# Commitments for Agent-Based Supply Chain Management

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As supply chain networks are becoming more and more global, process coordination must be considered a crucial point for successful business management. The need for a suitable management and communication framework is thus becoming evident. We already have some examples showing that information sharing is a key-point at certain levels of a supply chain network. As there are several analogies between a company in a business network and an agent, the Multi-Agent System paradigm can be a valid approach for modelling supply chain networks. We consider commitment as a concept that underlies the whole multi-agent environment, that is, an inter-agent state, reflecting a business relation between two companies that make themselves represented by software agents. We present a data structure for commitments that can be used in the agent-based communication framework for the management of a supply chain. Business partnership between companies leads to the creation of a "channel" through which we can identify three different kinds of flow (products, money and information). We show how commitments that deal with these flows are related to one another and how they can affect the supply chain.

Categories and Subject Descriptors: C.2.4 [**Computer-Communication Networks**]: Distributed Systems; K.4.3 [**Computers and Society**]: Organizational Impacts

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## 1. INTRODUCTION

A supply chain is a network of business units that enables the collection of raw material, its transformation into products and the delivery of these products to consumers through a distribution system. The aim of supply chain management (SCM) is to manage these activities so that products go through the business network in the shortest time and at the lowest costs possible [Lee and Billington 1995]. As supply chain networks (SCNs) are becoming more and more global, process coordination must be considered a crucial point for successful business management.

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The focus of SCM is shifting from production process engineering, whose purpose is to obtain *point-wise* efficiency, to supply chain activity coordination, aiming at *global* efficiency. The need for a suitable management and communication framework is thus becoming more and more evident. In this paper we first stress that information sharing is a critical factor for successful business process management (Section 2). Then we argue that one of the most effective ways to achieve the above-mentioned information sharing is to build an agent-based framework which models the dynamic structure of today's supply chain networks (Section 3). Finally, we provide a model for the social concept of commitment which in our opinion can support the construction of an effective communication standard for the agents that are interacting throughout a supply chain network (Section 4).

## 2. SUPPLY CHAIN ISSUES

We already have some examples showing that information sharing is a key-point at certain levels of a supply chain network. Just-In-Time (JIT) is a production process approach that strives to eliminate sources of manufacturing waste by producing the right part in the right place and time. Transportation and storage are among those activities that increase costs without adding significant value and thus may cause this waste. JIT should improve profits and return on investment by reducing inventory levels (increasing the inventory turnover rate), improving product quality, reducing production and delivery lead times, and reducing other costs (such as those associated with machine setup and equipment breakdown). Continuous Replenishment Program (CRP) is considered to be one of the most effective means of supporting an efficient consumer response strategy. The program is based on a close cooperation between supplier and retailer and is aimed at the optimization of their common supply chain. CRP transforms the traditional process of the supply of goods directed by retailing into a process of mutual cooperation, where the supplier determines the demands on replenishment according to the information provided by the retailer. The whole process begins with the receipt of a daily stock level report via electronic information channels (for instance EDI). The received data is evaluated, filed and processed further for order proposals. It is clear that both of these methodologies are strictly based on the distribution of information about scheduling, shipments and production among all the parties involved in those processes. This data deployment reduces warehouse costs and production times because it improves the coordination of supply chain processes, making the material flow faster throughout the business network [Strader et al. 1998].

Now that we have seen some benefits coming from information sharing throughout a supply chain network, let us examine what may be the effect of the lack of it. One of the most blatant examples is the *bullwhip effect* [Lee et al. 1997], in which petty variations of consumers's demand get amplified along the supply chain and finally become wide fluctuations at suppliers's level. Among the causes this effect is ascribed to, in our opinion the most important is *demand signal processing*. If sales data are not transmitted to the supply chain upstream levels, the business units at each chain node are compelled to predict demand only on the basis of their next downstream node's orders. Thus, multiple forecasts are made and prediction errors grow bigger and bigger as biased demand data moves up the supply chain.

At the same time information about the suppliers's production processes, including capacity and inventory data, is not shared with the downstream nodes. All this results in a vicious cycle of shortage gaming and wide demand oscillations [Tan et al. 2000]. All the effective solutions to this problem, like sharing capacity and inventory data or continuous replenishment programs, can be naturally identified as the need for information sharing and for a proper infrastructure to support it [Shaw 1999].

Such an information framework is also necessary to implement new supply chain paradigms. There are two consolidated SCN paradigms, make-and-sell and sense-and-respond [Bradley and Nolan 1998], which respectively correspond to two fundamental aims of supply chain management – making the products flow efficiently along the value-added chain at low costs and conforming the products provided to the market's demand. A make-and-sell company's business processes are focused on manufacturing so to exploit economy of scale, and then on offering the ready-made articles to consumers in an appealing way. On the other hand, sense-and-respond companies aim at quickly responding to specific needs expressed by the market. The physical product and other value-added services compose the whole response of the enterprise to the consumers, whose requests (together with the market's conditions) guide the production process. The type of product usually determines the best paradigm to adopt in a supply chain network [Fisher 1997]. The make-and-sell paradigm is well-suited for the production of articles of wide consumption, characterized by a very long life cycle, a stable demand pattern, and low differentiation. On the other hand, products like fashion apparel, which changes from season to season, or high-tech goods, which become quickly obsolete, have a short life cycle and need a sense-and-respond supply chain paradigm. The great diffusion of the Internet and the rapid evolution of Web technologies enabled the consumers to enjoy new kinds of purchasing experience, among which the most remarkable is customization. Customizable products are characterized by high differentiation, which prevents companies from stocking all the possible product variations in their warehouse. Even if the total demand from the market is relatively stable, the real challenge is to predict the correct product mix. This new category of products needs a solution that combines the benefits from both of the above-mentioned approaches. The new "assemble-to-order" paradigm provides that product components are manufactured and stocked in great quantities, so to exploit economy of scale and decrease production, warehousing and transportation costs. The components are to be assembled into final products on the basis of the orders coming from the consumers, thus improving customers's satisfaction and reducing response time between the receipt of an order and its completion [Yang 2000]. The role of the information coming from the consumer end of a supply chain is more important in this SCN paradigm than in all the others, because in this case it directly affects the manufacturing process of the final product and thus involves several nodes of the business network. As the mass customization phenomenon is becoming more and more widespread, we have another notable evidence of the fundamental role played by information sharing in supply chain networks.

## 3. THE AGENT PARADIGM FOR SUPPLY CHAINS

We don't have a universally accepted definition of *agent* yet, but most researchers agree upon a weak notion of agency [Wooldridge and Jennings 1995]. According to it, a computer system or a program that is characterized by the properties of *autonomy*, *social ability*, *reactivity* and *pro-activeness* can be denoted as an agent. Being autonomous means being able to act with no intervention by other entities (humans or computer systems), and having control upon one's own actions and, to some extent, internal state. Social ability is the capability to interact with others by means of a language, that is, an agent communication language (ACL) in the case of agents. An agent is reactive if it is equipped to perceive the environment around itself and is able to respond to its changes. If these responses are not simply immediate reactions to stimuli but are part of a more complex goal-directed behavior, the agent is said to be pro-active. We are able to recognize all these properties also in a business company. A single business unit in a supply chain is a company, which operates autonomously to achieve its own objectives, organizing its possible actions into plans on the basis of the available knowledge. Companies that are not able to react to changes in the market, which can be considered as their environment, are very likely to fail. In Section 2 we have already stressed the importance of information sharing between organizations to achieve the goals of a supply chain network. A supply chain can be considered as a network of autonomous business units aiming at the procurement, manufacturing and distribution of related products [Swaminathan et al. 1998]. So, if we keep in mind the above-mentioned analogies between a company in a business network and an agent, it becomes clearer that the Multi-Agent System (MAS) paradigm is a valid approach for modelling supply chain networks and for implementing supply chain management applications. Multi-agent computational environments are well-suited for analyzing coordination problems involving multiple agents with distributed knowledge and relying on a communication framework [Bond and Gasser 1988]. Thus, a MAS model seems to be a natural choice for supply chain management, which is intrinsically dealing with coordination and coherence among multiple actors. There are already several examples of knowledge-based multi-agent systems related to manufacturing [Roboam et al. 1991; Pyke and Cohen 1994]. The benefits of adopting agent technology also in supply chain management are several. The inherent autonomy of software agents enables the different business units of a supply chain network to retain their autonomy of information and control, and allows them to automate part of their interactions in the management of a common business process [O'Brien and Wiegand 1998]. The great advantages of information sharing between organizations are achievable only if the information structure is characterized by a common semantics, that is, if the transmitted data have the same meaning at every node of the communication framework. Otherwise, if each business unit applies a different interpretation to the information that reaches it flowing throughout the supply chain network, there is effective knowledge sharing only in proportion to what all these interpretations have in common, or their intersection, which is empty in the worst case. The abstraction offered by an agent-based framework deals with this issue by requesting that all parties involved subscribe to a common terminological system, also known as an ontology, that is, they agree upon one interpretation of data that is unique and universal within the scope of the relevant communication framework [Shepherdson et al. 1999]. If this shared interpretation differs from the local one, a mapping system should be put up to automate the translation process. Enterprise Application Integration (EAI) provides solutions to this kind of tasks [Linthicum 1999; Lutz 2000]. There already exists a model for representing the knowledge of an agent and the dynamics of its changes with respect to new information and modifications in the environment. It is called BDI model [Rao and Georgeff 1991] and it is named after *beliefs*, *desires* and *intentions*, on which it bases a rational agent's actions. These concepts take origin from British philosopher Bratman's studies about practical reasoning [Bratman 1987], and they were originally aiming at modelling human rational actions. The BDI model provides that all the knowledge of a rational agent about the world is organized in statements that are its beliefs. An agent's desires depict some states of the world that the agent "would like" to be realized. If those desires lead to the elaboration of a plan of actions the agent becomes committed to, they reach the status of intentions [Wooldridge 2000]. The theory underlying this model makes use of modal logic operators [Chellas 1980] to represent agent properties. We can use BDI as a model for the reasoning mechanisms of rational agents, so to transfer the knowledge and the business plans, or at least a subset of them, from a company within a supply chain network to the agent framework. Thus, part of the business processes of a company, participating to a virtual enterprise created upon the information framework of a supply chain, can be delegated to software agents that populate the network. The process of modelling the internal architecture of an agent representing a business unit lies beyond the scope of our paper, which is instead focusing on inter-agent communication that reflects inter-company business process management.

## 4. COMMITMENTS IN A SUPPLY CHAIN

In Section 3 we have pointed up the common aspect of autonomy shared by business companies and software agents. The functioning of a supply chain network is strictly depending on the management of this autonomy. If companies took arbitrary decisions with no consideration of the other units they are related to in a business network, the supply chain would not work properly and would soon collapse. Thus, there is a need for a set of rules that work as a "social contract" [Rousseau 1762] between companies, constraining their behavior so to safeguard the interests of all the business network nodes and consequently the existence of the supply chain itself. These rules can be seen as *commitments* that a company makes with respect to the others, so the implementation of a mechanism for the construction and the management of commitments seems to be a natural choice to deal also with agents's autonomy in a supply chain network [Jain et al. 1999]. Now, let us have a closer look to what commitments are and propose some guidelines on how they can be implemented and utilized in an agent-based communication framework. We consider commitment as a concept that underlies the whole multi-agent environment of a supply chain network. More precisely, a commitment is an inter-agent state, reflecting a business relation between two companies, that binds an agent (the *debtor*), relative to another agent (the *creditor*) to the fact that it will take some actions within a determined time interval. We adopt the object oriented paradigm [Fornara and Colombetti 2002] and give commitments a class-like structure, whose fields contain all relevant information, as below:

—debtor: an agent who is the debtor of the commitment

—creditor: an agent who is the beneficiary of the commitment

—content: a proposition expressing the content of the commitment

—condition: a condition that must be satisfied to activate the commitment

—state: the state of the commitment

In order to have plain commitments, which don't depend on a condition, we can simply set condition to 'true', so that it is at any time satisfied. A commitment's states are the following:

—*Unset*: in general, an agent is not allowed to commit another agent, that is, creating a commitment with another agent in debtor. Instead, it is able to make a request for a commitment. This request, which we call *precommitment*, is a commitment whose state is *unset*, the addressee is its debtor, the sender its creditor.

—*Pending*: if a precommitment is accepted, its addressee asserts the will to commit itself, and the state of the commitment becomes *pending*. This means that the agent in debtor becomes committed to execute all the tasks in content when the commitment's condition becomes true.

—*Active*: the debtor is committed, so it must complete what is expressed by content.

—*Fulfilled*: the agent in debtor has succeeded in completing all the tasks of the content, so the commitment is fulfilled and the agent is discharged from its duties.

—*Violated*: the debtor has failed in completing its duties, so the commitment has been violated. The commitment is no longer working, so the former creditor needs to create another one, and the former debtor is discharged, but is liable to a sanction or other measures, according to previous business agreements.

—*Cancelled*: the commitment has been cancelled and is no longer relevant to any agent.

Commitment management relies on some principles that have to be always obeyed in order to keep the whole system consistent: once created, a commitment cannot be destroyed, and even if it is cancelled, there will always be a relevant record. Besides, commitment states are mutually exclusive, and their evolution in time follows a precise dynamics (see Figure 1) as follows:

*→UNS.* An agent $a$ can make a proposal to another agent $b$ for a commitment, with $a$ in creditor and $b$ in debtor. Agent $a$ is able to achieve this with a primitive action called `MakeCommitment` (`MC` in Figure 1) with '*unset*' as a parameter expressing the state of the new commitment (`UNS`).

*UNS→PEND.* The agent in debtor uses primitive action `Set Commitment` (`SC`) with '*pending*' as a parameter to accept a precommitment. Thus, the state becomes *pending* (`PEND`) and the agent in debtor becomes committed to content as soon as condition becomes true.

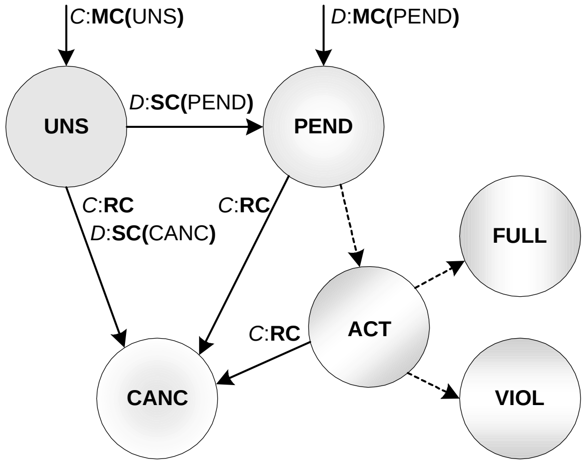


Fig. 1. The dynamics of commitment states.

*→PEND.* An agent may immediately commit itself without being asked – this is the case of promises. A commitment is thus created, with state equal to *pending*. This also is obtained with `MakeCommitment`, this time with '*pending*' as a parameter. Only an agent which thus becomes a debtor ($D$ in Figure 1) is allowed to act like this.

*PEND→ACT.* condition becomes true, so a pending state becomes *active* (`ACT`). This transition is represented in Figure 1 with a dotted arrow because it is not dealing directly with agents's primitive actions, but it depends on other events. If the commitment is plain, that is, its condition is 'true', this transition takes place as soon as state becomes *pending*.

*UNS→CANC.* The state of a precommitment can turn into *cancelled* (`CANC`) for two reasons – a precommitment can be retracted by its creditor ($C$ in Figure 1) with the primitive action `RetractCommitment` (`RC`) or rejected by the debtor with `SetCommitment` with parameter '*cancelled*'. This is the only case in which the debtor is allowed to cancel its commitment.

*PEND→CANC and ACT→CANC.* The creditor of a commitment can retract it while its state is *pending* or also *active* with `RetractCommitment` (`RC`).

*ACT→FULL and ACT→VIOL.* Depending on whether the agent in debtor has managed to complete its duties in content or not, the active commitment's state becomes respectively *fulfilled* or *violated*. Again, in Figure 1 these transitions are depicted with dotted arrows because they do not result from any primitive action.

Let us now examine how commitments can be used to model business relationships between companies in a supply chain network. A SCN has obviously a network-like structure, but we are able to identify a modular framework, whose base unit is a pair of business partners – a supplier and a client. A company may indeed have more than one supplier or one client, as depicted in Figure 2, but its business relationships in terms of commitments to a partner are not to *explicitly*

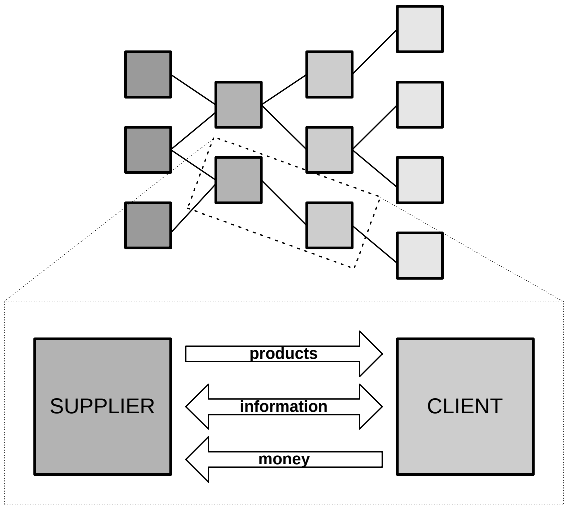


Fig. 2. The supply chain network structure.

affect the company's duties to other actors in the supply chain. Thus, there is no need for considering other entities when we analyze the possible commitments between a supplier and its client. We will broaden our scope to include more than just a pair of business units when we consider the influence of commitments over the entire supply chain. Business partnership leads to the creation of a "channel" through which we can identify three different kinds of flow (see Figure 2):

—*Product flow* from supplier to client: it may be comprised of raw material, semifinished or also final products, according to the supply chain tier the companies belong to.

—*Money flow* from client to supplier: it consists of the payments in return of the above-mentioned products.

—*Information flow* from supplier to client and vice versa: information exchange is necessary both for the negotiation phase and for the notification of the state of ongoing business processes.

Even if we can model the commitments that enable these three flows with the same data structure that we have already illustrated, their consequences upon the supply chain are different. Commitments dealing with product flow are the ones that affect the supply chain in the most immediate and direct way. Let us illustrate this fact with a simple example. Company A in Figure 3 is a fabric supplier, B is a clothing factory and C is an apparel store. In our notation, $C^p_{AB}$ stands for a commitment dealing with product flow in which A is debtor and B creditor. If the supply chain network structure is so that B's only fabric supplier is A, the fulfillment of $C^p_{BC}$ is strictly dependent on the state of $C^p_{AB}$, as factory B would not be able to provide finished clothes to retailer C without fabric from A to make those clothes with. We can represent this situation with a formula

$$\mathsf{state}(C^p_{AB})=\text{'}\mathit{violated}\text{'} \Rightarrow \mathsf{state}(C^p_{BC})=\text{'}\mathit{violated}\text{'}$$

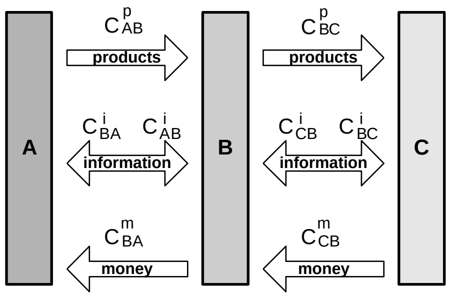


Fig. 3. The commitments between companies in a supply chain

meaning that if A fails to fulfill its duties to B, the latter is compelled to do the same with respect to C. These issues are to be dealt with both by supplier A and by retailer C, involving other business units that are not in Figure 3. Thus, according to the supply chain network structure created by the business relations among companies, a *chain of commitments* is also created. It consists of a sequence of commitments whose final state propagates along the relevant path of the supply chain network. Commitments dealing with money flow ($C^m_{XY}$ in our notation) may also form a chain, but their influence upon the business network is less direct. The fulfillment of $C^m_{BA}$ in Figure 3 depends on $C^m_{CB}$ only if factory B does not have enough liquidity and retailer C's payments are sufficient to clear B's debts to supplier A. It is clear, then, that all these factors are partly beyond supply chain management, as they depend on a company's settling strategy. Anyway, it is important to notice that if there is a final state propagation for money flow commitments, it goes upstream from clients to suppliers, that is, in the opposite direction of product flow commitments, which propagate downstream from suppliers to clients. As far as now, we have considered commitment as a concept strictly related to actions (including product and money transfer), but let us give an example of a different use of it. If content is not containing a task that must be completed but more simply a statement $s$, the agent in debtor can be considered as committed to the *truth* of $s$. Thus, the commitment data structure can be used to model not only a business company's commitments in their literal sense, but also its assertions, whose truthfulness it becomes committed to. In our opinion, this use of commitments enables the construction of a communication framework for information sharing that safeguards every unit's interests and reputation, as any source of incorrectness can be easily identified. Finally, then, we have information flow commitments ($C^i_{XY}$), which are not depending on any direction, as every business unit needs to share information both with suppliers and clients. We could identify a chain also for this kind of commitments, when some data, for instance sales data or raw material availability, is transmitted up or downstream along the supply chain. In Section 2 we have already illustrated in detail what may be the consequences of the lack of effective information sharing upon a SCN. The most effective way of exploiting these mechanisms for communication between agents representing business units is to base their language upon the very concept of commitment [Singh 1998]. So far, we have not dealt with some interesting issues that we intend to investigate in our future works. These topics include the possibility to renegotiate already established commitments and loosening the strict boundaries between *fulfilled* and *violated* states, to model also obligations that are only partially fulfilled.

## 5. CONCLUSIONS

In this paper we have proposed some guidelines for the construction of an agent-based and commitment-based communication framework for managing a supply chain network. We on purpose omitted any detail about modelling and implementing a company's business processes with a software agent. Thus, some reader may wonder to what extent an enterprise should automate its processes and delegate them to an agent representing it in the supply chain network. There is no unique solution to this issue, as every business environment has its own characteristics and dynamics, and only the actors that are in it know the boundaries of the tasks that can be fully executed by programs. We think that the framework that we have outlined is flexible enough to let managers decide what part of their company's processes they want to model with it.

## REFERENCES

Bond, A. H. and Gasser, L. 1988. An analysis of problems and research in distributed artificial intelligence. In *Readings in Distributed Artificial Intelligence*, A. H. Bond and L. Gasser, Eds. Morgan Kaufman Publishers, 3–35.

Bradley, S. and Nolan, R. 1998. *Sense and respond: capturing value in the Network Era.* Harvard Business School Press, Boston, MA.

Bratman, M. E. 1987. *Intention, Plans, and Practical Reason.* Harvard University Press.

Chellas, B. 1980. *Modal Logic: An Introduction.* Cambridge University Press.

Fisher, M. L. 1997. What is the right supply chain for your product? *Harvard Business Review*.

Fornara, N. and Colombetti, M. 2002. Operational specification of a commitment-based communication language. In *Proceedings of the First International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 02).* Bologna, Italy.

Jain, A. K., Aparico IV, M., and Singh, M. P. 1999. Agents for process coherence in virtual enterprises. *Communications of the ACM 42,* 3, 62–69.

Lee, H. L. and Billington, C. 1995. The evolution of SCM models and practice at Hewlett-Packard. *Interfaces 25,* 5 (September–October), 42–63.

Lee, H. L., Padmanabhan, V., and Whang, S. 1997. Information distortion in a supply chain: the bullwhip effect. *Management Science 43,* 4 (April), 546–558.

Linthicum, D. 1999. *Enterprise Application Integration.* Addison-Wesley, Boston, MA.

Lutz, J. C. 2000. Eai architecture patterns. *EAI Journal 1,* 3 (March).

O'Brien, P. and Wiegand, M. 1998. Agent based process management: applying intelligent agents to workflow. *The Knowledge Engineering Review 13,* 2, 161–174.

Pyke, D. F. and Cohen, M. A. 1994. Multiproduct integrated production distribution systems. *European Journal of Operations Research 74,* 1, 18–49.

Rao, A. S. and Georgeff, M. P. 1991. Modeling rational agents within a BDI-architecture. In *Proceedings of the 2nd International Conference on Principles of Knowledge Representation and Reasoning*, J. Allen, R. Fikes, and E. Sandewall, Eds. Morgan Kaufmann publishers, 473–484.

Roboam, M., Sycara, K., and Fox, M. 1991. Organization modeling as a platform for multi-agent manufacturing systems. In *Proceedings of the Fourth IFIP Conference on Computer Applications in Production and Engineering.* Bordeaux, France.

Rousseau, J. J. 1762. *Du Contrat Social, ou Principes du Droit Politique.* Marc Michel Rey, Amsterdam, NL.

SHAW, M. J. 1999. Web-based enterprise resource planning. In *Enterprise Management and Resource Planning: Methods, Tools and Architectures (EMPRS'99) Proceedings*. Venice, Italy.

SHEPHERDSON, J. W., THOMPSON, S. G., AND ODGERS, B. R. 1999. Cross organizational workflow co-ordinated by software agents. In *Workshop on Workflow Interoperability at The International Joint Conference on Work Activities Co-ordination and Collaboration*. San Francisco, CA.

SINGH, M. P. 1998. Agent communication languages: Rethinking the principles. *IEEE Computer 31*, 40–47.

STRADER, T. J., LIN, F., AND SHAW, M. J. 1998. Simulation of order fulfilment in divergent assembly supply chains. *Journal of Artificial Societies and Social Simulation 1,* 2.

SWAMINATHAN, J. M., SMITH, S. F., AND SADEH, N. M. 1998. Modeling supply chain dynamics: A multiagent approach. *Decision Sciences 29,* 3.

TAN, G. W., SHAW, M. J., AND FULKERSON, W. 2000. Web-based supply chain management. In *Hanbook on Electronic Commerce*, M. J. Shaw, R. Blanning, T. Strader, and A. Whinston, Eds. Springer-Verlag.

WOOLDRIDGE, M. 2000. *Reasoning about Rational Agents.* MIT Press, Cambridge, MA.

WOOLDRIDGE, M. AND JENNINGS, N. R. 1995. Intelligent agents: Theory and practice. *The Knowledge Engineering Review 10,* 2, 115–152.

YANG, B. R. 2000. Supply chain management: Developing visible design rules across organizations. In *Hanbook on Electronic Commerce*, M. J. Shaw, R. Blanning, T. Strader, and A. Whinston, Eds. Springer-Verlag.