Study of the Optimization of Logistics Network for 3PL Companies Based on Genetic Algorithm

YI Chunguang, JU Songdong
Center for Infrastructure Research (CIR), School of Economics & Management, Beijing Jiaotong University, P.R.China, 100044

Abstract
The optimal operation of 3PL companies’ logistics networks has a direct impact on their business performance, and will further influence optimal operation of social logistics network. After analyzing the operation characteristics of 3PL companies’ logistics network, we construct a basic model for optimizing operation of logistics network for 3PL companies with emphases on the three optimization models, namely Logistics Network Optimization Model with Time Windows (LNOMTW), Logistics Network Optimization Model with Price Discount (LNOMPD) and Logistics Network Optimization Model with Multi-transport Mode (LNOMMM). Based on the basic theory of genetic algorithm, we put forward the general steps and method of using genetic algorithms to solve these optimization problems of 3PL companies’ logistics network and hope to support decision makings for optimally operating of their logistics networks for 3PL companies.

Key words 3PL, logistics network, genetic algorithm, optimization model

1 Introduction
After entry into the 21st century, 3PL companies in China have changed the traditional “Point-to-Point” operational mode, and speeded up to reform into the modern logistics companies by way of constructing regional or national logistics networks. However, on account of lacking theoretical research and operational experience, although some efforts have been made, the results are not satisfactory. Therefore, it is of great theoretical and practical significance to make deep research on the related issues of logistics network programming and managerial operation of logistics nodes for 3PL companies. The optimization problems of logistics network relate to the various decisions for the whole material-flowing process from the suppliers, via the intermediate distribution centers, to the final customers. It aims to achieve the minimal operational costs of logistics network under a certain customers’ service level. The optimal operation of logistics network has a direct impact on the 3PL companies’ business performance. Thus, this article, taking the perspective of 3PL, researches the optimal problems that relate most to the operation of logistics network for 3PL companies.

Traditionally, there exist many methods to solve optimization problems of logistics network, most of which are related with the managerial and mathematic knowledge. The common methods include linear program, mixed integer program, etc. These methods, as for solving the problems, to some extent, can work well, but will cost enormous resources of time and space when solving the big-scale problems. The research indicates that the optimization problems of logistics network are NP hard problems. Only there are less supply and demand points, and the structure of logistics network is simple, can we get the exact solution. Actually, it is worthy for us to conduct a deep research on how to construct a simple and optimal algorithm with better searching capability focusing on the characteristics of 3PL companies’ logistics network.

The appearance of genetic algorithms offers a new tool to optimize the operation of logistics network for 3PL companies. As is known to us, the genetic algorithms are put forward by an American professor, John Holland, in the year of 1975. They are adaptive procedures that find solutions to problems by an evolutionary process based on natural selection. More exactly, genetic algorithms are a class of probabilistic algorithms that start with a population of randomly generated candidates and “evolve” toward better solutions by applying genetic operators, modeled on the genetic processes occurring in nature. They are capable to solve complicated problems and have characteristics of collateral, universal, robust, operational, simple and totally optimal, thus they are especially suitable to solve complex and non-linear problems that can not be easily solved by the traditional searching methods. By way of
using these optimal searching methods, we construct relative genetic algorithms to solve optimization problems of logistics network with a consideration to the characteristics of 3PL companies’ business operations.

2 Analyses on Optimal Operation of Logistics Network for 3PL Companies

When a business process is outsourced to a 3PL company, the 3PL company will propose business solutions that include the re-design of the logistics distribution network. Such a modified logistics network will be designed using the facilities and transportation resources owned or leased by the 3PL, to leverage on the economies of scale and scope provided by the 3PL, with the customers’ demand. The typical business operation process and its structure can be illustrated by Figure 1.

![Figure 1  Structure of logistics network operated by 3PL company](image)

For the logistics network shown in the Figure 1, 3PL companies are in charge of all the integrated logistics service from suppliers to customers under a certain service requirement committed by the 3PL companies to their customers. The integrated service generally includes: through transport service from suppliers to customers (optional); consolidated transport service from suppliers to distribution centers (optional); and distributing transport service from distribution centers to customers (optional); storage service conducted in the distribution centers, as well as the related value-added service, such as handling, loading and unloading, information service.

When 3PL companies offer logistics service to their customers, they need maximizing customer service level and their operation cost. In the operational practice, to attain new customers or keep the old customers loyal, 3PL companies general take various feasible measures to realize optimal operation and meet customers demand, which include the requirements by the suppliers and customers for the service time: ① total service time taken by 3PL companies; ② the exact service time required by customers, i.e., the service can only be offered to the customers at a certain time or period (Time Window); and also ③ price-discount marketing mix to attract customers. On the other hand, 3PL companies operate their logistics network with optimal considerations too, which include ④ selection of transport modes among the multi-transport modes, and ⑤ planning of vehicle routing, and ⑥ storage and operational management of distribution centers. All the above-mentioned factors will have vital impacts on the economical and healthy operation of logistics network for 3PL companies, and also make them hard or even impossible for the traditional mathematics methods and programs to solve the optimization problems related to the 3PL companies’ logistics network.

3 Optimization Models Research on 3PL Logistics Network

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The optimization problems of 3PL companies’ logistics network put forward in the section 2 are essentially to solve the problems of network optimizing operation beginning from the various suppliers, via/ not via distribution centers, to the final customers. The goal for logistics network optimization is to achieve the minimal operation cost for the whole logistics network. And the constraints include all kinds of conditions as typically above mentioned ①-⑥. Thus, the basic optimization model for 3PL companies’ logistics network can be as follows,

\[
Z = \min \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} f_{cost}(x_{ij}, t_{ij}) + \sum_{j=1}^{n} f_{j} Y_{j}
\]

\[
\sum_{j=1}^{n} x_{ij} = a_{i} \quad i = 1, 2, ..., m
\]

\[
\sum_{i=1}^{m} x_{ij} = b_{j} \quad j = 1, 2, ..., n
\]

\[
s.t. \quad G_{k}(x_{ij}, t_{ij}) = 0 \quad k = 1, 2, ..., 6
\]

\[
Y_{j} \in [0, 1]
\]

\[
x_{ij} \geq 0, t_{ij} \geq 0 \quad i = 1, 2, ..., m \quad j = 1, 2, ..., n
\]

In the model (1), the target function is to minimize transport costs, storage costs and managerial costs of the whole logistics network. Here, the function (1) has taken storage costs generated in and through the distribution centers into considerations, as Cheong Lee Fong[4] has proved that the storage cost for the items in distribution centers is nearly linear to the logistics volume that pass though the centers. Thus for the function (1), the item of \( f_{cost}(x_{ij}, t_{ij}) \) is the universal form of cost function for the operation of the 3PL companies’ logistics network. The target function is a cost function of transported items through the logistics network together with the stored items in the distribution centers, and the constraints include the requirements for supply and demand from the suppliers and customers, and the various conditions illustrated by the equation of \( G_{k}(x_{ij}, t_{ij}) = 0 \), which demonstrates the different types of conditions as shown in section 2 from ① to ⑥. The decision variables are mainly the quantity of transported and stored items in the logistics network, and the binary decision variables to decide which distribution centers are involved and operated by 3PL companies.

For the optimization problems of logistics network subject to the various types of constraints from ① up to ⑥ mentioned in the section 2, the conditions ① and ②, are essential to solve the network optimization problems with constrains of time window, and can be discussed together; the condition ③ can be changed to solve the network optimization problems with transport price discount; and the condition ④ is to solve the network optimization problem with multi-transport modes to select; while conditions ⑤ and ⑥ are to solve the network optimization problems of distribution routing planning and storage and can be discussed together with the above-mentioned scenarios. With these thoughts in mind, we will put emphases on the three network optimization models derived from the above analysis.

The three optimization models of logistics network namely are Logistics Network Optimization Model with Time Windows (LNOMTW), Logistics Network Optimization Model with Price Discount (LNOMPD) and Logistics Network Optimization Model with Multi-transport Mode (LNOMMM).

3.1 Logistics Network Optimization Model with Time Windows

Logistics Network Optimization Model with Time Windows (LNOMTW) is essentially to take service time constraints of suppliers or customers to the optimization model in the process of realizing network optimization operation. For years in and out, many scholars have conducted some researches on this related optimization problems, of whom Thangiah S R[5] once solved the Vehicle Routing Problems (VRP) with time window constrains based on genetic algorithms, and Song[6] discussed the VRP by way of constructing a mixed genetic algorithm.

LNOMTW can be described as follows. There exist suppliers, \( S_1, S_2, ..., S_m \), and customers, \( C_1, C_2, ..., C_n \). The distance between them can be illustrated by a matrix, \( D = [d_{ij}] \), \( 0 < i, j < n \). Here, the
distance between \( s_i \) and \( c_j \) is \( d_{ij} \). The 3PL company has a number of the same vehicles to serve for the suppliers and customers, and several distribution centers to store products for its clients. The quantity of the products supplied by the supplier \( s_i \) is supposed to be \( a_i \), here \( 1 < i < m \). And the customer \( c_j \) has a service demand for quantity of the products, \( b_j \), here, \( 1 < j < n \). The suppliers or the customers have definite requirement for the service time. \( S_{jk} \) is the time when 3PL company begin to serve the supplier \( s_i \) or customer \( c_j \), and the time constraint for the 3PL company can be described by \([t_j, k_j]\), which shows that 3PL company can only serve the suppliers or customers beginning from the time \( t_j \) and finishing before the time \( k_j \). Thus, LNOMTW is to optimize the operation of logistics network for 3PL companies with the above-mentioned constraints considered. Basically, LNOMTW can be constructed as follows:

\[
Z = \min \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} [d_{ij} + f_{cons}(x_{ij}, t_{ij})] + \sum_{j=1}^{n} f_j y_j
\]

\[
\begin{align*}
\sum_{j=1}^{n} x_{ij} &= a_i & i = 1, 2, \ldots, m \\
\sum_{i=1}^{m} x_{ij} &= b_i & j = 1, 2, \ldots, n \\
st. & t_j \leq S_{jk} \leq k_j & j = 1, 2, \ldots, n \\
y_j & \in [0, 1] \\
x_{ij} & \geq 0, t_j \geq 0 & i = 1, 2, \ldots, m \quad j = 1, 2, \ldots, n
\end{align*}
\]  \hspace{1cm} (2)

The model (2) is the basic model for this kind of optimization problem. The part of \( f_{cons}(x_{ij}, t_{ij}) \) in the model (2) is the cost related with products in and through the distribution centers of logistics network, and the part of \( \sum_{j=1}^{n} f_j y_j \) is operation cost for the distribution centers that can be attributed to the products stored and managed at the distribution centers. For the exact optimal problems, it is necessary to involve binary decision variables \([0, 1]\) to show the different operation modes of logistics network. And for the solution of the LNOMTW, the problem itself is non-linear and big-scale, thus it is useful and meaningful to construct genetic algorithms to solve it rather than to use the traditional programs or methods.

### 3.2 Logistics Network Optimization Model with Price Discount

Logistics Network Optimization Model with Price Discount (LNOMPD) is essential for 3PL company to offer transport or managerial price discount to the suppliers or customers, or use price discount to entice customers to accept a longer delivery lead time, so as to improve the inventory level distribution and operation management within its logistics network \([7]\). Thus the cost parts in the target function and the constraints are changed and LNOMPD is to solve such kind of problems.

In the LNOMPD, the cost part of the target function for per product per mile transported and stored in the logistics network is not deterministic, and is changed into a function of the product’s demand and its lead time, i.e., \( D_{ij} = f_d(x_{ij}, t_{ij}), i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \).

The price-discount scenario can be that the 3PL company sets and offers different cost function for the different customers’ requirements, and for the different lead time. This is much common in practice in that the 3PL service is a differentiated service and the 3PL company makes its best to offer differentiated service to its customers, and the price is first and most sensitive part for them to compete in the 3PL market.

If we leave the effect of changing lead time of customers service to the model, LNOMPD can be shown as follows:
In the model (3), the same parts with the model (1) and (2) have almost the same meanings. Thus we needn’t explain them in detail.

### 3.3 Logistics Network Optimization Model with Multi-transport Mode

Logistics Network Optimization Model with Multi-transport Mode (LNOMMM) is essential to solve the optimization problems subject to the various constraints in the material flowing process from the Origin of the suppliers to the Destination of the customers, with multi-transport modes existed between the different logistics nodes connecting with each other in the logistics network. The transport time, freight, network capability for the different transport modes are not the same. And changes of transport modes from one to the others, will take a certain cost, at the same time, the total time for the product flowing through the logistics network is defined by the customers’ demand. LNOMMM is to find the best combined transport modes with minimizing the total operation costs of logistics network, satisfying all the requirements, and optimizing the operation of logistics network for 3PL companies.

If we set the target function, the decision variables and the constraints with reference to the above model (1), (2) and (3), LNOMMM can be shown as follows:

\[
Z = \min \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} [f_d(x_{ij}, t_{ij}) + f_{cov}(x_{ij}, t_{ij})] + \sum_{j=1}^{n} f_j Y_j
\]

\[
\begin{align*}
\sum_{j=1}^{n} x_{ij} &= a_i \quad i = 1, 2, \ldots, m \\
\sum_{i=1}^{m} x_{ij} &= b_j \quad j = 1, 2, \ldots, n \\
Y_j &\in [0,1] \\
x_{ij} &\geq 0, t_{ij} \geq 0 \quad i = 1, 2, \ldots, m \quad j = 1, 2, \ldots, n
\end{align*}
\]

For model (4), the same parts with the model (1), (2) and (3) have almost the same meanings. Thus we needn’t explain them in detail.

We can construct a logistics network with virtual supply and demand points, involve binary decision variables \([0,1]\), and change LNOMMM to a network optimization problem (O-D) with time and capability constraints, then construct genetic algorithms to solve LNOMMM.[8]

### 4 Applications of Genetic Algorithms to Solve Logistics Network Optimization Models

#### 4.1 General process of applying genetic algorithms to solve optimization problems

As is known, genetic algorithms, being one of the probabilistic algorithms, are the optimal processes that search a binary string in the genetic pool beginning from the initialized feasible one. The whole process is quite simple, and it starts with a population of randomly generated candidates, and repeatedly executes the process of selection, crossover and mutations of genomes, until to reach so-called termination-condition.

The genetic algorithms are a typical iterative search method with a characteristic of “generate and test”. The basic progress for genetic algorithm to find the optimum of a problem can be shown as Figure 2.
Encoding of the problem in a binary string

Random generation of an initiative population $P_0$

Reckoning of a fitness value for each subject $P(t)$

Evaluation and termination?

Selection of the subjects that will mate according to their fitness from $P(t-1)$

Genomes crossover

Genomes mutation

Output

End

Figure 2  The basic progress of genetic algorithms

Generally speaking, the termination rule can be defined as follows:

$$\frac{u^*(G + 1) - u^*(G)}{u^*(G)} < \varepsilon$$  \hspace{1cm} (5)

In the inequation (5), $u^*(G)$ refers to the fitness value of the best descendant in the generation $G$, and its value can be defined as follows:

$$u_k = \begin{cases} 
\frac{F_k}{F_{\text{max}} + F_{\text{min}}}, & \text{if to maximize target function} \\
1 - \frac{F_k}{F_{\text{max}} + F_{\text{min}}}, & \text{if to minimize target function}
\end{cases}$$  \hspace{1cm} (6)

In the equation (6), $F_k$ refers to the value of the target function for the subject $K$, $K = 1,2,\ldots,N$. $F_{\text{max}}$ is the maximal value of the target function in the population, and $F_{\text{min}}$ for the minimal value of that. $u_k$ is the fitness value for the subject $K$. And the higher $u_k$, the better the quality of the subject, vice versa.

4.2 Applying genetic algorithms to the optimization models of 3PL companies’ logistics network

In recent years, the scholars have put forward the various solutions to the non linearity program focusing on the different problems. Here, based on the basic progress of genetic algorithms, we will utilize and construct genetic algorithms to solve logistics network optimization problems for 3PL companies mentioned in the section 3, i.e., the optimization models (2), (3) and (4).

1) a genetic representation of solutions to the problems: the solutions to the optimization problems of 3PL logistics network can be represented by the following matrix, $X_L$. 

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Here in (7), $X_L$ represents the genome $L$ (solution); $x_{ij}$ is the related decision variable to the optimization problems.

2) creation of an initial population of solution: firstly we need create solutions and then search and optimize on the basis of this initial solution. If the initial solution is created randomly, with the essentiality of genetic algorithm, we can still find the satisfactory solution. If the constraints of the problems are rather strong, the random creation of initial population of solution will be relatively “bad”, and the speed to the final termination will be slow. Thus to create the initial population of solution that meets all the constraints, we adopt the method put forward by G. A. Vignaux and Z. Michalewicz [10] to construct an initial population of solution.

3) evaluating and rating solutions in term of their fitness: for each subject that illustrates one of the optimization solutions to the logistics network, the evaluation of solutions can be done in two ways, one is to judge whether it meets the constraints of logistics network optimization problems, and the other one is to calculate the value of the target function for the subject. Then, we can get the “fitness” for each subject.

4) functioning of genetic algorithms: ① Selection of the subjects that will mate according to their share in the population fitness. Firstly we will rate all the subjects $N$ from the highest one to the smallest one according to their “fitness”. The subject with the highest “fitness” has a best character and will reproduce directly to the next generation, and the other subjects $N-1$ in the next generation will be selected and reproduced by way of “roulette wheel selection” [11] based on their “fitness”. ② Genomes crossover. Crossover is the basis of genetic algorithms, there is nevertheless other operators like mutation. For the new generation produced by the above selection and the subjects N-1, except for the subject with the highest “fitness”, genomes crossover occur at probabilities of reproduction. ③ Genomes mutations. In fact, the desired solution may happen not to be present inside a given genetic pool, even a large one. Mutations allow the emergence of new genetic configurations which, by widening the pool improve the chances to find the optimal solution. Other operators like inversion are also possible, but we won’t deal with them here. For the selection method we use is to keep the best subjects in the next generation, we propose to make mutations for many times, thus getting the diverse subjects in the next generation. The mutation operators function at probability of $P_m$. Once the mutation occurs, the mutation operators will function for the times $T$ which is random generated, and the subjects in the next generation will be mutated for the times $T$. The position for the genes that mutate will be random selected.

This is the basic steps which apply genetic algorithms to solve logistics network optimization models (2), (3) and (4) put forward in the section 3. For the length limit of the paper, we will not make mathematic experiments.

5 Conclusions

We make a study on the optimization of logistics network for 3PL companies based on the genetic algorithms and conclude the study with this part.

The optimal operation of 3PL companies’ logistics networks has a direct impact on their business performance, and will further influence optimal operation of social logistics network. In this paper, we construct the optimization models for the 3PL companies’ logistics network with our understanding on how 3PL companies design, plan and operate their logistics network, and how they compete in the real market conditions. By solving these optimization models, we can support decision makings for the 3PL companies, improve their capabilities to serve the customers much more satisfied, and finally improve
their core competencies to compete in this supply-based markets environment. And then, based on the basic theory of genetic algorithm, we put forward the general step and method of using genetic algorithms to solve these optimization problems of 3PL companies’ logistics network. Theoretically, we have discussed how to solve these models with genetic algorithms, for the lack of real data that concord with the optimization models, and we will make further research in the future to testify how the models and methods of this paper function well.

References