A Double Agent-Based Framework of CSET Negotiation Model for Optimal Supply Chain Formation

Yang Hang, Simon Fong, Zhuang Yan

***Abstract* -- In an effort to compose an optimal supply chain, this paper tries to bring forward a new double agent-based Single Machine Earliness/Tardiness (SET) model. It includes the Sub-agent, which is designed for fairly coordinating and distributing job orders at the mid-stream levels. Extending from the precedent SET model, Collaborative-SET (CSET) has a coordinating Parent-agent, which is responsible for optimizing the information flow and scheduling of the whole supply chain. This is done by coordinating the information flow at the Sub-agents in each stream. In a long run, this new model makes a complex dynamic supply chain more efficient, and improves response time of the whole supply chain. A stimulator that implements the algorithms in this paper is programmed, in order to calculate the amount of information transfer, time and cost incurred between SET model and CSET model. The results generally indicate that the more streams a supply chain has, the better the performance gain is yielded.**

***Index Terms*—Automated negotiation agent, Dynamic supply chain, SET model**

I. INTRODUCTION

Nowadays, automated negotiation has been paid more attention all around the world. Mediator Agent, which is usually used in automated negotiating system with *Pareto-optimality*, is being prevalent in such electronic commerce applications as online traveling agents, Bi-party B2B e-commerce, etc.

For optimizing workflows and resource allocations, automated negotiation method also finds its use in the dynamic supply chain management [1][2]. For example, some research focuses on determination of optimal scheduling and the supply chain formation based on this scheduling [3], and some others consider minimizing the total cost keeping the total lead time within the orders' due date submitted by the customers [4]. In this application domain, both of them indicate that scheduling is playing a key role in a modern supply chain.

Typically there are multiple streams and many participants within a dynamic supply chain. Because of the dependence of participants between every two streams, this participants' relationship between these two streams is usually collaboration. However, there may be more than one participant in the same stream expecting profitable orders from his upstream. Hence, that relationship between all the participants in the same stream could well be competition.

Under the competitive relation, Mediator Agent is a solution with Pareto-optimality, which supports negotiation by searching for an agreement that benefits every party as much as possible. Many automated negotiation research on supply chain focus on the price coordination through offers and counter-offers. But some others emphasize how to recover loss within the extent of total profits, like SET model-based make-to-order. Because of the automated negotiation system in this model, every participant can't suffer the loss due to the nature of Pareto-optimality based on the given current resource.

Nevertheless, in SET model, Dynamic Suppler Chain Formation Problem (DSCFP) [5] is seen to be the target that shall be solved. As shown in Figure 1, because it uses scheduling method to pass information along the supply chain, before making an optimal solution, the information has to be transferred from every participant through each stream back and forth. Usually there are dozens of participants inside a make-to-order dynamic supply chain. If working on SET model, it will take a lot of time and cost because of the inter-streams connections in the supply chain.

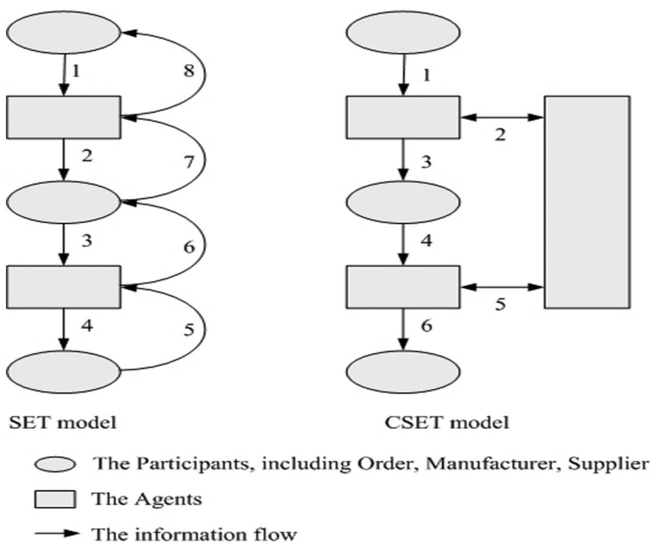

Figure 1. Comparison of SET model and CSET model in terms of steps

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In order to improve on this issue, this paper attempts to suggest a supply chain automated negotiation model to shorten the scheduling and manufacturing cost.

II. BACKGROUND

The SET model (Single Machine Earliness/Tardiness Model) is the base model our work built upon. This model aims to solve the allocation problem of dynamic supply chains. It is a scheduling model that considers the earliness costs and tardiness costs in the production of a single machine.

Such model is established for Make-to-Order and for optimizing the supply chain formation using automated negotiation agents [3].

The function to minimize the Manufacturing and Supply costs is as follow:

$$Min\sum^{s}(MC+FC+MPC_{MissDeliveryDate}+MPC_{Inventory})$$

$$+\sum^{m}(MC+FC+MPC_{MissDeliveryDate}+MPC_{Inventory})$$

MC: manufacturing cost;
FC: fixed cost;
MPC: marginal penalty cost;

Figure 2 indicates the overall workflow in a dynamic supply chain, which includes three downstream participants (Orders), three midstream participants (Manufacturers) and four upstream participants (Suppliers).

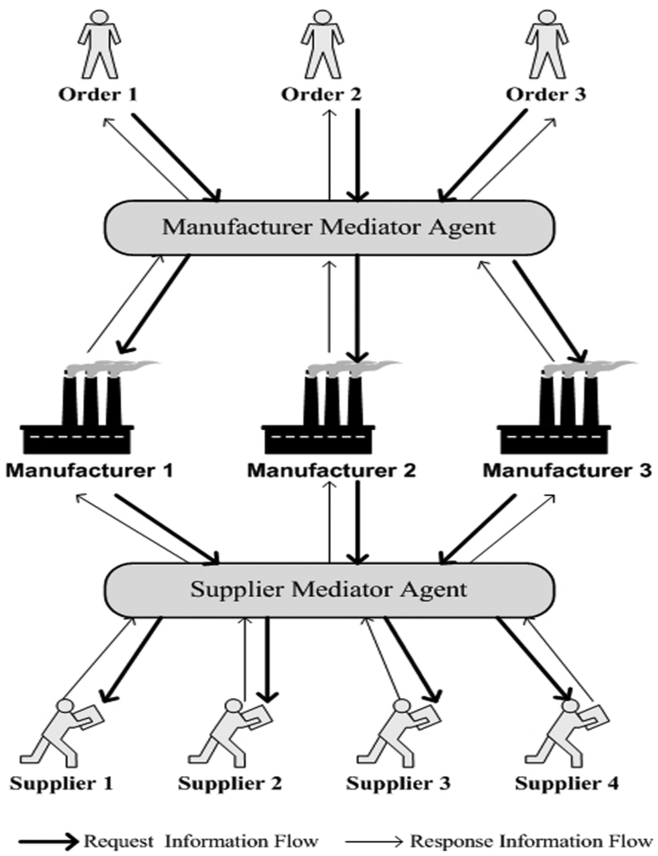

Figure 2. Order placement and manufacturing process of mediator agent

First step, each order makes a request for an estimate through the *Manufacturer Mediator Agent*, and then the agent sends order information to all the manufacturers participated in the supply chain. According to the orders, every manufacturer makes a request for an estimate through *Supplier Mediator Agent*, which sends the orders information to all the suppliers. Then the suppliers make scheduling. This step is the orders information passing from Orders to Suppliers.

Second step is the scheduling information returning from Suppliers to Orders. Each Manufacturer selects the least supply cost, the agent schedules to send the information to the Orders.

This negotiation principle aims to minimize the additional costs caused by concurrent orders, for instance, when an order is placed with a manufacturer, and when the concurrent orders take place owing to overlapping orders. The definitions of the objective function, constraints, and variables are as follows:

$$Min\sum_{p\in M}\sum_{j\in N}c_p^j x_p^j+\sum_{j\in N}\sum_{e\in E}o_{pq}^j z_{pq}^j(p\in M;j\in N)$$

c^j_p : The least cost of manufacturer $j \in N$ for order $p \in M$;
x^j_p : In case that order $p \in M$ is placed with manufacturer $j \in N$, 1 or 0 ;
o^j_{pq} : The additional cost of manufacturer $j \in N$ when both orders (p,q) E have been placed with him ;
z^j_{pq} : In case that order $p \in M$ and $q \in M$ $(p!q)$ are placed simultaneously with manufacturer $j \in N$, 1 or 0 ;

With this automatic negotiation agents system embedded into a dynamic supply chain, every participant won't suffer a loss because of Pareto-optimality. Furthermore, in this case, even if a negotiation fails, it shows that current resource allocation adheres to a Pareto optimal solution.

III. PROPOSED MODEL

Scheduling is the key point in SET model. However, to optimize the dynamic supply chain formation with agents, the SET model makes an optimal determination after the upstream (Suppliers) offering the cost and the schedule to all of the previous streams (Manufacturers and Orders).

But if the supply chain contains many participants as well as more than three streams, it is difficult for the supply chain to maintain the schedule and cost in SET model.

Hence our study proposes a new SET model-based on make-to-order to optimize supply chain formation called Collaborative-SET (CSET) model, which adds a *Parent Agent* into the SET model. This *Parent-Agent* is responsible for optimizing different *Sub-Agents* in the supply chain with Pareto-optimality method. It coordinates the operations of the Sub-agents across all the streams.

The new CSET model works also for scheduling costs. The CSET model offers a pipelining solution which means the upstream can start working as soon as sending out the orders to the Sub-agents. Then the Sub-Agent will send the order information to his downstream participants and the Parent-Agent simultaneously.

With constant connections of each participant with its Sub-agent, this Sub-agent is able to monitor the conditions and the information of each participant, which in turn are conveyed to the Parent-agent (PA). Consequently, the PA masters the overall situation of the whole supply chain. For this reason, before the PA makes a Pareto-optimal solution for its Sub-agents, it would have collected enough relevant information of the whole supply chain participants. The main task of Parent-Agent is to optimize all the Sub-agents so that each Sub-agent is able to communicate with his upstream and downstream participants, making an optimal branch decision on the resource allocation.

In the CSET model, before an order is sent, in terms of the information collected from the SC, PA knows whether it is workable or not. For this reason, those orders which are infeasible won't entre into the make-to-order supply chain.

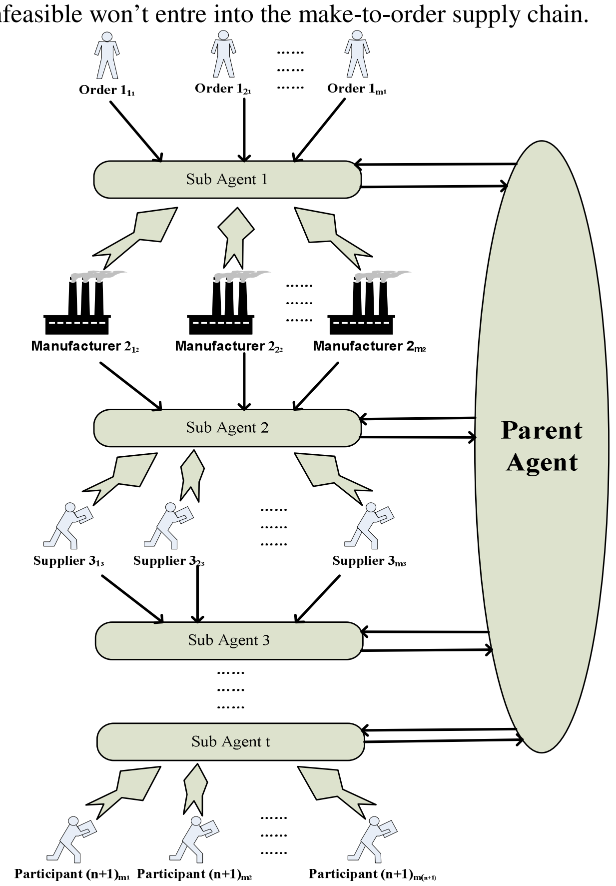

Figure 3. Order placement and manufacturing process of CSET agent

Figure 3 shows how CSET model optimizes a supply chain formation. The sequence diagram indicates the details of how the information flows as shown in Figure 7 in the appendix.

Step 1

Buyer makes an order request to *Sub Agent 1*. The order information is sent to the *Parent-Agent (PA)* simultaneously. After calculating the relevant data, *PA* returns an optimal suggestion to *Sub Agent 1*. With the input of the suggestion, it can make an optimal ordering-branch solution. Then the order is accepted and will be transferred to Manufacturers.

Step 2

For the orders, each manufacturer calculates the corresponding manufacturing schedule and cost, and then it sends a plan and the budget to the *Sub Agent 2*. That information is sent to the *Parent-Agent (PA)* simultaneously as well. After calculating the relevant data, *PA* returns an optimal suggestion to *Sub Agent 2*. According to the suggestion, the agent can make an optimal manufacturing-branch solution. Then the information will be transferred to Suppliers and the Manufacturer can start manufacturing.

Step 3

This procedure is passed to every participant until the terminal stream. Once the *Sub-Agents* make a solution, the information shall be transferred to *PA* first. After *PA* calculates the relevant data and returns an optimal suggestion to *Sub-Agent*, the optimal solution is made available.

IV. DISCUSSION

When the CSET model is adopted over some time, the more complex dynamic supply chain is, the more manufacturing schedule could have been shortened. We assume that in the dynamic supply chain:

1. All the participants must participate in the supply chain workflow;

2. There are only two kinds of streams in the supply chain: the manufacturers and suppliers;

3. There are *n+1* streams, each stream has m_{n+1} participants ($m>2, n\geqslant 0$);

4. And between every two streams there is a sub-agent A_t ($t\geqslant 1$);

For a Sub-Agent *t*, the function to find a Pareto-optimal solution is:

$$SAU_{f(t)} =$$

$$Min\sum_{m_n=1}^{n}\sum_{j=1}^{d}\sum_{k=1}^{d_j}(mc^n_{m_n jk}+fc^n_{m_n jk}+tard^n_j\times T^n_{m_n jk}+earl^n_j\times T^n_{m_n jk})x_{m_n jk}$$

$$+\sum_{m_{n+1}=1}^{n+1}\sum_{j=1}^{d}(mc^{n+1}_{m_{n+1}j}+fc^{n+1}_{m_{n+1}j}+tard^{n+1}_j\times T^{n+1}_{m_{n+1}j}+earl^{n+1}_j\times T^{n+1}_{m_{n+1}j})y_{m_{n+1}j}$$

$$s.t\sum_{m_{n+1}=1}^{n+1}y_{m_{n+1}j}=1,\quad \forall j;$$

$$\sum_{m_n=1}^{n}x_{m_n jk}=1,\quad \forall k,\forall j;$$

$$x_{m_n jk}=0\quad or\quad 1,\quad y_{m_{n+1}j}=0\quad or\quad 1$$

* If stream *n* is consisted of suppliers, participant n_{m_n} must consider the component *k* for order *j*; If *n+1* is a stream of manufacturers, participant $(n+1)_{m_{n+1}}$ needn't consider the component *k* for order *j*

$x_{m_n jk}$: a variable indicates participant n_{m_n} producing component *k* for order j

$y_{m_{n+1}j}$: a variable indicates participant $(n+1)_{m_{n+1}}$ producing order j

n : the number of streams

m_n: the number of participants in the n stream

j: the number of orders

d_j : the number of components for order j

$mc^{n}_{m_n jk}$: manufacturing cost of participant n_{m_n} for component k for order j

$fc^{n}_{m_n jk}$: fixed cost of participant n_{m_n} for component k for order j

$tard^{n}_{j}$: participant n_{m_n} 's marginal penalty cost for missing delivery date for order j

$earl^{n}_{j}$: participant n_{m_n} 's marginal penalty cost for inventory for order j

$T^{n}_{m_n jk}$: time by which participant n_{m_n} 's delivery of component k for order j is late. This is function of sequence of $x_{m_n jk}$

$mc^{n+1}_{m_{n+1}j}$: manufacturing cost of participant $(n+1)_{m_{n+1}}$ for order j

$fc^{n+1}_{m_{n+1}j}$: fixed cost of participant $(n+1)_{m_{n+1}}$ for order j

$tard^{n+1}_{j}$: participant $(n+1)_{m_{n+1}}$'s marginal penalty cost for missing delivery date for order j

$earl^{n+1}_{j}$: participant $(n+1)_{m_{n+1}}$'s marginal penalty cost for inventory for order j

$T^{n+1}_{m_{n+1}j}$: time by which participant $(n+1)_{m_{n+1}}$'s delivery of order j is late. This is function of sequence of $y_{m_{n+1}j}$

For every sub-agent, it has its distinct parent-optimal solution function $SAU_{f(t)}$. To harmonize all the sub-agent solutions the Parent Agent shall maintain the overall manufacturing cost and schedule of the whole supply chain formation. We calculate the $PAU_{function}$ depending on the close connection between the weight method and each $SAU_{f(t)}$. [6] The estimating function of the whole supply chain optimality is as follow:

$$PAU_{function} = MAX \sum_{t=1}^{SAU} \sum_{z=1}^{R} SAU_{f(t)} \bullet w_z$$

t : the number of Pareto-optimal solution
z : the index number of relevant variable
$SAU_{f(t)}$: sub agent t Pareto-optimal solution;
w : a nonnegative weight coefficient for each sub agent
w_z : a relevant variable

V. EXPERIMENT

This study is conducted for an optimization test to find out how much the CSET model can save in terms of scheduling cost of the whole supply chain.

From Figure 4, we can see that using CSET model, the whole supply chain information transfer flow has been reduced a lot. To calculate the higher work efficiency of CSET model than SET model, the efficiency algorithm is implemented using program language PHP.

We assume that each of the information flow takes the same time, which is also called the transfer cost.

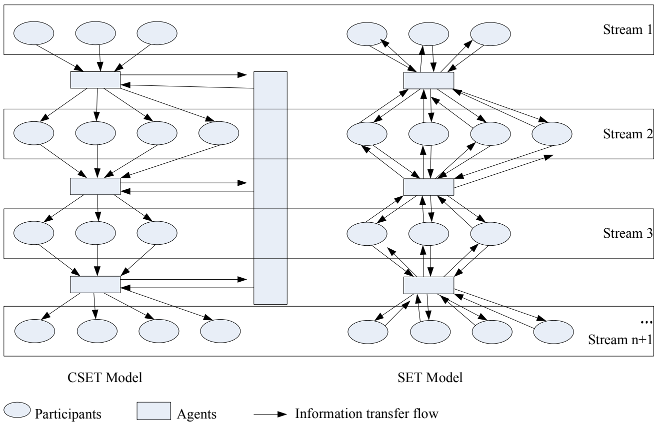

Figure 4. The workflow comparison between CSET model and SET model

For the SET model, the information transfer cost is:

$$2m_1 + 4(m_2 + m_3 + ... + m_n) + 2m_{n+1}$$

For the CSET model, the information transfer cost is:

$$m_1 + 2(m_2 + m_3 + ... + m_n) + m_{n+1} + 2n$$

m: the number of participants in the same stream
$n+1$: the number of stream, n>=0

If every stream $n+1$ has the same participants' number m_{n+1} the following results can be obtained via the simulation program as shown in Figure 5.

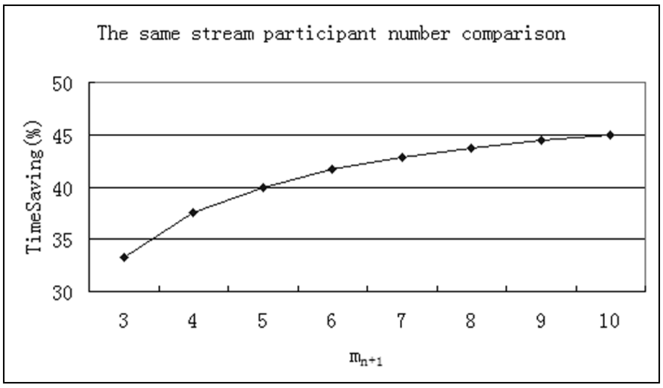

Figure 5. Time saving comparison of same stream participant number

Figure 6 shows the simulation results of having the same stream $n+1$ that has different participants number m_{n+1} :

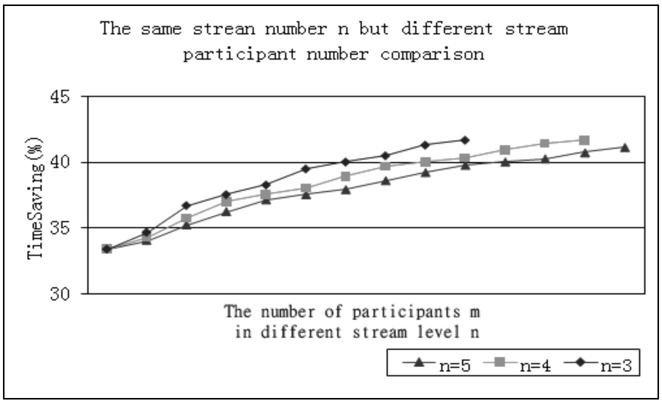

Figure 6. Time saving comparison of different stream participant number

From Figure 5, we can see an obvious increasing trend of the Time Saving (TS) percentage of CSET model compared with SET model. We choose a consistent number *m* as a stream participant number. As a result, although the marginal speed of TS percentage is getting down, CSET model saves more time cost than SET model does.

According to Figure 6, our experiment chooses different stream levels (*n*=3, 4, 5) as samples; When there are only three streams, stream 1 and stream 2 have three participants respectively, while stream 3 has four. Compared with SET model, CSET model saves 34.62% time. When the participant's number changed, stream 1 has three, stream 2 and 3 have four respectively, the time saving increases to 36.67%. In this way, we change the participant number in each stream from 3 to 6 consistently. Likewise, this experiment is also taken when there are four and five streams respectively. As a result, there is a TS growth as well in all cases.

VI. CONCLUSION AND FUTURE WORK

This study is focused on bringing a new automated negotiation model based on optimal supply chain formation.

The new model, called CSET model, considers the relationship of every participants in a supply chain, using the sub-agent to give a competition-based solution while the parent-agent to give a collaboration-based solution. It aims to give an overall optimal solution to the whole of the supply chain and all its participants. With the collaborative-efforts of Sub-agents and Parent-agent, even in a complex supply chain all the participants won't suffer any loss in terms of transfer cost.

In addition, CSET features a pipelining solution that shortens a lot of the participants' manufacturing and scheduling time. Thus, the whole supply chain can be made more efficient.

In the future, we will continue working on the research of CSET model especially on the quantitative aspects. Analytical models as well as detailed scenario-based simulation will be built. We will try to formulate a function that computes how much the overall cost is minimized, and let the results be cross-validated by that of the simulation program.

APPENDIX

Figure 7, the Sequence Diagram of CSET model using in Supply Chain

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APPENDIX

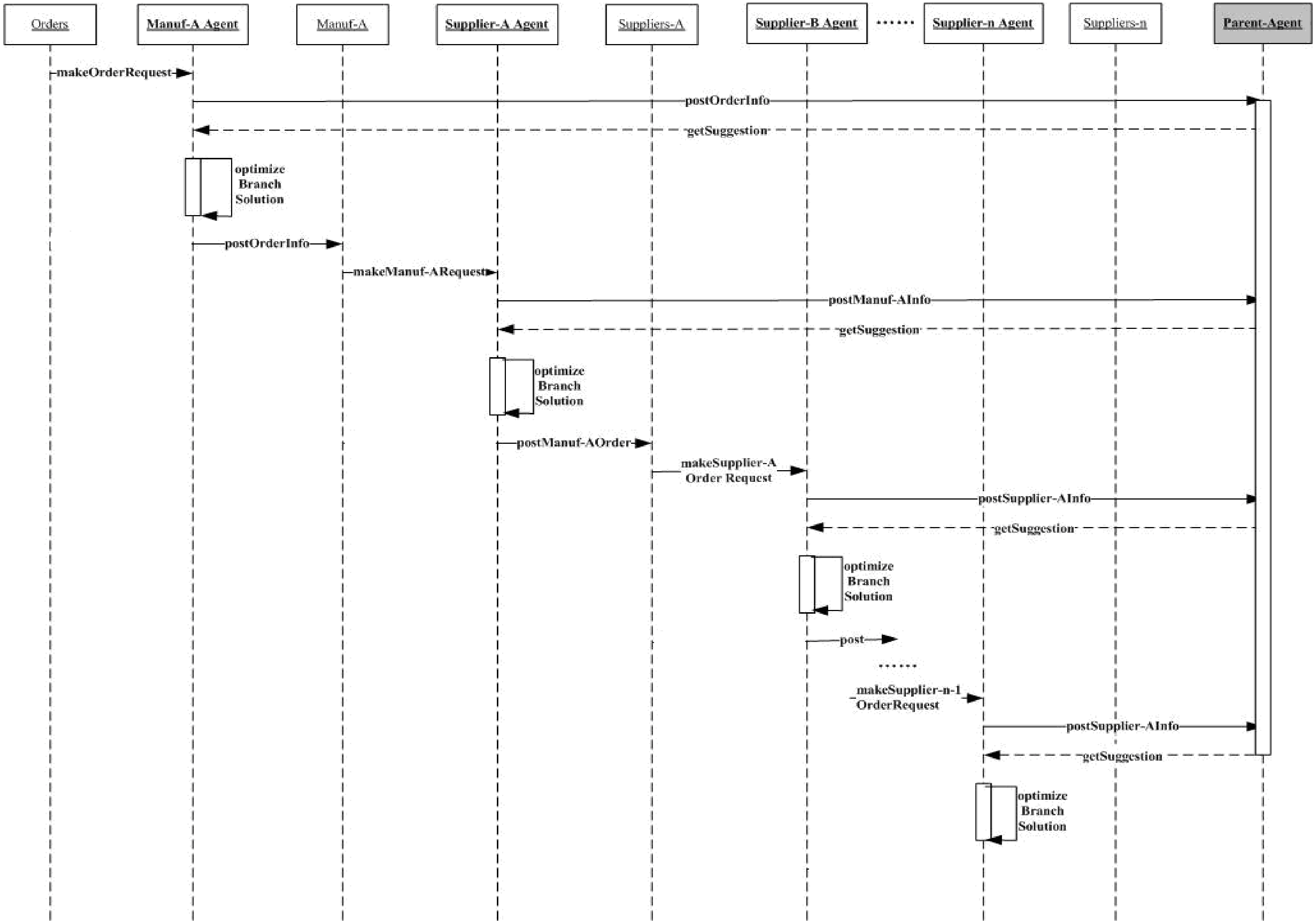

Figure 7. Sequence Diagram of CSET model using in Supply Chain