Double-agent Architecture for Collaborative Supply Chain Formation

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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

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
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.

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.

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.

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.

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;

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.

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.

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.
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: $O_i(\text{OAmt, ST, ET, } \Theta)$

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

From Suppliers: $\text{Sup}_{mn}^j(\text{SAmt, ST})$

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: $\text{RFr}_{jk}^i(\text{FAmt, ST, ET, MC, FC, TardC, EarlC})$

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:

$$\text{MaxPsc} = \sum_{i=1}^{m} \frac{\text{FAmt}_i}{\text{ET}_i - \text{ST}_i}$$

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:

$$\text{AvgPoi}_i = \frac{\text{OAmt}_i}{\text{ET}_i - \text{ST}_i}$$

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

IF $\text{MaxPsc} \geq \text{AvgPoi}$ THEN
set $\Theta = 1$ and send it to JIT CA
ELSE
set $\Theta = 0$, refuse and return to customers

5.4 Response Reconstruction

The valid orders (with $\Theta = 1$) 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 $T = ST \cup ET$, which contains the starting time and the ending time information of $i$ orders. According to the SReq Reconstruction Algorithm [2], all $t_i$ 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.

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 sequential time so that the whole SC workflow will be pipelining.

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).

$$\min_{i \in i} \sum_{m} \sum_{j \in j} \sum_{k} \sum_{l} \left[ MC_{k}^l + FC_{k} \times \left( ET_{l} - ST_{l} \right) \right] + \left[ TardC_{j} \times \left( ET_{j} - ET_{j} \right) \right]$$

subject to $$SR \cdot \text{Amt}_i \leq \sum_{m} \sum_{j \in j} \text{FAmt}_j$$

$$\min \sum_{i \in i} \sum_{j \in j} \sum_{k} \left( ET_{j} - ET_{j} \right)$$

$i$: the sequent request number; $m$: the supplier’s reply number; $j$: the factory’s reply number; $k$: the factory number; $MC_{k}^l$: manufacturing cost of factory $k$ for order $i$; $FC_{k}^l$: fixed cost of factory $k$ for order $i$;
$TardC_i$: daily tardiness cost of factory $k$ for order $i$;
$EarlC_i$: daily earliness cost of factory $k$ for order $i$;
$ET_j$: delivery time of supplier reply $m$ for factory reply $j$;
$ST_k$: manufacturing start time of factory $k$ for order $i$;
$SR_i.Amt_i$: amount of Seq.Req $i$;
$FAmt_k$: amount in factory reply $k$ to Seq.Req $i$;
$ET_i$: 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 follows:

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 sequential request.

Table 1 Orders Recon. Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Quantity</th>
<th>Starting Time</th>
<th>Ending Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order_1</td>
<td>1000</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Order_2</td>
<td>800</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>SReq_1</td>
<td>600</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>SReq_2</td>
<td>1040</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>SReq_3</td>
<td>260</td>
<td>23</td>
<td>25</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>ID</th>
<th>Quantity</th>
<th>Delivery Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sup_1</td>
<td>200</td>
<td>23</td>
</tr>
<tr>
<td>Sup_2</td>
<td>500</td>
<td>16</td>
</tr>
<tr>
<td>Sup_3</td>
<td>800</td>
<td>16</td>
</tr>
<tr>
<td>Sup_4</td>
<td>700</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3 Factories’ scheduling

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

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 follows: 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.

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
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9. REFERENCES