Research Article

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Research on logistics management layout optimization and real-time application based on nonlinear programming

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Abstract: To solve the problem of long logistics delivery time in supply chain, a Mixed Integer Non-linear Program (MINLP) model is built by using Mixed Integer nonlinear programming theory. Firstly, the General algebraic modeling system (GAMS) is used to build the model to fully integrate each parameter of logistics transportation, the total distribution time of the supply chain network, the coverage radius of the logistics base, the number of users, the total capacity of the logistics base, the mode of railway and road transportation, the nonlinear programming model is built and solved by DICOPT solver in GAMS. The cost of logistics can be decreased, transportation time can be reduced, and the logistics system's operating efficiency can be increased in the long term with the help of this algorithm. The proper operation of the logistics system is critical in encouraging the supply chain circulation of various industries and has a direct impact on the society's economic development. The optimal logistics distribution plan with 5 logistics bases covered users of 18 and railway capacity of 2. With the same railway capacity and the same total budget, the larger the number of covered users, the greater the total distribution time increases, but the larger the total budget, the growth of the total distribution time slows down significantly. Experiments show that MINLP model can solve the problem of logistics-based layout optimization in nonlinear logistics management.

Keywords: Logistics management; nonlinear programming; Layout optimization; General algebraic modeling system

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1 Introduction

See Figure 1, scientific and reasonable logistics management is conducive to promoting the agglomeration of logistics resources and the improvement of logistics operation efficiency, supporting the transformation and upgrading of urban industries, and realizing the high-quality development of logistics and economy. Most cities lack systematic planning when planning and constructing logistics nodes. In addition, urban economic development, industrial spatial layout, residents' living consumption, and other demand-side factors are constantly changing. Therefore, the current and future logistics demands are taken into account in a scientific and reasonable way to adapt to the changes in the scale and distribution of logistics demands in different periods. Non-linear planning of logistics-based nodes can practice the reasonable division of labor and coordinated layout among different logistics nodes, create a low-cost and efficient logistics service network, and better support the development of economic industry and protect people's lives, which is a common problem faced by all city government departments. At present, logistics is gradually establishing a new ecology with algorithms as the tool and data as the core. The optimization of logistics management through nonlinear programming can effectively improve the transportation efficiency of the logistics system and avoid repeated construction, homogeneous competition, inefficient operation, and other long-term problems in the physical industry.

Bhagavatula S.K. believes that in the era of big data, logistics should be reserved and considered in a nonlinear thinking mode. There are five technological aspects that drive the development of many traditional industries. At the technical level, mobile Internet, social network, cloud computing, big data, and Internet of Things. In the field of logistics, with the development of big data, it is necessary to overcome the thinking mode brought about by natural changes and shift from application-centric to data-centric. The mode of distribution management, warehouse management, supplier management, and marketing management

Figure 1: Optimization of logistics management layout based on nonlinear programming

has been changed from a single application to a big data mode [1]. K. Liang and W. Zhang used a genetic algorithm to optimize logistics nodes. Taking the total cost of logistics network operation as the goal, the model is an embedded through a nonlinear mixed integer programming containing two allocation problems to determine the optimal layout and logistics management of the precooling stations and logistics centers of fresh agricultural products [2]. S. Kong found that demand forecasting was a difficult problem to manage in the supply chain. He further considered checking the required optimization model and proposed a new supply chain nonlinear system behavior model [3]. A. Alessandri proposed a method based on logistics operation optimization to solve the efficiency of container terminals, which mainly includes two methods: explicitly dealing with the nonlinearity of binary variables models and cost functions. A discrete-time dynamic model of container flow from arrival to departure is established. Based on this model, the predictive control method is used to minimize the performance cost function within the forward time range of the current moment to make decisions on the allocation of available loading and unloading resources in container terminals [4]. From the perspective of port cargo throughput, N. Yu analyzes the characteristics and influencing factors of port logistics demand. Considering the characteristics of nonlinear and small sample modeling of logistics demand, the model adopts GM (1, 1) combined

prediction model and BP neural network single prediction model to calculate [5, 6]. Fox W. established a logistics base layout optimization model. The proposed model can not only be used to generate the optimization scheme of logistics base layout, but also quantify the evaluation index of logistics base layout, thus laying a foundation for the evaluation of logistics base layout [7]. Rakhra M. Based on the in-depth analysis of the logical characteristics of various operations in the process of crop straw collection, storage and transportation, a general mathematical model for the optimization of crop straw collection, storage and transportation machine system was constructed, and an evaluation index system was established for the key machine (baler) and the selection was studied [8]. Wang W. Further analysis between the gear stress distribution, this paper to the inside of the gear box of a pair of straight bevel gear pair, and a pair of gears as the research object, has carried on the contact analysis by finite element method, the stress contours and strain contours of gear, and analyzed the contact stress distribution, and contact strength check, through comparing with traditional stress formula of [9], Mehrbod M. The mining planning mode based on the 3D orebody model is more economical, reasonable and efficient than the traditional mining planning mode, which not only improves the management level and economic benefits of mining enterprises, but also reduces the possibility of enterprises facing internal and external risks [10].

Lin Y.-C. at present, the existing hybrid logistics vehicles at home and abroad mostly adopt series and parallel configurations, which have limited fuel saving capacity compared with planetary hybrid systems. The application of planetary hybrid power system to logistics vehicles will further reduce the negative impact of logistics transportation on the environment [11]. Zhang D. A multi-objective optimal allocation model of manufacturing resources is constructed. G test equipment manufacturing company as an example, combined with the self-compiled MATLAB algorithm to solve, and then put forward the computer aided algorithm, using EXCEL to test; The empirical results show that under the constraints of production factors, the optimal allocation of multi-objective resources is realized, production customization is completed, and customer needs are met [12]. Qin X. H. established a nonlinear programming location selection model aiming at minimizing the sum of the product of material transport volume and transport distance at each emergency point and solved it by LINGO for several iterations. Example analysis shows that the model can determine the location of reserve points and the transportation plan of each emergency point and solve the problem of the location of reserve points of railway emergency supplies [13].

It has been proved that the combined prediction model has higher accuracy and stronger stability than the single prediction model, which can effectively reduce the prediction error rate and make the prediction results closer to the reality and has a guiding significance for the future port logistics development planning. Based on the nonlinear programming theory, previous studies have built models for many aspects of the logistics field. In this study, on the basis of the previous proposed algorithm and model research results, based on mixed integer nonlinear programming theory, the problem of logistics base layout is solved, through Mixed Integer Non-linear Program (MINLP) model to solve the supply chain network distribution time minimization problem. The proposed algorithm proved out to be cost as well as time efficient. Through experiments it was observed that, this model can solve a problem of logistics-based layout optimization in nonlinear logistics management.

2 Model hypotheses

The logistics-based layout optimization model is based on the following assumptions:

1. The total distribution time of the supply chain network includes material loading time, material distribution time, and material unloading time;

2. The coverage radius of the logistics base is fixed, and the coverage area is circular.
3. Each user can only choose one location to the open logistics base;
4. The total capacity of the logistics base includes fixed construction capacity and safety reserve, which can fully meet the material needs of users who establish distribution relations with it [14].
5. Assume that the logistics base has both road and rail distribution methods, the distribution capacity of roads and railways is a fixed value determined by the base's own distribution capacity, the total transport capacity of the whole supply chain network is the sum of the road and railway distribution transport capacity;
6. The material demand of users and the fixed construction cost and maintenance cost of the logistics base are fixed values, and the total fixed construction cost does not exceed the total budget of the construction of the logistics base [15].
7. The number of logistics bases is determined by the decision makers and is a fixed value.
8. Only delivery of a single material type, that is, the matching degree of materials is 100%.

3 Model construction and implementation

3.1 Model parameters and variables

Various parameters in logistics distribution are set as follows:

- Set J , JP set of candidate locations of logistics base
- Set I A set of user locations
- Set I set of distribution methods
- Set V A set of users within the coverage of the logistics base
- FC_j the fixed construction cost of logistics base j
- MC_j maintenance and construction cost of logistics base j
- CAP_j construction capacity of logistics base j
- DEM_i Material requirements for user i
- $TIMELIM_i$ the material requirement time limit of user i
- DIS_{jik} time limit of material demand from logistics base j to user i by means of the distribution k
- V_{jik} the speed of distribution from logistics base j to user i using distribution mode K

- C_{jik} distribution cost per unit distance from logistics base j to user i using distribution mode k
- Z_{jik} the number of materials distributed by Logistics Base j to user i through distribution mode K
- P number of logistics bases planned to open
- Q number of users
- B Total cost budget
- W the number of times that railway distribution can be used in the logistics base
- LT loading time per ton of material
- ULT unloading time per ton of material
- A maximum coverage of supply chain network
- SER_j the coverage radius of logistics base j
- $DB_{j,jp}$ distance between logistics bases (j and jp are the same set)
- TV_j number of distribution tools in logistics base j (highway)
- MSD material reserve degree of supply chain network
- SPD Sustainability of supply chain network
- REP Timely recharge of supply chain network
- T the total delivery time of supply chain network
- TTD minimum total distribution distance of supply chain network
- TTC minimum total distribution cost of supply chain network
- $TRANSCAP$ total capacity of supply chain network
- $NWAGON_{jik}$ the number of vehicles from logistics base j to user i using distribution mode k
- $TRANS$ distribution service degree of supply chain network (highway)
- $WAGON_k$ distribution method K Quantity of bicycle supplies delivered
- $TOTAREA$ the total coverage area of supply chain network
- G_i whether the demand node i is within the coverage range of the supply node is a 0-1 variable, among them $G_i = 0$ means not covered, $G_i = 1$ means within coverage.
- X_{jik} whether the supply node j and the demand node i have established the material distribution relationship in the mode of distribution, is a 0-1 variable, among them, $X_{jik} = 0$ means no contact has been established, $X_{jik} = 1$ is for making connections.
- Y_j whether to open logistics base j , is a 0-1 variable, among them, $Y_j = 0$ means not open, $Y_j = 1$ means open.

3.2 Model description

The optimization model of logistics base layout is a mixed integer nonlinear programming (Mixed Integer Non-linear Program MINLP) model, and its objective function and constraint conditions are (in the model is an integer function):

$$T = \min \sum_i \sum_j \sum_k \left(\frac{DIS_{jik}X_{jik}}{v_{jik}} + DEM_iX_{jik}(LT + ULT) \right) \quad (1)$$

$$\text{s.t.} \sum_i iG_i = Q \quad (2)$$

$$\sum_{j \in V} Y_j \geq G_i \quad (3)$$

$$\sum_{j \in I} Y_j = Q \quad (4)$$

$$\sum_j (FG_j + MC_j) Y_j \leq B \quad (5)$$

$$\frac{DIS_{jik}X_{jik}}{v_{jik}} + DEM_iX_{jik}(LT + ULT) \leq 2 \times TIMELIM \quad (6)$$

$$\sum_i \sum_k \sum_{jik} \leq (CAP_j + RES_j) Y_j \quad (7)$$

$$\sum_j \sum_k \sum_{jik} \geq DEM_iG_i \quad (8)$$

$$X_{jik} \leq Y_j \quad (9)$$

$$\sum_j \sum_k \sum_{jik} = G_i \quad (10)$$

$$\sum_i X_{jik} \leq W \quad (11)$$

$$Z_{jik} = X_{jik}DEM_i \quad (12)$$

$$X_{jik}, Y_j, G_i \in \{0, 1\} \quad (13)$$

$$MSD = \frac{\sum_j CAP_j Y_j}{\sum_i DEM_i G_i} \quad (14)$$

$$SPD = \max \left(\left(\frac{DIS_{jik}X_{jik}}{v_{jik}} + DEM_iX_{jik}(LT + ULT) \right) \times [MSD] \right) \quad (15)$$

$$REP = \max \left(\left(\frac{DIS_{jik}X_{jik}}{v_{jik}} \right) \right) \quad (16)$$

$$+ DEM_i X_{jik} (LT + ULT) \Big) / PTIME_{jik} X_{jik} \Big)$$

$$TTD = \sum_i \sum_j \sum_k DIS_{jik} X_{jik} \quad (17)$$

$$TTC = \sum_i \sum_j \sum_k DIS_{jik} X_{jik} C_{jik} \quad (18)$$

$$TRANSCAP = P \times W + \sum_j TV_j Y_j \quad (19)$$

$$NWAGON_{jik} = \frac{z_{jik}}{WAGON_k} \quad (20)$$

$$TRANS = \frac{\sum_{j \neq k \neq l} NWAGON_{jik}}{2 \sum_j TV_j Y_j} \quad (21)$$

$$\begin{aligned} TOTAREA = & \sum_j \pi (SER_j)^2 Y_j \\ & - \left(\sum_{j, jp \in jp'} DB_{j, jp} \sqrt{2} \right. \\ & \times SER_{j, across} \left(\frac{DB_{j, jp}}{2 \times SER_i} \right) (SER_j)^2 \times 2 \\ & \left. - DB_{j, jp} \sqrt{(SER_j)^2 - \left(\frac{DB_{j, jp}}{2} \right)^2} \right) Y_j Y_{jp} \end{aligned} \quad (22)$$

In the model, the goal of objective function (1) is to minimize the total distribution time (if each distribution relationship can achieve the shortest distribution time, then the total distribution time must also be the shortest); Constraint (2) is to make the number of users that the logistics base can cover meet the requirements of decision makers; Constraint (3) to ensure that at least one logistics base can cover users; Constraint (4) limits the number of logistics bases; Constraint (5) Ensure that the total cost of logistics base construction does not exceed the total cost budget; Constraint (6) Ensure that the material distribution time of the established distribution relationship does not exceed the time limit of material demand; Constraint (7) to ensure that the materials distributed by the logistics base do not exceed its capacity; Constraint (8) Ensure that the material delivered to the user is greater than the quantity demanded; Constraint (9) Ensure that users can only establish distribution relations with established logistics bases; Constraint (10) Ensure that users can only establish material distribution relationship with one logistics base and only adopt one distribution method; Constraint (11) limits the transport capacity of K2 distribution mode in the logistics base; Constraint (12) is the quantity of goods delivered in the established distribution relationship; Constraint (13) determines the value range of the parameter; Constraint (14)–(22)

is to calculate some indexes in the evaluation index system on the basis of the layout optimization model, they are respectively material reserve degree, guarantee continuity degree, timely supply degree, total distribution distance, total distribution cost, total transport capacity (including road and railway transport capacity), number of distribution tools to be used, distribution service degree and total coverage area [16].

3.3 Model Implementation

As the calculation amount of MINLP model increases exponentially with the increase in the number of supply nodes and demand nodes, the general generation modeling system GAMS is adopted to implement the model [17]. In actual development, the DICOPT (Discrete and Continuous OP Timizer) solver in GAMS is used to solve the model. DICOPT is a MINLP problem solver developed by J. Viswanathan and I. Grossman of the Engineering Design Research Center (EDRC) at Carnegie Mellon University, which is an extension of the external approximation algorithm based on equality relaxation strategy [18, 19]. The MINLP algorithm within DICOPT can solve a series of NLP and MIP subproblems that can be solved with any NLP and MIP solver running under GAMS.

4 Application examples

4.1 Case description

As per the proposed algorithm, the cost of logistics can be decreased, transportation time can be reduced, and the logistics system's operating efficiency can be increased in the long term. The proper operation is critical in encouraging the supply chain circulation of various industries which impact the society's economic development. The basic The supply chain network in the example contains two types of nodes: Logistics base and user, among which there are 8 candidate nodes of logistics base, numbered B1-B8; 18 user nodes, numbered T1-T18. Logistics base provides materials to users, each logistics base and each parameter of users are known [20, 21]. The objective of logistics base layout optimization is to select several nodes among the candidate nodes to establish logistics bases to minimize the total delivery time of the supply chain network [22]. The specific parameters involved in the example are shown in Table 1, Table 2, Table 3, Table 4, and Table 5.

4.2 Calculation results and analysis

The results of solving the model by GAMS are shown in Figure 1 and Figure 2.

Figure 2: Relationship between total budget and distribution time

As shown in Figure 2, under the condition of the same railway capacity and the same number of covered users, the total delivery time can be reduced by increasing the total budget [23]. The main reason for this phenomenon is that increasing the total budget can open more logistics bases, thus shortening the total distribution distance and reducing the total distribution time [24]. It can also be found from Figure 1 that under the condition of the same total budget and the same number of users covered, increasing railway capacity can reduce the total delivery time [25]. The reason is that in the case of the same distribution distance, the railway transportation is least affected by various emergency road conditions, and the railway distribution speed is faster, and the distribution time is shorter, therefore, increasing the railway capacity can reduce the total distribution time [26].

As can be seen from Figure 3, under the condition of the same railway capacity and the same total budget, the total delivery time increases with the increase of the number of covered users, the increase in the number of users itself adds up to a longer delivery time. However, the larger the total budget, the slower the growth of the total delivery time [27]. This is because an increase in the total budget can open more logistics bases, increase the number of logistics industry bases, and have more convenient and optimal routes to choose, thus establishing the distribution relationship with a shorter distribution time and reducing the total distribution time [28].

Figure 3: Relationship between the number of covered users and the total delivery time

On the basis of the above analysis, Figure 4 presents the optimal material distribution scheme when the total budget is 15-million-yuan, 5 logistics bases are opened, the number of users covered is 18, and the railway capacity is 2. These schemes are the best delivery schemes based on the algorithm, which can make the most scientific use of logistics bases and railway transport tools [29].

Figure 4: Optimal material distribution scheme

5 Conclusions

The most critical part of the scientific construction of the logistics system is the selection of the distribution center, which directly determines the decision-making of the distribution route. The main reason is that the distribution center and logistics nodes are the core bridges between the goods supplier and the goods buyer. The design of the distribu-

tion center will directly affect the distance, mode, and time of logistics delivery, which can directly affect the overall efficiency and smoothness of logistics delivery and affect the working efficiency of both buyers and sellers of goods. Nonlinear planning logistics can accurately calculate the most appropriate geographical location of the logistics distribution center through big data and algorithmic modeling tools. Based on the mixed integer nonlinear programming theory, the relevant parameters of the construction of the logistics distribution center are modeled by the general generation modeling system GAMS, set up to solve the problem of logistics base layout (Logistics Base Location Problem, MLBLP) model. In the actual case demonstration, it can be seen that the model can effectively optimize the logistics management layout and can effectively save time and reduce costs. The layout of logistics bases is an important problem in modern logistics research, and how to choose the location of logistics bases and determine the distribution relationship between logistics base and users is an important content of logistics base layout research. Once the location of the logistics base is determined, it is difficult to change in a short time, therefore, the scientific and reasonable layout of the logistics base can not only shorten the distribution time of materials, but also reduce the distribution cost and storage cost of materials and improve the operation capacity of the supply chain network. Under the concept of nonlinear logistics, the layout and construction of logistics distribution center, the planning and design of logistics routes all rely on the algorithm model for scientific planning. Under the planning of the algorithm, the logistics cost can be reduced, the transportation time can be reduced, and the operation efficiency of the logistics system can be accelerated in the long run. Result shows the best material distribution method for a 15 million budget. Five logistics bases have opened, with a total of 18 users and a capacity of two trains. These are the best delivery schemes based on an algorithm that can make the most scientific use of logistical bases and railway transportation instruments. The efficient operation of the logistics system plays an important and positive role in promoting the supply chain circulation of various industries and plays a direct role in the economic development of the society. With the design and launch of various algorithm models, logistics planning and layout will also move toward a more refined, comprehensive, comprehensive, and efficient direction.

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