A GLOBAL PRODUCTION PLANNING MODEL WITH CONSIDERATION OF MARINE TRANSPORTATION FACTORS

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Abstract
In previous studies regarding production-distribution problems, sales planning was not considered and transportation processes were simplified. Such non-consideration and simplification can lead to decreased profits, since both sales planning and distribution directly influence production planning. Therefore, the present study develops a global production planning model that integrates production and sales planning, while considering marine transportation factors (hub selection) as decision variables in order to optimize global production planning. Since the proposed model is a nonlinear problem with a nonconvex objective function and nonlinear constraints, the model was remodeled into a mixed-integer linear problem so that it could be solved with an optimization solver (IBM CPLEX 12.6). Moreover, computational experiments were conducted and manufacturing and sales planning were integrated to determine the potential profits of improving vessel load efficiency. The findings show that, under different manufacturing or transportation environments, the hub selection approach showed a variance in total profits, compared with the hub predefined approach. More specifically, when the proportion of transportation costs increased, the importance of using the hub selection approach was greater, since it helped determine the potential profits by utilizing various marine transportation factors.

Keywords: Global production planning; Integrated approach; Marine transportation; Hub selection; Mathematical model

1 INTRODUCTION
Production planning is the planning of manufacturing modules in a firm, and it utilizes the resource allocation of production capacity activities in order to serve market demand. Global production planning is production planning that considers global factors such as labor capabilities, tariff rates, exchange rates among different regions, long distance transportation, main hub selection problems, etc. Several fundamental changes (e.g., manufacturing and transportation policies) over the last two decades have forced enterprises to re-evaluate how they manage their businesses as well as determine where and how business value can be created in this new environment.

International trade has experienced continuous growth during the 21st century, due to the increase in the global population and the standard of living [1]. In regard to global manufacturing and transportation, marine transportation remains popular, based on its cost-effectiveness and ability to transport a wide range of products. Furthermore, the routing patterns from the plants to the markets usually include two levels. The first level from the plants to the hubs uses main lines, while the second level from the hubs to the markets uses branch lines. Overall, there are three main modes of marine transportation: industrial, tramp, and liner. In industrial shipping, the cargo owner controls the vessels and the routing. In tramp shipping, the cargo owner is always a German partner with the vessel renter, and the cargo owner does not own the vessels, but controls/plans the routing. In liner shipping, the cargo owner neither controls the vessels nor the routing, and the cargo is outsourced to a shipper.

Due to the increasing need for faster responses to the markets, more manufacturing firms are changing from industrial shipping to tramp and liner shipping [2]. However, since the route and schedule in liner shipping is predetermined, the long lead time can result in inventory problems. As a result, increasing attention has been placed on tramp shipping, due to its flexibility.

Recently, in addition to the changes in the network construction and operation costs of hubs, determining the most advantageous hub for each market has become the subject of focus. For example, after the reorganization of the Busan hub, its operation costs and capacity have been becoming attractive to both the Japanese and Asian markets. Hence, rather than using the Tokyo hub, the Busan hub has become a popular choice.

This study develops a global production planning model that integrates production and sales planning, while considering marine transportation factors (hub selection) as decision variables in order to optimize global production planning. The remainder of this paper is as follows. Section 2 includes a review of the relevant literature regarding production-distribution problems, while Section 3 describes the research problem and presents the formulated model. Section 4 discusses the model’s simplification and transformation as well as the results of the numerical experiments. Finally, Section 5 summarizes the conclusions.

2 REVIEW OF RELATED TOPICS

2.1 General production-distribution problems
Production-distribution problems are generally the main issues in production planning, and they can be classified into location-allocation and production-allocation, based on a strategic/tactical perspective. Location-allocation problems are related to locating the optimal number of facilities in a certain area in order to minimize transportation costs, while satisfying market demand. This problem occurs in many practical settings in which facilities provide homogeneous services, including the determination and location of warehouses, distribution centers, and production facilities [3]. Production-allocation problems are related to determining the most efficient way to use given resources, while satisfying market demand. For manufacturing firms,
production-allocation problems usually occur during medium-term planning (approximately 1–3 years). However, due to the rapidly changing production and distribution environment, managers have been redesigning their medium-term production planning with increasing frequency.

The majority of previous production-distribution models only considered transportation factors as a fixed cost [4]. Moreover, the transportation cost of each product was calculated by the unit manufacturing cost plus the unit transportation cost. However, in practice, when conducting production planning for the following year, an accurate unit manufacturing cost and unit transportation cost cannot be obtained. More specifically, the unit manufacturing cost constantly changes with the quantity of a plant’s production line, while labor costs, setup frequencies, and operational rates of the production line have an effect on the unit manufacturing cost. Meanwhile, the unit transportation cost also changes according to certain factors such as transportation patterns, fuel costs, labor costs, etc.

Based on this review, since transportation is assuming an increasingly important role in today’s global production networks, transportation factors should be considered in production-distribution problems. Furthermore, non-consideration of such factors can lead to inaccurate production allocation in production planning, thus resulting in decreased profits.

2.2 Production-distribution problems with consideration of transportation factors

For the purpose of this study, previous papers on production planning with truck transportation have been examined. [5] and [6] both included an integrated model of production-distribution problems. In their distribution processes, the truck numbers were decided beforehand in order to calculate the distribution costs. However, since the production plant for the product was also pre-decided, there was only one route for the product to be distributed to the market. Consequently, transportation inefficiency problems occurred, since less than a truckload was assigned for each route. [7] considered this transportation inefficiency problem and extended the research of [5] and [6] by proposing multiple transportation patterns. More specifically, multi-routings was considered to increase transportation efficiency, while products of less than a truckload were merged by visiting multiple plants until each truckload was filled to capacity. In land transportation, a delay from two to three days is not a serious problem. However, in marine transportation, a delay in a vessel’s travel time from two to three months can have serious ramifications. Hence, other approaches for increasing transportation efficiency should be considered.

Since visiting multiple ports is not suitable in marine transportation, hub selection is considered for increasing transportation efficiency and production profits. In addition, a production-distribution model with consideration of marine transportation factors is proposed, while utilizing cost functions (e.g., the fixed vessel-hire cost and the variable cost of vessel operation) and global factors (e.g., tariff rates, labor costs, and procurement rates among different regions). Furthermore, since production planning is simultaneously decided with transportation planning, the results of product allocation and the number of vessels used will also change with hub selection.

3 PROBLEM DESCRIPTION

The purpose of this proposed approach is to maximize the profits of manufacturing, transportation, and sales, while using vessel-hire and hub selection as marine transportation factors. In this global production network, there are markets, plants, and hubs in different regions. As shown in Figure 1, the types of products for each market have different demands and they are transported from the plants via the hubs to the markets.

![Figure 1. Global production network.](image)

For the markets, demand quantities and sale prices are not fixed in this study. However, when the demand quantities of products are decided, the sale prices are also decided from the demand curve function. For the plants, although the fixed and variable costs of each plant differ, it is possible that the various types of products can be produced in each plant. However, each region may have a popular product and production capacity may be limited in each plant. Finally, for the hubs, the types of products are collected from various plants, but they are gathered in the closest hubs to the markets.

4 NUMERICAL EXPERIMENT

In order to illustrate the application of the synchronized production planning model with consideration of marine transportation factors, the hub predefined approach is used, which conducts production planning without considering the aforementioned factors.

1. Total Profits, Revenues, and Costs of the Global Production Network

Comparing total profits through the hub selection approach with those of the hub predefined approach in different production environments

The hub predefined approach is a traditional method means that through which hub to receive the products from various plants is predefined. For example, when market demand is generated from Tokyo, decision-makers generally use Tokyo’s port to receive their products from around the world, since the distance from the hub to the market is the closest.

The hub selection approach (which is proposed in this study) means that though which hub to receive the products is not determined; that is, some products may come from hub A, while others may come from hub B. In this case, such decisions are simultaneously made with sales planning and production allocation. For example, when the market demand is near Tokyo, then the various products would come from the ports of Tokyo in Japan, Busan in Korea, and Shanghai in China, respectively.

Each approach includes its strengths and weaknesses. Thus, determining how these two approaches function under different production and transportation environments is the aim of this experiment.

There are four scenarios that highlight the proportion of the transportation cost to the manufacturing cost. Both the transportation cost and the manufacturing cost are
calculated by the average unit cost. As the proportion of the transportation cost increases, the four stages are defined as

![Graph showing total profit ratio change under different environments](image)

**Figure 2.** Comparing the profit ratio change under the different environments.

![Cost comparison of two approaches](image)

**Figure 3.** Comparing the cost details of the two approaches (i.e., Hub Selection/Hub Predefined).

small (1:10), middle (1:6), big (1:2) and very big (2:1). Figure 2 shows that the ratio of the transportation unit cost to the manufacturing unit cost increases from 1:10 to 1:2. Thus, the hub selection approach shows a higher potential profit, compared to the hub predefined approach, since selecting a hub to receive the products provides an opportunity for manufacturing firms to increase transportation efficiency. Consequently, saving costs from advantageous balance between both manufacturing and transportation processed can increase total profits. However, when the ratio of the transportation unit cost to the manufacturing unit cost further increases from 1:2 to 2:1, then the effectiveness of the hub selection approach decreases. This indicates that, when the transportation environment undergoes significant changes, strategic transportation planning should be redesigned (e.g., using industrial shipping, instead of tramp shipping in marine transportation).

2. Analyzing the cost details of the two approaches

Figure 3, which compares the cost details of the two approaches, indicates that the hub selection approach is more effective than the hub predefined approach. Moreover, the amount of money, including income (such as revenue) and expenses (such as costs) is compared. Scenario 3 (big (1:2)) of the transportation unit cost to the manufacturing unit cost has been chosen for explanation.

Based on the results, the hub selection approach receives less sales revenues, but greater profits, compared with the hub predefined approach. In addition, the relationship between sales revenues and costs are not linear. In other words, more sales revenues do not represent greater profits. Although sales revenues tend to decrease in the hub selection method, the aggregation costs of manufacturing, transportation, and sales processes hardly decrease, thus increasing total profits. Furthermore, since the products have greater freedom to be combined in the vessels, transportation costs are significantly reduced. As a result, overall transportation efficiency increases and the number of vessels is reduced.

5 CONCLUSION

In this study, a global production planning model with consideration of marine transportation factors was proposed. In addition, the transportation process was simultaneously determined with manufacturing and sales planning. Since the hub selection approach can allow decision-makers to select which hub can send certain products, it can increase overall transportation efficiency.

The proposed model in this study was a nonlinear problem with a nonconvex objective function and nonlinear constraints. In addition, the cubic/quadratic equation was transformed and the variables were eliminated in order to obtain a mixed-integer linear problem that could be solved with a general optimization solver.

The findings show that, under different manufacturing or transportation environments, the hub selection approach showed a variance in total profits, compared with the hub predefined approach. More specifically, when the proportion of transportation costs increased, the importance of using the hub selection approach also increased, since it helped determine the potential profits by utilizing the factors of sales, manufacturing, and transportation in production planning. The results also indicated that, by decreasing sales quantities, it helped increase profits, and vessel load efficiency. The implications of the findings are that production planning in marine transportation should be conducted by considering the aforementioned factors, and that the hub selection approach is more effective for determining a firm’s performance in a changing global environment.

6 REFERENCES


