Global Supply Network Configuration using Air-cargo Free Trade Zones: A Simulation-based Approach

Jun-Der Leu1, Yu-Tsung Huang2, Min-Hui Chen3

1,2,3 Department of Business Administration, Jhong-da road 300, Jhong-Li 32001, Taiwan
leujunder@mgt.ncu.edu.tw1; ythuang@mgt.ncu.edu.tw2

Abstract - A Free Trade Zone (FTZ) is an economic zone that an international business can utilize to optimize its supply network. It provides the advantages of operational efficiency as well as financial benefits. For these reasons, many international businesses choose to locate their manufacturing factories or distribution centers in an FTZ. However, the deployment of business sites in such an area necessitates the re-designing of their supply network and also requires decision support analysis. In this study, we develop an economics evaluation model and a simulation model for the use of an air-cargo FTZ by an international business. The feasibility of the two models is illustrated by applying them to an international business. The results show how the global supply network is re-configured after the application of air-cargo FTZs.

Keywords - Global supply network, Free Trade Zones (FTZ)

I. INTRODUCTION
A variety of factors need to be considered when an international business configures its global supply network, such as costs, resources, ports, regulations, policies, and so on [1]. Many international businesses configure their supply network considering economic regulations. Free Trade Zone (FTZ) is one of these economic regulations. It is a specific economic area in which an international enterprise can devote to the assignments of warehousing, packaging, the inspection, labeling, exhibition, assembly, fabrication, or transshipment [2]. An air-cargo FTZ allows improved operational efficiency to an international business specializing in high value-added products and emphasizing the time-to-market requirement. These advantages allow an international business to allocate its resources more efficiently and impact the decisions to manufacture locally or to rely on foreign imports.

In this research, we study the supply network configuration problem for an international business using an air-cargo FTZ. First, we develop a mixed integer linear programming (MILP) model of the global supply network configuration. Then, we develop a simulation model for considering the dynamic problem. The MILP and simulation models are applied to evaluate the benefits of the air-cargo FTZ application. Finally, some management insights are discussed. In the next section, a review of the global supply network configuration is presented. In section 3 the decision model is explained. In section 4 the simulation model is described while in section 5 the application of the air-cargo FTZ by an international business is discussed. Finally in section 6 the conclusions and directions for further research are noted.

II. LITERATURE REVIEW
Issues that need to be considered in the configuration of a supply network include market development, location decisions, supplier selection, business partner collaboration, process integration, etc [3]. In the past, these configuration problems have been solved using mathematical programming approaches. Bhutta et al. [4] developed an MILP model and discussed several scenarios with different levels of exchange rates and tariffs. These studies provide decision models for global supply network configuration, without the consideration of economic regulations. Wilhelm et al. [5] developed an MILP model that took into consideration North American Free Trade Agreement (NAFTA) applications but did not consider a dynamic environment. Lee et al. [6] applied optimization and simulation approaches to deal with strategic problems in supply networks and also applied a simulation approach to design, evaluate and optimize supply networks.

III. DECISION MODEL
We study the supply network configuration problem of distribution centers including an air-cargo FTZ. We decide the location of distribution centers and select suitable suppliers. The distribution center obtains orders through given channels. It assembles and distributes several final products. These final products are assembled from semi-finished products and components. Semi-finished products are provided by foreign up-stream manufacturers and components are provided by foreign component suppliers. Each supplier provides only one kind of semi-finished product or component. We also consider the capacity of the distribution center, transportation and suppliers, operational costs, exchange rates, tariffs and so on. The indices, parameters, decision variables and constraints are described below.

Indices

- $f$ index of semi-fished product supplier \{1, 2, 3, ..., $F$\}
- $n$ index of component supplier \{1, 2, 3, ..., $n$, ..., $N$\}
- $w$ index of distribution center \{1, 2, 3, ..., $W$\}
- $r$ index of semi-fished product \{1, 2, 3, ..., $r$, ..., $R$\}
- $k$ index of component \{1, 2, 3, ..., $k$, ..., $K$\}
- $p$ index of final product \{1, 2, 3, ..., $p$, ..., $P$\}
- $c$ index of channel \{1, 2, 3, ..., $c$, ..., $C$\}

Parameters
demand for product $p$ from channel $c$

quantity of final product $p$ at distribution center $w$

quantity of semi-finished product $r$ from semi-finished product supplier $f$ to distribution center $w$

quantity of component $k$ from component supplier $n$ to distribution center $w$

quantity of final product $p$ from distribution center $w$ to channel $c$

supply capacity of semi-finished product $r$ from semi-finished product supplier $f$

supply capacity of component $k$ from component supplier $n$

required quantity of semi-finished product $r$ for final product $p$

required quantity of component $k$ for final product $p$

unit transportation capacity for semi-finished product $r$

unit transportation capacity for component $k$

unit transportation capacity for final product $p$

transportation capacity from semi-finished product supplier $f$ to distribution center $w$

transportation capacity from component supplier $n$ to distribution center $w$

transportation capacity from distribution center $w$ to channel $c$

unit production capacity for final product $p$

unit transportation cost for semi-finished product $r$

unit transportation cost for component $k$

unit transportation cost for final product $p$

unit procurement cost of semi-finished product $r$

unit procurement cost of component $k$

unit procurement cost of final product $p$

operating cost of distribution center

fixed transportation cost from semi-finished product supplier $f$

fixed transportation cost from component supplier $n$

fixed transportation cost from distribution center $w$

transportation capacity from semi-finished product supplier $f$ to distribution center $w$

transportation capacity from component supplier $n$ to distribution center $w$

transportation capacity from distribution center $w$ to channel $c$

exchange rate of currency for country of semi-finished product supplier $f$

exchange rate of currency for country of component supplier $n$

exchange rate of currency for country of distribution center $w$

exchange rate of currency for country of channel $c$

tariffs on semi-finished product $r$ from semi-finished product supplier $f$

tariffs on component $k$ from component supplier $n$

tariffs on final product $p$ from distribution center $w$

tariffs on channel $c$

total customs clearance cost

total operating cost of distribution center

total manufacturing cost

total procurement cost

total tariffs

total customs clearance cost

Decision variables

Capacity of final product $p$ in distribution center $w$

1, distribution center $w$ is selected; 0, else

1, distribution center $w$ operates; 0, else

1, semi-finished product supplier $f$ provides distribution center $w$; 0, else

1, component supplier $n$ provides distribution center $w$; 0, else

1, distribution center $w$ provides channel $c$; 0, else

Constraints

Distribution centers need to arrange the shipment of final products to channels in (1) and (2). In it, M symbolically presents a huge positive number. In this process, the quantity of final products at the distribution centers must be greater than the demand quantity of the channels in (3) and (4).

$$A_{w} \times M \geq Q_{pwc}, \forall p, w, c$$ (1)
Transportation costs include fixed and variable ones in (5) and (6).

\[
TRFC = \sum_{w} \sum_{f} FC_{fw} \times E_{f} \times B_{fw} \\
+ \sum_{w} \sum_{w} FC_{ww} \times E_{w} \times Z_{ww} \\
+ \sum_{w} \sum_{w} FC_{ww} \times E_{w} \times A_{w}
\]  

(5)

\[
TRVC = \sum_{w} \sum_{f} PC_{rfw} \times DIS_{fw} \times Q_{rfw} \times E_{f} \\
+ \sum_{w} \sum_{w} PC_{kw} \times DIS_{kw} \times Q_{kw} \times E_{w} \\
+ \sum_{w} \sum_{w} PC_{pw} \times DIS_{pw} \times Q_{pw} \times E_{w}
\]  

(6)

Assembly assignments are only executed in the operating distribution centers (7). The capacity restrictions of distribution centers are considered in (8).

\[
A_{w} \leq X_{w}, \forall w
\]  

(7)
\[
V_{pw} \times J_{pw} \leq CW_{pw}, \forall p, w
\]  

(8)

Total operating costs of distribution center include both set-up and operating costs (9).

\[
TOC = \sum_{w} OC_{w} \times E_{w} \times A_{w}
\]  

(9)

Total manufacturing costs are summarized from manufacturing costs in all distribution centers (10).

\[
TMC = \sum_{w} MC_{pw} \times J_{pw} \times E_{w}
\]  

(10)

The transportation quantity of semi-finished products and components are restricted in (11) and (12). The transportation capacity restrictions of semi-finished product suppliers, component suppliers and distribution centers are considered and presented in (13), (14) and (15).

\[
B_{fw} \times M \geq \sum_{s} Q_{fs}, \forall f, w
\]  

(11)
\[
Z_{kw} \times M \geq \sum_{s} Q_{kw}, \forall n, w
\]  

(12)
\[
LM_{fw} \geq \sum_{s} Q_{fs} \times S_{f}, \forall f, w
\]  

(13)
\[
LM_{kw} \geq \sum_{s} Q_{kw} \times S_{s}, \forall n, w
\]  

(14)
\[
LM_{pw} \geq \sum_{s} Q_{ps} \times S_{p}, \forall w, c
\]  

(15)

The supply capacity of semi-finished product suppliers and component suppliers is considered in (16) and (17). The procurement quantity of semi-finished products and components has to be satisfied with distribution centers in (18) and (19).

\[
\sum_{w} Q_{rfw} \leq CF_{rf}, \forall r, f
\]  

(16)
\[
\sum_{w} Q_{kw} \leq CN_{kw}, \forall k, n
\]  

(17)
\[
\sum_{w} Q_{kw} \geq \sum_{p} U_{pw} \times J_{pw}, \forall w, r
\]  

(18)
\[
\sum_{w} Q_{kw} \geq \sum_{p} U_{pw} \times J_{pw}, \forall w, k
\]  

(19)

There are procurement costs for semi-finished products and components. The calculation of total procurement costs is presented in (20).

\[
TPC = \sum_{w} \sum_{r} Y_{rw} \times Q_{rw} \times E_{f}
\]  

(20)

When semi-finished products and components are transported between countries, there are tariffs to pay (21). Customs clearance costs are necessary when distribution centers are not locate in an FTZ (22).

\[
TTAX = \sum_{w} \sum_{r} \sum_{f} TAX_{rfw} \times Q_{rfw} \times Y_{rfw} \times E_{f}
\]  

(21)
\[
TGC = \sum_{w} GC_{w} \times E_{w} \times A_{w}
\]  

(22)

All 0, 1 variables are presented in (23).

\[
X_{w}, B_{fw}, A_{w}, A_{w} \in \{0,1\}
\]  

(23)

The objective function is to minimize total costs, including transportation costs, operating cost, manufacturing cost, tariffs and customs clearance costs (24).

\[
\text{Min } TOC + TPC + TMC + TRFC + TRVC + TTAX + TGC
\]  

(24)

IV. SIMULATION MODEL

In this research, the simulation model starts from customer orders. All inputs come from the results of the MILP model. The simulation model is developed by eM-Plant. It includes 11 sections: customer orders, capacity of semi-finished product supplier, distribution of semi-finished product supplier, transportation form semi-finished product supplier to distribution center, capacity of component supplier, distribution of component supplier, transportation form component supplier to distribution center, distribution center, distribution of distribution center, transportation form distribution center to channel, channel, and so on. The simulation model is illustrated in Figure 1.
I: Customer orders. Orders in each channel are designated by lot size with a normal distribution. The average lot size is applied to estimate the total demand. The total demand is applied to estimate the customer orders. The average is \( \sum \sum \bar{D}_{m} \) and the standard deviation is \( \sigma_{c} \cdot \bar{C} \).

II: Capacity of semi-finished product supplier. The capacity of semi-finished product supplier is calculated by \( \sum \sum C_{f} \).

III: Distribution of semi-finished product supplier. The material-flows of semi-finished products between semi-finished product suppliers and distribution centers are controlled in this section.

IV: Transportation from semi-finished product supplier to distribution center. The supply lead time of semi-finished product from supplier \( f \) to distribution center \( w \) is viewed as constant, \( LT_{fw} \).

V: Capacity of component supplier. The capacity of semi-finished product supplier is calculated by \( \sum \sum C_{n} \).

VI: Distribution of component supplier. The material-flows of components between component suppliers and distribution centers are controlled in this section.

VII: Transportation form component supplier to distribution center. The supply lead time of component from supplier \( n \) to distribution center \( w \) is viewed as constant, \( LT_{nw} \).

VIII: Distribution center. The cycle time of assembly is viewed as constant, \( LT_{p} \). The capacity of distribution center is calculated by \( \sum \sum C_{w} \).

IX: Distribution of distribution center. The material-flows of final products between distribution centers and channels are controlled in this section.

X: Transportation from distribution center to channel. The supply lead time of final product from distribution center \( w \) to channel \( c \) is viewed as constant, \( LT_{wc} \).

XI: Channel.

The results obtained from the decision model, which is solved by Lingo 8.0, are collected and form the initial inputs of the simulation model. This shortens the simulation time. The output of each section obtained for the simulation model, is illustrated in Figure 2 and explained in detail below.

V. APPLICATION CASE

The case company is a global electrical and electronics manufacturing enterprise that assembles and distributes three kinds of final products (P1, P2 and P3) to channels in Europe, America, China and Japan (C1, C2, C3 and C4). All final products are manufactured by distribution centers in America and Europe (DC+BE1 and DC+BE3). The European distribution center (DC+BE3) serves all channels while the American distribution center (DC+BE1) serves the channels in America (C2) and Japan (C4). The case has semi-finished product suppliers in China (F1), America (F2) and Taiwan (F3). It also has
component suppliers in China (N1), Thailand (N2) and Mexico (N3). In terms of operations, the semi-finished products are provided by the supplier in Taiwan (F3) and components are provided by the supplier in Thailand (N2). Figure 3 presents the logistics map of the case company.

![Fig. 3. Global supply network after FTZ application](image)

VI. CONCLUSIONS AND FURTHER RESEARCH

We proposed a MILP for the economic evaluation of air-cargo FTZs. We also consider a dynamic environment and develop a simulation model. The application case demonstrates the feasibility of these two models. The results show changes in the global supply network after consideration of air-cargo FTZ application. It also allows the enterprise to take the advantages of operational efficiency and financial benefits. These models can assist senior managers with decisions about production and distribution allocation, purchase of raw materials and network configuration. In fact, there are several different scenarios for FTZ application and require specific evaluation models. This can be a direction for future research.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of the Council of Economic Planning and Development, Taiwan, for the research project “Strategic Business Model of the Taoyuan Free Trade Zone: Perspective of Global Supply Chains (CEPD 95061308)”. We would also like to thank the Far Glory FTZ Air Cargo Park for the research support.

REFERENCES