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TOWARDS A FLEXIBLE SUPPLY CHAIN MODELLING SYSTEM

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ABSTRACT

There is a growing need to effectively model flexible supply chain management (FSCM) with a focus on control decisions that can alter the entity flows significantly. In this paper, a framework of an object-oriented supply chain environment is proposed. This system incorporates the independent decision making at each supply chain node by modelling each node as an autonomous module. In the proposed framework, independent supply chain nodes are connected to each other by mutual relationships. These relationships are determined using relevant control policies of each node. These relationships may change during execution of the simulation model in accordance with the control policies. This autonomous modelling also provides two additional advantages: distributed simulation capability and capability of role based simulation. In this way, this framework offers scope of learning, practicing and continually improving the flexible supply chain dynamics for supply chain practitioners, supply chain management students and new trainees in a supply management organization. The proposed framework can incorporate both manufacturing and non-manufacturing type of node. Here the supply chain system is studied in terms of multiple entity flows: material, information, money, resource and decision. The framework guides us towards an effective flexible supply chain modelling system.

Keywords: Flexible SCM, Simulation, Multiple Entity Flow, SC Control Decisions

Introduction

In this fiercely competitive business environment, effective and efficient management of supply chain is crucial. There are numerous variables that affect the performance of a supply chain. The performance of supply chain across different dimensions is needed. The changing nature of variables, their logical constraints and performance measures, demand flexibility in control decisions to effectively manage them. Under these complexities, simulation of flexible supply chain management (FSCM) can provide useful insights. Simulation can also assist the supply chain managers to analyze the consequences of alternative decisions before actually taking the decision. It is important to simulate SCs with suitable level of flexibility to deal with changes in demand etc. It is possible to improve flexible system performance by using simulation as shown by Wadhwa *et al.* (2005). This paper is motivated to apply it to supply chain domain. Law and Kelton (1991), Haapasalo and Hyvonen, (2001), Wadhwa and Rao (2003), Park (2005) and several researchers have promoted the use of simulation as a tool for improving the insights of enterprise systems. Object oriented simulation methodology has been used widely both in supply chains and manufacturing systems. Azevedo and Souza (2000) developed a decentralized information system for production planning of distributed manufacturing network. An object oriented methodology to develop a virtual flexible manufacturing system (FMS) has been proposed by

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Park (2005). Similarly, Kovacs *et. al.* (1999) and Anglani *et. al.* (2002) also used object oriented methodology for modeling the FMS. Völkner and Verners (2002) developed an object-oriented simulation based decision support system called GEPSIS for improving the business processes. A prototype object-oriented software system for discrete event simulation was developed by Karachal and Mize (1998). Similarly, Cheng and Fen (2006) developed a prototype web-based distributed problem solving environment (W-DPSE) for computer aided engineering (CAE) technologies. This motivates us to base our framework on the OOPs methodology.

We propose enabling technology of object oriented simulation modeling to deal with flexibility focused supply chains. A major limitation of simulation in modeling supply chain is that autonomous behavior of different supply chain nodes is not properly reflected since a single modeler or a group of modelers defines all the control decisions. However, in a supply chain, each supply chain node is an autonomous entity and each node takes its decisions independently. This characteristic of a supply chain cannot be reflected effectively unless each supply chain node is modeled as an autonomous entity. The exiting supply chain simulation efforts often do not reflect this feature. This paper proposes a supply chain framework where different supply chain nodes are modeled as autonomous agents capable of taking independent decisions. The proposed framework is based on a generic object-oriented architecture. This framework is an extension of multiple entity flow perspective proposed by Wadhwa and Rao (2003). Here a system is modeled and analyzed in terms of five entity flows: Material, Information, Money, Resource and Decision. The inner details of each supply chain node are also developed by combining some basic level entities. Another advantage of this framework over other similar models is the capability of distributed computing where simulation is divided over multiple computers to enhance simulation speed and capability. Additionally, this framework provides for analysis of various supply chain control policies. The proposed framework can immensely help both the supply chain practitioners and learners.

A Generic Model of FSCM

The Global Supply Chain Forum (Lambert *et. al.* (1998)) defines SCM as “the integration of business processes from end-user through original suppliers that provides products, services, and information that add value for customers”. Each stage of the Supply is defined as a link, echelon or node of the supply chain. Quinn (1997) indicated four basic processes involved in supply chains: *Plan, Source, Make* and *Deliver*. Supply-Chain Council (SCC) added: *Return*. Fig 1 shows a generic model of flexible supply chain.

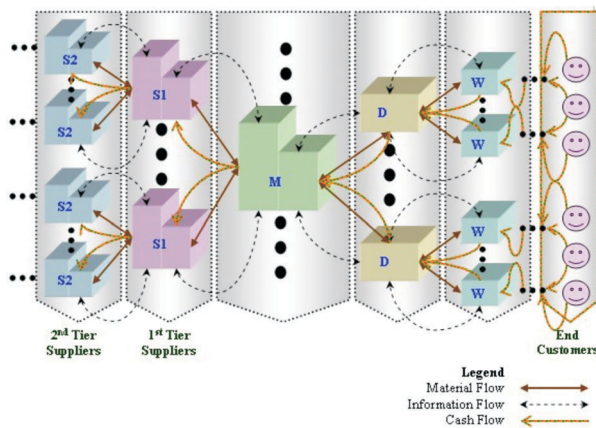


Figure 1: A Flexible Supply Chain Model showing multiple options at each level.

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Each of the above mentioned processes could again be broken down into sub-processes and their respective resources. For instance, *Plan* includes the processes of forecasting, capacity planning, resource planning etc. *Source* includes the processes of vendor selection and vendor management, *Make* includes the resources required for manufacturing or assembling the products. *Deliver* includes the distribution policies and *Returns* includes the return policies and rework policies. Thus we can see that each of the major processes could be further divided in smaller processes. Some of these sub-processes are independent of other processes while some others are dependent on other processes. For example, *Make* is dependent on the *Plan* and its processes. *Make* decisions are also modified by the sourcing policies and by the amount of material that need rework. There are generally three kinds of flows along any two nodes of the supply chain as shown in Figure 1: *Flow of Physical Goods or Materials*, *Information Flow* and *Cash Flow*. The flow of goods is mostly one sided while the flow of information is bi-directional. The flow of goods may also be bi-directional e.g. in the case of defective or returned goods, but that is usually in case of closed-loop supply chains. The information flows from higher to lower echelons is generally includes information regarding the quantity and the quality of the goods required (purchase order, etc.). The information from lower to higher level is regarding the status of the lower echelons' demands. If the orders are fulfilled, the necessary goods along with the information are sent to the higher echelon(s). Otherwise the information regarding the backlogs is sent. Cash flow shows the flow of capital along the chain. Different echelons are separated from each other by their physical boundaries. Performance of a supply chain is usually measured by using some predefined Performance Indicators (PIs) or Performance Metrics (PMs). In addition to the three flows discussed above, two more flow: *resource flow* and *decision flow* are also present within each supply chain node. Figure 2 shows the potential of using OOPS for FSCM.

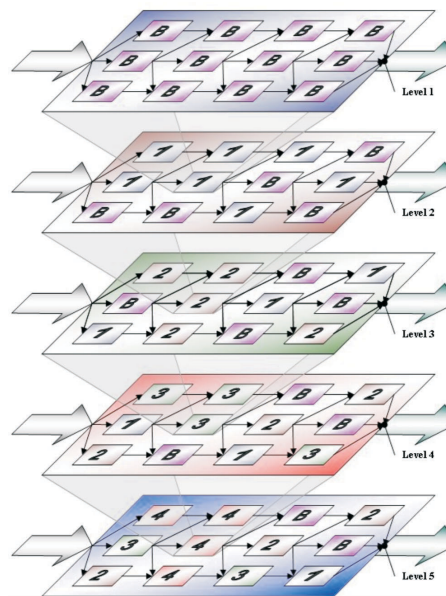


Figure 2: An FSCM Framework based on Object Oriented Modeling

Object oriented modelling is also suitable for modelling of dynamic systems that require changes over time like flexible supply chains. Karachal (1998), Azevedo and Souza (2000), Corbin (1998) promote the use of object-oriented paradigm for modeling complex systems. Grangeon *et. al.* (1999) consider the object-oriented paradigm as a natural extension of the

systemic approach which provides conceptual framework particularly well adapted for building conceptual models and particularly simulation models. According to them, object oriented simulation appears to be a logical choice for developing custom or dedicated simulation models. According to Marin *et. al.* (1998), this modularity provides a very high degree of code reusability. Additionally, the productivity of software development improves if code is reused since the specific modules are already extensively tested by their developers and it is generally not required to test them again (Biswas and Narahari 2004, Hindel 1993). However, Hyeon *et. al.* (1993) feel that these frameworks should be constantly updated in rapidly changing technological environment. The effort required to update these components can also be reduced if modular components are used. Object oriented modeling also provides a natural mapping paradigm which allows one-to-one mapping between objects in the system being modeled and their abstractions in the object model (Biswas and Narahari 2004, Alfieri and Brandimarte 1997). Additionally, object oriented modeling also offers potential advantages in the incremental development and verification of large-scale systems. Anglani *et. al.* (2002) view natural mapping as the possibility to translate each component in the real system in an equivalent element of code. This feature allows the developer to achieve a faster transition of the conceptual model into the software implementation. Baoszormenyi and Stopper (1999) feel that object-oriented models generally have a cleaner structure than the event oriented ones. Thus object oriented modeling applied to supply chain modeling and analysis can be potentially very beneficial (Biswas and Narahari 2004). Supply chain decision making requires rapid and flexible modeling approach at various levels of detail. Object oriented modeling can be used to design and implement reusable classes for building models of supply chains and create a supply chain object library. The concept of an object library facilitates rapid model development of any given supply chain and aids in application of the modeling architecture to specific scenarios at various levels of abstraction. Object oriented modeling can also play an important role in reengineering of systems with a focus on knowledge management. Wadhwa *et al.* (2007) show the benefit of reengineering in automotive sector from a knowledge management perspective. The modeling of these systems can significantly benefit from the proposed methodology.

Modelling of Flexible Supply Chain Constructs

Supply chain flexibility is a relatively new area with a growing number of publications appearing during recent times. Researchers as well as practitioners agree that, to be competitive in a dynamic business environment, supply chains must be more flexible. Hence, there is a considerable interest to enrich this domain. Recently, a number of authors started discussing flexibility from a supply chain perspective. For example, Koste and Malhotra (1999b), emphasised that the presence or absence of flexibility in supply chains and its relationship with performance should be explored and the effect of supply chain integration on the development of flexibility in supply chains should be examined. Duclos et al (2001) propose an integrated model of supply chain flexibility and argue that, if manufacturing flexibility improves performance, supply chain flexibility, which would include the manufacturing flexibility of firms within the supply chain, should further improve performance when measured across the entire supply chain. These observations bring out an important fact that the underlying concepts of manufacturing and supply chain flexibility are very similar and the idea of the flexibility can be extended from the manufacturing domain into the supply chain domain. This highlights the research motivations to focus on the underlying common conceptual framework behind the manufacturing and supply chain flexibility.

In object oriented modeling, any complex system can be modeled by using elementary building blocks called objects. Before presenting the detailed modeling framework, it is pertinent to discuss the elementary objects used in the modeling of a complex supply chain. This section

provides the necessary details of the elementary objects used for modeling the supply chains. In this direction, first a broad classification of these elementary objects is presented. This is followed by a brief discussion on multiple entity flow perspective proposed by Wadhwa and Rao (2003). Finally, the notion of decision points and action points is discussed and its application for modeling complex systems is elaborated.

Depending of the nature of objects, they can be classified as shown in Figure 3. Broadly speaking, there are two kinds of objects: *flow* objects and *non-flow* objects. Flow objects or *entities* move through the system and are transformed by one or more objects. On the other hand, *non-flow* objects remain stationary in the system. Thus flow objects move from one non-flow object to another until some termination condition is encountered. Five different flows are possible in a supply chain system. *Material* flow, *Information* flow, *Money* flow and *Resource* flow are the primary flows. The fifth flow object, called *Decision* flow is formed by the interaction of one or more primary flows or some other decision flow.

The non-flow objects are of two kinds: *Transformation* objects and *Delay* Objects. Transformation objects are the objects that change the state of any or all the flows entering through them. The transformation itself could again be value added or non-value added. The second type of non-flow objects are the delay objects. They simply, delay any or all of the flows entering through them for either a finite amount of time or until the time some release condition(s) is (are) met. Since, delays do not add any value the flows, all delay objects are non-value adding objects. All non-flow objects and the resource flow are resources in the system. *Resources* here are defined as the objects that deliberately modify or transform other flows according to some pre-defined decision rule. As shown in Figure 3, resources can both be flow and non-flow type. Flow resources transform the flow by converting them to decision flow. Non-flow resource objects transform the flows when any of the flow enters through them. Wadhwa and Rao (2005) has also worked on the flexible supply chain and there is a need to extend the work of them.

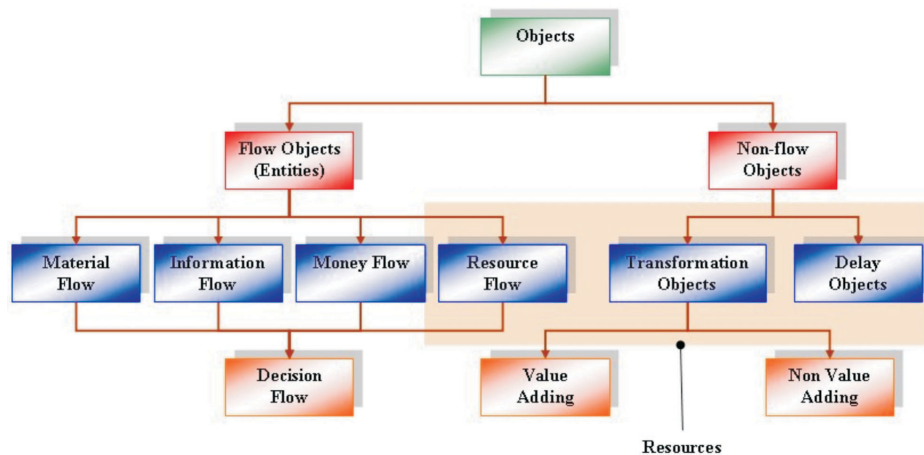


Figure 3: Classification of Objects

Multiple Entity Flow Perspective

From our research perspective, we propose to view the manufacturing systems and supply chains in terms of five types of flows, namely, information flow, decision flow, material flow, resource flow and money flow. In the works of Wadhwa et al. (1986), the concept of a decision

point framework was first proposed for exploitation of flexibility in discrete part manufacturing systems. This framework was used to model flexible assembly systems in which the decision points exercised control on flow of entities such as material, resources and information through a flexible assembly system. Subsequently, Wadhwa and Browne (1989) also suggested a focus on interaction delays caused by processes involving the control on flow of these entities. With a focus on flexible systems, they later proposed three types of decision points linking the decision (direction of status change) and information (system status) to exploit available flexibility in FMS in various forms. In this work, we extend the Multiple Entity flow perspective proposed by Wadhwa and Rao (2003). According to them, the performance of the manufacturing systems and supply chains depend on the complex interaction of these five flows. In the framework provided by Wadhwa and Rao 2003 (see Figure 4), information flow and decision flow were viewed as constituting the control system, which controls the material flow and resource flow. The information and decision flows meet at discrete points called the decision points, and the material and resource flows meet at discrete points called the action points. The decision points and the action points interact with each other to ensure smooth functioning of the system. Taking a generic view, we consider both these points as the events in the system. Here events are defined as the points in time when some change in the state of the system takes place. An event in discrete event simulation is a point in time when some change in the system takes place. Similarly, in discrete-event simulation terminology, an entity is defined as something that flows in the system. As already discussed, five entities could be identified in a supply chain system. These are information flow, decision flow, material flow, resource flow and money flow.

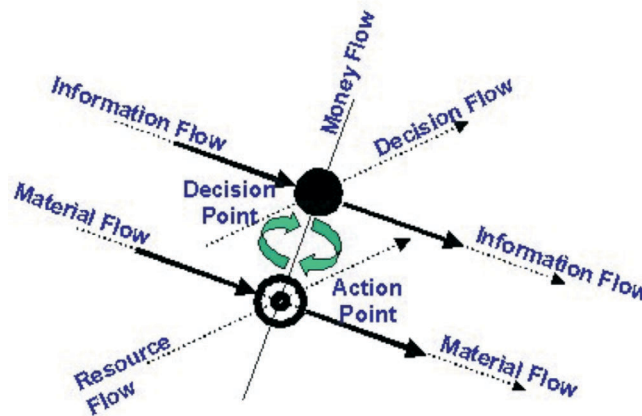


Figure 4: Action and Decision Points (Wadhwa and Rao 2003)

The result of an action is the transformation of the material whereas the result of a decision is a transformation of information. This view was very effective in analysing the manufacturing systems where transformation of the material always takes place. But a supply chain system includes both manufacturing and non-manufacturing nodes. No transformation of the material takes place in the non-manufacturing nodes. We extended this framework to include both manufacturing and non-manufacturing nodes. For this purpose, an action is defined as a sequence of events that intentionally changes the state of the system. Since an action is always intentional, it includes only the intentional events. Now a decision can be defined as something that determines What, When, Where, Who and How of an action. Therefore, a decision always precedes an action. A supply chain system could be modelled as consisting of a number of such action

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and decision points. In each decision or action, one or more of the other flows may be involved. This extended multiple entity flow view is presented in Figure 5. A decision point may involve all the five flows discussed above (Wadhwa and Browne, 1989). The works of Wadhwa and Rao (2005) needs to be extended to simulate flexible supply chain synchronization challenges

Depending on the material flow, there can be four types of actions:

- *Material In:* Material Storage
- *Material Out:* Material Release from a store
- *Material In Material Out:* Material transformation, similar to the action point described by Wadhwa and Rao 2003.
- *No Material Flow:* All other types of actions

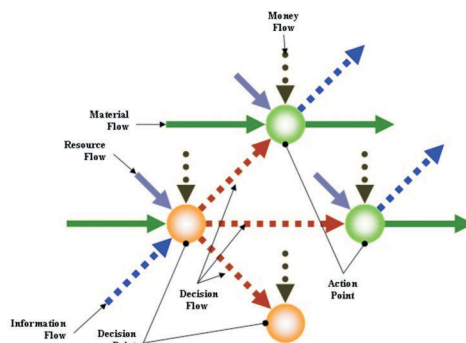


Figure 5: Decision Points and Action Points in Extended Multiple Flow Perspective

Action Points as Processes in the System

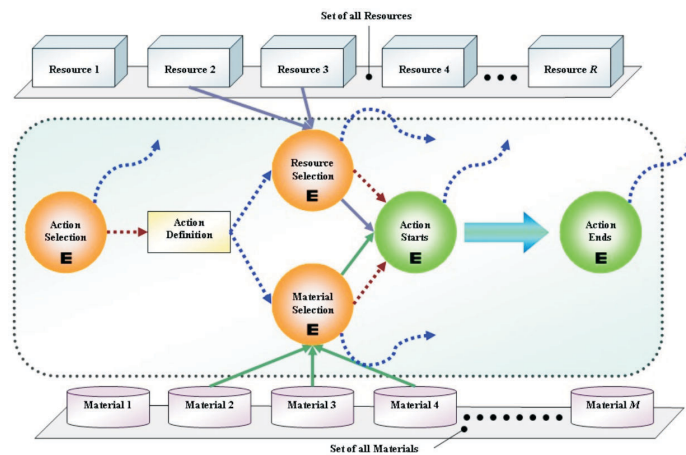


Figure 6: Action: the process view

In the multiple entity flow perspective proposed above, a system is modelled as a sequence of action and decision events. Each decision point or action point can further be analysed as a sequence of events. In the manufacturing system, a finite sequence of events that transforms an entity is called a process. An action point can also be analysed as a process as shown in Figure 6. Each action requires some resources or materials for its accomplishment. As we

have previously discussed, each action is preceded by some decision point. This decision selects the specific action to be taken according to some pre-defined decision rule. Once the action is decided, the next step is to select the resources or materials required for performing this action. These are two decision points that take the required information from action definition. Once, the required resources and materials are available, the action commences. Each action has finite starting and ending points. Both these points are separate events for the simulation system. Each decision point can also have finite starting and ending points represented by separate events. But in our model, we are not concerned with decision delays and therefore, each decision is represented as a single point. Each event in the action point is shown with a symbol “E” in Figure 6. Each event in this process view may also lead to some other decisions or actions. Therefore, at each event an extra information flow arrow is added. For resource selection, it could mean that the list containing the available resources is updated. For material selection, this may mean that the inventory position of the available materials is updated. Similarly, at the start of an action this may mean that the state of the allocated resource is updated. Finally, when the action terminates, it is necessary to transmit the information regarding the status of the resources and the updated status of the inventory.

In the simulation of a manufacturing system, a sequence of events that transforms an entity is referred to as a process. The sequence of action and decision points can again be represented as a sequence of processes as shown in Figure 7. From this figure, it can be inferred that each action always requires one or more resources for its completion. On the other, hand the material requirement at each action is not necessary. Some actions may require one or more materials while some may not require any external material (e.g. the action to store the material). The action takes place when the required resources and resources are available. The completion of an action again leads to a new decision. This decision selects the new action to be taken. This again leads to resource and material selection and accomplishment of the action. This whole process repeats until the termination condition is satisfied. The next section discusses the hierarchy of objects used in the framework.

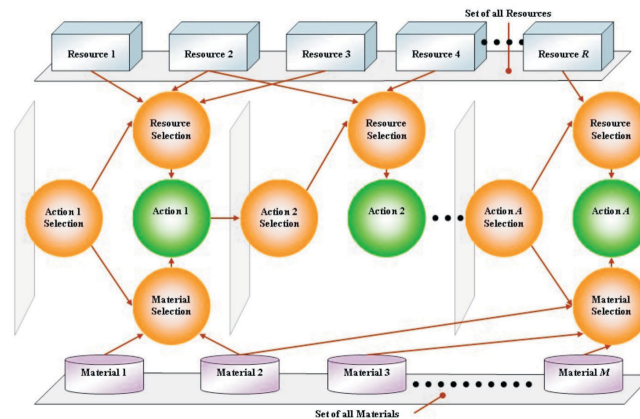


Figure 7: Action and Decision Points as Sequence of Processes

Conclusions and Future Directions

A framework for an object-oriented supply chain modelling was proposed in this paper. This framework is based on object oriented methodology that allows building complex simulation models by combining some basic or primitive objects. This proposed framework provides several advantages over existing supply chain systems. First of all, this system incorporates the

independent decision making at each supply chain node by modelling each node as an autonomous entity. Different supply chain nodes are connected to each other by mutual relationships. This autonomous modelling also provides two additional advantages. Firstly, the simulation can be distributed over multiple computer systems to enhance to simulation speed and capability. Secondly, this environment is also suitable for role based simulation of a supply chain where decision making at each node is performed by flexible supply chain managers. This also offers scope of learning supply chain dynamics to supply chain management students or new trainees in a supply management organization.

References

- Alfieri A., Brandimarte R., (1997), Object-oriented Modeling and Simulation of Integrated Production/Distribution Systems, *Computer Integrated Manufacturing Systems*, 10(4), 261-266
- Anglani A., Grieco A., Pacella M., Tolio T. (2002), Object-oriented Modeling and Simulation of Flexible Manufacturing System: a Rule-based Procedure, *Sim. Mod. Prac. Theory*, 10, 209–234
- Azevedo A.L., Sousa J.P. (2000), A Component-based Approach to Support Order Planning in a Distributed Manufacturing Enterprise, *Journal of Materials Processing Technology*, 107, 431-438
- Biswas S., Narahari Y., (2004), Object Oriented Modeling and Decision Support for Supply Chains, *European Journal of Operational Research*, 153, 704–726
- Böszörményi L., Stopper A., (1999), Semi-automatic Parallelization of Object-oriented Simulations, *Simulation Practice and Theory*, 7, 295-307
- Cheng H., Fen C., (2006), A Web-based Distributed Problem-solving Environment for Engineering Applications, *Advances in Engineering Software*, 37, 112–128
- Corbin M., (1998), Applications of Mobile Agents and Ambassadors in Distributed Simulation, *Simulation Practice and Theory*, 6, 505–532
- Garavelli A.C.; (2003); Flexibility Configurations for the Supply Chain Management; *IJPE*; 85; 141–153
- Grangeon N., Tanguy A., Tchernev N., (1999), Generic Simulation Model for Hybrid Flow-shop, *Computers and Industrial Engineering*, 37, 207-210
- Haapasalo H. and Hyvonen J., (2001), Simulating Business and Operations Management – A Learning Environment for the Electronics Industry, *Int. J of Production Economics*, 73, 261-272.
- Hindel B., (1993), How to ensure software quality for real-time systems, *Con. Eng. Pract.*, 35-41
- Hyeon H.J., Hamid R.P., Sullivan W., (1993), *Principles of Concurrent Engineering*, London: Concurrent Engineering, Chapman and Hall, 3-23
- Jansen D.R., Weert A., Beulens A.J.M., Huirine R.B.M.; (2001); Simulation Model of Multi-Compartment Distribution in the Catering Supply Chain; *European Journal of Operational Research*; 133; 210-224
- Kaihara T.; (2003); Multi-agent Based Supply Chain Modelling with Dynamic Environment; *Int. J. Production Economics*; 85; 263–269
- Karachal S.C., (1998), A Novel Approach to Simulation Modeling, *Computers in Industrial Engineering*, 34(3), 573-587
- Karachal S.C., Mize J.H., (1998 March), A Formal Structure for Discrete event Simulation. Part II: OO Software Implementation for Manufacturing Systems, *IIE Transactions*, 30(3), 217-226
- Kimbrough S.O., Wu, D.J. Zhong F.; (2002); Computers Play the Beer Game: Can Artificial Agents Manage Supply Chains?; *Decision Support Systems*; 33; 323–333
- Kovacs G.L., Kopacsi S., Nacsa J., Haidegger G., Groumpos P., (1999), Application of Software Reuse and Object-oriented Methodologies for the Modeling and Control of Manufacturing Systems, *Computers in Industry*, 39, 177–189
- Lambert D., Stock J., and Ellram L.; (1998); eds: The Global Supply Chain Forum, in

Fundamentals of Logistics Management, Irwin-McGraw Hill; Boston

- Law A.M. and Kelton W.D., (1991), *Simulation Modeling and Analysis*, Second Edition, McGraw-Hill Series in *Industrial Engineering Series and Management Science*, Singapore
- Machuca J.A.D., Barajas R.P.; (2004); The Impact of Electronic Data Interchange on Reducing Bullwhip Effect and Supply Chain Inventory Costs; *Transportation Research Part E*; 40; 209–228
- Marin R., Garrido J., Trillo J.L., Armesto J., Sáez J., (1998), Object-oriented Framework to Develop Automates Warehousing Systems Based on Step, *IRCIM*, 14, 253-261
- Mason S.J., Ribera P.M., Farris J.A., Kirk R.G.; (2003); Integrating the Warehousing and Transportation Functions of the Supply Chain; *Transportation Research Part E*; 39; 141–159
- Minegishi S., Thiel D.; (2000); System Dynamics Modeling and Simulation of a Particular Food Supply Chain; *Simulation Practice and Theory*; 8; 321-339
- Nagatani T.; (2004); Dynamical Transition in Random Supply Chain; *Physica A*; 335; 661–670
- Park S. C., (2005), A Methodology for Creating a Virtual Model for a Flexible Manufacturing System, *Computers in Industry*, 56, 734–746
- Quinn F.J.; (1997); What's the Buzz?; *Logistics Management*, 36(2), 43-47
- Rumbaugh J., Blaha M., Premerlani W., Losenson W., (1991), *Object-Oriented Modeling and Design*, Prentice Hall Inc., Englewood Cliffs, NJ, 1991
- Shehab E.M., Abdalla H.S., (2001), Manufacturing cost modelling for concurrent product development, *Robotics and Computer Integrated Manufacturing*, 17, 341-353
- *Supply Chain Operations Reference Model: Overview of SCOR Version 8.0*; Supply Chain Council, 1400 Eye Street, Suite 1050, Washington DC, 20005, www.supply-chain.org
- Völkner P., Werners B., (2002), A Simulation-based Decision Support System for Business Process Planning, *Fuzzy Sets and Systems*, 125, 275–287
- Wadhwa S., Rao K.S., (2003), Enterprise Modeling of Supply Chains Involving Multiple Entity Flows: Role of Flexibility in Enhancing Lead Time Performance, *SIC*, 12(1), 1-16
- Wadhwa S., Felix C., Browne J., (1986), *A Goal Directed Data Driven Simulator for FAS Design*, paper presented at European Simulation Multi-Conference, Vienna, Austria, published as Feature Article in *Simulation News Europe, A European Forum on Simulation Activities*, 2 (3), 13-19.
- Wadhwa S., Browne J., (1989), Modelling FMS with Decision Petri Nets, *The International Journal of Flexible Manufacturing Systems*, 1, 253-280.
- Wadhwa, S., Bhagwat, R., “Judicious Increase in Flexibility and Decision Automation in Semi-Computerized Flexible Manufacturing (SCFM) Systems”, *SIC*, 1998
- Wadhwa S., Rao K.S., (2000), Flexibility: An Emerging Meta-competence for Managing High Technology, *International Journal of Technology Management*, 19 (7-8), 820-845.
- Wadhwa S., Rao K.S., Chan F.T.S., (2005), Flexibility-enabled Lead-time Reduction in Flexible Systems, *International Journal of Production Research*, 43 (15), 3131–3162
- Wadhwa S., Saxena, A., Bibhushan, “Flexible Supply Chains: A Context for Decision Knowledge Sharing and Decision Delays”, *Global Journal of Flexible Systems Management*, 7(3&4), July -Dec 2006
- Wadhwa S., Bibhushan, Bhoon K.S., Chan F. T. S., (2007), Postponement Strategies for Re-engineering of Automotive Manufacturing: Knowledge-management Implications, *IJAMT*, Article in Press, doi 10.1007/s00170-006-0679-z.