Multi-Objective Supply Chain Model through an Ant Colony Optimization Approach

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ABSTRACT
In this paper, we first describe a multi-objective supply chain model and the optimization problem in Supply Chain Management (SCM).It mainly includes measurements of cost, customer service fill rates and delivery flexibility. This model incorporates production and delivery. Then, we present an Ant Colony Optimization (ACO) application to the solution of some multi-objective optimization problems. The control of each sub-system in a supply chain is a complex optimization problem where optimal performance can be achieved using meta-heuristics. We then depict how our approach may be useful for the Multi-Objective supply chain optimization.

Keywords
Multi-Objective Optimization, Multi-Objective Supply Chain model, Supply Chain Management, Ant Colony Optimization

1. INTRODUCTION
Supply Chain Optimization (SCO) is an area that has been studied for more than two decades. Traditionally, the main focus of the research studies has been regarding minimizing the overall cost or maximizing the total revenue as a single objective optimization problem[2]. The main use of Supply Chain Management (SCM) is to setup resources across a supply chain to generate high-quality goods as cheaply as possible when the customers are in need of them. Ant Colony Optimization (ACO) is an efficient method for solving combinatorial optimization problems, and some ACO algorithms have been effectively useful to the travelling salesman problem [3], the quadratic assignment problem[9], job-shop[10], and multi-objective vehicle routing problems[11]. In this paper, we describe a multi-objective supply chain model including measurements of cost, customer service fill rates and delivery flexibility. The performance of each level will be optimized considering customer demand, production lead-time, and supply lead times throughout the supply chain. Supply chain network refers to the fact that many individual enterprises are involved, and every enterprise is happy to take part in a supply chain network, in which they can gain benefits and a larger market share[5]. We present an ACO application to the solution of the multi objective Supply chain problem. In a general Multi-Objective Optimization (MOO) problem, there exists no single optimal solution with respect to all available objectives, it might be optimal in one objective but it is possible that it might be worst in the other objective. In this problem, a decision maker is presented with Pareto-optimal solutions, which are a set of tradeoffs between the different objectives. These solutions are called non-dominated solutions, i.e., there exists no other solution which would increase a performance measure without causing a simultaneous decrease in at least one of the other objectives. [2]

2. THE MULTI-OBJECTIVE SUPPLY CHAIN MODEL
MOO is a discipline has been studied since 1970's, and its application areas range widely from resource allocation, transportation, investment decision to mechanical engineering, chemical engineering, automation applications, to name but a few. The main concept of MOO is to evaluate two or more conflicting objectives against each other. A simple method to solve an MOO problem is to make a composite objective function as the weighted sum of the conflicting objectives. Because the weight for an objective is proportional to the reference factor assigned to that specific objective, this method is also called preference-based strategy [7].It seems that, preference-based MOO is easy to apply, because by scalarizing an objective vector into a single composite objective function (e.g. combining all performance measures into a weighted average objective function to represent the overall system cost), an MOO problem can be converted into a single-objective optimization problem and thus a single tradeoff optimal solution can be solved effectively. However, the major drawback is that the trade-off solution obtained by using this procedure is very sensitive to the relative preference vector. Therefore, the choice of the preference weights and thus the obtained trade-off solution is highly subjective to the particular decision maker. For a decision maker, it would be useful if the posterior Pareto front can be generated quickly by using an MOO algorithm, as shown in Figure 1, so that he/she can choose the most suitable configuration among the trade-off solutions generated.In this project, we are also providing security to cars by using GSM modem. When any human sits in the car, there is sensor in the sit sense it and send signal to the modem and then modem send SMS to the numbers which we are fed in the program of controller. Due to this the car owner comes to know that any one is in his car and he will try to catch that theft. By examining a supply chain one obviously sees that a supply chain is a complex system consisting of multiple entities like suppliers, manufacturers, distributors and retailers, which independently have their own performance measures and objectives to optimize for their internal process e.g. maximizing the throughput. However, optimizing these individual entities is not sufficient when optimizing a supply chain as it is a dynamic network consisting of multiple transaction points with complex transportations, information transactions and financial transactions between entities. [2] Hence, optimizing the supply chain as a whole is as critical as optimization of the individual entities, and the aim of SCM is to align and combine all these objectives, individual as well as supply chain, so that they can work together towards a common goal - increasing the efficiency and profitability of the overall supply chain. SCM is thus multi-objective in nature and involves several conflicting objectives, both on the individual entity level and on the supply chain level.

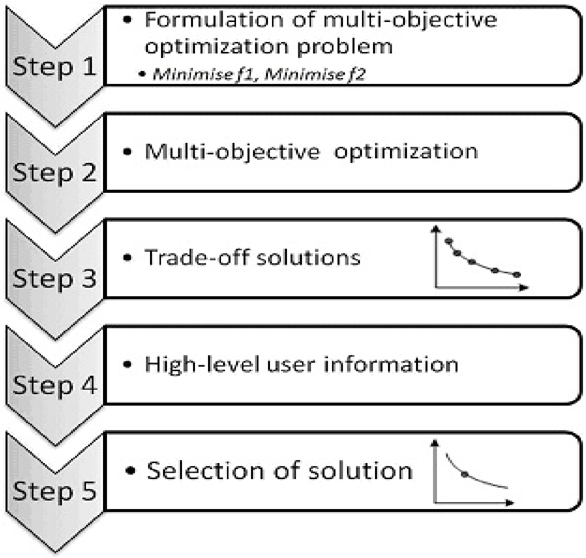

Fig 1. General MOO Procedure

The request is a bundle consisting of n items to be purchased. This bundle is denoted by set O = {1, 2 , ..., n}. A set of m sellers, denoted by V = {1, 2 , ..., m}, is been known as candidate suppliers. Each seller sells at least one item from bundle O. For each item i, seller j publishes selling price Pij. And for seller j, if one or more than one items are ordered, it charges the buyer a fixed transaction fee denoted by Sj, irrespective of the number of items ordered.[1] The above procurement problem with the objective of minimizing the total procurement cost can be formulated as an integer problem U. The decision variable is as xij for i ∈ O and j ∈ V. Assume xij = 1, if seller j is chosen for item i, and xij = 0 otherwise. In this model, a set of auxiliary variables yj for j ∈ V is also used. Let yj = 1, if seller j is chosen for at least one item, and yj = 0 otherwise, denote by a sufficiently large constant M. We now present:

$$U = \min \sum_{i \in O} \sum_{j \in V} P_{ij} x_{ij} + \sum_{j \in V} S_j y_j \quad (1)$$

subject to:

$$\sum_{j \in V} x_{ij} = 1, \; i \in O \quad (2)$$

$$M y_j \, C \sum_{i \in O} x_{ij}, \; j \in V \quad (3)$$

$$x_{ij} = 0, 1, \; i \in O, \; j \in V \quad (4)$$

$$y_j = 0, 1, \; j \in V \quad (5)$$

The objective (1) formalizes the goal of minimizing the total procurement cost. The constraints (4) guarantee that all individual items in bundle O are ordered from some sellers. The constraints (5) assure that yj = 1 if at least one item is ordered from seller j.

3. ANT COLONY OPTIMIZATION ALGORITHM

Ant colony optimization (ACO) meta-heuristic, a novel population-based approach was recently proposed in 1992 by Marco Dorigo et al. to solve several discrete optimization problems [13]. The ACO mimics the way real ants find the shortest route between a food source and their nest. The ants communicate with one another by means of pheromone trails and exchange information about which path should be followed. The more the number of ants traces a given path, the more attractive this path (trail) becomes and is followed by other ants by depositing their own pheromone. This auto catalytic and collective behaviour results in the establishment of the shortest route. Ants find the shortest path from their nest to the food source with the help of pheromone trail. This characteristic of ants is adapted on ant colony optimization algorithms to solve real problems with using exactly some characteristics of ants and some new addition [13]. The method improved by modelling real ants use exactly the same specifications taken from real ants are below :

- The communication established with ants through pheromone trail.
- Paths deposited more pheromone preferred previously.
- Pheromone trail on short paths increase more rapidly.
- Addition of new specifications to this new technique is below:
- They live in an environment where time is discrete.
- They will not be completely blind, they will reach the details about the problem.
- They will keep information formed for the solution of the problem with has some memory.

(a) Ants following a path between their nest and food source
(b) Encountering a obstacle of ants
(c) Selection of ants
(d) Finding the shortest path of ants
As shown in Figure 2-a, ants start from their nest and goes along a linear path through the food source.

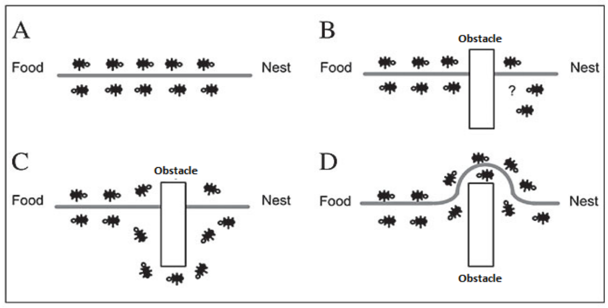

Fig 2. Behaviours of real ants between their nest and food source

Essentially, if there exist a difficulty on the path while going to the food source (Figure 2-b), ant lying in front of this difficulty cannot continue and has to account a preference for the new outgoing path. In the present case, selection probability of the new direction alternatives of ants is equal. In other words, if ant can select anyone of the right and left directions, the selection chance of these directions is equal (Figure 2-c). Namely, two ants start from their nest in the search of food source at the same time to these two directions. One of them chooses the path that turns out to be shorter while the other takes the longer path. But it is observed that following ants mostly select the shorter path because of the pheromone concentration deposited mostly on the shorter one.

The ant moving in the shorter path returns to the nest earlier and the pheromone deposited in this path is obviously more than what is deposited in the longer path. Other ants in the nest thus have high probability of following the shorter route.

These ants also deposit their own pheromone on this path. More and more ants are soon attracted to this path and hence the optimal route from the nest to the food source and back is very quickly established. Such a pheromone-meditated cooperative search process leads to the intelligent swarm behaviour [13].

The instrument of ants uses to find the shortest path is pheromone. Pheromone is a chemical secretion used by some animals to affect their own species. Ant deposit some pheromone while moving, they deposit some amount of pheromone and they prefer the way deposited more pheromone than the other one with a method based on probability. Ants leave the pheromone on the selected path while going to the food source, so they help following ants on the selection of the path (Figure 2-d). [13]Most ant colony optimization algorithms use this algorithmic diagram demonstrated below:

Initiation of the parameters which determines the pheromone trail

While (until result conditions supplied) do

Generate Solutions

Apply Local Search

Update Pheromone Trail

End

4. ANT COLONY OPTIMIZATION APPLIED TO MULTI-OBJECTIVE SUPPLY CHAIN MODEL

ACO algorithm is based on the above explained ideas. In general, the bundle O and V in each tier of our model is performed by corresponding ants. From the SCM viewpoint, the core operation of the ACO application method is the updating policy of the pheromones and the action selecting policy in the algorithm. As the exploitation, ants are given both pheromones and heuristic values,

$$\max v2 \in Jk(v1)\{[\tau(v1,v2)][\eta(v1,v2)]\mu\} \quad (6)$$

where Jk(v) is the feasible tier nodes of ant k on node v for the valid solution; pheromone $\tau(v1, v2)$ is used as indication of better choice in long term, η is the amount of pheromone related with item at each iteration; 5 is the value of a problem-dependent heuristic function, which is used as short term heuristic. The higher the value of η, the lesser the procurement cost is, and so the higher its probability of being chosen. As the biased exploration, ants in our algorithm are guided by the probabilistic transition policy:

$$pk(v1,v2)=\{[\tau(v1,v2)]v[\eta(v1,v2)]\mu\} / \{\Sigma v \in Jk(v1)[\tau(v1,v)]v[\eta(v1,v)]\mu\} \quad (7)$$

Which favours the choice of paths those are shorter and have a greater amount of pheromones, 6 and µ is used to determine the relative importance of pheromone versus heuristic. The current ant iteratively adds one item at a time to its current the supplier-selecting rule. Let item ij be a supplier selecting rule condition of the form Ai = Vij, where Ai is the i-th auxiliary variable and Vij is the j-th value of Ai. The probability that item ij is chosen to be added to the current supplier-selecting rule is given by:

$$Pij= \{\eta ij \tau ij\} / \{\Sigma i=1 at xi \, \Sigma j=1 \, bi(\eta ij \tau ij)\} \quad (8)$$

where at is the total number of auxiliary variables; xi is set to 1 if the auxiliary variable Ai is not yet used by the current ant, or to zero otherwise; bi is the number of values of the i-th auxiliary variable. An item ij is chosen to be added to the current supplier-selecting rule with probability proportional to the value of Equation (8) subject to the auxiliary variable Ai. In order to satisfy this restriction the ants record which items are contained in the current supplier-selecting rule.

5. RESOURCE INTEGRATION DECISION USING SUPPLY CHAIN MODEL

At present, the successful operations of the fourth party logistics (4PL) in practice gradually demonstrate that it is an effective mode to integrate the supply chain's complicated resources rationally, efficiently and flexibly. In order to thoroughly analyze the supply chain resources integration problem in 4PL from a quantitative perspective and to guide the integration practice, based on the previous study results, this paper takes the multi-objective optimization action of the integration decision as an analysis pivot, builds a improved ant algorithm to resolve the integration decision optimization process. Finally, the reasonability and feasibility of the algorithm are validated through the simulation of a calculation case.

In this aspect, our preliminary study has analysed the supply chain integration framework and operation characters in 4PL based on the evaluation of the dominant factors; we analysed how to build an optimization mathematical model and how to give a solution to the model. On these bases, this paper will introduce the integration completion time as a main objective into the integration decision, analyse the multi-objective optimization process, build a relevant solution by improving the ant algorithm and give a validity test by the simulation of a calculation case. According to system value theory, the key issue of 4PL integration is how to systematically integrate supply chain resources that are corresponding to a certain kind of production or service. On the premise that each sub-system individual will achieve its satisfied value, the whole value chain should be optimized and the value increment of operation activities should be realized. The result of resources integration will bring the rational flow of objects, capital and information and the smooth linkage of these factors between each individual along the supply chain system so as to realize the value increment of the system.

6. SIMULATION OF ALGORITHM

To test the feasibility and availability of the ant algorithm, we select a calculation case of building a new chain shop by a retail enterprise. To achieve the timely operation and the satisfactory completion of this building activity and at the same time, to make the individuals in the supply chain associated with this activity gain their expected and make the supply chain system improve its overall competitive edge, the retail enterprise decide to make resources integration by 4PL mode aimed at this building activity.

Here we select the decision process of integrating the consulting firm individual resources and the 3PL individual resources (be

responsible for the transports of the relevant equipments and materials and so on) as an example of the integration optimization to verify the validity of the algorithm. In verification, let the activity ability demand of the building task to the consulting individuals be 0.78 (all data has been normalized and unified.)

Let the activity ability demand of the building task to the 3PL resource individuals be 0.59. All the operating parameters of the individuals are shown in Table 1 and 2. In the algorithm operation, let the ant batch equal 100 and let the ant class A be aimed to choosing the consulting individuals and let the ant class B be aimed to choosing the 3PL resource individuals as an example. By using MATLAB V7.1 R14 SP3 to simulate, the simulation results are shown in Fig. 3 and 4. In the algorithm of integrating the consulting individuals, let $\alpha=0.24$, $\beta=0.30$, $\gamma=0.35$, $\delta=0.11$ and $\xi=0.05$. We can analyse from Fig. 3 that to the ant class A, because of its domain nodes (including the consulting individual 1 and 2 and the new self building one by the retail enterprise) have no other tasks simultaneously, the problem of congestion does not exist in these nodes. After several batches of operations, the ant current reached the stable state and all of the ants select the consulting individual 2.

This is because although the integration cost of the individual 2 is higher, but its integration completion time and its time-limit tolerance value are accordance with the basic requirement of the building activity. The tendency of the ant number through the self building consulting individual ascended first, and then dropped as also can be seen from Fig. 3. This is because the initial integration cost ascendant of this individual attracts a lot of ants, and with the advance of operating, the number of ants is oriented to the control of the integration completion time and of the time limit tolerance value, thus decreasing. This reflects the ant algorithm's operational flexibility in the complex multi-objective optimization process of the resource integration in 4PL.

For ant class B, let $\alpha=0.34$, $\beta=0.28$, $\gamma=0.17$, $\delta=0.21$ and $\xi=0.05$. From the view of activity capability constraint, only the 3PL individual 2 can complete the tasks independently. However, due to its higher integration cost, the 3PL individual 1 and 3 are chosen by the ants ultimately. The reason for more ants selecting 3PL individual 1 is because although this individual has higher integration costs than 3PL individual 3, its integration completion time is shorter. So, selecting 3PL individual 1 has more advantages for the retail enterprise to develop its chain shop business as soon as possible and grab the market chances. From the distribution results of the ant number in Fig. 3, the algorithm has greater flexibility in settling the capability constraint of the production or service activities. This is the role of the exclusion probability in algorithm and will reflect the algorithm's ability to settle the operating congestion problems in some nodes of the supply chain.

Table 1. Operational parameters of the consulting individual resources in the supply chain

Operational parameter	Consulting individual 1	Consulting individual 2	Self building consulting individual
Integration cost *C*	0.41	0.62	0.17
Integration completion time *T*	0.55	0.42	0.76
Tolerance value of time limit	0.43	0.32	0.71
Production or service activity ability	0.63	0.87	0.78

The simulation also indicate that we can obtain the better convergence time and effect by the appropriate adjustment of the value of the parameters α, β, γ, δ and ξ according to the practical circumstances of the supply chain resources integration in 4PL and obtain the satisfactory results.

Table 2. Operational parameters of 3pl individual resources in the supply chain

Operational parameter	3PL individual 1	3PL individual 2	3PL individual 2 I
Integration cost *C*	0.34	0.45	0.26
Integration completion time *T*	0.28	0.31	0.43
Tolerance value of time limit	0.44	0.21	0.35
Production or service activity ability	0.41	0.70	0.41

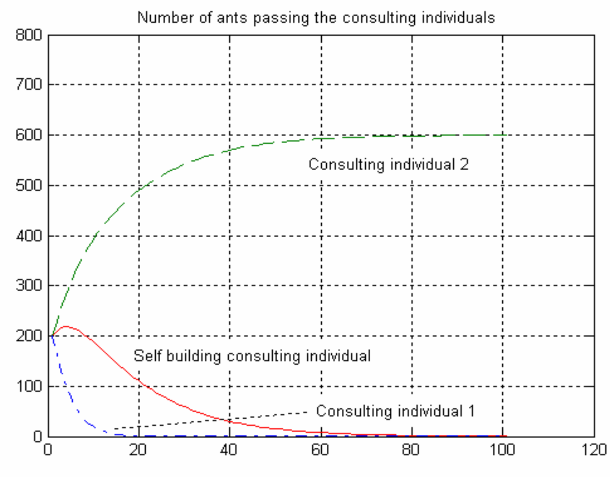

Fig 3. The simulation result about the consulting individuals

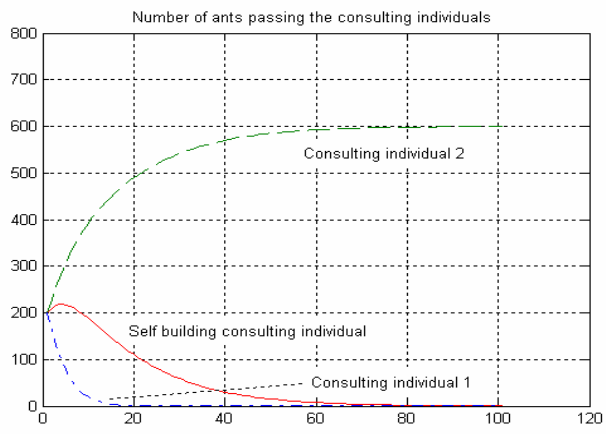

Fig 4. The simulation result about 3PL individuals.

7. CONCLUSIONS

This paper proposes an ACO algorithm to the multi-objective optimization problem in SCM that can satisfy the requirements of the customers more efficiently

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