Double-agent Architecture for Collaborative Supply Chain Formation

Yang Hang
Faculty of Science and Technology
University of Macau
SAR Macau, China
+853 66874953
ma76562@umac.mo

Simon Fong
Faculty of Science and Technology
University of Macau
SAR Macau, China
+853 3974473
ccfong@umac.mo

ABSTRACT
Supply chains have evolved to web-applications that tap on the power of internet to expand their networks online. Recently some research attention is focused on make-to-order supply chain formation where orders are scheduled to be optimally distributed among online manufacturers and suppliers for mutual benefits. A SET model was proposed in [1] using Pareto theories. The model is then extended into a collaborative manner throughout the whole supply chain by incorporating it with the Just-in-Time (JIT) principle, known as CSET. The CSET framework was proposed, and the advantage of time efficiency was shown in [2]. The core of the CSET model is based on intelligent agent technology. Specifically the model is supported by double-agent architecture with each type of agents who makes provisional plans of order distribution by Pareto optimality and JIT coordination respectively. This paper defines such double-agent mechanisms in details, as well as demonstrating its merits via simulation study.

Categories and Subject Descriptors
I.2.11 [**Distributed Artificial Intelligence**]: Multi-agent systems

General Terms
Algorithms, Management, Design, Economics, Experimentation.

Keywords
Collaborative Agent, CSET Model, Just-in-Time, Pareto-optimal, Multi-Agents System.

1. INTRODUCTION
Supply Chain Management (SCM) has evolved to be complex, large-scale, decentralized, and yet collaborative in nature. With the advent of web technology, industries are moving away from slow-moving, vertically integrated manufacturers to becoming dynamic networks of specialized companies that collaborate to bring a complete product to market [3]. Even small companies are part of a large and dynamic value chain when they can easily be connected through the WWW [4].

A typical dynamic example is a make-to-order supply chain (MTOSC) where the customer's demand drives production schedule and material procurement. The variety and volume of resources and capacity of supply and production processes had to be allocated online in timely manner [5]. Such supply chains, which are formed dynamically upon the arrival of orders from the lower streams, need to select the appropriate manufacturing partners in real-time [6]. This dynamic formation is known to be a complex decision-making problem that involves negotiation, resource reallocation and heuristic cost evaluation [1].

For this reason, Intelligent Agent System (IAS) has been an important research paradigm to explore ways of coordinating each loosely-coupled component of a supply chain, with intelligent capabilities. Many researches focus on applying IAS technology to SCM. Some are business administration problem-driven, for example, to reduce the Bullwhip Effect in SC [7], a multi-agent system (MAS) with collaborative strategies that uses companies' incentive to share information [8]. While some IAS researches target on the Dynamic Supplier Chain Formation Problem (DSCFP) [9], for example, Single Machine Earliness/Tardiness Model (SET model) uses Pareto-optimal automated negotiation method [10] into a MTOSC.

In our previous research, we studied the optimization of supply chain formation problem as a whole chain. In addition to matching the suitable manufacturing partners by Pareto optimization, we considered that time sequence plays a vital role in a MTOSC workflow. All the activities along the SC processes are synchronized in a coordinated effort by JIT [11]. This helps reducing manufacturing cost and improving time efficiency. The CSET model is based on the concept of having a double-agent with one of them taking care of the Pareto negotiation in between each pair of streams (horizontally) and coordinating the agents along the whole chain (vertically). The CSET framework and its integration with JIT were discussed in [12] [2]. The contribution of this paper is mainly focused on the double-agent mechanisms and the evaluation of their effects in CSET.

In this paper, Session 2 gives a brief background of our previous CSET model framework. Session 3 focuses on the system architecture design. Session 4 drills down to the details and explains how the four-phase inter- and intra-interactions happen under the double-agent framework. Session 5 presents functions of each module. In order to prove the improved effort

iiWAS2008, November 24–26, 2008, Linz, Austria.

of double-agent based CSET model, a simulation model and its analysis outcomes are given in Session 6.

2. CSET MODEL FRAMEWORK

CSET model consists of two different intelligent agents in supply chain application: one is called Pareto-optimal Agent (PA); the other is Collaborative Agent using Just-in-Time principle (JIT-CA in short) [12].

Each IA has its own role. JIT-CA is for controlling SC workflow with Just-in-Time principle, distributing and reconstructing requests in terms of time sequence. While PA plays a role as information sensor, in addition, it also uses the manufacturing cost, fixed cost as well as the tardiness and earliness cost to calculate a Pareto-optimal solution. PA is also used to allocate the solution to every participant along the SC.

From the experimental result, CSET model is more suitable for certain supply chain with a pyramid formation [2], which have more participants in upstream (e.g. suppliers) than in downstream (e.g. retailers). For this reason we chose two participants in down-, four in middle- and four in upstream (Figure 1). It shows a CSET model that applies three agents (2 PAs and 1 JIT-CA). The agents regulate the information flow, resource allocation and time coordination in this supply chain. This formation is used in our experiment later on.

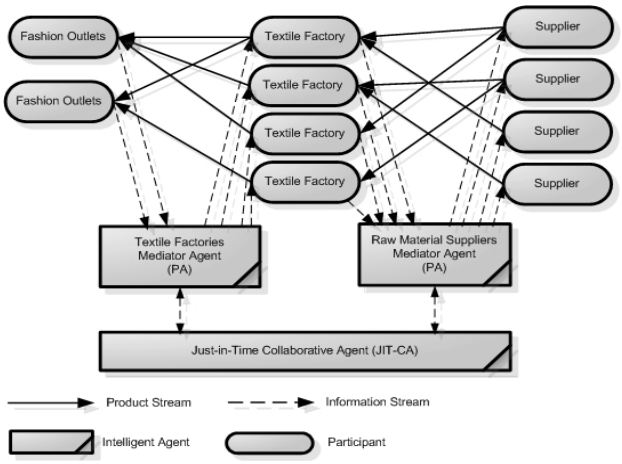

Figure 1 CSET model used in simulations

As an example of dynamic supply chain formation, we chose a scenario of fashion manufacturing SC which is characterized by dynamic fluctuation of consumer demand, seasonal market trends and a variety of availabilities of factories who are capable of producing the same goods. The example is simplified with only three streams which are: two Fashion Outlets (downstream), four Textiles Factories (midstream) and four Raw Material Suppliers (upstream) as shown in figure 1.

In CSET model framework, PA's requests distribution becomes more efficient than using PA's alone because of JIT is in control. Moreover, CSET model shortens waiting time so that the whole supply chain production flow achieves pipelining.

3. AGENTS ARCHITECTURE

In our example, the IAS consists of two Pareto-optimal mediator agents (PA): the Textiles Factories Mediator Agent between outlets and factories, and the Raw Material Suppliers Mediator Agent between factories and suppliers. Also, there's a Just-in-Time Collaborated-agent (JIT-CA) linking up the two PA's.

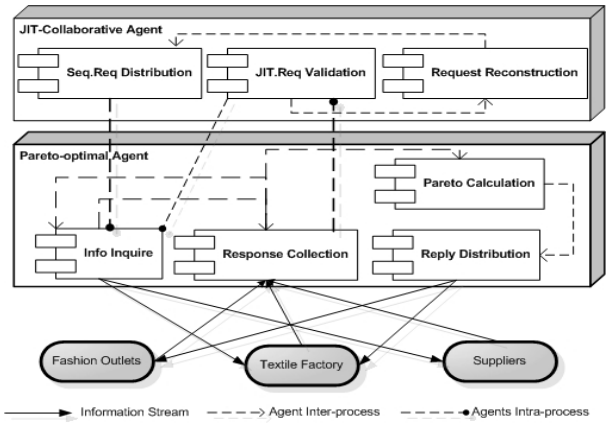

Figure 2 Agent architecture

According to Figure 2, on one hand, the architecture shared by the PA is composed with four main functional modules: Information Inquiry is responsible for sending inquiring information to participants. This module works dependent on the Response Collection module, which is used to capture replies from the participants. Pareto Calculation module is accountable for computing a Pareto-optimal solution for each request for the fellow factories. It also transfers the result to Reply Distribution module, which is designed for allocating the Pareto solution requests to the corresponding participants.

On the other hand, there are three different modules in JIT-CA: JIT.Req Validation Module is used to check the validity of the requests which are collected from PA. A valid request is divided in terms of time and reconstructed to multiple Sequent Requests (Seq.Req) by Request Reconstruction module. After the Request Reconstruction procedure, the Seq.Req is arranged by Seq.Req Distribution module and sent to PA.

4. AGENT' INTERACTIONS

This section presents the information interactions inter and intra in both PA and JIT-CA. Generally, CSET model information stream and agent processes are specified into four phases presented in Figure 3(a-d) and resolved step by step in Session 4.1 to 4.4.

4.1 Phase 1 (Fig 3a): Orders to Factories

(1) Orders are sent to Factories Mediator Agent (PA1)

(2) PA1 collects the order information by Response Collection module and sends them to JIT-CA;

(3) Orders are validated by JIT.Req Validation module; if available, then sent to next module, else return to Order sender by Info Inquire module;

(4) Validated orders are reconstructed to new sequent requests by Request Reconstruction module, and ready to transfer to PA1 in terms of time sequence, by Seq.Req Distribution module.

(5) Info Inquire module receives Seq,Req and allocates them to Factories.

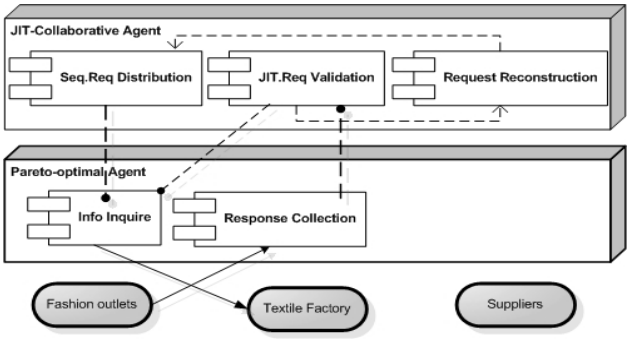

Figure 3a Phase One

4.2 Phase 2 (Fig 3b): Factories to Suppliers

(1) When Seq.Req is received, Factories estimate their own manufacturing conditions and send the raw materials supplying request to Suppliers Mediator Agent (PA2);

(2) PA2 collects the factories' requests by Response Collection module and inquires to Supplier through Info Inquire module;

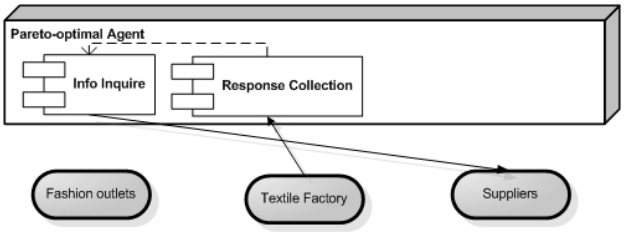

Figure 3b Phase Two

4.3 Phase 3 (Fig 3c): Suppliers to Factories

(1) In terms of realistic conditions, Suppliers reply the factories' supplying requests to PA2;

(2) Depending on the information transferred by Response Collection module, PA2 computes the optimal suppliers and replies distribution solution through the Pareto Calculation module;

(3) Then suppliers reply is allocated to each Factory by Reply Distribution module.

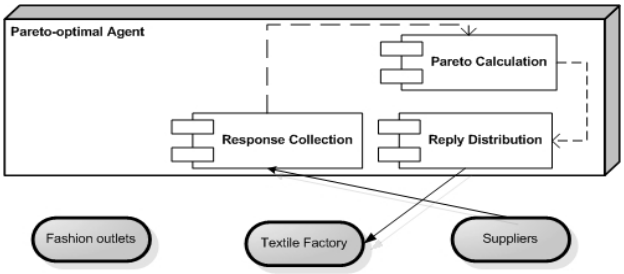

Figure 3c Phase Three

4.4 Phase 4 (Fig 3d): Factories to Orders

Similar with what happens in Phase Three, after considering the self-condition, Factories return order requests confirmation to PA2. Then PA2 calculates the Pareto-optimal, selecting the best distribution proposal with the minimum cost, and allocates to Orders.

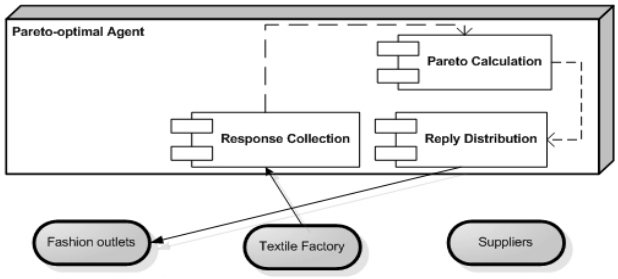

Figure 3d Phase Four

After these four-phrase interactions are done in the agents, the information of each participant along the SC is able to pass through the double-agent architecture system. Furthermore, a CSET system can compute the Pareto-optimal solution with Just-in-Time principle along the whole SC as well. Thus, the waiting time of factories and suppliers can be shortened in pipelining.

5. AGENT"S FUNCTIONAL MODULES

As far as the aforementioned, each agent has its specific functional modules: four in PA and three in JIT-CA. This session shows the strategy of every module, which is stepped by 5.1 to 5.7.

5.1 Info Inquiry

Info Inquiry module is used to claim responses from the participants in SC. The procedure contains two activities: one is inquiring manufacturing reply from midstream (Factories); the other is inquiring raw materials supplying reply from upstream (Suppliers). The flow is presented as a sequence diagram in Figure 4.

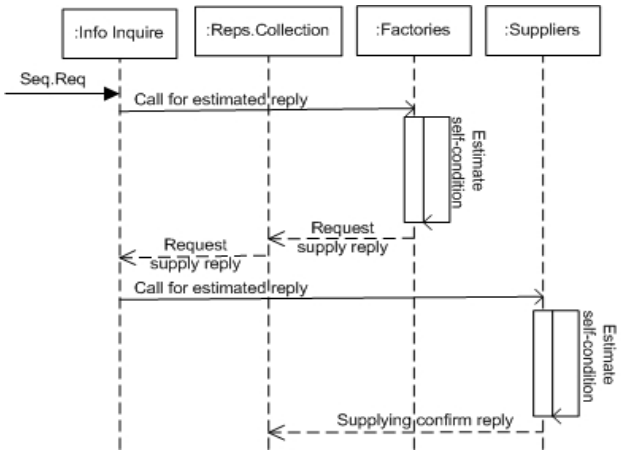

Figure 4 Info Inquire Sequence Diagram

5.2 Response Collection

The information collected from Outlets, Factories and Suppliers contains different details, which is important for double-agent system computing.

From Outlets: $O_i(OAmt, ST, ET, \Theta)$

Order i contains three mean attributes, OAmt means the amount; ST is the starting time while ET is the ending (delivery) time. Θ represents the validity: one means true while zero means false, default is zero. It is represented in the format of Seq.Req.

From Suppliers: $Sup^j_{mn}(SAmt, ST)$

After estimating the current condition, the suppliers reply a supply confirmation to the factories. The reply m from supplier n for request j. SAmt means the amount that supplier n can offer given ST starting time.

From Factories: $RFr^i_{jk}(FAmt, ST, ET, MC, FC, TardC, EarlC)$

After estimating the current condition, the factories reply a manufacturing confirmation to the customers. Manufacturer replies j from refining factory k for Seq.Req i. FAmt means the amount; ST is the starting time while ET is the ending time (delivery time). MC is the manufacturing cost and FC is the fixed cost. Both MC and FC are constants for a particular factory. TardC and EarlC are the unit cost of Tardiness and Earliness. It depends on how much long suppliers offer raw materials later or earlier than manufacturer planned..

5.3 JIT.Req Validation

In terms of the information obtaining from SC, the Supply Chain Maximum Productivity (MaxPsc) is computed as the following function:

$$MaxP_{SC} = \sum_{k=1}^{k} \frac{FAmt^i_k}{ET^i_k - ST^i_k}$$

To check whether the order requests could be accepted by the following stream (factories), it is necessary to find the average productivity (AvgPoi) of order i. The formula is:

$$AvgPo_i = \frac{OAmt_i}{ET_i - ST_i}$$

The validation process compares MaxPsc with AvgPoi , which is presented in the following:

```
IF MaxPsc≥AvgPoi THEN
   set Θ=1 and send it to JIT-CA
ELSE
   set Θ=0, refuse and return to customers
```

5.4 Response Reconstruction

The valid orders (with Θ=1) are transferred to this module, reconstructing into Seq.Req by the Just-in-Time principle. [2]

As it is shown in Figure 5, the ST and ET values will be joined as a new time aggregate T = ST∪ ET, which contains the starting time and the ending time information of i orders. According to the SReq Reconstruction Algorithm [2], all ti in T will be re-ordered in ascending order. This module is also responsible for calculating the average productivity of order i (AVGpi), and reconstructing all i Orders into k new Seq.Req.

After finishing with this process, the system obtains a set of Seq.Req k, which is calculated in the light of time sequence of the whole SC. It is able to reduce a lot of waiting time so as to improve the whole SC's flow.

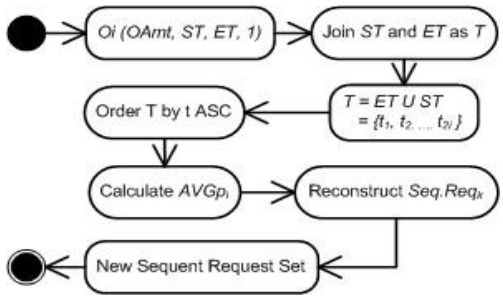

Figure 5 Req. Recon. Module Activity Diagram

5.5 Seq.Req Distribution

Seq.Req Distribution is responsible for allocating the Seq.Req given the new starting time and ending time. In Figure 6, when a Seq.Req's ending time is approaching, it will distribute another Seq.Req which has the starting time on the heels of the previous one. In this case, the requests within the whole SC are dispatched by sequent time so that the whole SC workflow will be pipelining.

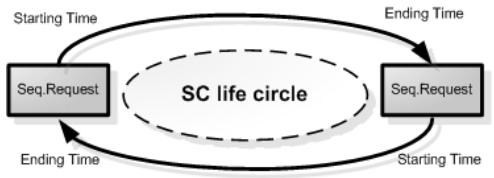

Figure 6 Seq.Req distributing

5.6 Pareto Calculation

The main function of Pareto Calculation module is modified from the SET model [1]. The SET model aims at solving the order distribution, hence the formation problem of dynamic supply chains. Thus, SET model is basically a scheduling model that considers the earliness costs and tardiness costs.

To find out the Pareto-optimal solution along the overall SC, this module does the calculation in functions (1) and (2).

$$Min \sum_{m=1}^{m} \sum_{i=1}^{i} \sum_{j=1}^{j} \sum_{k=1}^{k} \begin{bmatrix} MC^i_k + FC^i_k \\ + TardC^i_k \times (ET^j_m - ST^i_k) \\ + EarlC^i_k \times (ET_i - ET^i_k) \end{bmatrix} \quad (1)$$

$$s.t. \quad SR\_Amt_i \le \sum_{k=1}^{k} FAmt^i_k \quad (2)$$

$$Min \sum_{i=1}^{i} \sum_{j=1}^{j} (ET_i - ET^i_j) \quad (3)$$

i: the sequent request number;
m: the supplier's reply number;
j: the factory's reply number;
k: the factory number;
MC^i_k : manufacturing cost of factory *k* for order *i*;
FC^i_k : fixed cost of factory *k* for order *i*;

$TardC_k^i$: daily tardiness cost of factory *k* for order *i*;

$EarlC_k^i$: daily earliness cost of factory *k* for order *i*;

ET_m^j : delivery time of supplier reply *m* for factory reply *j*;

ST_k^i : manufacturing start time of factory *k* for order *i*;

SR_Amt_i : amount of Seq.Req *i;*

$FAmt_k^i$: amount in factory reply *k* to Seq.Req *i*;

ET_j^i : delivery time of factory reply *j* for order *i*;

ET_i : delivery time of order *i*.

Function (1) computes the minimum manufacturing cost of each factory in terms of manufacturing cost(MC), fixed cost(FC), raw materials supplied tardiness cost (TardC) of supplying delivery postpone and earliness cost (EarlC) of manufacture finished inventory . The formula of function (1) is shown as follow.

With reference to Function (2), function (1) is available only when the Factory(s)'s schedule's total manufacturing ability is able to sustain the suffering under the Seq.Req's quantity requirement.

In order to meet the delivery time requirement, if function (1) offers optional results, function (3) is used to select the minimum manufacturing cost solution with the earliest order delivery time, which compares the order delivery time with the factory delivery time.

5.7 Pareto Calculation

This module is accountable for dispatching the reply to the downstream. The procedure contains two activities: firstly, allocating the suppliers' reply to factories; secondly, allocating the factories' reply to customers. It plays an important role as a solution distributing filter in PA.

6. EXPERIMENTAL RESULTS

For testing the CSET double-agent system, we programmed a simulation program in Java that implements the example in Figure 1. As shown in Figure 7, the system obtains the orders information through the simulation interfaces. After the order validation, original orders are converted into sequent request.

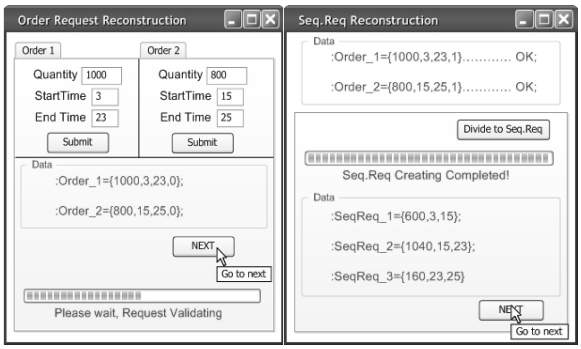

Figure 7 Orders collection interface

Table 1 shows experimental result of orders reconstruction. In Table 1, the first Seq.Req is SReq_1, which starts from day 3 to 15 with 600 amount requirements. When it is expired, the system sends the next SReq_2 which is followed by SReq_3.

Table 1 Orders Recon. Data

ID	Quantity	Starting Time	Ending Time
Order_1	1000	3	23
Order_2	800	15	25
SReq_1	600	3	15
SReq_2	1040	15	23
SReq_3	260	23	25

After the information request arrives at Suppliers, they estimate self-conditions and return the full duration supplying schedule as Table 2. By following the SReq and suppliers' timetable, each factory schedules its manufacturing as in Table 3.

Table 2 Supplying Schedule

ID	Quantity	Delivery Time
Sup_1	200	23
Sup_2	500	16
Sup_3	800	16
Sup_4	700	4

Table 3 Factories' scheduling

ID	Amt	ST	ET	MC	FC	Tard	Earl	T.C
F1_SR1	350	3	11	35	10	10	5	75
F2_SR1	400	4	15	40	10	10	5	50
F3_SR1	600	5	15	60	10	10	5	**70**
F4_SR1	200	6	10	20	10	10	5	55
F1_SR2	350	14	21	35	10	10	5	75
F2_SR2	650	18	22	65	10	10	5	**80**
F3_SR2	800	17	22	80	10	10	5	95
F4_SR2	400	16	22	40	10	10	5	**55**
F1_SR3	180	23	25	10	10	10	5	**20**
F2_SR3	80	24	25	8	10	10	5	**18**
F3_SR3	120	23	24	12	10	10	5	27
F4_SR3	120	22	25	20	10	10	5	40

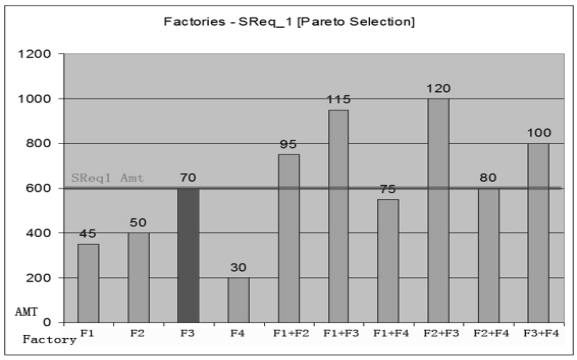

Figure 8 Pareto solution of SReq_1

We can see from Figure 8 that after Pareto-optimal calculation in PA, system selects the factory with the minimum of cost (70) to meet the SReq_1's quantity (600). The choice is Factory 3. Likewise, in Figure 9, the system selects the factory

with the minimum of cost (125) to meet the SReq_2's quantity (1040). The solution is choosing Factory 2 and Factory 4. In addition to Figure 10, the system selects the factory with the minimum of cost (38) to meet the SReq_3's quantity (260). Factories 1 and 2 are chosen.

Consequently, to meet the two original orders, the SC manufacturing scheduling solution is as follow: Day 3-5: Factory 3 uses the raw materials supplied by Supplier 4; Day 15-23: Factories 2 and 4 work simultaneously with Suppliers 2 and 3; Day 23-25: Factories 1 and 2 start manufacturing with Supplier 1.

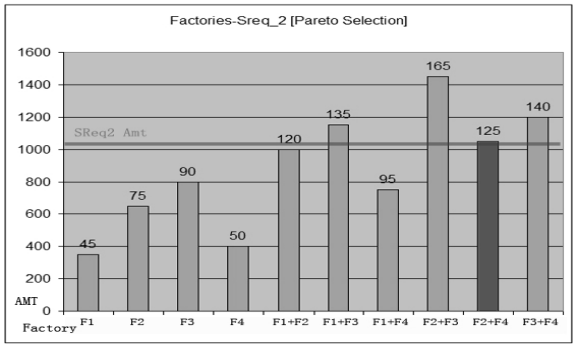

Figure 9 Pareto solution of SReq_2

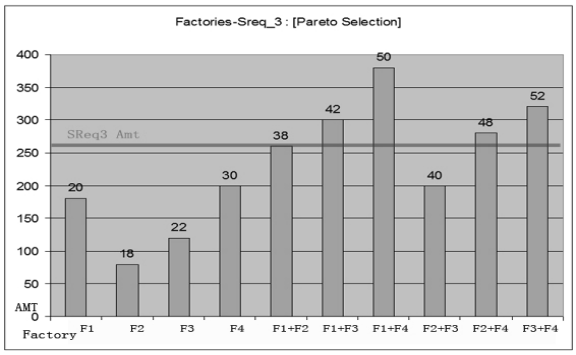

Figure 10 Pareto solution of SReq_3

7. CONCLUSION

In this paper we discussed the double-agent mechanism for our previously proposed CSET model. With a simulation, our system integrates Pareto-optimal method with Just-in-Time principle within a supply chain. As a result, pipelining manufacturing flow is achieved. This is significant to dynamic supply chain formation as it can help to optimize constraints and costs across production, distribution, inventory, and transportation. An optimized supply chain means improvement on service levels and delivered costs, as well as asset utilization. The ability to optimally form a dynamic supply chain as well as to improve on planning velocity can ensure that the supply chain is highly responsive to changes in the marketplace.

For future works, we plan to case-study this double-agent based CSET model with more complicated and realistic data via our simulation program. Also we will look into how this model can be integrated with other types of supply chains and workflows such as make-to-stock, make-to-order, and configure-to-order business scenarios across diverse industries such as automotive and industrial; consumer electronics; consumer packaged goods; process; semiconductors etc.

8. ACKNOWLEDGMENTS

The authors are grateful that this work is supported by the Research Council, University of Macau.

9. REFERENCES

[1] Hyun Soo Kim, Jae Hyung Cho, Hyung Rim Choi, etc, 2006. "Optimal Supply Chain Formation sing Agent negotiation in a SET Model-based Make-To-Order", ICEC'06, Frederiction, Canada, ACM 1-59593-392-1/08/0006, August 14-16

[2] Yang H., Simon Fong, Zhuang Yan, 2008. "Applying Pareto-optimal and JIT technique for supply chain", HIS2008, p. 308-313

[3] A.P. Sheth, W.M.P. van der Aalst, and I.B. Arpinar, Processes Driving the Networked Economy: Process Portals, Process Vortexes, and Dynamically Trading Processes, IEEE Concurrency, 7 (3), pp. 18-31

[4] Mani Subramani, 2004. "How Do Suppliers Benefit from Information Technology Use in Supply Chain Relationships?," MIS Quarterly, Volume 28, Number 1, March 2004

[5] Shang-Tae Yee, , 2002. "Simulation applications in the automotive industry: establishment of product offering and production levelling principles via supply chain simulation under order-to-delivery environment", 34th conference on Winter simulation

[6] D.D. Zeng and K.P. Sycara, 1999. Agent-facilitated real-time flexible supply chain structuring. In Proc. of the Agents'99 Workshop "Agent-Based Decision-Support for Managing the Internet-Enabled Supply-Chain"), pp. 21-28

[7] H. L. Lee, V. Padmanabhan, and S.Whang, 1997, "The bullwhip effect in supply chain". Sloan Management Review, pp. 93–102

[8] Thierry Moyaux, Brahim Chaib-draa, Sophie D'Amours, 2004. "Multi-Agent Simulation of Collaborative Strategies in a Supply Chain", AAMAS '04, Multiagent Systems (1)

[9] Jiang, T., Foleya, R., Xin, Y., Tianfield, H., 2006, "An Extendinged Contract Net Mechanism for Dynamic Supply Chain Formation, Multiagent and Grid Systems" – An International Journal, pp. 183-207

[10] Bagchi, T.P., Jayaram, K., Srinivas, T.D., 1999. "Pareto optimal production scheduling by meta-heuristic methods", Management of Engineering and Technology, International Conference on Technology and Innovation Management. PICMET '99. Volume 1, 25-29 July 1999, pp.448

[11] Safayeni, F., Duimering, P.R., Purdy, L., 1991. "Management of just-in-time production", Technology Management: the New International Language, pp. 444-447

[12] Yang H., Simon Fong, Zhuang Yan, 2008 "A double agent-based framework of CSET negotiation model for optimal supply chain", ICITA2008, p.15-20