Multi Agent Systems Coursework Report

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## Introduction

A business that has to produce products for customers that does not also produce the component parts of its product must rely on suppliers to fulfil this need. As a result, there is a necessity to ensure that the correct parts arrive from the supplier at the right time. These layers of production required to produce the end product for the customer is the supply chain.

Supply chains and their analysis is an important issue to many organisations that produce products in this manner as the management of the supply chain has a direct impact on their profitability and therefore success. In fact, it has been described as “an integral part of most businesses and is essential to company success and customer satisfaction.” (CSCMP, 2019). The main financial incentive is the fact that a properly managed supply chain reduces operating costs, but it can also improve both customer service and an organisations financial position. The more efficient an organization’s supply chain I means it is more likely to have a positive cash flow (Clarke, 2019).

It has been stated that the correct management of supply chains is difficult due to the complexity of the enterprise market, but numerous attempts have been made to model this using agents that can act as different parts of the supply chain (Safaeefard, Ramezani, & Akrami, 2014). The advantage of using a multi agent system to model supply chain management is that the agents act as parts of the system and the specific dynamics of how these agents interact arise in the simulation (Mandic & Delibasic, 2012). There have been previous attempts at supply chain management like enterprise resource planning (ERP) and advanced planning and scheduling (APS), however it has been stated that these systems do not necessarily achieve a collaborative supply chain (Li & Lau, 2005). This area of research into multi agent systems and their application to supply chain management is potentially a far better solution to the aforementioned methods allowing organisations to adapt to new situations as they arise in a dynamic environment (Rudenko & Borisov, 2006).

## Model Design

The model is designed with 5 agents, those being: Day Ticker, Customer, Manufacturer, Expensive Supplier and Cheap Supplier. An outline of these agents, their responsibilities, communication and the ontology will be given below.

### Day Ticker Agent

The day ticker agent tracks the days as they pass in the simulation and makes sure that the other agents are synchronised with this. On setup the agent registers with the “yellow pages as the day ticker”. The agent has a case switch which controls its function on each day. The first case statement is where the agent finds the other agents using the yellow pages and stores them in an array list used throughout the subsequent statements. It then informs all of the simulation agents that a new day is beginning, following which the step for the case statement is incremented.

The second stage of the case statement waits for the other simulation agents to inform it that they have finished their activities for the day after which the step is incremented again. When the step increments to 2 the case step variable is reset to 0 so long as there are days left in the simulation. If the hundred days are simulated the day ticker sends a terminate instruction to the other agents in the system. Both of the messages sent by the day ticker are inform messages as they tell the other agents either that it is a new day or that the simulation is over, and they should terminate.

### Customer Agent

The Customer agent sends the manufacturer agent one order every day. It does this in the method specified in the coursework brief. On setup the customer agent registers with the yellow pages. Everyday the Customer agent follows a cyclic behaviour called “Ticker Waiter” which has several sub-behaviours. This will either follow the sequence of sub behaviours if a “new day” message is received from the day ticker or terminate the agent if a terminate message is received. The main responsibility of the customer agent is to generate a new supplier order on a new day.

### Manufacturer Agent

The Manufacturer agent carries out the majority of the work. In the Setup method the build schedule is initialised, the daily production capacity is set and the agent registers with the yellow pages. In addition, a ticker waiter behaviour added to the agent similar to the Customer agent. The first two sub behaviours allow the manufacturer to find Customers and suppliers. Following this the sub-behaviours are added that allow the Manufacturer to decide whether to fulfil orders, schedule them, send supplier orders and build them when scheduled. This will be discussed in more detail later in the report. Essentially the Manufacturer’s main responsibility is to decide whether to accept orders then fulfil them at the correct time. The Manufacturer also has an instance of a warehouse class that tracks the stock and has a method to calculate the storage cost if parts are kept overnight, this is used in the profit calculation to evaluate how efficient the manufacturer is.

### Supplier Agents

The supplier agents function similarly, and essentially send the manufacturer parts with differing delays. They wait for orders from the supplier on each day until they receive an ordering done Supplier Order.

### Ontology Design

The ontology uses one predicate owns. The actions in the ontology are the orders which are used and tracked by manufacturers and suppliers. The main difference between the two order types being that Customer Orders are requests that are tracked and supplier orders have the additional use of requesting that the supplier stop supplying the manufacturer for the day, the supplier agents will wait until they receive this special order type. The Concepts are initially defined as items which have a price, all other phone parts inherit from this.

## Model Implementation

### Customer agent

The behaviours of the customer agent are added in its ticker waiter behaviour, which is sequential, all of the sub-behaviours are one shot behaviours. The first behaviour of “ticker waiter” is “find manufacturer” where the agent uses the yellow pages to find the Manufacturer. The second sub-behaviour is “generate order”. In this sub-behaviour the new Customer Order is generated. The Customer Order is very important as it is the part of the ontology that the manufacturer uses to decide whether to track as well as being tracked within the manufacturer to establish when accepted orders have been completed. Aside from specifying the components, quantity unit price, day due and the late penalty, it also has values for accepted, gross profit, net profit, net cost, net profit, fast turnaround, order id, scheduled and built and shipped. The second set of values is used by the manufacturer aside from order id which is set by the customer and used for tracking. The message type is a request, and the action sent is the customer order. The final sub-behaviour is an end day behaviour which informs the day ticker agent that the day is over.

### Manufacturer Agent

The behaviours of the manufacturer agent are added in the ticker waiter behaviour similarly to the customer agent. Similarly, to the customer agent the ticker waiter behaviour is cyclic with one shot sub-behaviours. The first two of these allow the manufacturer to find suppliers and customers. Following this there is an order handler behaviour that listens for customer orders. This behaviour will wait until an order has been received from each customer. In addition to this this behaviour also handles fulfilled supplier orders being received and updates the warehouse stock as appropriate. Following this there is an order decider behaviour that decides whether to accept orders based on if they can be fulfilled in time as a just in time (JIT) approach to order handling has been adopted. These orders are then checked against the manufacturer’s production capability to see if they can be scheduled appropriately. Following this an order sender behaviour is used to schedule the orders so that they arrive on the day required as dictated by the production schedule. There is then a pair of supplier order generator behaviours used to send the orders to the relevant supplier based on the supplier schedule. After this the next behaviour is the build behaviour which checks what orders are scheduled to be built that day and then subsequently checks if the necessary parts are in stock, if so, the order is built and shipped(using the built and shipped Boolean in the customer order). Finally, there is an end day behaviour similar to the customer agent, with the addition of the profit calculation being implemented in this behaviour.

### Supplier Agents

Again, both supplier agents have a ticker waiter sequential behaviour with several one-shot sub-behaviours. The first of these is a find manufacturer behaviour that use the yellow pages to find the manufacturer. The next behaviour is a Fulfil order behaviour that sends the fulfilled supplier order to the manufacturer based on the order schedule. This is where the two supplier types differentiate as the expensive supplier fulfils received orders on the next day, the cheap supplier doing the same after four days. Following this the next sequential behaviour is the order handler that receives supplier orders until a finisher order is received at which point the behaviour ends. The final behaviour is an end day behaviour that functions in the same way as the other end day behaviours.

### Constraints Implementation

The first constraint is enforced in the customer and manufacturer as well as the ontology due to the mandatory slots imposed on the customer order. Each phone must have certain parts, some being set in the manufacturer based on whether the supplier order is sent to either the cheap of expensive supplier at which point the remaining part prices are set. The delivery time constraints are enforced in the respective supplier types order schedules. The warehouse class fulfils the third constraint. The fourth constraint is enforced in the manufacturer’s build behaviour, as is the daily production capacity. The penalties for late delivery are also enforced in the manufacturer but are never really utilised due to how the manufacturer functions, similar to the warehouse cost. The final constraint is met in the manufacturers end day behaviour.

## Design of Manufacturer Control Agent Strategy

The overall approach adopted by the manufacturer is just in time (JIT). The reason for this is that it has been found that JIT is more competitive than non-JIT manufacturing strategies. However, the profit has been shown to have an inverse correlation to the risk involved (Callen, Morel, & Fader, 2003). As the suppliers never deliver orders late JIT has been adopted as there is effectively no risk.

### Deciding to Accept or Reject

The manufacturer agent’s first task is to look at the orders it has received and decide which to accept and which to reject. The first thing that the manufacturer considers is when the order is due as the manufacturer will never accept an order it can’t deliver on time. The first manufacturer considers all orders as the same after this, the second type of manufacturer tags the orders as either slow or fast turnaround so it can use the cheap supplier for orders due in in 5 days. Both manufacturers try and turn orders around as quickly as possible to try and maximise each customers cash flow, as new orders are always received it should be possible to implement both manufacturers in such a way that they can make profit every day.

The next consideration is the limited production capacity. Similar to the marketing manager strategy described in (Sardinha, Molinaro, Paranhos, Cunha, & de Lucena, 2005), both manufacturing agents takes a greedy approach as to which orders to accept. The first stage in both is to work out which order has the highest net profit. The first manufacturer will then schedule this order to be built the next day and all of the parts are scheduled to be ordered from the expensive supplier on that day. Following this it checks the other orders received that day and compares the order quantity to the remaining production the next day in an attempt to use up as much production capacity as possible to maximize the profit for that day. No matter how many good orders the agent receives it will never go above the production capacity for a day so that the warehouse is never used overnight. The second manufacturer differs in that it will check to see if the best order has been tagged as fast turnaround (Dui in less than four days) or not. If it is a fast turnaround it functions in the same way as the first manufacturer. If it is not fast turnaround it schedules the build for four days’ time and orders parts from the cheap supplier that day and puts the order for the remaining parts into the order schedule for three days’ time so the parts all arrive for the order at the same time. After scheduling the orders have been either rejected or accepted.

### Which Parts are Ordered from each Supplier

The first manufacturer orders everything from supplier 1. The logic for this is that as new orders are received from each customer every day, and the unit price for each phone is randomly generated, half of the orders received on a day will be highly profitable and the other half less profitable when averaged across the run of 100 days. The agent effectively adopts the attitude that it should turn around the orders for the next day, always taking the most profitable and as many other orders as possible that day, as there will be a new set of orders the next day, one of which being the most profitable.

As described above the second manufacturer orders parts as appropriate based on when they are due in. For this strategy to out compete the cost savings must off set the fact that if a cheap order is scheduled it may use up too much of the production capacity in four days’ time for the best order received in three days’ time to be scheduled i.e. does the loss of a percentage of the best orders get offset by the savings by using the cheap supplier. The two manufacturers performance will be evaluated experimentally.

### Warehouse Usage

As a JIT methodology has been implemented all parts are used immediately. The warehouse cost constraint has been implemented to penalise any errors in supplier ordering, although this will add up as the parts are ordered in total for each order.

### Order Building and Shipping

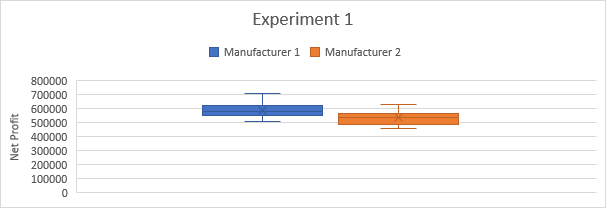
The orders are built and shipped as the parts arrive to conform with JIT manufacturing.

## Experimental Results

### Experiment 1

Experiment 1 will look at the performance of the two differing manufacturer strategies. The experiment was run using the default number of customers (3) as well as warehouse storage cost and per day late penalties. It is expected that manufacturer 2 will perform in a more profitable manner as it uses both supplier types. The experiment was run 15 times for each supplier.

|  |  |  |
| --- | --- | --- |
|  | Manufacturer 1 | Manufacturer 2 |
| Mean | 589438.2 | 534400.27 |
| Standard Deviation | 47584.35 | 49910.26 |
| Standard Error | 12286.23 | 12886.77 |



It has been observed that due to the way both agents function there are a number of days production quota wasted. It has also been observed that manufacturer 1 outperforms manufacturer 2. As a result the following experiments will be carried out on manufacturer 1.

### Experiment 2

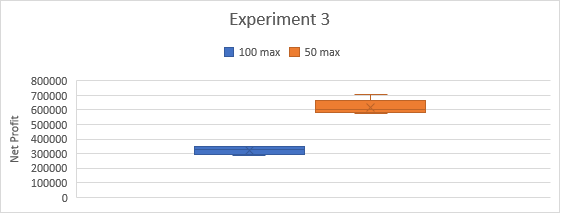
Experiment 2 will look at the effect of increasing the number of suppliers. In this Experiment the amount of profit is expected to increase as the manufacturer should be able to use more of its daily production quota. The experiment will be run three times for each 3, 5, 10, 15, and 20 suppliers.

As Hypothesised the increased number of customers increases the profit. The unused production quantity on each day was observed to be lower. This was due to the fact more orders could be fulfilled by the manufacturer.

### Experiment 3

This experiment will examine what happens to profit if the order quantity increases. This is done by increasing the maximum order number to 100. This should half the profits expected as half of the orders will be above the manufacturers production. This experiment should test how much less profitable the Manufacturer will be in this case. It is predicted that if the manufacturer strategy had a way to use the warehouse the experiment would not have an observable effect, but this has not been implemented in the current agent.

|  |  |  |
| --- | --- | --- |
|  | 100 max | 50 max |
| Mean | 323575.6 | 619115 |
| Standard Deviation | 22908.58 | 43425.31 |
| Standard Error | 10245.03 | 19420.39 |



The increase in order quantity does almost exactly half the profitability of the manufacturer, showing that the strategy is not robust to

## Conclusion

### More Realistic Supply Chain Scenario

The system could be modified in a variety of ways to reflect a more realistic supply chain scenario. The first of these would be to modify the customer agent so that the unit price took into account the components of the phones rather than being randomly generated. This would mean that there would be less variation in order profitability. A second possibility would be to have the customers continue to send the same order but increase the price until the order is accepted. This could be further extended to include the manufacturer negotiating the unit price with the customer based on quantity and the net potential profit of the order. Another adaptation could be to have the customer wait until an accepted order is returned to it before it can resume sending orders, this would reduce the number of orders received and could be affected by using the cheap supplier as it would reduce the number of potential orders received on a given day.

Another modification could be to add a degree of uncertainty to shipping between the agents. Orders arriving late would have a huge effect on a just in time manufacturer’s efficiency. In such a case the manufacturer may need to keep a stock of parts in case a delivery does not arrive on time. This amount of stock’s ideal value could be investigated through further experimentation. The next modification that could be made to the manufacturer would be to allow the manufacturer to start producing orders without having all of the required in the warehouse. This would allow orders to be produced in a just in time way without needing to use the warehouse. In addition to this, allowing the manufacturer to cancel orders if a more profitable order is received could be an interesting modification, particularly if a cancellation fee was implemented.

In addition to these the simulation could have multiple cheap and expensive suppliers which have varying levels of stock that can be depleted. The suppliers would then require a number of days to acquire or produce more stock. This may affect the manufacturers access to stock to complete orders. Further to this only allowing the manufacturer to ship a maximum number of parts per day or only selling them in quantities of a certain size could be an interesting modification. Further to this, manufacturers being able to offer discounts on larger orders may have an interesting effect on the simulation. A further modification to the suppliers that could be made is that the suppliers themselves could be implemented in such a way that they need to source parts from other suppliers to produce their products, in effect creating two or more levels of manufacturer and adding further layers of complexity to the supply chain. In addition to this, suppliers could be implemented so that they only produce a single component which would be a closer approximation of reality, an iPhone for example sources its component parts from many different suppliers. This could increase the complexity of the simulation a great deal but would be a more relevant analysis for organisations that produce phones.

Having competition between manufacturers and suppliers would also be an interesting modification to the system, particularly if the agents could negotiate and bid between each other. It would allow for experimentation to see if the market would stabilise or not, or if a monopoly might form. Agents in this system could have entirely different strategies to each other, for example there could be agents that always try to undercut the competition so long as they can still make a profit and other agents could prioritise fast turn around over price. This would also be interesting as agents adopting a just in time methodology could compete with agents that have adopted more traditional methods of manufacturing to see which performs better in a competitive environment.

### Improving Manufacturer Profitability

The first improvement that could be made to the manufacturer would be to order the received orders by profitability, so the manufacturer would have a preference for filling up it’s production schedule with more profitable orders rather than trying each order that isn’t the most profitable in the sequence they are received. Another possible alteration along the same lines would be to compare the order quantity to the remaining production quantity and chose the order that uses up the most days on each loop.

A further modification would be to allow the manufacturer to break its just in time strategy and schedule orders for subsequent production days that require the warehouse if the order is above a certain profitability threshold. This would allow the manufacturer to use up all of its production quota in a greedy way. Another potential modification would be to allow the manufacturer to schedule orders deliberately late if the profit is high enough and the late penalty is low enough. This may further improve profitability but would need to be experimentally evaluated.

# References

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## Appendix 1: Ontology

### Actions

### Concepts

### Predicates

## Appendix 2: Communication Protocols

## Appendix 3: Source Code

### Day ticker: 3.0

### Manufacturer 1: 3.1

### Manufacturer 2: 3.2

### Customer: 3.3

### Expensive Supplier: 3.4

### Expensive Supplier: 3.5