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12-2009

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Jeffrey Barker
School of Information Technology, Bond University, jbarker@bond.edu.au

Gavin Finnie
School of Information Technology, Bond University, gfinnie@bond.edu.au

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Jeffrey Barker and Gavin Finnie
School of Information Technology
Bond University,
Queensland, Australia
Email: {jbarker,gfinnie} @bond.edu.au

Abstract

Supply/Demand networks are undergoing rapid changes with the increasing use of dynamic rather than static information. This paper discusses the idea of intelligent products as both producers and consumers of dynamic information, before describing research in progress to develop a suitable simulation environment for experimenting with the intelligent product concept. The research will briefly consider the potential of a new Microsoft parallel programming environment (Axum) as a development tool.

Keywords

Supply/demand networks; intelligent products; dynamic information; packet-switching

INTRODUCTION

Dynamic information environments offer radical changes to the way in which supply/demand networks operate. In particular, the potential for intelligent products suggests that, for a variety of applications, the ability to respond dynamically to changes in demand offers considerable flexibility in the way that products may be redirected to areas of most utility and/or profit. In many large-scale operation e.g. a military deployment, managing the logistics and tracking items can be highly inefficient and result in significant loss of stock or the deployment of materials to the wrong location. In a scenario like a military operation, conditions change rapidly and the demand for materials may similarly change.

This paper looks at the concept of dynamic information in demand networks, the potential role of intelligent products and then outlines steps towards developing a suitable multi-agent parallel processing test environment to evaluate the ideas. The concept of intelligent products and prior research in this area is discussed in the packet switching and intelligent products section below. Although the basic ideas have been laid out, developments in technology have made the power and cost of intelligent products more feasible. A gap in the research lies in identification of suitable domains of application in evaluating the gains which may be realised in using intelligent products. The research question to be dealt with here is "how can we add value using intelligent products" and the proposed simulation environment provides a testbed for experimentation.

The next section describes the idea of dynamic information and intelligent products. This is followed by a brief review of multi-agent research in the supply/demand network area before moving to the idea of virtual warehouses. The paper then looks at an agent-based parallel programming simulation environment model. The overall goal of the research will be to develop a suitable test environment for the intelligent product concept and to evaluate Axum as an agent orchestration language.

DYNAMIC INFORMATION AND INTELLIGENT PRODUCTS.

Because of the term 'chain', Supply Chain Management (SCM) conjures a vision of a linear manufacturing and material flow chain (Figure 1). In reality, this is not the case. An entity in the chain (a factory or distributor) may have many suppliers and many customers. Each supplier and customer may, in turn, also have many of its own suppliers and customers. Thus, a network of material movement exists, creating a supply network rather than a chain. At the same time there has been increasing realisation that in many case, the role of demand in driving the supply chain should be recognised. Almirall et al (2003) argue that " From supply chains we are evolving to demand networks where the whole chain adapts and produces what is being sold at a tremendously fast pace." Helo et al (2009) prefer the term supply/demand networks as "the fact that relationships between different supply, manufacturing and distribution units are more complex than in a supply chain." We will use the same term except where referring to prior research. The supply/demand network is not a static system. Quantities, delivery times, due dates, start times, etc from various enterprises in the network may change at any time so the network is a dynamic system where values are changing continually.

Products in the traditional supply chain are simply units which flow through the system – they have no active role in the operation of the system. Barker and Finnie (2010) have proposed using the packet-switching paradigm with intelligent products as a framework to provide a new way of thinking which gives the flexibility necessary for dynamic networks. These concepts are described below before moving to outline a possible design for a simulation environment for testing the concept.

RFID (Radio Frequency Identification) technology offers the possibility of providing enterprise systems with truly dynamic information throughout the supply/demand network. (Schuster at al 2007; Asif and Mandiwala 2005; Bardaki et al 2007). Although RFID and more recently NFC(Near Field Communication) technology is the current technology of choice for product identification, as discussed below the intelligent product approach may be better served by more robust technologies such as wi-fi or zigbee. Real-time information can be captured throughout the entire global supply/demand network irrespective of its scale and complexity. However, current RFID applications tend to remain focused on a static view of information that RFID tags provide little more than replacement for barcodes. The emphasis has been placed on lowering the costs of passive tags with limited storage capability – in fact little more than is available on a bar code. Current barcode systems are only able to provide "semi-dynamic" information to enterprise systems as information can only be obtained at limited, designated segments in the supply/demand network. There is an information deficiency at many stations in the supply/demand network due to the lack of visibility and ability to capture real-time information. This creates bottlenecks and places various limitations on the efficiency and effectiveness of managing these supply/demand networks, obviously putting constraints on the ability for rapid response. The economics of basic RFID versus barcodes does not in many cases appear to justify the investment (e.g. Tellkamp 2006). Any effective use of RFID must add value to the process and one way to do this is not only to improve the visibility of information (the current approach and available via using bar codes) but also to improve the processing and the location of that processing i.e. by adding some enhanced capability to the RFID component.

Another issue which is inadequately addressed in much research in supply/demand networks is that demand itself may be volatile i.e. it may vary in volume and time constraints from the time the original order is placed to the final need for the product or service. For example, in the construction industry severe weather can have a significant impact on a construction schedule.

Although the technology exists and there is a move to perform more local processing at key points in the supply/demand network, there does not appear to have been any significant move to providing intelligent or smart sensors in these applications. The question arises as to what benefit there can be in proving some autonomy for each product or pallet in the network. Shuster and Brock (2004) introduce the concept of "smart products" that "sense and respond with the physical world".

Karkainnen et al. (2003) also describe "intelligent products" as a potentially valuable tool in international projects where a large number of individualized deliveries need to be managed through a sizable supply/demand network. Since the products and product delivery in such projects tend to be customized, the ability of products to actively participate in the supply/demand network can significantly improve overall project productivity. In their HUT system, deliveries can communicate their identity and handling instructions directly to the information system. Each product is managed by a software agent that is external to the product. Wong et al (2002) also investigate the role of intelligent products in the supply chain and define an intelligent product as having part or all of the following characteristics:

- Possesses a unique identity
- Is capable of communicating effectively with its environment
- Can retain or store data about itself
- Deploys a language to display its features, production requirements, etc.
- Is capable of participating in or making decisions relevant to its destiny.

Such products can negotiate resources via their software agents, adapt objectives based on updates from the environment, advise on adjusted picking schedules, etc. Intelligent products may be considered at the case or pallet level to make the option cost-effective.

The intelligent product concept does not appear to have had significant further development in the supply/demand network field, although there has been more interest in using the approach in manufacturing production planning and control with the work on product-driven control systems. Pannequin et al (2009) describe an architecture to support benchmarking to evaluate the relative efficiency of a product-driven manufacturing solution.

The location of intelligence could be implemented in different ways. The intelligent agent capability could be embedded in the device itself, rather than relying on an external agent to manage the product. As noted above, RFID technology is not the only feasible approach although it will probably remain the most economic for lower cost products. All that is required is a device with processor, memory and wireless transmission capability. If higher reliability is an issue and the cost justifies it, an a zigbee-enabled intelligent controller would be a suitable solution. Such products could be physical implementations of agents with processing performed locally. However the economics of this approach are likely to limit the effectiveness to high cost items and the processing capacity is likely to remain limited as well as becoming rapidly obsolete. The concept of a logical intelligent product is more likely where the processing could be distributed between the physical device attached to the product and processing capacity in the cloud. Local devices would retain some processing capability to be capable of active participation. Although the intelligent product concept has been considered for some time, there is no research which directly addresses the question of value in using such devices. This research will develop a suitable test bed to simulate the operation of a supply/demand network using intelligent products, identify applications of high potential payoff for the approach and model expected return under simulation conditions.

MULTI-AGENT SYSTEMS IN SUPPLY/DEMAND NETWORKS

There has been considerable research on the use of multi-agent systems (MAS) in SCM and this section provides only some examples of the area. Autonomous software agents have been considered for multiple applications such as managing scheduling, procurement, negotiation, etc. The MAS approach provides a useful programming paradigm for the provision of local intelligence by autonomous entities. Much of the research has focused on collaboration mechanisms for agents.

To provide a framework to consider MAS in supply chains, Ahn and Lee (2004) suggest that studies in agent-based SCM can be put into three categories:

1. using the technology to improve the operational efficiency of supply chains,
2. the use of dynamic information to improve network adaptability and efficiency
3. effective agent-based architectures for SCM.

As examples in category 1, an agent based framework which simulates the supply chain with agents at each station was defined by Fox et al. (2000). Cao and Leggio (2008) showed that a multi-agent approach could reduce the bull-whip effect as opposed to conventional supply chain management approaches.

In category 2 (using dynamic information), Ahn and Lee (2004) propose an agent-based network where agents form dynamic information networks to coordinate production and order planning. Hanebeck and Raisanghani (2007) discuss the use of RFID technology as a supply chain coordination mechanism. In the third category a large number of approaches to different architectures have been suggested. As an example, Sadeh-Koniecpol et al (2003) have worked on an agent-based decision support environment for dynamic supply chain management. In the system, called MASCOT, each agent uses a blackboard architecture for coordination and control and an agenda to drive activity. Finnie et al (2004) proposed a two-tier architecture of buyer/seller agents with buyer and seller coordinator agents.

For the intelligent product as envisaged in this paper, the intelligent agent approach provides a flexible programming methodology that suggests a distributed solution to controlling the supply/demand network. It does not matter whether the agent is embedded at the individual product level or higher in the process e.g. in the "edgeware" or in the cloud application provided that the communications language and infrastructure are well defined.

PACKET-SWITCHING AND INTELLIGENT PRODUCTS

The demand for a product is itself dynamic information, with the actual volume and location of demand possibly changing between the point of estimate and time of delivery. The longer the time interval, the higher is the probability that some change will occur. Viewing demand as static information reduces the flexibility offered by new technologies. The ability to view the supply/demand network as a packet-switching environment allows us to consider multiple sourcing and dynamic re-direction of products as needed. The details of the sale are fed as far back in the supply/demand network as needed. Various points in the network may form decision points which will decide how to source (or multi-source) product (in the information flow) or how to reroute product (in the product flow) as needed.

Instead of the traditional view of inventory tied to a specific supplier or warehouse, we can rather consider virtual inventory i.e. it exists somewhere in the pipeline. This may be in transit or resident in a supplier warehouse. Its location, volume, etc can be determined dynamically. The supply/demand network is self-adjusting in that inventory will be re-routed as demand appears. For certain materials, there are a range of potential suppliers and the type and quality of material is relatively consistent across suppliers. Dynamic information also suggests the ability to deal dynamically with excess inventory in the supply/demand network. Given that the majority of products consumed in the West come from China and other Asian sources, the time-lag between order and delivery may be considerable. The long time period may well exacerbate the changes in demand during this time. One way of dealing with this volatility is by splitting a product into components and trying to source the more volatile demand locally. The Spanish fashion retailer Zara, for example, imports low volatility garments from China (approximately 40%) and services the rest from local suppliers. Both classes of product can be more effectively managed with dynamic information and virtual inventory. The issue of balancing lead times and delivery times using intelligent products is discussed by Barker and Finnie (2010).

Figure 1 illustrates the traditional view of the supply chain with buffers to maintain supply for each unit or organization in the chain. As is well known, this model leads to the bull-whip effect problem for organizations further back in the chain. Figure 2 illustrates the dynamic supply/demand network with intelligent products forming a pool or virtual warehouse of available product. Companies can utilize inputs as needed.

Dealing with products which require an agile response (e.g. local manufacture or assembly from components) could fit the packet switching concept. The ability to dynamically adapt the ordering process allows for rapid response to changing conditions e.g. if a shipment is delayed it can be replaced as needed by another order. Multiple sources of material can be considered and the most effective combination selected. The flexibility inherent in this approach allows both assemble-to-order and make-to-order to be dealt with. The inventory in the pipeline can if necessary be redirected elsewhere. Although human management of this type of situation is feasible but not practical in terms of the complexity, a multi-agent environment could deal with this complexity and optimize delivery rates. For situations where the lead time exceeds the delivery time thus requiring forecasting (Barker 2007), the packet-switching view enables the supplier to identify any re-routing or alternative sourcing which may reduce lead-time for product development. If the constraint is delivery time based, redirection and the inventory in motion view could be used to reduce the delivery time.

The problem of dealing with returns (i.e. defective or excess material or product) is often ignored in SCM research but forms a major disruptive problem in the real world. Although formal models such as SCOR do provide for dealing with returns and have been adopted by a number of organizations, in the first authors experience of some 250 companies many of these do not manage effective processing of returns. The flexible model proposed in Figure 2 with intelligent product information would simplify the processing of returns i.e. once an item returns to the virtual warehouse it can be removed by any suitable party, including the original supplier.

It is possible to envision an environment in which products can act as agents with local processing capability and some autonomy. In keeping with the intelligent product concept, such a product would be capable of

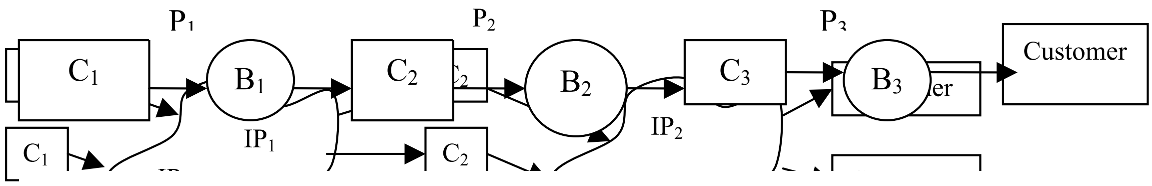

Figure 1: Traditional Supply Chain with companies C_i , buffers B_i and products P_i

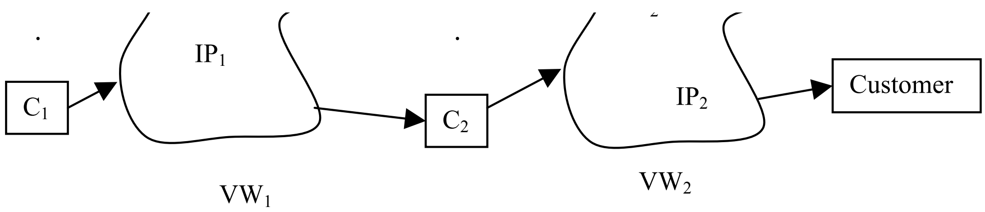

Figure 2: Demand Network with intelligent products IP_j, companies C_{ij} and virtual warehouses VW_i

reporting its status and evaluating whether action needs to be taken. As an example, one could consider perishable goods or materials that may be subject to change during transit. If there is any delay a smart product could evaluate its status and report to the nearest sensor that action needs to be taken. This action may involve negotiating with another product elsewhere in the supply/demand network for redirection e.g. to a more convenient location. As an example in construction, one could even envision concrete deliveries being redirected as demand changes or new constraints develop. Any product or service with a limited survival time would be a suitable candidate for this dynamic reassignment. In military situations, demand may change rapidly in line with developing situations on the ground. The ability to redirect materials flexibly and dynamically is appealing.

AN AGENT-BASED SIMULATION ENVIRONMENT TO MODEL INTELLIGENT PRODUCT OPERATION.

As discussed earlier, agent based approaches have been widely used as a framework to model supply chain operation, both from the perspective of a simulation test environment and as a framework for implementation of automation. (Fox et al, etc). There is an annual competition (The Trading Agents Competition http://www.sics.se/tac/page.php?id=13) to encourage research in agent based supply chains with the stated aim: "TAC SCM was designed to capture many of the challenges involved in supporting dynamic supply chain practices, while keeping the rules of the game simple enough to entice a large number of competitors to submit entries. "

The use of multi-agent systems for supply chain simulation has been of interest for quite some time. Swaminathan et al (1998) provided a seminal paper with an early supply chain modeling framework built around the use of agents. More recently, Nfaoui et al. (2006) describe a model for negotiation between collaborative agents using AUML (Agent Unified Modeling Language). Jiang and Sheng (2008) use simulation to evaluate learning techniques to help agents adjust to changes in the environment. Moyaux et al (2004) used a multi-agent approach to study the bullwhip effect in the Quebec Forestry industry supply chain. Sarker at al. (2005) describe a multi-agent simulation for a manufacturing supply chain.

However in these cases, products remain as static sources of information rather than dynamic participants in the supply/demand network. We will be extending the earlier work by adding another agent type (the product) which can react to messages and respond dynamically to changes in demand.

A supply/demand network consists of a number of producers and consumers of products. In order to model the operation of a network, we need to be able to simulate demand and other features such as delivery time, quality, etc. The use of intelligent products adds another component with dynamic behaviour.

The concept of a supply chain suggests a linear sequence of operation i.e. each station in the chain is triggered by the arrival of goods or raw materials. In reality, a demand network consists of companies operating in parallel. With intelligent products, we have another parallel component.

THE DEVELOPMENT ENVIRONMENT

A significant number of number of agent development environments exist although only a handful of these have made it past the academic experimental environment. However many of these have been more concerned with modelling agent intelligence, using for example the well-known Belief-Desire-Intention (BDI) reasoning model (see for example Wooldridge 2000) rather than the efficient operation of concurrent processes. Of these, possibly the best known is JADE (Java Agent Development Framework) with its extension JADEX to incorporate BDI extensions. In dealing with intelligent products, the model is essentially one of parallel operation with asynchronous communication between distributed processes. As noted above, there has been considerable research on collaborative processes between agents in the supply/demand network context and we propose to build on this where feasible. In particular, the issue of automating negotiation between supplier and customer has received considerable focus (e.g. Nfaoui et al 2006). The major difference proposed here is that the products themselves will have capacity to become involved in the negotiation process. As a result, the partial model discussed below omits implementation details on suppliers and customers although these will be a key part of the complete system.

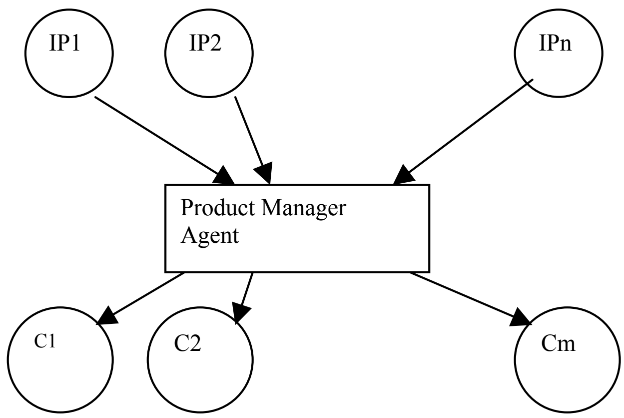

Figure 3: Basic Intelligent Products Simulation Model: IP_i are intelligent products and C_j are customers.

Microsoft currently is experimenting with a new parallel programming model for .NET called AXUM (previously called Maestro). (http://msdn.microsoft.com/en-us/devlabs/dd795202.aspx). It is an incubation project, which means that Microsoft has no commitment to developing a final commercial product and the developers are encouraging participation and feedback. It provides a development environment which appears well suited to modelling dynamic supply/demand network operation. Axum aims to "offer a language that allows programmers to arrange coordination between components in a way that is close to their natural conception of the problem". It is a .NET language so it can use any of the libraries available for other .NET languages e.g. C# or VB.Net. It operates with Visual Studio 2008 (or recently within Visual Studio 2010). The following is a very brief note on some of the key points of Axum - more detail can be found in the Axum Language Overview (Gustafsson, 2009) and the Axum Programmers Guide available from the above website. Agents in Axum communicate by passing messages over specifically defined channels which are a key component of Axum design. Channels define ports through which data passes as well as possible protocols that may define the communication. A channel is implemented as an agent that then becomes the server for messages on that channel.

Agents may communicate with each other via a control flow approach i.e. the sending and receiving messages is driven primarily by the application logic. Given a specific program state, the action taken is dependent on the data received from other agents and the coded sequence of actions i.e. similar to conventional programming.

Axum also provides the option of dataflow networks where the execution of the program is driven by the availability of data in the network i.e. actions are triggered as data moves through the network. Messages are sent and received from defined interaction points. An interaction point may be a message source, message destination or both. Intercation points are defined types e.g.

```
var interact = new OrderedInteractionPoint<int>;
```

Axum includes some interesting network operators which simplify managing the flow of information between agents. These include:

- Forward (==>) which enables the construction of pipelines by taking a source interaction point and forwarding it to a target interaction point.
- Multiplex (>>-) which takes a vector of sources as the left hand operand and forwards data from each into a single target as soon as it arrives at any of its sources.
- Combine (&>-) which takes a vector of sources, receives a message from each and packages these into an array.
- Alternate (-<) which propagates data from a single source to targets in a collection on a round robin basis.

Agent communication languages have dealt primarily with the issue of information transmission between agents, using message passing, blackboards or other means. Agent coordination is usually handled by interagent communication. Being designed primarily as a parallel programming language, Axum explicitly focuses on the coordination issues with these operators.

MODELLING AN INTELLIGENT PRODUCT ENVIRONMENT

Dealing with multiple intelligent products and multiple potential customers requires some form of centralised coordinator. In the simulation model this is done by a product manager agent that batches all products which might need action as well as a list of all customers currently available for product. Figure 3 gives a simple view of the flow between products and potential customers via a manager agent. As noted earlier, we leave the details of suppliers and customers.

The logical operations from the product and supplier are as follows.

For a new product arrival:

- Product message is sent to product manager
- Product details are recorded (added to a list)
- Product details are broadcast to potential customers (together with agent identification)
- Customers deal with intelligent product.
- If a deal is agreed on, the product notifies the manager agent to be removed from the list.
- The supplier notifies the manager to be removed from the supplier list.

For a supplier needing products:

- Supplier sends message to manager
- Supplier details are added to list
- Details of all products waiting are sent to supplier.
- Supplier opens negotiation with product.
- If selected, the product notifies the manager agent to be removed from the product list.
- The supplier notifies the manager to be removed from the supplier list.

There will also need to be periodic housekeeping and a resending of products waiting for a response. Given the inherent parallelism in Axum, there is no reason why simultaneous negotiation between a product and several suppliers cannot be performed which raises interesting questions on managing coordination and cooperation.

DISCUSSION

The intelligent product concept allied with a view of product movement loosely based on packet switching offers another way in which dynamic information can be used to improve the operation of supply/demand networks. In a world of ever-increasing need for speed and tighter margins of profitability, efficient and accurate delivery of products plays a crucial role. However testing these concepts under field conditions is not feasible as no company would be prepared to absorb the expense to try it out. In addition, the ideas will need widespread adoption before the approach makes sense. However, the idea is worth pursuing at a research level. In order to do this we need to develop a suitable simulation environment capable of parallel operation of the participants in a supply/demand network.

The system is currently under development and will be used to simulate operations in which intelligent products may make economic sense. A suitable domain would be a range of military operations, either in a peacetime deployment or during a war situation. The final product will certainly undergo considerable change. However, the Axum programming model could provide a very usable domain for experimenting with parallel operation, particularly in areas like supply/demand network simulation.

REFERENCES

Ahn, H.J.and Lee, H.,. 2004 "An Agent-Based Dynamic Information Network for Supply Chain Management" *BT Technology Journal*, Volume 22 (2), pp. 18– 27.

Almirall, E. Brito, I. Silisque, A.. Cortés U. 2003 "From Supply Chains to Demand Networks: The Electrical Bazaar-Agents in Retailing", http://www.minds-on-fire.com/zupc/publ/AiRCaepia2003.pdf

Asif, Z. and Mandiwalla, M. 2005 "Integrating the Supply Chain with RFID: A Technical and Business Analysis", *Communications of the Association for Information Systems*, Volume 15, 393-427

Bardaki,C., Pramatarim, K. and Doudakis, G.I. 2007 "RFID-Enabled Supply Chain Collaboration Services in a Networked Retail Business Environment", *20th Bled eConference eMergence: Merging and Emerging Technologies, Processes and Institutions*, Slovenia.

Barker, J.R 20-07 "Supply Chain Management: how it works with JIT, MRP II and SBM", *Proceedings of the 4th International Conference on Computer Integrated Manufacturing*.

Barker, J.R and Finnie, G.R (2009), Viewing Demand Networks with Intelligent products as Digital Business Ecosystems, Third IEEE International Conference on Digital Ecosystems and Technologies, Istanbul, Turkey 31 May-3rd June, ISBN 978-1-4244-2346-0

Barker,J.R. and Finnie,G.R. (2010), The Next Generation Demand Network in Quick Response Systems: Intelligent Products, Packet Switching and Dynamic Information" to appear in Cheng, T. C. Edwin; Choi, Tsan-Ming (Eds), Handbook on Innovative Quick Response Programs in Logistics & Supply Chain Management, Springer, 2010, ISBN: 978-3-642-04312-3

Cao, Q. and Leggio, K.B. 2008 "Alleviating the bullwhip effect in supply chain management using the multi-agent approach: an empirical study", *International Journal of Computer Applications in Technology*, Vol. 31 (3-4), pp.225-237.

Finnie, G., Barker J.R. and Sun., Z. 2004 "A Multi-agent Model for Cooperation and Negotiation in Supply Networks", *Proceedings of the Americas Conference on Information Systems,* New York, USA, August 5 – 8.

Fox, M. S. Barbuceanu, M. and Teigen, R. 2000 "Agent-Oriented Supply-Chain Management". *The International Journal of Flexible Manufacturing Systems* 12, 165-188.

Gustafsson, N. 2009 "Axum Language Overview" to be found at http://msdn.microsoft.com/en-us/devlabs/dd795202.aspx

Helo, P., Kitaygorodskaya, N., Salminen, S and Jiao R.J. , "Designing and Modeling Agile Supply-Demand Networks", in Rob Dekkers,(ed), Dispersed Manufacturing Networks, Springer London, 2009, ISBN 978-1-84882-467-6.

Jiang, C. And Sheng, Z, 2008. "Learning Framework for Multi-Agent Simulation of Supply Chain Systems", *Proceedings of the International Conference on Computer Science and Information Technology, ICCSIT '08,* Singapore, ISBN: 978-0-7695-3308-7, pp 425-431.

Karkkainen, M., Holmstrom, J.K.Framling, and Artto, K. 2003, "Intelligent products: a step towards a more effective project delivery chain", *Computers in Industry*, Vol50, No 2, pp141-151

Moyaux, T., Chaib-Draa, B. and D'Amours, S 2004 "Multi-Agent Simulation of Collaborative Strategies in a Supply Chain", *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems.* IEEE Computer Socety, ISBN:1-58113-864-4, 52-59.

Nfaoui, E.H., Ouzrout, Y., el Beqqali, O., Bouras, A., 2006. "An Approach of Agent-Based Distributed Simulation for Supply Chains: Negotiation Protocols between Collaborative Agents" *Proceedings of The 20th Annual European Simulation and Modelling Conference ESM 2006,* Edited by Alexandre Nketsa, Mario Paludetto and Cyrille Bertelle, Eurosi-ETI, ISBN 90-77381-30-9 pp. 290-295.

Sarker, R., Kara, S., Freeman, G., Kayis, B., Ray, T. And Abbass H. 2005 "A Multi-agent Simulation Study for Supply Chain Operation," *cimca*, pp. 728-733, International Conference on Computational Intelligence for Modelling, Control and Automation and International Conference on Intelligent Agents, Web Technologies and Internet Commerce Vol-1 (CIMCA-IAWTIC'05).

Schuster, E. W. and Brock, D. L. 2004 "Creating an Intelligent Infrastructure for ERP: The Role of Auto-ID Technology". 2004 Working paper, APICS.

Schuster, E.W., Allen, S.J. and Brock, D.L. 2007. *Global RFID: The Value of the EPCglobal Network for Supply Chain Management,* Springer-Verlag, New York.

Swaminathan, J.M., Smith, S.F. and Sadeh, N.M. 1998 "Modeling Suply Chain Dynamics: A Multiagent Approach" *Decision Sciences, 29(3), 607-632.*

Tellkamp, C. 2006 " The impact of auto-ID technology on process performance : RFID in the FMCG supply chain", Doctoral Thesis, Universität St. Gallen.

Pannequin, R. Morel, G. and Thomas, A. 2009 The Performance of Product-Driven Manufacturing Control: An Emulation-Based Benchmarking Study, *Computers in Industry*, vol 60.

Sadeh-Koniecpol, N., Hildum, D. and Kjenstad, H. 2003 MASCOT: An Agent-Based Architecture for Dynamic Supply Chain Creation and Coordination in the Internet Economy". *Production Planning & Control* v12(3).

Wong, C.Y., McFarlane, D., Ahmad Zaharudin A. and Agarwal, V. 2002 The intelligent product driven supply chain, *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics,* 2002.

Wooldridge, M. 2000 *Reasoning About Rational Agents,* The MIT Press (Cambridge, Mass. USA), ISBN 0-262-23213-8.

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ACKNOWLEDGEMENTS

The authors would like to thank the anonymous referees for their extensive and useful comments.