Technical Report:	*CSM-392*

PhD in Open Constraint Satisfaction

Technical Report 1:

The Simple Supply Chain Model (SSCM)

By

Timothy Gosling & Professor Edward Tsang

Contents

1.1 Introduction

At present various electronic market places, auctions and negotiation systems exist, in the near future full electronic supply chains will be possible and indeed desirable to improve efficiency [1].
This situation, however, presents a problem. While humans are good at negotiation and situation analysis there are less able to handle large volumes of information and numbers of transactions. What is need is a computer-based strategy for handling these situations. The strategy does not need to be the perfect negotiation, although it must be competent, but it must be able to deal with more negotiations more rapidly than a human operator could. A core objective of this work is to develop strategies that are able to make a profit in a situation where customers are continually requesting bundles of products and may need to be negotiated with, suppliers must be negotiated with and there is a limit to both the communication capacity available and the amount of information about the market place.

To realise a computer based strategy for handling supply chain situations it is first necessary to define the problem more specifically. The Simple Supply Chain Model (SSCM) provides a way to precisely model *some* supply chain situations. The model is sufficiently rich to allow for a wide range of scenarios but ties the situations down sufficiently to make tackling the problem manageable.

The development of the SSCM was begun with the selection of a business scenario to act as a template. The chosen scenario was that of a travel arrangement system, thus the following SSCM definition is couched in terms of flights, accommodation and entertainment products. While a different scenario would have yielded different product elements (and perhaps different element names), the underlying structure would have remained largely the same.

The remainder of this document provides the details of the Simple Supply Chain Model (SSCM) being used to investigate supply chains along with some discussion on possible future changes.

1.2 The Basic Model

1.2.1 Introduction

In order to be clear about the problem to be solved a model has been developed that precisely describes the different component parts of the system in question. The basic model defines the problem for a single destination system, with no distinction between types of accommodation or flight tickets, very limited preferences on the part of the customer and uncomplicated suppliers. Complexity in this system is most likely to be found in implementing middlemen although suppliers and customers still have scope to optimise their operations. This basic model is comparatively simple yet will not prove trivial to provide solutions for. In addition the basic model is open for extension, potentially providing a more complex system in the future.

1.2.2 Model top-level

The first step in the model is to define its core component parts thus:

$$Model = (S, M, C, P, T_{total}, T_{active}, Com)$$
$$S - \text{The suppliers (of products)}$$
$$M - \text{The middlemen (travel agents)}$$
$$C - \text{The customers (travellers)}$$
$$P - \text{Product types}$$
$$T_{total} - \text{The total time (in days) over which this simulation system runs}$$
$$T_{active} - \text{The length of activity time (in days) that occurs at the end of total time}$$
$$Com - \text{A communications protocol}$$

Most of the above elements require little explanation however, the use and reasoning of total and active time does require some consideration. As will become apparent later agents (suppliers, middlemen and customers) have a need to complete transactions some time before the travelling that is being arranged begins. To this end the first thing we define is the total time within which the travel arrangements can be made and travelling done. Following this we define how long the active (travelling) period is. The difference between these two values provides a lead-time in which initial arrangements can be made. Without this lead-time customers with early travel requirements will find they are unable to make arrangements in time This failure would occur not because of a lack of strategic competence but because it would be impossible for them to ever fulfil their time constraint requirements. The lead-time can help prevent this situation and so stop unnecessary failures.

Next we look at *P*, the products:

$$P = \{flight\_in, flight\_out, accomodation, Ent_0, ..., Ent_{ne}\}$$

$flight\_in$	Inbound (returning) flights
$flight\_out$	Outbound flights
$accomodation$	Hotel accommodation at the destination
Ent_x	An entertainment type ranging 0 to ne
ne	$ne+1$ is the total number of entertainment types available at the destination i.e. entertainments ranged 0 to ne inclusive.

As can be seen the above essentially provides a list of product types and little else, it is however important and is defined first to help improve understanding of later definitions.

1.2.3 Suppliers

We now look at the suppliers, *S*:

$$S = \{S_o, ..., S_{ns}\}$$

S_x	A supplier in the range 0 to ns inclusive.
ns	The total number of suppliers in the system –1.

Now looking at an individual supplier:

$$S_i = (p_i, n_i, comm\_outS_i, base\_value_i, MidBaseS_i)$$

p_i	Supplies a product selected from the set of products $P, (p_i \in P)$
n_i	The total available supplies of the product available to this supplier for each active day (assuming a constant supply for each day without rollover of products from previous days).
$comm\_outS_i$	The total number of outbound communications this supplier is allowed to make each day
$base\_value_i$	The basic value of an individual product to the supplier (e.g. manufacturing and or running cost).
$MidBaseS_i$	The middlemen this supplier initial knows about, $MidBase_i \subseteq M$

The suppliers above are quite simple entities although strategies for operating a supplier may not be entirely trivial. An extension to the suppliers might include a more complex mechanism for determining the number of products available for sale. For flight suppliers this might mean determining the operation and maintenance timetables of aircraft that might in turn mean an adjustment of the model to take into account different classes of supplier. A more simple and generally applicable change might be to include a vector of products available over the active period.

The inclusion of specific knowledge of middlemen provides an interesting aspect. If so desired this provides the suppliers the ability to be pro-active – targeting specific middlemen with offers of supplies rather than being purely passive and waiting for requests for supplies to reach them.

1.2.4 Middlemen

Next we look at the middlemen:

$$M = \{M_0, ..., M_{nm}\}$$

M_x	A given middleman (0 to nm inclusive)/
nm	$nm+1$ is the total number of middlemen, i.e. middlemen range from 0 to nm inclusive.

And an individual middleman:

$$M_i = (comms\_outM_i, CusBaseM_i, SupBaseM_i)$$

$comms\_outM_i$	The number of allowed outbound communications by this middleman per day.
$CusBaseM_i$	The customers this middleman initial knows about, $CusBase_i \subseteq C$
$SupBaseM_i$	The suppliers this middleman initial knows about, $SupBase_i \subseteq S$

The middlemen are again quite simple in terms of initial information although complexity will arise in how they deal with the interaction between customers and suppliers. The customer and supplier bases provide the middleman with its initial options for obtaining products and selling them on. Other suppliers might however contact the middleman with product offers and customers would be expected to make contact with the middleman.

1.2.5 Customers

We now focus on the customers within the system:

$$C = \{C_0, ..., C_{nc}\}$$

C_x	A customer (0 to nc inclusive).
nc	The upper customer number (i.e. range 0 to nc inclusive).

And an individual customer:

$$C_i = (budget_i, duration_i, t_{start_i}, t_{end_i}, complete_i, comms\_outC_i, Pref_i, MidBaseC_i)$$

$budget_i$	The total amount the customer will spend maximum on a travel package.
$duration_i$	The trip duration the customer is interested in (in days).
$t_{start\,i}$	The inclusive start time in days (1 being the first day of the active period) from which the customer is willing to travel.
t_{end_i}	The inclusive end time in days that is the latest day the customer is willing to return on.
$complete_i$	The number of days before the outbound travel that the customer must complete its travel arrangements.
$comms\_outC_i$	The number of outbound communications the customer is allowed to make per day.
$Pref_i$	A set of preferences (in this case basic travel requirements).
$MidBaseC_i$	The set of initially known middlemen, $MidBase_i \subseteq M$

Preferences are structured thus:

$$Pref_i = (flights\_out, flights\_in, accommodation, Ent_0, ..., Ent_{ne})$$

The preference of customers is, as previously mentioned, quite simple in the basic model. The preferences consist of a vector of required products. This vector matches the types *P*. Thus for a problem in which we have five entertainment types there would be eight elements in the vector. Each element specifies the number of each product required. In this model by default the first three elements will be numbered one, one and the duration of the stay. Future modification to the preferences could include preferences for different types of entertainments, classes of flights and types of accommodation.

1.2.6 Communication – top-level components

Having defined the customers the final element to be considered is the communications protocol, *Com*.

$$Com = \{StoM, MtoS, CtoM, MtoC\}$$

$StoM$	Communications from a supplier to a middleman.
$MtoS$	Communications from a middleman to a supplier.
$CtoM$	Communications from a customer to a middleman.
$MtoC$	Communications from a middleman to a customer.

As can be seen the communication protocol is itself split into four separate entities. Each entity defines the manner in which one type of agent may communicate to another. Thus *StoM* represents all the different outbound communications that a supplier can send to a middleman. The middleman's outbound messages are themselves split between communication with the supplier and communication with the customer (*MtoS* and *MtoC*).

The exact nature of the communications between agents is one of the things most likely to change very rapidly especially with the introduction of different communication techniques such as auction by a third part however to initially complete the model a basic communication system is defined here.

First let us deal with communication between suppliers and middlemen. In order to facilitate this discussion initially we must define some basic communication components:

$$ActiveDay = (1,..,T_{active})$$

The days of activity in order from 1 to the specified number of active days $T_{actiive}$.

$$DateAmount = \{(ActiveDay, amount),...\}$$

$ActiveDay$	A given active day.
$amount$	An integer, the amount of something on a given day.

DateAmount is used to define a given amount of a product required or requested on a given active day. By convention all values for the same day should be added together to form one entry.

$$\mathrm{Re}\,sponse = \{accept, reject\}$$

Used to provide an ultimate acceptance or rejection response. If an accept or reject response is received during negotiations it signals the completion of that negotiation either in agreement or disagreement. It does not preclude the possibility of new negotiations beginning between the parties but does indicate the end of this dialog.

1.2.7 Supplier to Middlemen communication

Having defined some base concepts it is now necessary to provide the supplier to middleman and middleman to supplier communications mechanisms.

$$StoM = \{SuggestionS, \mathrm{Re}\,sponseS\}$$

$SusgestionS$	The supplier suggestion of goods at a price to a middleman.
$\mathrm{Re}\,sponseS$	The response message to a given suggestion or response from a middleman.

Now to define a suggestion:

$$SuggestionS = (m\_num, s\_num, id, resto, p, amnt(DateAmount), price, \exp ire(ActiveDay))$$

m_num	The number of the middleman the message is being sent to (0 to *nm* inclusive).
s_num	The number of the supplier sending this message (0 to *ns* inclusive).
id	A positive integer. A unique (to the specified supplier) number for this message.
$resto$	If responding to a previous communication from the specified middleman, the message number of the message this is a response to. Otherwise –1.
p	A product being suggested for purchase, $p \in P$.
$amnt(DateAmount)$	The number of goods on a set of specified days that the supplier is willing to supply.
$price$	The total price the supplier is willing to accept to supply the specified goods.
$\exp ire(ActiveDay)$	A suggested response by day, if the middleman doesn't respond on a day up to and including the expiry day the supplier shouldn't be obligated to respond to a reply to this message.

This forms the core component (along with its middleman counter part) of negotiation between middlemen and suppliers. A supplier can suggest a given product deal to a middleman by sending such a message or suggest an alternative arrangement in response to a middleman's request. Not that suggestion messages are binding, if the middleman agrees the contract is formed.

To accept to reject a suggestion outright:

$$\mathrm{Re}\,sponseS = (m\_num, s\_num, id, resto, \mathrm{Re}\,sponse, \exp ire(ActiveDay))$$

m_num	The middleman to which this message is being sent (0 to *nm* inclusive).
s_num	The supplier sending this message (0 to *ns* inclusive).
id	A positive integer. A unique (to the specified supplier) number for this message.
$resto$	The message id of the message this is a response to.
$\mathrm{Re}\,sponse$	As defined above, the acceptance to rejection message.
$\exp ire(ActiveDay)$	When initially providing a positive response the day (inclusive) by which a counter response is required or negative is assumed.

This provides a mechanism for a supplier to effectively agree or reject suggestions from a middleman. If accepting or rejecting a suggestion no further contact (within this negotiation) is required.

1.2.8 Middlemen to Supplier communication

Having defined the communications system for a supplier to a middleman it is now necessary to define the communications from the middleman back to the supplier. This mechanism is essentially identical to that for the supplier to the middleman.

$$MtoS = \{SuggestionM, \mathrm{Re}\,sponseM\}$$

$SusgestionM$	The middleman's suggestion of required goods for a price.
$\mathrm{Re}\,sponseM$	The response to a given suggestion or response from a supplier.

Now define the suggestion message:

$$SuggestionM = (s\_num, m\_num, id, resto, p, amnt(DateAmount), price, \exp ire(ActiveDay))$$

s_num	The supplier to which this message is being sent (0 to *ns* inclusive).
m_num	The middleman sending this message (0 to *nm* inclusive).
id	A positive integer. A unique (to this middleman) number for this message.
$resto$	If responding to a previous message from the specified supplier, the number of that message. Otherwise –1.
p	A product being requested for purchase, $p \in P$.
$amnt(DateAmount)$	The number of goods on a set of specified days that are required.
$price$	The price the middleman is willing to pay for these products in total.
$\exp ire(ActiveDay)$	A suggested response by day (inclusive). If no response to this message is received within the time specified the middleman shouldn't be expected to take any action relating to this message or a response.

And the response:

$$\mathrm{Re}\,sponseM = (s\_num, m\_num, id, resto, \mathrm{Re}\,sponse, \exp ire(ActiveDay))$$

s_num	The supplier this message is to be sent to (0 to *ns* inclusive).
m_num	The middleman sending this message (0 to *nm* inclusive).
id	A positive integer. A unique (for this middleman) number assigned to the message.

$resto$	The message id of the message this is a response to.
$\mathrm{Re}\,sponse$	The response itself as defined above.
$\exp ire(ActiveDay)$	When initially providing a positive response the day (inclusive) by which a counter response is required or negative is assumed.

Now that we have both middleman and supplier mechanisms in place it is possible to see how negotiation can be initiated and undertaken. The supplier or middleman would initially contact the other with a suggested set of goods at a specified price. The other may then counter with another suggestion linked to the original message so both know what is being responded to specifically. Negotiation can continue in this fashion until either party sends a response message. If the response is rejection the negotiation terminates immediately with no response required. If the response is acceptance then the previous suggestion is accepted and negotiations are completed in agreement.

1.2.9 Customer to Middlemen communication

Finally we must define the communications mechanism for use between the customer and the middleman. This is based on a similar mechanism to above.

First we define elements to help with customer to middleman and middleman to customer communication:

$$Entertainment = \{(Ent_i, amount),...\}$$

Ent_i	A given entertainment (0 to *ne* inclusive).
$amount$	The amount of the given entertainment required/suggested.

This allows us to specify how much of a given entertainment can be supplied or is required. By convention all amounts for the same entertainment should be added together.

Now we define the customer to middleman communications system:

$$CtoM = \{PackageC, Cus\,\mathrm{Re}\,sponseC\}$$

$PackageC$	The communication from a customer about a package.
$Cus\,\mathrm{Re}\,sponseC$	A response message ending negotiations.

Here we see the top-level customer to middleman communication system, the format is roughly the same as that of supplier to middleman communication.

We now define the package communication mechanism:

$$PackageC = \begin{pmatrix} m\_num, c\_num, id, resto, out(ActiveDay), in(ActiveDay), \\ want(Entertainment), price, \exp ire(ActiveDay) \end{pmatrix}$$

m_num	The middleman this message is being sent to (0 to *nm* inclusive).
c_num	The customer sending this message (0 to *nc* inclusive).
id	A positive integer. A number for this message unique to the specified customer.
$resto$	If responding to a previous message from the middleman, the id of that message, Otherwise –1.
$out(ActiveDay)$	The outbound flight date the customer is interested in.
$in(ActiveDay)$	The inbound flight date the customer is interested in.
$want(Entertainment)$	Defined above, a list of requested entertainments and amounts.
$price$	The price the customer is willing to pay for this package.
$\exp ire(ActiveDay)$	The day (inclusive) by which the customer expects a response and will respond.

The *PackageC* communication allows a customer to do two things. Firstly a customer can request a particular deal from a middleman and see what happens. Secondly this allows a customer to reply to a middleman's offer, possible suggesting alternative flight times, entertainments or price.

Next we define the return response message:

$$CusResponseC = (m\_num, c\_num, id, resto, Response, expire(ActiveDay))$$

m_num	The middleman this message is being sent to (0 to *nm* inclusive).
c_num	The customer sending this message (0 to *nc* inclusive).
id	A positive integer. The unique (to this customer) number for this message.
$resto$	The id of the message this is in response to.
$Response$	The response (defined above).
$expire(ActiveDay)$	The day (inclusive) by which the customer expects a response and will reply if this is a positive response to a previous request (package).

1.2.10 Middlemen to Customer communication

We have now completed the customer communication mechanism. We now go on to define the middleman to customer communication mechanism.

Firstly the top-level:

$$MtoC = \{PackageM, CusResponseM, InformM\}$$

$PackageM$	Package suggestion communication/negotiation with customer.
$CusResponseM$	Response to a customer package or response.

Now to define the package mechanism (very much as above):

$$PackageM = \begin{pmatrix} c\_num, m\_num, id, resto, out(ActiveDay), in(ActiveDay), \\ want(Entertainment), price, expire(ActiveDay) \end{pmatrix}$$

c_num	The customer this message is to be sent to (0 to *nc* inclusive).
m_num	The middleman sending this message (0 to *nm* inclusive).
id	A positive integer. A unique (to the specified middleman) number for this message.
$resto$	If responding to a previous message from the specified customer, the id of that message.
$out(ActiveDay)$	The outbound flight date the middleman suggests.
$in(ActiveDay)$	The inbound flight date the middleman suggests.
$want(Entertainment)$	Defined above, a list of suggested entertainments and amounts.
$price$	The price the middleman wants for this package.
$expire(ActiveDay)$	The day (inclusive) by which the middleman expects a response and will reply.

And finally the response mechanism:

$$CusResponseM = (c\_num, m\_num, id, resto, Response, expire(ActiveDay))$$

c_num	The customer to which this message is to be sent (0 to *nc* inclusive).
m_num	The middleman sending the message (0 to *nm* inclusive).
id	A positive integer. A unique (to the specified middleman) number for this message.
$resto$	The message id of the message this message is a response to.
$Response$	The response (defined above).
$expire(ActiveDay)$	The day (inclusive) by which the middleman expects a response and will reply if this is a positive response to a previous request

will reply if this is a positive response to a previous request.

We have now fully defined both the customer and supplier messages. As can be seen the mechanism for negotiation exists as with suppliers and is intended for use in the same way. Overall the communication system is comparatively simple but allows for relatively complex negotiation between customers, middlemen and suppliers.

1.3 Future expansion

As has already been noted, there are a fair number of enhancements that could be made to the model as it stands. These enhancements would introduce additional complexity forcing more complex agent implementations and allow modelling of a larger range of problems and more realistic problems.

Along with the specific changes suggested so far in discussion of the basic model some others are worth considering.

One element of the model that is very likely to change is that of the communication system. By enriching this element the dialog between customer and middlemen and indeed middleman and suppliers can be improved and made to be more productive. An initial enhancement would allow for the communication of why certain deals are not desirable. If a customer can tell a middleman why a particular offer is unacceptable it may be possible for the middleman to offer a more favourable package. This communication would not be in the form of the customer simply supplying all of its preference information but rather a more directed sense of preference (i.e. instead of saying "my price range is between 500 and 1500" the customer would say "this is too expensive"). Communications between suppliers and between middlemen could also be considered, this would allow for each to trade possessed goods and commitments to supply. With this change it would be possible that a middleman that is committed to providing some travel package but can't get the flights might be able to buy them from another middleman. Communications of this nature also opens up the possibility of collusion and information sharing, something that could be worth considering.

The introduction of different types or classes of products is worth considering. This would make the system closer to the real world where it is likely that products of the same type will still be dissimilar in some way and some thus more desirable than others. For flights this might equate to the seat classification (economy, business and first-class for instance) while for accommodation this might take on various meanings either star rating or B&B versus a full hotel. Entertainments might consider the same problem in the vein of either better seats (a private box or in with the rabble) or better access to facilities (gate fee or gate fee and all the rides). Whatever the real world mapping the changes to the model could be relatively simple and consistent across products. These product changes would necessitate changes in the customer preference system, either specifying minimum requirements or actual preferences.

A broader change that would dramatically increase complexity would be the introduction of multiple destinations. With multiple destinations in mind the operation of flights would have to be considered more carefully than is done so at present, at the very least all suppliers would likely need a base location from which they operate and supply their products. This would also naturally lead to changes in the customers (minimum, where they want to go) and potentially to the communications system (different communications between destinations perhaps or different costs associated with local and distant communication).

An extremely important aspect of future expansion is that of using the model in representation of other problems. At present consideration is given in terms of flights, accommodation and entertainments. This however is simply a real world way of looking at the model. In reality, and to be more useful, the model and the techniques developed to tackle it must be applicable to other domains. Ultimately this expansion is necessary to help validate the research being undertaken.

1.4 References

[1] On Agent-Mediated Electronic Commerce
Minghua He, et al, 2003