is an expansion of our previous research, supply-chain business activity model by using IDEF0 modeling method [5]. Figure.1 represents an example of hybrid schedule- and stock-driven supply chain.

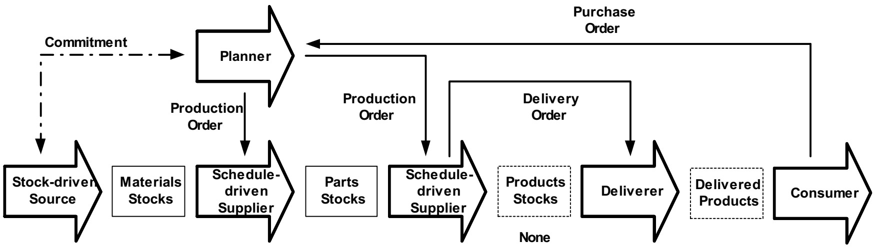


**Fig. 1.** A configuration example of hybrid schedule- and stock-driven supply chain

## 2.2 Dynamics of supply-chain enterprise environment

Supply-chain activities have relevance to its business environment. Suppose that a supply-chain system realizes a high performance and it shorten the consumers' purchase lead-time. In this case, the demand volume in market would increase because of the shortened purchase lead-time; the system would be busier by the increased demands. These activities give favorable or harmful influences to its external world, and their feedbacks can also give similar influences to the supply-chain. Similar scenarios would be applicable to relations between other supply-chain systems' activities and their feedbacks. They are, for examples, quality improvement programs in factories, manufacturing process automation programs, and operational improvement in parts/products transportation between suppliers.

System dynamics has been defined as 'a method of analyzing problems in which time is an important factor, and which involve the study of how the system can be defended against, or made benefit from, the shocks which fall upon it from outside world' [7]. This approach is useful to capture complex real-world situations, which include delays and feedback mechanisms. Practical applications include understanding market environments and assessing possible future scenarios. Dynamics complexity is not related to number of nodes or actors concerned, but the behavior they create when acting together [6].

Based on the above considerations, we defined the following dynamics models that represent supply-chain enterprise environment.

- Market dynamics represents market mechanisms, which produces, raises, and reduces the demand of the product provided by the supply-chain.
- Plant dynamics represents quality mechanisms, which represents a relationship between quality management and machining/assembling process control.
- Traffic dynamics represents traffic mechanisms, which provide supply-chain logistics.

### 2.3 Hybrid simulation-modeling framework for supply-chain

The proposed hybrid modeling method combines discrete-event models with system dynamics models. The formers represent business and operational processes such as manufacturing, inspections, shipping, transportation, and their planning. Meanwhile, the later represents external management environment such as marketing, logistics, and plant engineering issues.

The box diagram in Figure.2 represents an example of a supply-chain system. This system is a noteworthy supply-chain system, so-called "Vender-Managed-Inventory (VMI) system". A VMI system belongs to a mixed system of "Schedule-driven"(push) control and "Stock-driven"(pull) control. This model poses two planners, named "Prime planner" and "1st–tier planner". These work autonomously, and they generate independent production orders to each manufacturing plants by using inventory data in the final product plant. This type of supply-chain needs the most complex communication among the chain members.

The behaviors of market place are represented in "Market dynamics" model. The data, generated here, are for examples, selling status, customers' preference, competitive products trends, end etc. Both "Prime Planner" and "1$^{st}$ Tier Planner" receives marketing data in the market places, and use them to predict future demands and orders for production and shipment. Customers also receive these data and generate purchase orders. Dynamics model, simultaneously receives feedback data from these actors.

Other two dynamics models generate the similar data, and send/receive between supply-chain members. They also exchange feedback data, when it is required. The connections of chain members to dynamics models are generated dynamically according as simulation run.

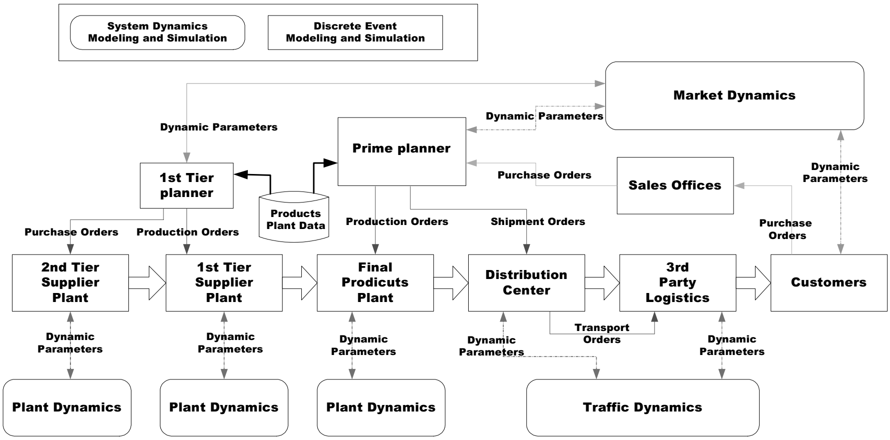


**Fig. 2.** Hybrid modeling framework for supply-chain simulation

# 3 An application example

## 3.1 A scenario of a simplified VMI model

Simulation scenario has been designed to verify the proposed hybrid simulation-modeling framework. As the first stage, we defined a simplified simulation model to clarify the relation between discrete-event business process models and a system dynamics business environment model.

Figure.3 represents the chain configuration and the data-flow among these chain members. The system is composed of five chain member models ("Planner", "Stock-driven Source", "Schedule-driven Supplier", "Schedule-driven Storage", "Consumer",). "Source", "Supplier", "Storage", and "Consumer" are connected with "Deliverer". The "Market dynamic" is an independent model of chain configuration.

Planner gives orders to a product factory ("Schedule-driven Supplier") and a distributor ("Schedule-driven Storage") according as the predicted demand by using past demands data. And, it also decides the stock-replenishment level and the stock-volume level for the "Stock-driven" members.

Stock-driven source continuously observes the stock volume of a particular chain member. Both stock-volume level and stock-replenishment level are critical variables to keep inventories to proper quantity. Assigning proper values to these variables enables to avoid both excessive and shortage of parts inventories. When the materials volume of the target supplier becomes lower than the stock-replenishment level, this source generates materials in its own buffer. Work continues until the stock volume reaches the stock-volume level. When it finishes a sourcing operation for a predefined lot-size, it sends a delivery order to the attached deliverer. This shipment will stop once the volume of materials at the specified supplier reaches or exceeds the stock volume level.

Outline of a dynamics model is shown in Figure.4. The role of Market dynamics model is to generate the average demand data, periodically. At that time, it uses feedback data from consumers ("Satisfaction" in Figure.4) to generate the demand data.

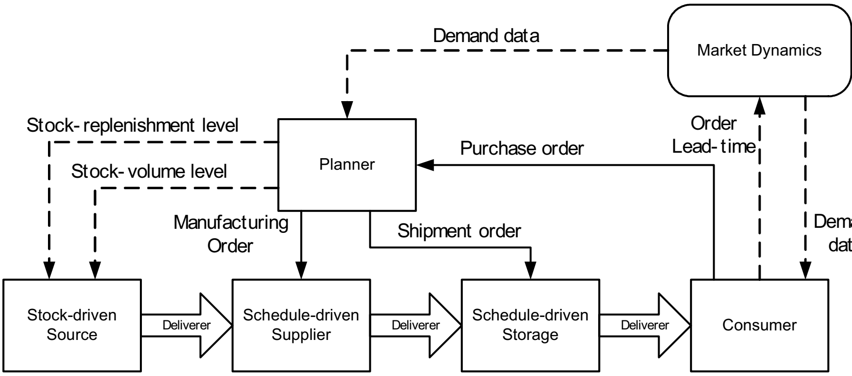


**Fig. 3.** Simplified VMI-based supply-chain simulation model

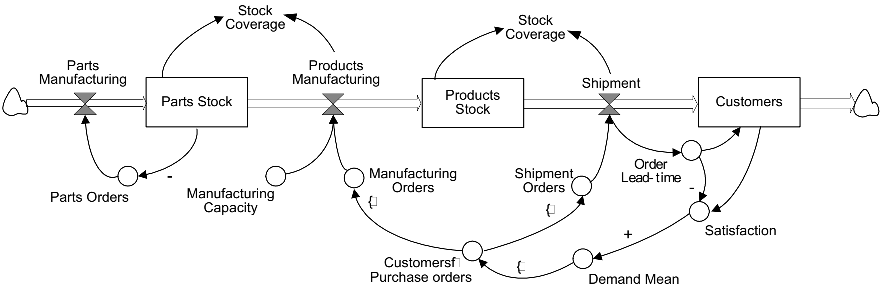


**Fig. 4.** Supply-chain business dynamics model

### 3.2 Simulation experiments

The objective of this experiment is to demonstrate that the proposed "Hybrid-modeling framework" is successful in representing characteristics of supply-chain system. We assigned a simplified form to "Satisfaction" function by the following formula, because the simulation shows an easy-to-understand result. When the satisfaction is greater than 0.5, the next-term "Demand-mean" increases. On the contrary, it decreases, when this is smaller than 0.5.

Satisfaction = c-a*Lead-time (a,c > 0)

(a: Decreasing index c: Constant) ($0 \leq$ Satisfaction $\leq 1$)

Demand-mean(i) = Demand-mean(i-1)*(Satisfaction+0.5)

(Demand-mean $\leq$ Max(Demand-mean))

The transitions between discrete-event simulation and system-dynamics simulation are as follows.

(1) Discrete-event models generate consumers' order by using demand-mean as a random number parameter.
(2) Discrete-event models simulate production activities of ordering, manufacturing, shipping, and receiving, and etc.
(3) This simulation (2) calculates order lead-time to every ordering activity.
(4) The lead-time in (3) is input data to system dynamics model.
(5) Dynamics model estimates this lead-time.
(6) Dynamics model calculates demand-mean.
(7) This demand-mead (6) is used to the next random number generation.

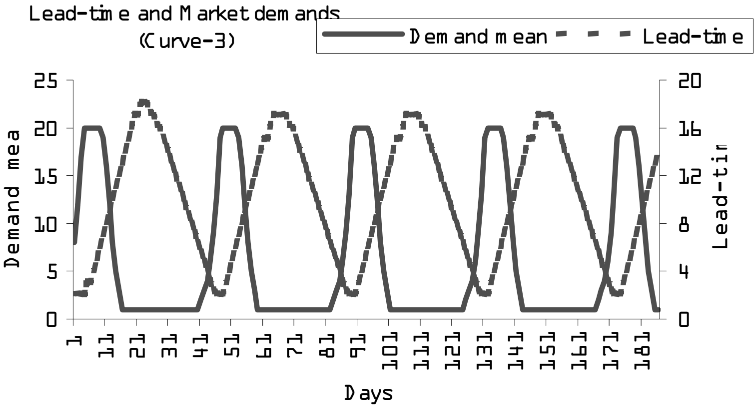


**Fig. 5.** Simulation output data transition (Lead-time and Market demand mean)

Figure.5 represents transitions of "Demand mean" that consumer generates and "Delivery lead-time" that consumer receives. At the initial stage, supply-chain system can provide products to consumer in very short lead-time, because the system is not so busy. Accordingly, the "Satisfaction" index and the demands (orders) increase. The system can affords to accept more orders at that time, and the system becomes gradually busy. The demand finally reaches full production status (the upper limit of the market). As the system becomes busy, the order lead-time becomes longer, and the "Satisfaction" decreases. This consequently makes down demand magnitude. The system becomes not so busy again.

## 4 Conclusion

This paper proposed a novel hybrid simulation-modeling framework combining supply-chain business process models and dynamics models representing enterprise management environment. This framework helps system analysts to evaluate system performance in a long-term period.

Supply-chain systems' activities and external phenomena give favorable or harmful influences each other. And, transition of supply-chain system performance has been performed. The effectiveness of the proposed framework has been confirmed.

A future direction of this research is development of a gaming methodology applied to supply-chain decision-making. Gaming is one of general-purpose methodologies to support management decision-making. Decision makers would play games by using the proposed hybrid- modeling simulator to make management decisions in supply-chain operations under various management hypotheses.

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