An integrated approach for production and distribution planning using a two-level routing pattern in global production networks

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Abstract. Production planning redesign is significantly important for global manufacturing firms due to the large changing in demand markets yearly. In order to cope with the changing environment, there should be some corresponding evolutions in supply pattern of production-distribution networks. In this work, we focus on deciding production and distribution planning simultaneously without limiting total profits increasing. Meanwhile, we propose a two-level routing pattern which can effectively decrease average transportation lead times among production plants and sales markets. Furthermore, we discuss a mathematical model of profits maximization in global production networks (GPN) and present cost functions for manufacturing, distribution and sales process separately. A meta heuristic algorithm for multi-product, multi-plant, multi-hub, multi-transport path, and multi-market problem is also developed in this work. From numerical experiments, we found the two-level routing supply pattern is very effectively when demand dispersion is in a mid-high level over all the markets.

Keywords: Production; Distribution; Two-level routing pattern; Mathematical model; Meta heuristic

1. INTRODUCTION

Effective management among procurement, production, distribution and sales activities in the supply chain is an important issue in global manufacturing. Especially, the production and distribution efficiency represents a core competition for a global manufacturing company because be faced with the significant changing in demand environment, effective and efficient decision-making should be determined on demand uncertainty for their supply system in order not to lose any profits opportunity.

However, production and distribution activities have usually been studied separately by industry and academia, mainly because each of them is a complexity problem and the two departments always have different year-end objectives. The manufacturing department devotes itself to minimizing manufacturing costs which prefer a fewer number of changeovers among products for economic production and frequent shipments to markets for reducing holding costs, but the distribution department prefer a fewer shipments frequent because of full-load shipments in big size vehicle for economic transportation and a minimum number of stops for time saving. Confliction between the two departments would limit saving in operational costs. Therefore, an integrated planning of production and distribution is significantly necessary. Furthermore, along with global economic growth special in developing countries, markets demand is becoming decentralization all over the world present and more seriously in near future. And production plants could not have the capability to locate their new plants everywhere nearby the markets because of investment risks and some of international trade barriers. Hence, distribution lead times between production plants and markets would become more longer in global environment of products diversification. Consequently, the longer lead times would lead to increased holding costs extremely among markets. Furthermore, if the value of stocked products is very high, there would not only be the high holding costs problem, but also have no cash flow, existing a big risk for inventory management. Therefore, an effective supply pattern that can reduce the lead times among production plants and markets is significantly important to think over when integrating the production and distribution planning. In this paper, we propose a two-level routing pattern which will be discussed in detail in the following sections to reduce lead times.

The organization of the paper is as follows. Section 2 presents an overview of the current literature on manipulated variable of various models. Section 3 provides our two-level routing supply pattern and discusses model formulation. Section 4 considers the algorithm design of this research and discusses results of numerical experiments. Section 5 summarizes the conclusion of this research.

2. LITERATURE REVIEW

The literature contains numerous papers related to these issues. We categorized these papers into three dimensions on the basis of the manipulated variable: (1) production decision problem, (2) distribution decision problem, and (3) production and simultaneous distribution decision problem.

First, the production decision problem occurs when decision variables are based on production activities, such as production facility/equipment numbers, production quantities, and production sequence/batch size. Many studies integrate the sub-processes in a GPN but actually only coordinate them in the form of cost functions, not through manipulated variables between multiple processes. From the viewpoint of manipulated variables, we call these types of problems production decision problems. Single-product models, multi-product models, and single-plant models exist (Garavelli, A.C. et al., 1996, Hou, Y.C., and Chang, Y.H., 2002, Chang, Y.H., and Hou, Y.C., 2008). Moreover, studies exist on multi-product, multi-plant, and multi-market problems (Cunha, C.B., and Mutarelli, F., 2007, Aydinel, M. et al., 2008, Tsiakis, P., and Papageorgiou, L.G., 2008).

Second, the distribution decision problem occurs when demand among markets and plants are known and entail deciding on distribution activities, such as distribution facility/equipment numbers, distribution modes, distribution quantities, and routing. Fagerholt, K. (1999), Bendall, H.B., and Stent, A.F. (2001) present decisions related to fleet size problems. Lirn, T.C. et al. (2004), Guy, E., and Urli, B. (2006) discuss port selection problems. Fagerholt*, K. (2004) considers the routing problem in a global environment. Agarwal, R., and Ergun, Ö. (2008) develops scheduling planning for logistics network problems.

Third, another problem is the production and distribution simultaneous decision problem, meaning that at least one manipulated variable exists in both production and distribution activities. With those types of studies as the background, Sakawa, M. et al. (2001), Tang, J., Yung, K.L. et al. (2007), Aydinel, M. et al. (2008) consider distribution activities as manipulated variables that belong to production activities. They decide on distribution activities, such as truck numbers for inland distribution and multiple distribution mode to select. But there are always single-transport path models. In order to cope with those problems, Bilgen, B. (2010) discusses the route selection problem of whether to use a direct distribution or a multi-distribution path through other depots as multiple-transport path models. These types of studies are rare but important in tactical and operational decision support systems for real-life enterprises.

However, it is not difficult to find that neither the single-transport path nor multiple-transport path models, lead times which mean transit time among production plants and demand markets are constant. Because locations of production, distribution and sales based are given advance, supply pattern of demand is fixed, therefore, optional combination candidates for locations and lead times among them are also fixed. This is not a shortcoming when locations not far from each other, as inland supplying or regional supplying. However, while globalization tendency of market demand in on the way, there is a fact that the locations of markets would get far away from production plants and discrete with each other. Therefore, in order to decrease holding costs caused of long distribution lead times, redesign of global production networks (GPN) by changing supply pattern is important. In other words, there is a significant necessary to determine the lead times among each locations combination, this is to say, lead times should not be constant and given but to determine in GPN problems.

To the best of our knowledge, there is no paper discussed locations combination problems considering lead times in production and distribution planning of GPN. Therefore, in this paper, we propose a two-level routing pattern to adjust lead times among locations as a supply pattern in GPN.

3. MODEL FORMULATION

3.1 A two-level routing pattern

A routing pattern means how spots and links construct in

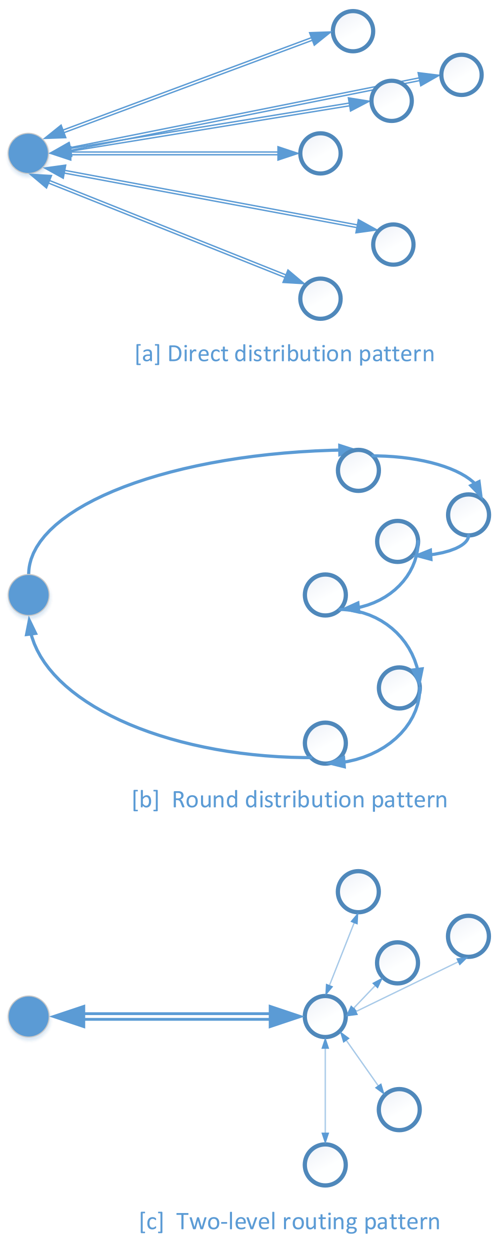

Figure 1: Proposed two-level routing pattern

a network. In global transportation, maritime transport is the backbone of international trade. Around 80 percent of global trade by volume and over 70 percent of global trade by value are carried by sea and handled by ports worldwide. Therefore, in this study we consider sea shipping as our transportation mode in GPN. With the increasing requirement for quicker response to customers, more and more manufacturing enterprises are beginning to change the way they handle product shipment, from relying on an internal transportation system to using subcontracted vehicles in a production-distribution network (Tang, J., Yung, K.L. et al., 2007). Therefore, also in our study, we consider to hire vessels from maritime company by year-based.

There are two popular pattern in maritime transport. One is a direct distribution pattern, a vessel sails back and forth between two ports (Figure 1[a]). The other is a round distribution pattern, a vessel sails in only on direction, to call all of ports and go back to the original port (Figure 1[b]). The two patterns seem convenience and efficient in simple distribution system. However, if considered in a production-distribution system, the direct pattern would cause load waste and the round pattern would lead to increased holding costs because of long round route.

Therefore, a two-level routing pattern proposed that does not stand alone but is combined with the other two patterns so as to make distribution more efficient. It is a location-allocation problem. A complete graph with many ports is given, where some ports play roles as hubs whereas others are depots. Each port corresponds to origins, destinations and possible hub locations. These hubs are visited roundly by main line vessels and are the transshipment points for products to/from the deport because of direct route. Figure 1[c] describes the simply way of the two-level routing pattern. In that, the routes connecting production plants and hubs are considered as the first level, meanwhile the ones connecting hubs and depots are considered as the second level.

Compared with the other two patterns. The two-level pattern is more efficient especially in long distance production-distribution system. In other words, the proposed pattern is not load waste comparing with the direct pattern, and can decrease lead times comparing with the round pattern. That is to say, to cater for quicker response to markets with long lead times, the manufacturing enterprise may consider to hire a flexible number of vessels while maintaining control both of the production and distribution system.

3.2 Problem description

This work considers the optimal design and operation of multi-product, multi-plant, multi-hub, multi-transport path, and multi-market problem of a GPN. We divide activities occur in a GPN into manufacturing process, distribution process and sales process. Corresponding costs appear in each sub-process. Regardless of production bases as plants or sales bases as markets, sending and receiving activities are both at a main port of that area.

In manufacturing process, final products belong to each group are produced through lot production way. There is a set-up cost between different product group. If production allocation for one group is higher than a standard production capacity of that in a plant. Over time labor costs would happen for the product group produced in the plant.

In distribution process, we use the two-level routing

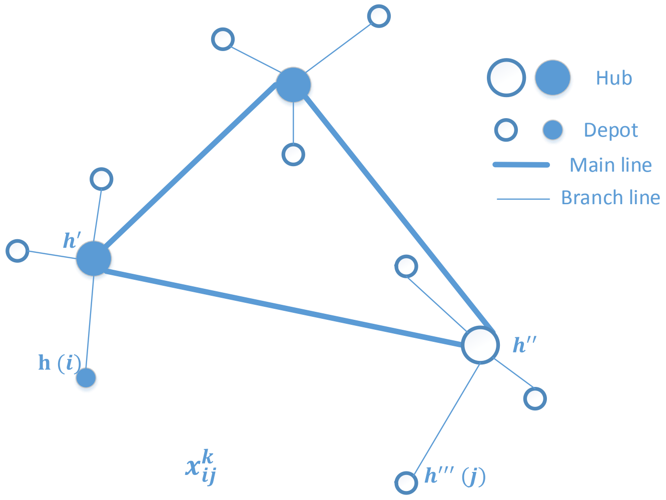

Figure 2: An example for two-level routing pattern network

pattern. Where each port $h = 1,2,\dots,H$ is possible be a origins, destinations and hub locations. And $T_{hh'}$ is transportation lead time between port h and h'. The path from an origin port h to destination port h''' includes three situations in two-level routing pattern. Case 1 is the production port h is equal market port h''', therefore, transportation lead time $T_{hh'''} = 0$; Case 2 is that the production port h and market port $h'''$are in the control of same hub h', therefore, transportation lead time $T_{hh'''} = T_{hh'} + T_{h'h'''}$; Case 3 is that the production port h and market port $h'''$are in the control of different hub h' and h'', therefore, transportation lead time $T_{hh'''} = T_{hh'} + T_{h'h''} + T_{h'h'''}$. All of the three situations, port h seems as a production plant i with product k which should be distributed to port h''' seems as sales market j. An example of distribution network with three hubs is given in Figure 2.

In sales process, we consider duty cost varies with routing, the same product group produced in different plant has different duty coefficient if this cargo even goes to same destination. Stock costs construct with average stock and safe stock, both of them varies with transportation lead time L, and the calculate method of lead time is corresponding to the three situations described in distribution process. We can adjust the average lead time of GPN through hub selection work. That is to say, lead times of our model is flexible, they are evaluated by stock level in each market, hub establishing costs in each area and manufacturing variety in each plant.

3.3 Problem formulation

In the following, an integrated mixed integer programming (MIP) optimization model for the production-distribution planning problem is developed.

3.3.1 Notation

Index and set

i	plants $i \in I$ $(i = 1,2,\dots,I)$
k	products $k \in K(k = 1,2,\dots,K)$
g	product groups $g \in G(i = 1,2,\dots,G)$
h	port nodes $h \in H(i = 1,2,\dots,H)$
v	vessel types $v \in V(i = 1,2,\dots,V)$
j	market zones $j \in J$ $(i = 1,2,\dots,J)$
p	sales prices $p \in P$ $(i = 1,2,\dots,P)$
k_g	product k that belong to group g

Parameters

Production process

$PCap_i^g$	standard production capacity for group g in plant i
$\hat{P}Cap_i^g$	maximum production capacity for group g in plant i
$PLab_i^g$	annualized fixed labor cost for group g in plant i
CTK_i^k	manufacturing man-hours for product k in plant i
C_k^{materi}	unit material cost for product k
$a_{ig}^{overtime}$	overtime labor cost coefficient for group g in plant i
T_{ig}^{chang}	change over time for group g in plant i

Distribution process

$C_{hh'}$	unit transportation cost for direct distribution from node h to node h'
$T_{hh'}$	transportation lead time between node h and node h'
C_v^{unit}	per unit-time shipping cost of vehicle type v for round distribution
$C_{h'}^{infra}$	fixed cost of hub using at node h'

Sales process

p_k^j	candidate sales price of product k in market j
D_j^k	demand of product k in market j
α_{ijg}^{proc}	procurement coefficient for group g from plant i to market j
β_{ijg}^{duty}	duty coefficient for group g from plant i to market j
C_j^{inter}	interest rate for cash in bank for market j
Sp_k	floor space for product k
C_j^{floor}	unit floor space rental price for warehouse in market j
∂_j^k	service level in market j for product k
α	standard deviation of demand
I_0^{kj}	initial stock of product k in market j

Decision variables

x_{ij}^k	production quantity of product k from plant i to market j
O_i^k	1 if product k is set-up in plant i, and 0 otherwise
$Z_{hh'}$	1 if node h is allocated to the hub located at node h', and 0 otherwise

3.3.2 Objective function

The problem is formulated using MIP with an objective function of total profits maximization:

Max

$$\sum_j \sum_k p_k^j D_j^k - manufacturing\ \ cost - distribution\ \ cost - sales\ \ cost \quad (1)$$

Subject to:

$$\sum_i \sum_k x_{ij}^k \geq D_j^k \quad (2)$$

$$\mathrm{CTK}_i^k * x_{ij}^k \leq \hat{P}Cap_i^g \quad k \in k_g \quad (3)$$

$$\sum_{h'} Z_{hh'} = 1 \quad (4)$$

$$Z_{h'h'} - Z_{hh'} \geq 0 \quad (5)$$

$$x_{ij}^k \leq M * O_i^k \quad (6)$$

The maximization of total profits in the objective function includes total manufacturing cost, distribution cost and total sales cost. In detail, manufacturing cost includes standard and overtime production costs, product change-over costs and material costs. Distribution cost includes round distribution costs from plants to hubs (first-level), direct distribution costs from hubs to depots (second-level) and hubs using costs for each path. Sales cost contains of import duties, stock costs, and interest costs.

The objective (1) is to maximize total profits associated with manufacturing cost, distribution cost, and sales cost. Constraint (2) is the demand constraints for market j, which indicates that demand for product k should not exceed the production quantity in each plant. Constraint (3) is the production capacity constraints for product k belong to group g, which indicated that product produced in plant i should not exceed the production capacity in plant i. Constraint (4) ensures that each port is assigned to exactly one hub. Constraint (5) ensures that port h is assigned to port h^' when port h^' is a hub. Constraint (6) enforces that if no corresponding set-up is performed for product k in plant i, the production quantity for product k in plant i is zero.

3.3.3 Cost function

- Manufacturing cost:

Case 1: Assembly costs (Annualized fixed labor) + change-over costs + material costs

If $0 \leq \sum_g \mathrm{CTK}_i^k * x_{ij}^k \leq PCap_i^g$

$$\sum_i \sum_g PLab_i^g + \sum_i \sum_k (O_i^k - 1)\, T_{ig}^{chang} * \frac{PLab_i^g}{PCap_i^g} + \sum_i \sum_k C_k^{materi} * x_{ij}^k \quad k \in k_g$$

Case 2: Assembly costs (Annualized fixed labor + overtime work costs) + change-over costs + material costs

If $PCap_i^g \leq \sum_g \mathrm{CTK}_i^k * x_{ij}^k \leq \hat{P}Cap_i^g$

$$\sum_i \sum_g PLab_i^g + \sum_i \sum_g \frac{PLab_i^g}{PCap_i^g} * a_{ig}^{overtime} * (\sum_g \mathrm{CTK}_i^k * x_{ij}^k - PCap_i^g)) + \sum_i \sum_k (O_i^k - 1)\, T_{ig}^{chang} * \frac{PLab_i^g}{PCap_i^g} + \sum_i \sum_k C_k^{materi} * x_{ij}^k \quad k \in k_g$$

- Distribution cost:

Case 1:

If Local production local sales

Distribution cost = 0

Case 2: Hub using costs + main lines visiting costs + branch lines visiting costs

If General production General sales

$$\sum_{h'} Z_{h'h'} C_h^{infra} + \sum_h \sum_{h'} Z_{hh'} \sum_{h'''} \sum_{h''} Z_{h'''h''} (\sum_{h'} \sum_{h''} T_{h'h''} + T_{h''h'})\, C^{unit} + \sum_i \sum_j x_{ij}^k \sum_{h'} C_{hh'} Z_{hh'} + + \sum_i \sum_j x_{ij}^k \sum_{h''} C_{h'''h''} Z_{h'''h''}$$

$notes: production\ \ plant\ \ i = port\ \ h; sales\ \ warehouse\ \ j = port\ \ h'''; \ port\ \ h', h'' = hubs$

- Sales cost:

Duty costs + Stock costs + Interest costs

Duty costs =

$$\left(\sum_i\sum_k C_k^{materi} * x_{ij}^k + \sum_i\sum_k assembly\ \ costs * \frac{x_{ij}^k}{\sum_i\sum_k x_{ij}^k}\right) * \ \alpha_{ijg}^{proc} * \ \beta_{ijg}^{duty}$$

Stock costs =

$$\sum_j\sum_k Sp_k * [\frac{(I_0^{kj} + \sum_j\sum_k x_{ij}^k)L}{30 * 2} + \ \partial_j^k \alpha\sqrt{L}\ \ ] \ * \ C_j^{floor}$$

Interest costs =

$$\sum_i\sum_j\sum_k C_j^{inter}\left(\sum_i\sum_k C_k^{materi} * x_{ij}^k + \sum_i\sum_k assembly\ \ cost * \frac{x_{ij}^k}{\sum_i\sum_k x_{ij}^k}\right) * \frac{x_{ij}^k}{\sum_i\sum_k x_{ij}^k} * \ \alpha_{ijk}^{proc}$$

4. COMPUTATIONAL STUDY

In this section, we describe our computational experiments to evaluate the effectiveness of our model. The model proposed in part 3 is based on MIP, which has been certified to be much more difficult to solve using mathematical techniques when the scale of the problem increases. Numerous studies consider solutions to production-distribution optimization models using genetic algorithms (GA). GAs are proven to be highly effective and efficient at solving complex SCM problems because directed and stochastic search methods can find good solutions easily and in a shorter period (Garavelli, A.C. et al., 1996, Hou, Y.C., and Chang, Y.H., 2002, Chan, F.T. et al., 2005, Chang, Y.H., and Hou, Y.C., 2008,). Therefore, in this study, we use the concept of a GA to develop our global production planning system.

The GA procedure was coded in Python 2.0 and has been built to be applied to a scenario characterized by 20 sales markets' demand of 20 kinds products and 10 production plants of a global manufacturing firm. The example was modeled with 3 levels of demand dispersion among markets. That is to say, the total demand quantity of all kinds products is constant. How the demand curve gets shifted determines market tendency. If demand of products for all candidate markets are increased, the demand dispersion is said to be shifted outward and average demand for each market becomes higher. We let the lower demand dispersion be level 1, middle be level 2 and higher be level 3 in our numerical experiment.

The result from our algorithm is shown in Fig 4. The results indicate that the integrated method of production and distribution model using two-level routing pattern is more effective in middle-high demand dispersion. When the degree

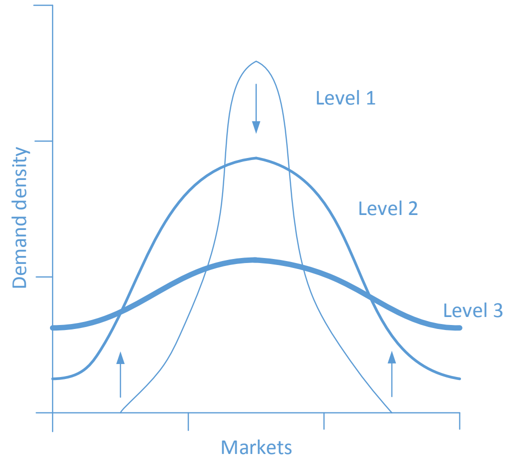

Figure 3: Demand dispersion of different level

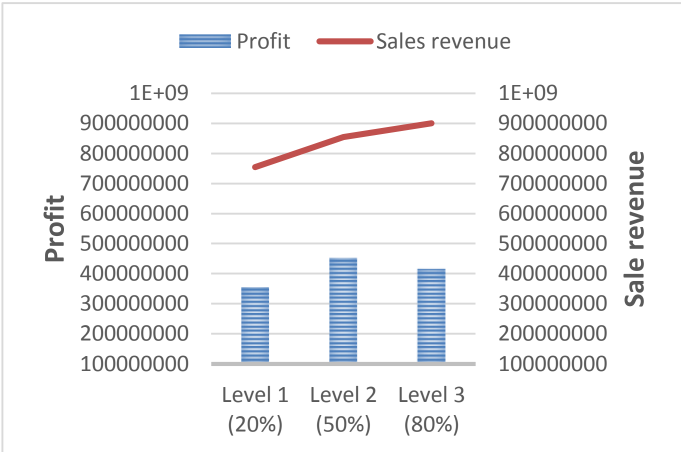

Figure 4: Numerical results for two-level routing pattern in global production networks

of demand dispersion is low and approximately 20%, total profits of GPN are low. Potentially, this might be when demand dispersion is low, the demand is centralized in fewer markets, to copy with this, supply pattern should be not far from the centralized demand, as regional production, a plant could deal with the demand within a specific region for all kinds. At this point, demand-sales price curve of each product in each market is known, normally, the much demand in one area means sales unit price in this market is low, therefore be likely to lead to a lower sales revenue. Furthermore, when demand dispersion is growing to middle-high, there are more markets need the same product but far away from production plants. However, the two-level routing pattern could effectively decrease the transportation lead times among plants and markets. The holding costs in market caused by long lead times would sharply decreased thanks to the proposed supply pattern, and meanwhile, as the change from regional production to global production, permission of mass production for a kind of product could be in one plant, so in this level, advantage of sales economic in production is also obtained. Furthermore, because demand becomes fewer of each product in each market, the corresponding sales prices become higher. Therefore, due to increase in scale economics in production, decrease in holding costs and more possible sales revenue in markets, the total profits become higher in level 2 comparing with level 1. But in level 3, there is an obviously decreasing in profits, it indicates that, when the demand of all kinds increase to a standard, the holding costs significantly increase due to diversity in product kinds. And production change over costs also increase in each plant. In general, from the numerical experiment, we know that the demand dispersion of products extremely affect the effectiveness for production and distribution system of a GPN. In other words, in our research, we found the proposed integrated method of production distribution planning using two-level routing pattern is more effective in middle-high demand dispersion markets.

5. CONCLUSION

Along with economic growth in global environment, especially in developing countries, mid-to-long term decision-making of production and distribution planning for global manufacturing firms is very important. We proposed an integrated method of this problem using two-level routing pattern, which can sharply decrease the holding costs in markets by reducing the lead times among production plants and sales markets. The method has been verified very effectively especially when demand dispersion of products in markets change to middle-high range. In order to let the integrated model not far from real world, we also used a time-dependent calculation method to formulate the model, and proposed the production, distribution and sales costs functions in each process. Our model presented is developed using the concept of GA, which has been proven to be an effective method to address GPN problems. Furthermore, other experimental analysis as labor cost difference, production efficiency, vessel sizes, harbor remain quantity and transshipment costs should also be considered in the further study. In addition, total demand increasing refers to production and distribution capacity expanding is also an interesting extend of this paper.

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