

A Supply Chain Management Game for the Trading agent Competition

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Abstract

In this paper we discuss the motivation behind the design of the supply chain management trading agent competition game (TAC SCM). We look at some of the new challenges introduced by the game and summarize what we view as key research challenges that need to be addressed in designing successful game agents. Finally, we look at some possible future extensions to the game.

1 Introduction

Supply chain management (SCM) is concerned with the planning and co-ordination of activities from procurement to production, through finally to distribution of goods. With trillions of dollar traded in supply chains annually the impact of adopting better practices is tremendous. In a marketplace with shrinking product life cycles and fast changing market trends, the need for real time supply chain coordination is vital. Corporations are thus keen to adopt more dynamic supply chain practices, enabling the rapid formation of alliances between suppliers and customers, to best exploit prevailing market conditions and gain competitive advantage.

The Internet boom of the late nineties saw the emergence of a number of companies that sought to build businesses by deploying e-market places, notably in the form of exchanges, and developing technologies to support dynamic supply chain practices. The fact that, today, a few years down the line, a very small fraction of these businesses exist, tells us that there still is a lot to be learned before we can design and deploy effective strategies to manage such highly dynamic supply chain situations. To successfully operate under very dynamic market conditions will require the evaluation of a large number of options very rapidly, making the use of automated programs (or trading agents) imperative. The development of market mechanism that support such automated agents in enabling dynamic supply chain management has been the topic of increasing interest in the research community, often under the banner ‘dynamic supply chain formation’. Supply chains are characterized by highly competitive

interactions among large number of entities trying to achieve a multiplicity of objectives. Consequently, a key factor in the success and viability of a trading agent is to be able to reason about adversary agent strategies and adapt its own behavior. Thus, isolated evaluation of agent designs and market protocols are limiting.

The trading agent competition (TAC) is one in a list of successful attempts by the AI community to device competitive game scenarios that focus the energies of the research community on a common problem, enabling the evaluation of various approaches and extending the state of the art. The TAC, thus, is a natural choice as a forum to stimulate the development of exciting new solutions to the dynamic supply chain formation problem.

In the rest of the paper we look at the design of the TAC SCM game and the challenges posed by it. We also look at key decisions that need to be made by agents to successfully compete in the game. Finally, we look at possible future extensions to enrich the game.

2 Design rationale and new challenges posed

A cursory look at other attempts at creating games depicting SCM scenarios indicated that the TAC SCM game is by no means the first such endeavor. For many years the beer game [Chopra 2001] has been an integral part of many a operations management curricula. Developed at MIT in the mid sixties, the game allows players to experience the well known ‘bull whip effect’. Poor information exchange, particularly demand by downstream entities, results in a rippling effect that magnifies the perceived demand upstream, leading to excessive ordering and large inventories further upstream. The supply chain depicted by the game is fairly simple. It consists of four stages (a beer producer, distributor, wholesaler, and retailer) with a single player operating at each stage. An important feature is that the game assumes infinite capacity.

Levy et al. [Levi 2003] have further extended the game by implementing the game on a computer (the original

was a board game). The game allows players to study various information sharing policies and levels of centralized and decentralized control, giving an insight into the factors that cause the bullwhip effect. Other minor variations of the beer game have also been created over time. The motivations being primarily to act as a teaching tool to introduce students to aspects (typically a single aspect was emphasized) of supply chain behavior. To the best of our knowledge we are not aware of any game developed with a view to study the design and analysis of automated trading agents, in the context of dynamic supply chain management.

The design of the game began very much on similar lines to the original TAC game (now commonly referred to as 'TAC Classic') [Wellman 2001], though the sophistication and complexity intrinsic to SCM, no doubt, introduce many new and interesting challenges. Two key objectives in designing the game were:

1. To enrich the trading scenarios by introducing new challenges not present in earlier renditions of TAC (classic TAC).
2. Overcome the limitation inherent in studying the dynamic supply chain formation problem in isolation, by creating a competitive environment to evaluate different solutions.

A candidate game needed to exhibit the following properties:

- **Strategizing:** Addressing the strategic behavior of the many entities that constitute the supply chain is fundamental to effective SCM and must be an important part of the game scenario.
- **Uncertainty and incomplete information:** One of the challenges in effective SCM is making decisions when faced with uncertainty and incomplete information. The inclusion of these elements is thus vital.
- **Realism:** The applied nature of SCM dictates that any effort in this area needs to be made with an eye on actual practice. If the lessons learned from designing successful agents have to find wider acceptance, scenarios depicted in the game need to be plausible. We use the term plausible deliberately, and it is not the intention to restrict the game in depicting current supply chain scenarios. On the contrary the objective is to stretch the state of the art and examine futuristic ways of conducting dynamic SCM.
- **Generality:** The challenges introduced in the game need to be representative of a broad class of supply chain situations.

- **Simplicity:** To be successful as a game and encourage participation, it is vital that the game be simple enough to enable a number of competitors. This of course, to a degree, runs counter to the aforementioned realism requirement. Getting the right balance has been one of the challenges in designing the game.

A key ingredient in any supply chain formation protocol is the underlying negotiation mechanism. Although there are other approaches, auctions have dominated as the preferred means of conducting automated negotiation. A multitude of auctions can be devised and many exist in practice, though most operate by clearing the auction based on a single attribute, typically price. While price based auctions have been successful in a few marketplaces, such as those that trade in unique goods with very subjective valuations (art) or in goods that are highly perishable, their application to supply chains have been less so. The relatively short histories of the many internet exchanges that sprung up during the recent 'dot com' boom could partly be blamed on their inability in attracting a large number of potential suppliers to sign up. Suppliers are often found reluctant to enter into competition solely based on price- all this does for them is shrink already slim profit margins. Suppliers would much rather like the ability to exhibit the richness of their offerings by more sophisticated negotiation that emphasizes their competitive advantage. For instance, a supplier may wish to exploit their responsiveness by promising competitive due dates for supplies, or the ability to satisfy orders of large quantities.

Similarly, from the point of view of the customer the added value in negotiating other attributes beyond price is valuable. It enables them to select the best match based on their current constraints in capacity, pending orders, capital etc.

The supply chain situation is also challenging in that it requires agents to concurrently compete in multiple markets (markets for different components on the supply side and markets for different products on the customer side). It is also of a repetitive nature in that it simulates a large number of time intervals where the same agents compete with one another, subject to delivery commitments they entered in preceding intervals. Accordingly, it offers a number of opportunities for long term planning.

3 The TAC SCM game basics

The game depicts the scenario of a personal computer (PC) assembly supply chain, [Figure1] consisting of a PC assembler, suppliers who supply components for the PC assembly, and customers who have a demand for the products. The PC assembler has the task of procuring four key components from potential suppliers, and using its resources (capacity) to assemble PCs. Each component is available in two different specifications and can

be procured from two potential suppliers [Figure 2]. Each player agent has the task of managing the PC assembler. The aim of each competitor agent is to maximize its profit by competing with other agents for customer orders and supplier commitments, while managing the assembly of products to meet its delivery commitments. Detailed specification of the game can be found on the TAC website (<http://www.sics.se/tac>).

The supplier responds to the agent with an offer containing:
 Offer ::= <Offer-Id, RFQ-Id, Component-type, Quantity, Price >

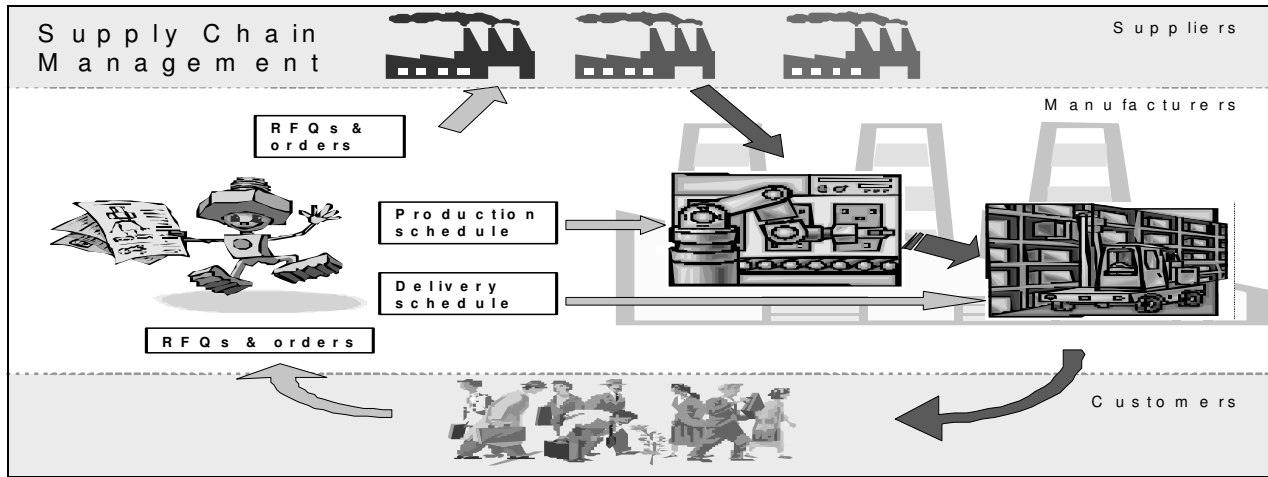


Figure 1: The TAC Supply Chain Management Game Scenario

Each competitor enters an agent that is responsible for the following tasks:

- 1) Negotiate supply contracts
- 2) Bid for customer orders
- 3) Manage daily assembly activities

The game is played over a period of 250 simulated days where the above three tasks are performed by the agent daily.

3.1 Negotiating Supply contracts

The agent issues RFQ (requests for quote) to potential suppliers. The RFQ specifies the type of component required, quantity and due date. The suppliers based on their existing and projected inventory reply to the RFQ by issuing bids (or quotes). These bids include the price at which they offer to supply the component, a quantity and promised delivery date. The agent then has to select the bid that best satisfies its needs.

RFQ ::= <RFQ-Id, Component-type, Quantity, Due-date>

If the supplier can satisfy the order specified in the RFQ in its entirety, an offer is sent as a response. The supplier based on available capacity determines the price specified in the offer. The function used for this purpose is made available explicitly in the specification. All offers made by suppliers are valid for a day and hence require the agent, if interested, to send a confirmation by issuing a purchase order:

Purchase order ::= <Offer-Id::=Integer>

Suppliers have finite capacity and thus may not be able to satisfy a RFQ in its entirety. In such a case the supplier responds by issuing two amended offers, each of which relax one of the two parameters- quantity and due date.

- An **earliest complete offer**, which reflects the first day that the supplier can satisfy the entire request, if at all possible (due date relaxed).
- A **partial offer** is also included in case the supplier can satisfy some part of the quantity on the requested due date (quantity relaxed).

The agent then has a choice of choosing between one of the two offers, not both.

Components	Suppliers	Component specification
CPU	Pintel	2 GHz
		5GHz
	IMD	2 GHz
		5GHz
Motherboard	Basus	For Pintel CPUs
		For IMD CPUs
	Macrostar	For Pintel CPUs
		For IMD CPUs
Memory	MEC	1GB
		2GB
	Queenmax	1GB
		2GB
Hard Drive	Watergate	300 GB
		500 GB
	Mintor	300 GB
		500GB

Figure 2: The TAC Supply Chain Management Game- Suppliers and Components

3.2 Suppliers

Each supplier employs a dedicated production line of finite capacity for each component it produces. For every component produced by a supplier, $C_{nominal}$, denotes the nominal capacity. The nominal capacity is the expected or mean capacity and is the baseline operation level of the plant. Suppliers operate in a ‘make to order basis’ and use the nominal capacity to determine if they may accept an order or not. Each Order may require multiple units to be produced. If more than one days of production is required to satisfy an order, inventory is carried over. The suppliers ignore inventory-carrying costs. Any excess capacity available on the day of production is used to satisfy future orders in the book., though, the order is shipped only on the due date. A random walk is used to determine the number of units actually produced each day. If an order cannot be produced on time due to reduced capacity on any particular day, the order is produced at the given priority over all other later orders. Thus, delays ripple across the production schedule.

3.3 Customers

Multiple customers are generated by the game based on a stochastic distribution made available in the game specification to all the competitors. Demand for various products varies during the course of the game. A random walk is used

to model this. Based on its demand each customer places one or more orders for PCs. Each order comes with a particular set of specifications, a required quantity and delivery date (“due date”). The customer issues RFQ (request for quotes) containing this information to the agents and receives bids from the competing agents.

RFQ ::= <RFQ-Id, PC, Quantity, DueDate, Penalty, ReservePrice >

The penalty specified in the RFQ is the price that the agent has to pay if he fails to ship by the promised due date. The reserve price is the maximum price that the customer is willing to pay for the item specified by the RFQ. The customer will discard all bids indicating prices above the reserve price. The RFQs are transmitted to all the competing agents at fixed intervals of time during the course of the game. The customer uses a very simple heuristic to select the PC vendor. At the end of every day the customer evaluates all the bids it has received and places an order with the agent that offers the cheapest PC that is available at or before the due date specified in the RFQ. In case of a tie the customer makes a random choice.

3.4 Assembly process

Each competitor agent is endowed with an identical simplistic PC factory capable of assembling any of the sixteen PCs. Each product type requires a pre-specified amount of processing and each agent has a fixed amount of processing time available each day – its “capacity”. The available capacity remains constant throughout the game.

Agents can only assemble PCs for which they have the required component supplies. At the beginning of each day, the supplies available to an agent are updated taking into account deliveries received from suppliers and supplies consumed to assemble PCs. At the end of each day, the agent forwards an assembly schedule to the PC factory. The factory based on available supplies and capacity uses the assembly schedule to produce PCs. PCs in the assembly schedule are processed sequentially until all capacity has been exhausted.

At the end of each day, assembled PCs are moved to inventory, from where they can be shipped. Shipping occurs based on the shipping schedule submitted by agents and delivery to the customer occurs the following day.

3.5 The bank

A bank is used to monitor the progress of the agents and determine the winner at the end of the game. All competing agents have an account at the bank and start the game with no money in the account. Money is added to the account when an agent ships a product (to reflect payment by the customer) and is deducted when agents receive supplies from suppliers, or when agents default on deliveries. The

bank pays out Interest on savings in an account or deducts interest when an account goes 'into the red'. No restrictions are imposed on the amount of debt in an account.

3.6 Information exchange

In addition to information that can be gained from the supplier RFQs/offers and customer demand, periodic reports are generated by the system summarizing the supplier and customer markets. The supplier reports present the aggregate quantities produced and aggregate quantities sold by all suppliers in a given period. Similarly, the customer reports make available the average price and volumes sold of each PC type requested during the specified period.

3.7 Format of a game

Six agents compete in each game. The game is played for a fixed (250) number of TAC days. Each TAC day lasts for a pre-specified number of seconds and at the end of game the agent with the highest sum of money in the bank is declared the winner. An agent interested in competing in a game requests the time for the start of the next game. The agent then is responsible for maintaining its own clocks and staying in step.

4 Challenges faced by agents

During the course of a TAC day agents need to make three key decisions:

- 1) Which customer RFQs to bid on?
- 2) What supplier RFQs to generate?
- 3) Which supplier bids to accept?

To successfully make all the above three decisions involves coping with uncertainty through incomplete information and strategizing by adversary agents.

The fixed capacity of each agent limits the number of customer bids it can handle without defaulting on its delivery commitments. A competitive agent will need to maximize its use of capacity by submitting competitive bids to customers and securing supplies in a timely and cost effective manner. Aggressive agents may be able to win more customer orders by lowering their price and over committing their capacity, however, they run the risk of failing to meet their customer obligation and incurring high tardiness penalties. In contrast, less aggressive agents run the risk of missing prime orders and underutilizing their capacity and consequently reducing their money making potential.

A similar situation also arises when securing supplies. An aggressive (or long term) strategy would be to acquire a large amount of delivery commitments from suppliers and hold supplies in inventory, while a conservative (or short term) strategy would be to only secure supplies that are definitely going to be required. Here the more aggressive

agent is more responsive but will incur higher inventory costs, while the conservative agent has less capital tied up in inventory (more cost effective) but is less responsive to customer demand. The strategy employed also will depend on how adversary agents behave. For example, if a number of agents adopt conservative strategies, an effective counter could be to employ a more optimistic or long term procuring strategy. Such a strategy could very well result in acquiring cheaper supplies due to reduced competition and a possible monopoly on customers that value responsiveness. Of course, the state of the suppliers and customers would also have to be taken into account before embarking on such a strategy.

Allowing bidding over multiple attributes means the possibility of receiving a large number of bids from suppliers. Filtering through these bids and identifying potentially profitable supplier bids is not an easy task. Merely choosing the cheapest bid will not suffice. The interdependencies between various components in terms of availability and the constraint of capacity among other factors influence the choice of suitable bids. Preliminary work [Jiong 2003] in techniques for bid selection indicates that this is an NP hard problem and the underlying interdependencies need to be exploited to make the problem more tractable.

In short, the game encapsulates many of the trade offs faced in managing actual supply chains and there is no one winning strategy. Devising an optimal strategy for dealing with customers and suppliers undoubtedly depends on what other competing agents do. As order books and market conditions fluctuate over time, agents need to be able to revise their bidding strategies. The game thus provides exciting opportunities for learning adversary agent behavior and adapting one's strategies to remain competitive.

5 Future enhancements and extensions

The game in its current form provides ample opportunity for exploring the role of automated trading agents in the context of supporting dynamic supply chain practices. As mentioned earlier, the design of the game involved maintaining a fine balance between capturing many of the challenges in supporting dynamic supply chain practices while still remaining simple enough to encourage participation. Adding further facets to the game may very well deter from the aforementioned ideal. However, in the spirit of stretching the state of the art we envisage the following enhancements to the game in the coming years.

1) Long-term and short-term contracts: In an entirely dynamic supply chain all contracts among suppliers and customers will be of a short-term nature. The agents in the SCM game depict such behavior. However, in current practice the use of long-term contracts is also widespread. Both suppliers and customers hedge against market uncertainties and procure a significant portion of their supplies using

long-term contracts. Hence, allowing agents to undertake a mixture of long term and short term contracts could be of value and studying mechanisms that allow agents to select one or the other, or more likely a combination based on market realities could prove interesting. The RFQ mechanism currently employed for procurement of supplies could be extended to accomplish this.

2) Information sharing: The degree to which entities in a supply chains are willing or should share information is a hard question. The periodic reports in the supplier and customer markets provide information sharing in the game but experience should provide guidance to whether this level of information sharing is satisfactory or more or less information sharing occur. Further, the multi attribute nature of the negotiation can be enhanced by allowing the degree to which information is shared be part of the contractual agreements. For instance, entities engaging in long-term contracts may very well decide to make available to each other inventory levels and capacity constraints for their mutual benefit.

3) Outsourcing and secondary markets: The relationship between trading agent need not always be adversary. Circumstances may arise were strategic alliances between seemingly adversary agents may be desirable. For example, an agent may have been too enthusiastic in bidding for customer orders and may be unable to satisfy an order. Another agent may have temporary excess in capacity. A sub-contracting agreement in such a circumstance between the two would be of mutual benefit. Secondary markets can be added to the TAC SCM game to allow such transactions to be made. Making sub-contracting decisions adds an interesting strategic challenge to the TAC SCM game.

4) Flexible product types: Often the needs of the customer are not as well defined as customer RFQ depict in the game. Allowing negotiation that takes this into account can again be of value, further enriching the multi-attribute nature of the negotiation.

5) Supplier/customer complexity: The inclusion of more sophisticated suppliers and customers who exhibit strategic behavior could make the game more exciting and real. An interesting option would be do adapt the top 4 performing agents in TAC SCM 2003 to behave as suppliers and customers in the competition the following year.

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