CSET automated negotiation model for optimal supply chain formation

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Abstract: In an effort to compose an optimal supply chain (SC), this paper tries to bring forward a new collaborative agent-based single machine earliness/tardiness (SET) model. It includes the sub-agents, which are designed for fairly coordinating and distributing job requests at the mid-stream levels. Extending from the precedent SET model, collaborative-SET (CSET) has a coordinating collaborative agent, which is responsible for optimising the information flow and scheduling of the whole SC. This is done by coordinating the information flow at the sub-agent between each two streams. In a long run, this new model makes a complex dynamic SC more efficient and shortens response time. A stimulator that implements the algorithms is programmed in order to calculate the amount of information transfer, time and cost incurred between SET and CSET model. The results generally indicate that the more streams a SC has, the better the performance gain is yielded.

Keywords: automated negotiation; dynamic supply chain formation; CSET model; collaborative agent; CA.

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1 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 travelling agents, Bi-party B2B e-commerce, etc.

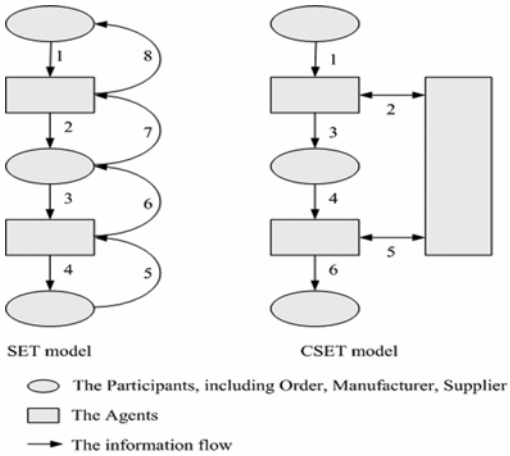
For optimising workflows and resource allocations, automated negotiation method also finds its uses in the dynamic supply chain (SC) management (You and Grossmann, 2007; Nam, 2003). For example, some research focuses on determination of optimal scheduling and the SC formation based on this scheduling (Kim et al., 2006) and some others consider minimising the total cost keeping the total lead time within the orders' due date submitted by the customers (Moncayo and Zhang, 2004). In this application domain, both of them indicate that scheduling is playing a key role in a modern SC.

Typically, there are multiple streams and many participants within a dynamic SC. 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 its upstream. Hence, that relationship between all the participants in the same stream could be well competition.

Under the competitive relation, mediator agent is a solution with Pareto-optimality, which supports negotiation by searching for an agreement that benefits every participant as much as possible. Many automated negotiation research on SC focus on the price coordination through offers and counter-offers. But some others emphasise how to recover loss within the extent of total profits, like single machine earliness/tardiness (SET) model on basic of make-to-order SC. Because of the automated negotiation system of this model, each participant cannot suffer the loss due to the nature of Pareto-optimality based on the given current resource (Kim et al., 2006).

Nevertheless, in SET model, dynamic suppler chain formation problem (DSCFP) (Tiana et al., 2006) 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 SC, 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 SC. If working on SET model, however, it will take a lot of time and transfer cost because of the inter-streams connections in SC.

Figure 1 Comparison of SET and collaborative-SET (CSET) model workflow



In order to improve on the issue above, this paper attempts to suggest a SC automated negotiation model to shorten the scheduling and transfer cost, which optimises SET model.

2 Backgrounds

The SET model is the fundamental model of our work built upon. This model aims to solve the allocation problem within dynamic SCs. 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 optimising the SC formation using automated negotiation agents (Kim et al., 2006).

The function to minimise 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 SET order placement and manufacturing process

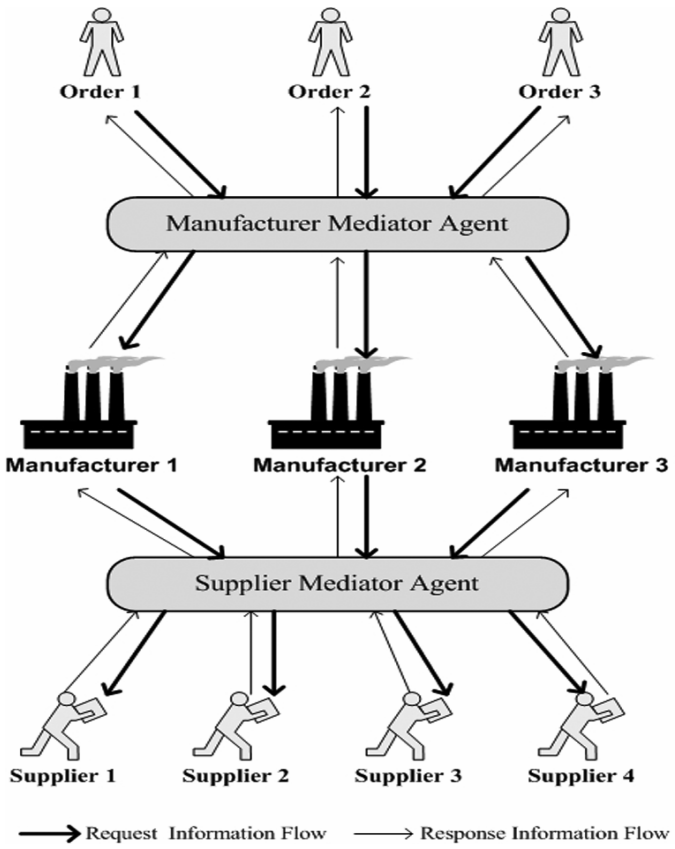


Figure 2 indicates the overall workflow in a dynamic SC, which includes three downstream participants (orders), three midstream participants (manufacturers) and four upstream participants (suppliers).

- *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 SC. 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 minimise the additional costs caused by concurrent orders, for instance, when an order request is placed with a manufacturer and when the concurrent requests 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_p^j the least cost of manufacturer $j \in N$ for order $p \in M$

x_p^j in case that order $p \in M$ is placed with manufacturer $j \in N$, 1 or 0

o_{pq}^j the additional cost of manufacturer $j \in N$ when both orders (p, q) E have been placed with him

z_{pq}^j 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 SC, every participant will not 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.

3 Proposed model

Scheduling is the key point in SET model. However, to optimise the dynamic SC formation with agents, SET model makes an optimal determination after the upstream (suppliers) offering the cost and a schedule to all of the previous streams (manufacturers and orders).

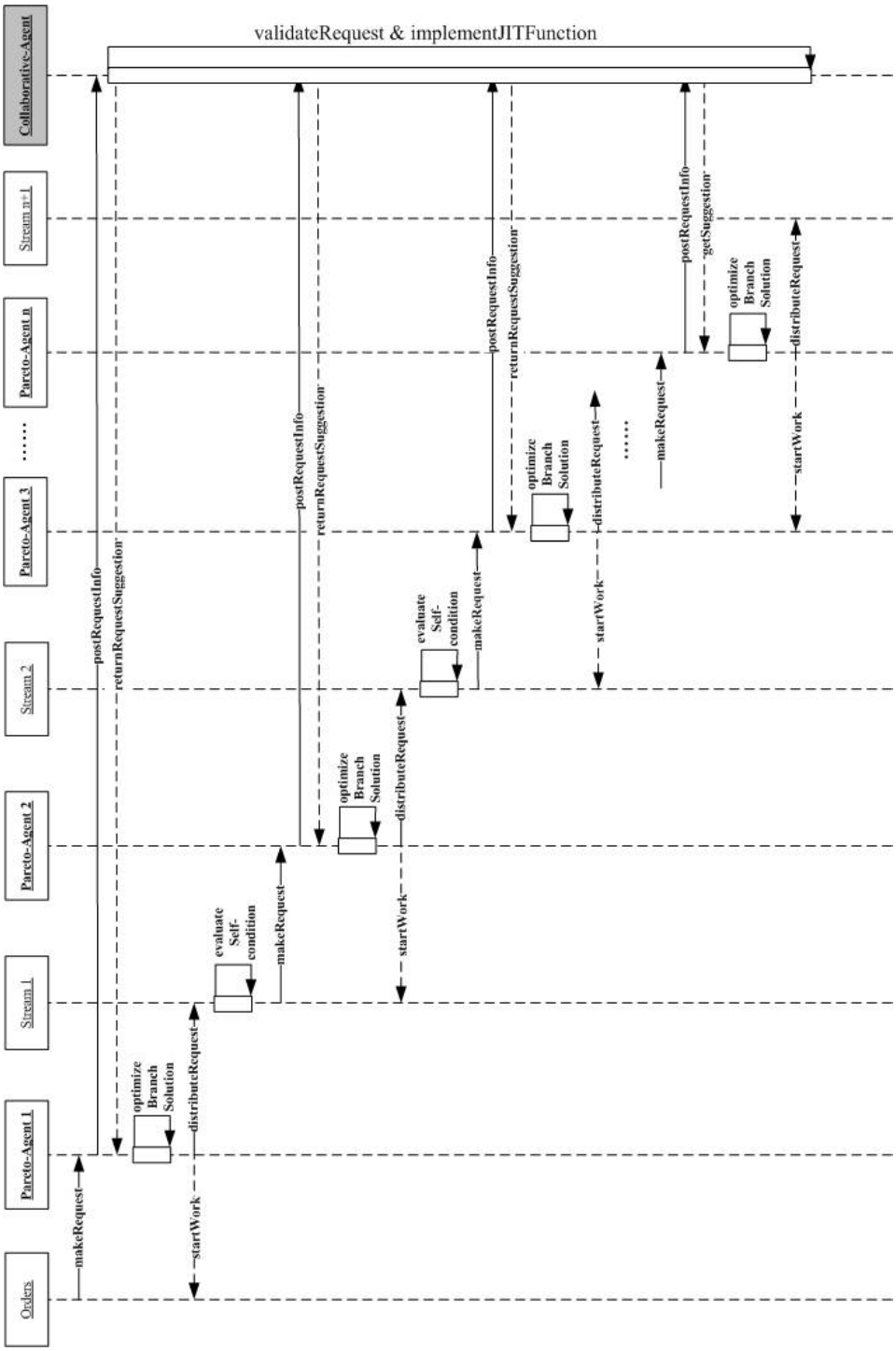
But if the SC contains many participants, usually more than three streams, it is difficult for SC to maintain the schedule and cost in SET model.

Hence, this study proposes a new SET model-based on make-to-order to optimise SC formation called CSET model, which adds a 'collaborative agent' (CA) into the SET model. (Figure 1) This CA is responsible for optimising different 'Pareto-agents' (PA) in the SC with some SC management method, for example, just-in-time technology. It coordinates all the requests distributed by 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 PAs. Then, the PA will send the order information to his downstream participants and the CA simultaneously.

With constant connections of each participant with its PA, this PA is able to monitor the conditions and the information of each participant, which in turn are conveyed to the CA. Consequently, the CA masters, the overall situation of the whole SC, especially the whole SC's productivity. For this reason, before the CA makes a collaborative solution for its PA, it would have collected enough relevant information of the whole SC's participants. The main task of CA is to optimise all the requests distribution workflow by PAs, so that each PA is able to communicate with its upstream and downstream participants, making an optimal branch decision of the resource allocation.

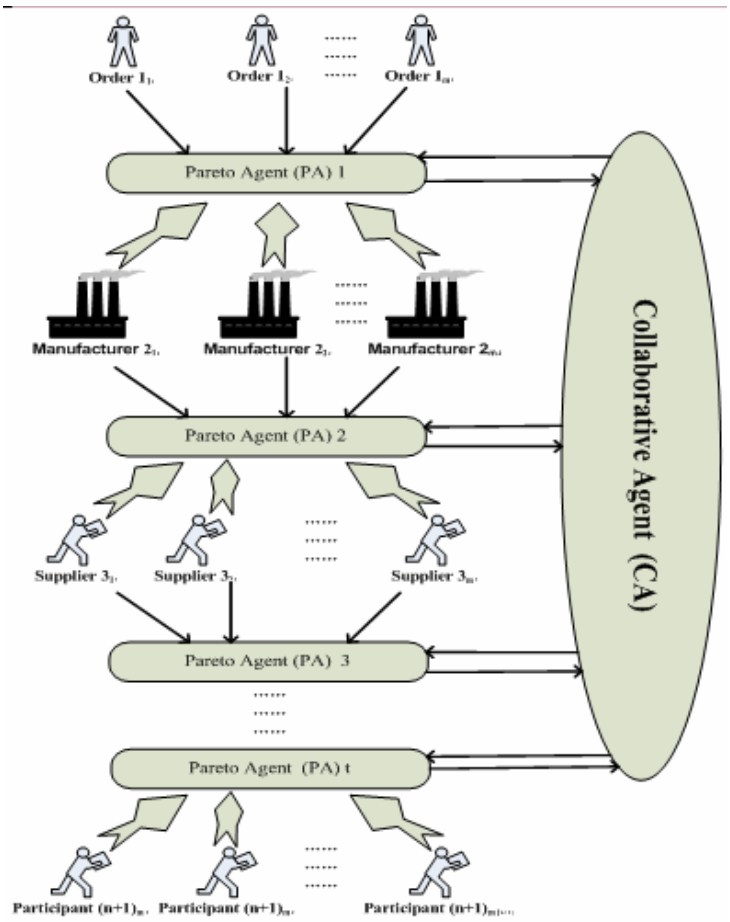
Figure 3 Sequence diagram of CSET model using in SC



In the CSET model, before an order is sent, in terms of the information collected from the SC CA knows whether this order is available or not in terms of the monitoring of the whole SC conditions. For this reason, those orders, which are infeasible will not come into the make-to-order SC.

Figure 4 shows how CSET model optimises a SC formation. The sequence diagram indicates the details of how the information flows as shown in Figure 3.

Figure 4 CSET order placement and manufacturing process (see online version for colours)



Step 1 Buyer makes an order request to 'Pareto-agent 1' (PA1). The order information is sent to the CA simultaneously. After calculating the relevant data and request validation, the PA returns an optimal suggestion to PA1 in terms of SC management technology. With the input of the suggestion, PA1 can make an optimal ordering-branch solution. Then, the order request is accepted and will be transferred to manufacturers.

Step 2 For the order requests, each manufacturer calculates the corresponding manufacturing schedule and cost and then it sends a plan and the budget to PA2. That information is sent to the CA simultaneously as well. After calculating the

relevant data, CA returns an optimal suggestion to PA2. According to the suggestion, PA2 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. Before PA makes a solution, the information shall be transferred to CA first. After CA calculates the relevant data and returns an optimal suggestion to PA, the optimal solution is made available by PA.

4 Discussions

When the CSET model is adopted over some time, according to the experimental result, the more complex dynamic SC is, the more manufacturing schedule could have been shortened. In the case of our experiment, we assume that in the dynamic SC:

- All requests from all participants are available in the SC workflow. In other words, all the requests within the SC are available.
- Besides the orders, there are only two kinds of streams in the SC: the manufacturers and the suppliers.
- There are $n + 1$ streams, each stream has m_{n+1} participants ($m > 2$, $n \geq 0$).
- And, between every two streams, there is a 'Pareto-agent' *(PA)* A_t ($t \geq 1$).

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

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

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

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

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

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

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

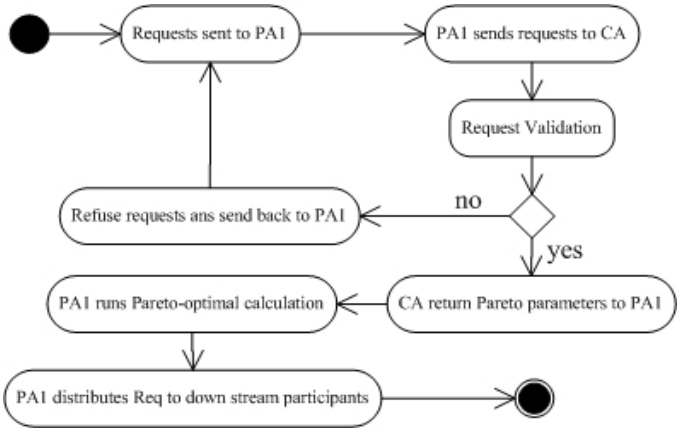
* If stream n is consisted of suppliers, participant n_{m_n} must consider the component k for order j; if $n + 1$ is a stream of manufacturers, participant $(n+1)_{m_{n+1}}$ need not consider the component k for order j:

$x_{m_n jk}$	a variable indicates participant n_{m_n} producing component *k* for order *j*
$y_{m_{n+1} j}$	a variable indicates participant $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$ 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 $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$ for order *j*
$fc^{n+1}_{m_{n+1} j}$	fixed cost of participant $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$ for order *j*
$tard^{n+1}_j$	participant $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$'s marginal penalty cost for missing delivery date for order *j*
$earl^{n+1}_j$	participant $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$'s marginal penalty cost for inventory for order *j*
$T^{n+1}_{m_{n+1} j}$	time by which participant $(\mathrm{n}+1)_{\mathrm{m}_{\mathrm{n+1}}}$'s delivery of order *j* is late. This is function of sequence of $y_{m_{n+1} j}$.

For every PA, it has its distinct parent-optimal solution function $PAU_{f(t)}$. To harmonise all the PAs solutions, the CA shall maintain the overall manufacturing cost and schedule of the whole SC formation. We resolve the CA's function as the just-in-time SC management method (Ohno, 1988; Menberu and Black, 1986). Generally speaking, CA is responsible to validate and optimise the requests distribution in terms of the scheduling time within the dynamic SC, Also, the result returned from CA plays an important role in $PAU_{f(t)}$ function calculation.

Seeing from the Figure 5, the combined actions of PA and CA occur when requests are delivered from top to bottom. Common requests are transferred from PA to CA. CA validates and optimises the requests distributing them to PA. Likewise, this course happens between each stream's PA and CA. The activity diagram (PA1 and CA) is shown in Figure 5. Likewise, the activity happens in other PAs as well.

Figure 5 Flowchart of PA and CA inter-processing

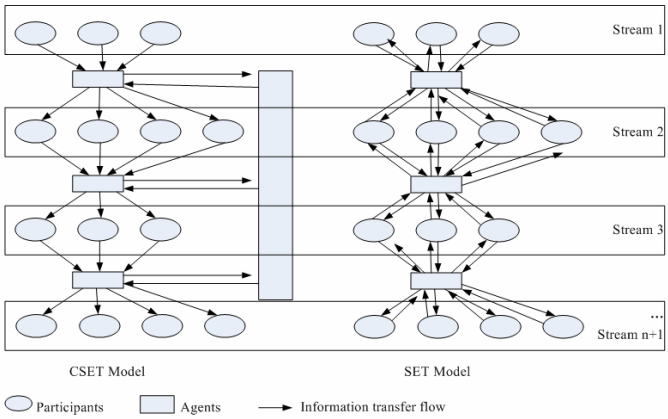


5 Experiments

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

From Figure 6, we can see that using CSET model; the whole SC information transfer flow has been reduced dramatically. To calculate the higher work efficiency of CSET model comparing to SET model, the efficiency algorithm is implemented by PHP program language. We assume that each of the information flow takes a same time, which is also called the transfer cost.

Figure 6 The workflow comparison between CSET and SET (see online version for colours)



For the SET model, the information transfer cost is:

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

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.

Figure 7 shows the simulation results of having the same stream *n* + 1 that has different participants' number m_{n+1}. If every stream *n* + 1 has the same participants' number m_{n+1} the following results can be obtained via the simulation program.

From Figure 7, we can see an obvious increasing trend of the time saving (TS) percentage of CSET model compared with SET model. The authors 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 does save more time cost than SET model.

Figure 7 TS comparison of same stream participants' number

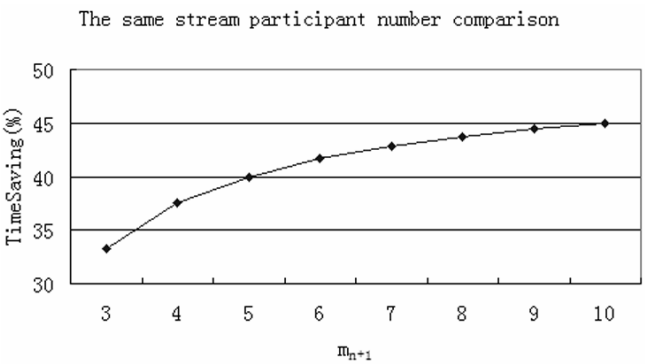
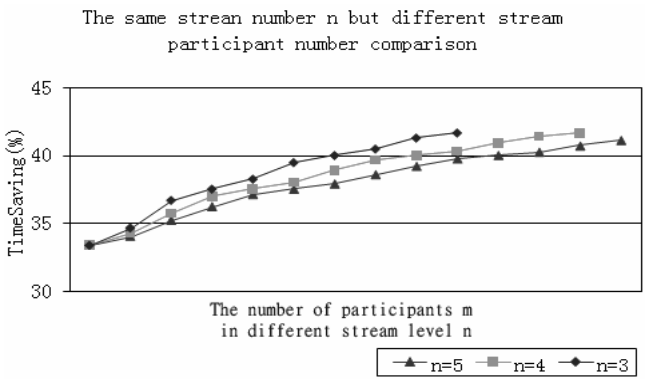


Figure 8 TS comparison of different stream participants' number



According to Figure 8, 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 up to six consistently in each stream. 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.

6 Conclusions and future works

This study is focused on bringing forward a new automated negotiation model based on optimal SC formation. This paper proposes a new model called CSET model, which is combined just-in-time SC management technology with Pareto-optimal method. Considering the relationship of every participant in a SC, the PA is able to give a competition-based solution while the CA to give a collaboration-based solution. It aims to give an overall optimal solution to the whole SC and all its participants. With the collaborative-efforts of PAs and CA, even in a complex SC all the participants will not 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 (Hang et al., 2008). Thus, the whole SC can be more efficient and feasible.

In the future, the authors 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. The authors will try to formulate a function that computes how much the overall cost is minimised and let the results be cross-validated by that of the simulation program.

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