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# SELECTING THE LOCATION OF DISTRIBUTION CENTRE IN LOGISTICS OPERATIONS: A CONCEPTUAL FRAMEWORK AND CASE STUDY

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## ABSTRACT

This paper presents the outcomes of a study of the choice of location for distribution centres in logistics operations. A conceptual framework of location selection for distribution centre is worked out through three main stages. At the first stage, a general geographical area for distribution centre is identified based on the Centre of Gravity principle, taking into consideration socio-economic factors. The second stage of the selection process involves the identification of alternative locations for the distribution centre and the airports and seaports to be used for inbound and outbound cargo flows within the defined general geographical area. The third stage focuses on specific site selection among the identified alternative locations for the distribution centre based on the quantitative approach. This involves a mathematical model which aims to optimise either the total distribution cost or the integration of total distance transport with given relevant volumes of cargo. In order to illustrate the conceptual framework, a case study of a logistics service provider will be provided. Data from the case study proved that the conceptual framework for selection is valid and can be of value to logistics companies in their operations and management.

**Key words:** *logistics, selection, location, distribution centre*

## 1. INTRODUCTION

During the last few decades, the term logistics has been studied with the increasing recognition about its importance to enterprises, organisations as well as national economy. For example, a recent study carried out by Michigan State University in the USA showed that logistics alone represented between 10-15% GDP of most major North American, European and Asian/Pacific economies (Rushton, Oxley & Croucher 2000). Part of the logistics chain is physical distribution, which describes a wide range of activities taking place after the production of goods and before they reach customers or end users. These activities include materials handling, storage and warehousing, packaging and unitisation, transportation from plants to depots/distribution centres and later to customers/final users. In fact, what physical distribution is aiming at is to 'bridge the gap between the producer and consumer' (Benson and Whitehead 1985). If the task of marketing is to create customers' demand, then the objective of physical distribution is to satisfy them. Most of these activities take place in

warehouses/distribution centres, and therefore a rationalisation of them in terms of not only quantity, size, level of automation, equipment and handling techniques used but also their locations will affect the customers' satisfaction.

Cargo consolidation and distribution services for customers, both for inbound and outbound operations, seaborne and airborne freights, are thus one of key scopes of services of the logistics service providers. During the process of strategic planning in performing these operations, as mentioned earlier, one of the fundamental issues for these logistics companies is the selection of the location for distribution centres. This includes choosing the location for these facilities that provide the lowest costs and greatest efficiency while meeting operational and strategic needs. In this respect, an appropriate location for distribution centre could perform a good linkage role between upstream suppliers and downstream customers in the supply chain. Moreover, the advantage of an optimal location for distribution centre is not only to reduce the transportation costs, but also to improve business performance, increase competitiveness and profitability.

The fundamental objective of this paper is thus to discuss the conceptual framework for selecting the location for distribution centre in logistics operations, in the context that gateway seaports and airports for seaborne and airborne cargo flows should also be integrated into the selection process. The paper is organised in four sections. First, a literature review is provided covering both location decisions for manufacturing facilities and retailer facility network, from both quantitative and qualitative approaches. This is followed by the conceptual framework which comprises the three-stage hierarchy of selection. A case study is provided to illustrate the discussion. Finally, concluding comments and future research directions are outlined.

## **2. LITERATURE REVIEW**

A location issue is defined as a 'spatial resource allocation problem', in that one or more service facilities, or 'servers', serve a spatially distributed set of demands, or 'customers' (Brandeau and Chiu 1989). This issue has long been receiving attention from both academicians and practitioners. From a holistic perspective, it can be generally classified into two most popular categories of location research issues, namely, locating the manufacturing facilities (such as plants, warehouses etc) and distribution centres in a retailer facility

network. The research approaches in solving these issues can also be categorised into two streams of cost-based and quantitative variable models and models that consider key qualitative variables in the location decision. The following section will outline the main directions of these research studies.

### **Locating the manufacturing facilities**

The research literature on manufacturing facilities location issue is substantial. As far as the cost-based models of location selection are concerned, various research projects have been done in this respect. One of the objectives of cost-based location problems is the minimisation of discounted costs associated with the plant location or expansion, for instance, costs of expansion, maintenance and inventory. Models working on this type are suggested in the studies of Khumawala (1972), Erlenkotter (1974, 1981), Geoffrion and Graves (1974), Van Roy and Erlenkotter (1982). Louveaux and Peeters (1992) study how the uncapacitated facility location problem is transformed into a two-stage stochastic program with recourse when uncertainty on demand, selling prices, production and transportation costs are introduced. Revelle and Laporte (1996) use various mathematical models to solve the plant location problems with different categories of costs (such as opening and expansion costs) and other objectives like return on investment, and in the contexts of multiple products and machines. The issue of plant location and expansion decisions was also discussed in other research models of Aikens (1985), Eppen *et al.* (1989), Fong and Srinivasan (1981), Francis *et al.* (1983), Krarup and Pruzan (1983), Murphy and Weiss (1990), Siha and Das (1996) among other scholars.

While the literature on locating manufacturing facilities based on costs and quantitative variables models is extensive, it possesses a major shortcoming – that of focussing only on the cost and quantitative variables aspects of the locational decision. Other researchers have attempted to investigate other qualitative variables in location research of manufacturing facilities. Scott (1989) suggests a checklist of qualitative factors involving site selection, including location of major markets, location of materials and/or services and the availability of labour and suitable transportation links. He also argued that site selection involves gathering and analysing many different pieces of information, and relating them to the enterprise's overall corporate goals and objectives. In his studies, Schmenner (1979, 1983) argues that if a location strategy focused mainly on financial assessment it could often result

in a poor solution involving recommended relocation and opening of new branches over on-site expansion. Miller (1993) argues that qualitative factors, for instance, the availability and quality of labour among alternative locations, the firm's perception of the interest level that government shows in having the company locate in the community, the strength of a potential location's local transportation infrastructure as well as the availability of a wide array of alternative long-haul transportation services to and from a location, and the relative cost of living in a potential location, play a critical role in most facility location decisions and may often outweigh quantitative modelling results in an organisation's ultimate location decision.

MacCormack *et al.* (1994) argue that manufacturing site location has received limited exposure in strategic planning literature, since approaches often emphasise quantitative data such as transport costs, exchange rates, taxes, labour rates and other cost based variables while location decisions based primary on costs underestimate the importance of qualitative factors that are more likely to provide long-term advantages. For example, plant location decisions that ignore skill levels of the local workforce could significantly affect the ability of the firm to implement new process technologies, or limit the effectiveness of total quality management programs. It was suggested that global corporations of the future will develop a manufacturing network of decentralised plants whose locations will be based more on regional infrastructure and local skills than on purely cost-based factors. Bhatnagar *et al.* (2003) examine the relative importance of plant location factors in a cross national comparison between Singapore and Malaysia. The study's findings revealed that three factors of infrastructure, suppliers and consumer/market have a significant impact on the ultimate choice of plant location.

### **Locating the Distribution Centre in a retailer facility network**

The research literature regarding location decisions of distribution centres (DCs) in a retailer facility network are quite limited in comparison with ones of manufacturing facilities locational decisions. Rosenfield (1987) applies a specialised mathematical approach to the issue of locating distribution centres in a retailing network by considering a three-stage discussion of a retailer location problem: formulation and solution, execution and decision-making. Gooley (1998a, 1998b, 1998c) discusses the qualitative factors which affect the decisions of locating facilities in manufacturing or logistics operations from the generic perspective as well as in Asia and Latin America. He argues that in choosing the right

location for manufacturing or distribution facilities, it is essential to consider many factors which can vary considerably from company to company depending on each firm's strategic plans, products, and markets. However, some issues are important to all companies regardless of what they make or to whom they sell their products, especially the following four factors: physical infrastructure, proximity to suppliers and customers, political and tax considerations, and international trade conditions. McKnight (1998) argues that selecting the location for warehouses or distribution centres should begin with development of a long-range strategic plan to determine the status of current operations, including the warehouse strategic master plan (WSMP) and a logistics strategic master plan (LSMP). The LSMP, which contains eight steps, would define the general geographical location of the new facility. Once this general area for the facility has been determined, the companies would be able to select the right site through the process of community selection which involves several factors such as attitudes of the local government, level of community progress, availability of support services and economic incentives offered such as local tax on inventories.

Jedd (2001) reports the views towards site selection for distribution centres of various site selection experts in the industry. John Porter, senior vice president with CB Richard Ellis, an Atlanta-based real estate consultancy with specialisation in the logistics industry, argued that the obvious selection criteria for distribution centres location are transportation, operations and technology. However, one also needs to consider other details such as the real estate itself, tax considerations, labour issues, available incentives, market dynamics of a specific region or global port and the financial engineering. Dick Powers, president of Manassas also suggested that where the distribution centres should be put would depend on where the customers and stores of firms are located, indicating the fact that customers and suppliers proximity are important factors in site selection as mentioned previously by other authors. Renshaw (2002) argues that the primary drivers of the site selection process are operating costs and customer service objectives, and to minimise transportation is critical since this cost category, both inbound and outbound, often comprises up to 50%-60% of a company's total distribution costs. Similarly to Renshaw (2002), the report by Gentry (2003) also revealed that transportation costs is the most important factor, followed by the right labour market and other factors such as proximity to customers, convenient access in choosing the right site for distribution centres in retailer facility network.

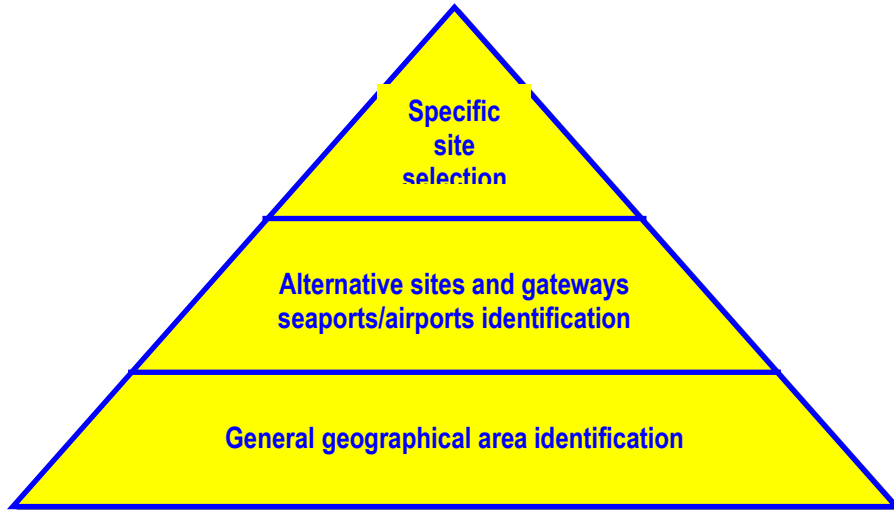
Another approach to location decisions of distribution centre is Quality Function Deployment (QFD) applied by Chuang (2002). The distribution's location model is constructed from the perspective of a firm's customers, suppliers, and employees. The QFD procedure begins by collecting possible candidate location requirements, followed by conducting the first stage of a sampling survey to identify the secondary location requirements. These were then sorted into major categories of location requirements. After that, the location evaluating criteria would be derived from the location requirements and a central relationship matrix is established to display the degree of relationship between each pair of location requirements and location evaluating criterion. The evaluating criteria would comprise both quantitative and qualitative factors. It was found from this research that the initial and operating costs and the transportation conditions location criteria were more important than others, which implied that the costs and transportation issues still played very important roles in the distribution's location decision.

While the literature on locational decisions is rich with various models some important gaps can be pointed out, especially in the context of globalisation and integrated logistics approach. First, in spite of the fact that there are various optimisation models related to locational decisions, they are basically focused on quantitative factors with costs as the primary concern. However, the selection of a facility location is a multi-objective problem which cannot be addressed purely from either quantitative or qualitative approach. Secondly, there has been limited attempt to address the locational decision model for distribution centre of logistics service providers, especially in connection with the seaport and airport to be used as the gateways in an international logistics network. In this paper, we seek to address these gaps by presenting a holistic conceptual framework of selecting location for distribution centres in logistics operations. We believe that suggestions from this research can make an important contribution to the literature of location decisions in general and of distribution centre's location in logistics operations in particular.

### **3. THE CONCEPTUAL FRAMEWORK**

In this section, the conceptual framework of site selection for the distribution centres, including for seaports and airports, combining both qualitative and quantitative perspectives and comprising a three-stage hierarchy of selection is discussed. Figure 1 illustrates this.

Figure 1: The three-stage hierarchy of site selection



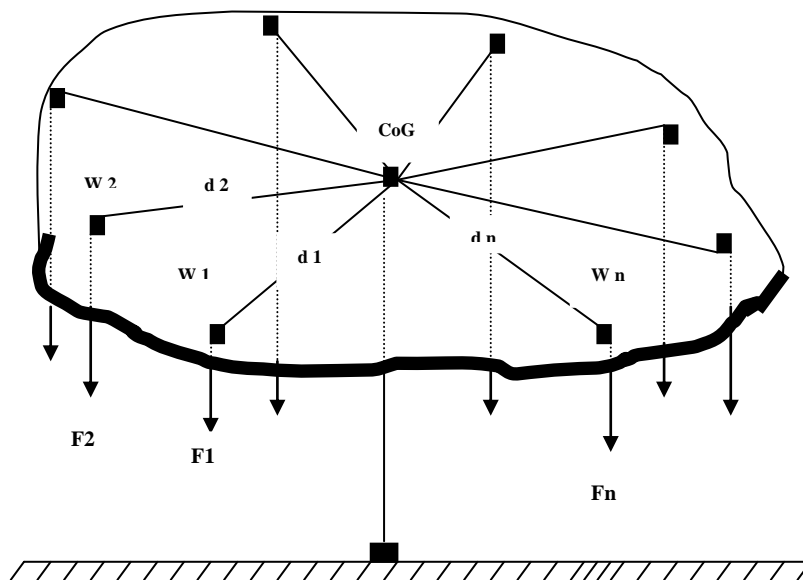
Source: The Authors

### 3.1. General geographical area – Centre of Gravity (CoG) principle

#### 3. 1. 1. Centre of gravity (CoG) in physics

In physics, the Centre of Gravity (CoG) of a collection of masses is defined as an imaginary point where all the weights of the object can be considered to be concentrated through that point, and hence, there is no momentum arm to make the object unbalanced. Figure 2 represents the idea of this concept.

Figure 2: Centre of Gravity model



Source: Adapted from Burley et al. (2001)



Suppose that an object carries a collection of weights  $W_1, W_2, \dots, W_n$  and the relevant distances from these to an imaginary CoG are  $d_1, d_2 \dots d_n$ . The forces exerting on this object at various locations are calculated based on Newton's law of gravity as follows:

$$F_1 = W_1 \times d_1, \quad F_2 = W_2 \times d_2, \quad \dots \quad F_{n-1} = W_{n-1} \times d_{n-1}, \quad F_n = W_n \times d_n$$

In order to make the object balanced, the CoG should be placed where the following equation is satisfied:

$$F_1 + F_2 + \dots + F_{n-1} + F_n = 0 \quad \text{or} \quad \sum_{i=1}^n (F_i \times d_i) = 0 \quad (1)$$

The equation (1) indicates that all weights of the object have a mutual relationship, and any changes in one direction of a weight should be reflected in the other direction of the other weight so that the balance status is maintained. Furthermore, as the force exerting from a weight depends on weight and distance to CoG, an increase in weight will be reflected by the decrease in that distance so that the object is still kept balanced. The CoG in this case will, therefore, shift to the new area which is near the heavier weights. Further realisation can be mentioned here, as a diagnosis from equation (1), is that in order to have the balance status quo the CoG will tend to locate in the area near major weights to offset other lighter ones in further distances.

### 3. 1. 2. Shaping the general geographical area of the distribution centre

From the general geographical level, the population concentration points are analysed as 'weights' because cargoes are transported over relevant distances from the distribution centre to these points and vice versa. In order to optimise and balance the transport function, the CoG principle should be preserved. The general geographical area of distribution centre should, therefore, be the area where the 'weights', meaning population concentration points, are 'heavier' or more concentrated. Other factors like population growth estimation in a certain period of planning should also be considered to ensure the same development arrangement in future and the CoG is maintained without shifting.

In shaping the general geographical area for distribution centre, it is also necessary to take into consideration other additional factors which reflect the socio-economic conditions of a region such as GDP growth, transport and telecommunication infrastructures, unemployment ratio, and quality of labour workforce. This approach is useful when there are several potential regions having more or less similar 'weights' in terms of population concentration in the same general geographical area.

## **3.2. Alternative locations of DC and associated gateway airports/seaports**

### **3.2.1. Identification of alternative locations of distribution centre**

In order to identify the alternative sites of distribution centre, a qualitative approach should be applied at this stage. As indicated from the literature review, the following eight factors have been frequently used as the criteria for evaluation:

- (1) Proximity to customers' bases
- (2) Availability and quality of labour workforce
- (3) Availability of utilities
- (4) Local tax environment, especially on inventories
- (5) Inland transport infrastructures
- (6) Expansion capability
- (7) Customs administration and regulations
- (8) Local standards of living

Based on the general geographical area of the distribution centre shaped from the first stage, the logistics companies will be able to pinpoint some possible sites within this area as alternative locations for the distribution centre. In order to assess the appropriateness of each site, the Weighed Marking Method is utilised. Each possible location is allocated with the point of evaluation related to each evaluating criterion, ranging from 1 to 10 with 5 as the average. Each evaluating criterion mentioned above would also be allocated with its weighting factor (percentage), indicating its share of importance in the total evaluating criteria. The summation of these weighting factors equals 100%. The composite point of each possible location is calculated as follows:

$$\text{Composite point} = \sum_1^8 (\text{point related to each criterion} \times \text{weighting factor of that criterion})$$

Suppose that there will be  $n$  sites within the general geographical area identified from the first stage as possible locations for the distribution centre, it is suggested that those sites whose composite point is greater than or equivalent to 5 (the average point) would be selected as the alternative locations. Table 1 illustrates the Weighed Marking Method just mentioned.

Table 1: The matrix of possible sites for distribution centre's location

Possible sites	Criterion 1		Criterion 2		Criterion 3		Criterion 4		Criterion 5		Criterion 6		Criterion 7		Criterion 8		Composite point (PPT)
	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	$\Sigma$
SITE 1																	$\Sigma$
SITE 2																	$\Sigma$
SITE 3																	$\Sigma$
....																	$\Sigma$
SITE $n$																	$\Sigma$

*Source: The Authors*

Although this qualitative approach can be seen as relatively subjective and the outcome may depend on the preferences of the Location Selection Team, it is important to note that the objective of the Weighed Marking Method described above is not to select the specific location for the distribution centre, but rather several alternative locations. In the third stage, these alternative locations, together with alternative gateway seaports and airports, will be put into a mathematical model and the specific site for distribution centre's location is identified based on the result from this model's simulation.

Having described the alternative sites for distribution centre's location, the next step is the identification of alternative seaports and airports as gateways for inbound and outbound, seaborne and airborne cargo flows.

### **3.2.2. Identification of alternative gateway seaports and airports**

The process of identifying alternative gateway seaports and airports for cargo flows in the integrated logistics network should begin with identifying available airports and seaports in the area which are capable of handling international freight. For this, several factors have to be considered. There have been some studies about shippers' choice of seaports. While the literature on airport selection criteria is more limited, they should be more or less similar to the ones for seaports as they have the same nature as nodes in the transport network. The

issue of port selection decision was studied by, inter alia, Murphy, Dalenberg and Daley (1989, 1991, 1992). It was found from these studies that considerations regarding port facilities, services and performance do have impacts on the choice of port. The aggregate results from these studies indicated that the most important attributes of port evaluation are equipment availability, loss and damage record and convenient pick-up and delivery time. Moreover, it was also revealed that equipment availability, loss and damage performance, large shipment capabilities and convenient pick-up and delivery time are important factors in choosing a port. Tongzon (2002) enriched the discussion on port selection decision with his study on the key determinants of port choice. Factors affecting the port choice decision identified in this study are named as frequency of ship visits, port efficiency, adequate infrastructure, location, competitive port charges, quick response to port users' needs and port's reputation for cargo damage. Results from the study indicated that port efficiency is the most important factor in port choice and performance. It is therefore suggested that the following frequently cited factors, as indicated in the literature, be used as evaluating criteria in identifying the airports/seaports as possible gateways:

- Equipment availability
- Loss and damage record
- Convenient and reliability of pick-up and delivery
- Frequency of ship/airplane visits
- Efficiency of seaports/airports
- Strategic location
- Competitive fees and charges
- Quick response to customers' needs and requirements

In order to identify the alternative gateway seaports and airports for cargo flows to and from the distribution centre, it is also recommended that the Weighed Marking Method mentioned in the previous section be utilised. The seaports and airports would be selected as alternative gateways for seaborne and airborne cargo flows if their respective composite point is greater than or equivalent to 5, indicating the average level. Again, this method is somewhat subjective, yet the purpose of this section is not to select a specific seaport and airport but rather identify a series of several alternative gateway seaports and airports for the inclusion in the mathematical model in the third stage that follows.

Table 2: The matrix of possible gateway sea/airports

Possible sites	Criterion 1		Criterion 2		Criterion 3		Criterion 4		Criterion 5		Criterion 6		Criterion 7		Criterion 8		Composite point (PPT)
	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	PPT	%	Σ
SP/AP 1																	Σ
SP/AP 2																	Σ
SP/AP 3																	Σ
....																	Σ
SP/AP n																	Σ

Source: The Authors

Note: SP= Seaport, AP=Airport

### 3.3. Specific site selection

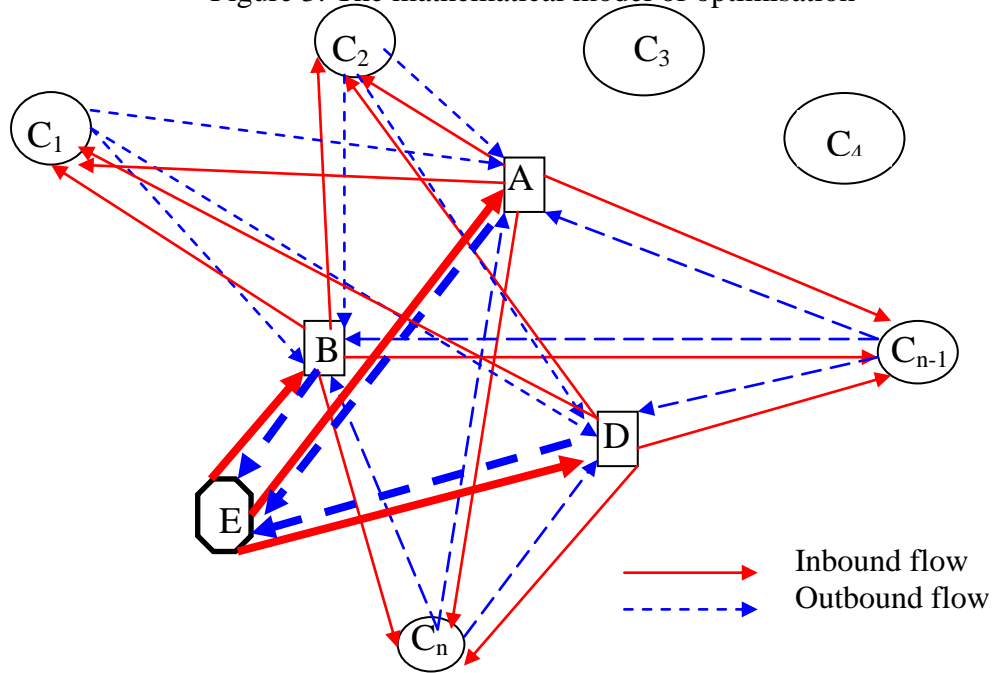
Once the alternative sites for the distribution centre's location and alternative gateway seaports and airports for seaborne and airborne, inbound and outbound cargo flows have been identified, it now comes to the third stage of the conceptual framework of selecting the specific site for the distribution centre's location. One of the main objectives in transport logistics is to optimise the integration of distances and given volumes of cargoes to be transported. The distribution centre chosen should therefore be placed where the integration of volumes transported and distances involved is the minimum. Also, the *total distribution cost* concept is one of the most important issues in logistics, especially when assessing the whole physical distribution process for the sake of meeting customers' requirements. As a consequence, this should also be considered as the criterion in choosing location for the distribution centre. In other words, taking this principle into account, the distribution centre should be placed where the total distribution cost is least. Basically, the total distribution cost ( $\Sigma C$ ) includes warehousing cost (W), inventory cost (I), distribution centres operating cost (O) and transportation costs (transport from airports or seaports to depots – trunking cost and transport from depots to customers – local delivery cost). The result is:

$$\Sigma C = W + I + O + T \quad (2)$$

Since the transportation cost often comprises up to 50%-60% of a company's total distribution cost (Renshaw 2002), it is critical that this cost is kept as low as possible. In this paper, we assume that warehousing, inventory and depot operating costs are more or less similar at all alternative sites of distribution centre's location. As a consequence, the task of

this study now is to optimise either the integration of distances with given volumes of cargo to be transported or the transportation cost in relation to respective volume of cargo. Figure 3 illustrates the model with a single gateway airport or seaport.

Figure 3: The mathematical model of optimisation



Source: The Authors

In that:  $C_1, C_2, C_3, \dots, C_n$  are customers' locations 1, 2, 3, ... and  $n$  respectively; A, B, and D are alternative sites of the distribution centre; E is the alternative airport or seaport. Some basic indications are as follows:

### Distances

$D_{EA}, D_{EB}, D_{ED}$  are trunking distances from alternative airport or seaport E to alternative sites A, B and D.

$D_{AC1}, D_{AC2}, D_{AC3}, \dots, D_{ACn}$  are local delivery distances from alternative site A to customers' locations  $C_1, C_2, C_3, \dots, C_n$  respectively.

Similar inferences can be drawn with  $D_{BC1}, D_{BC2}, D_{BC3}, \dots, D_{BCn}$  with alternative site B and  $D_{DC1}, D_{DC2}, D_{DC3}, \dots, D_{DCn}$  with alternative site D.

### Volume

$V_{IAC1}, V_{IAC2}, V_{IAC3}, \dots, V_{IACn}$  are volumes of inbound cargo from site A to customers' locations  $C_1, C_2, C_3, \dots, C_n$  respectively.

Similar inferences can be drawn with  $V_{IBC1}, V_{IBC2}, V_{IBC3}, \dots, V_{IBCn}$  and  $V_{IDC1}, V_{IDC2}, V_{IDC3}, \dots, V_{IDCn}$

$V_{OAC1}, V_{OAC2}, V_{OAC3}, \dots, V_{OACn}$  are volumes of outbound cargo from customers' locations  $C_1, C_2, C_3, \dots, C_n$  respectively to site A.

Similar inferences can be drawn with  $V_{OBC1}, V_{OBC2}, V_{OBC3}, \dots, V_{OBCn}$  and  $V_{ODC1}, V_{ODC2}, V_{ODC3}, \dots, V_{ODCn}$ .

### **Transport cost**

$P_{IAC1}, P_{IAC2}, P_{IAC3}, \dots, P_{IACn}$  are transport costs for inbound cargo from alternative seaport or airport E through alternative site A to customers' locations  $C_1, C_2, C_3, \dots, C_n$

Similar inferences can be drawn with  $P_{IBC1}, P_{IBC2}, P_{IBC3}, \dots, P_{IBCn}$  and  $P_{IDC1}, P_{IDC2}, P_{IDC3}, \dots, P_{IDCn}$ .

$P_{OAC1}, P_{OAC2}, P_{OAC3}, \dots, P_{OACn}$  are transport costs for outbound cargo from customers' locations  $C_1, C_2, C_3, \dots, C_n$  respectively through site A to seaport or airport E.

Similar inferences can be drawn with  $P_{OBC1}, P_{OBC2}, P_{OBC3}, \dots, P_{OBCn}$  and  $P_{ODC1}, P_{ODC2}, P_{ODC3}, \dots, P_{ODCn}$ .

### **Integration of total distances transport with given relevant volumes**

$\sum VD_A$  is the integration of total distances transport with given relevant volumes from/to seaport or airport E through site A.

Similar inferences can be drawn with  $\sum VD_B$  and  $\sum VD_D$ .

### **Total transport cost over relevant distance with given volume**

$\sum C_A$  is the total transport cost for inbound and outbound cargo volume transported over relevant distances from/to seaport or airport E through site A.

Similar inferences can be drawn with  $\sum C_B$  and  $\sum C_D$

We have the results:

$$(3) \quad \begin{aligned} \sum VD_A &= D_{EA} \times \sum_{i=1}^n (V_{IACi} + V_{OACi}) + \sum_{i=1}^n \left[ (V_{IACi} + V_{OACi}) \times D_{ACi} \right] \\ \sum VD_B &= D_{EB} \times \sum_{i=1}^n (V_{IBCi} + V_{OBCi}) + \sum_{i=1}^n \left[ (V_{IBCi} + V_{OBCi}) \times D_{BCi} \right] \\ \sum VD_D &= D_{ED} \times \sum_{i=1}^n (V_{IDCi} + V_{ODCi}) + \sum_{i=1}^n \left[ (V_{IDCi} + V_{ODCi}) \times D_{DCi} \right] \end{aligned}$$

$$(4) \quad \begin{aligned} \sum C_A &= \sum_{i=1}^n (V_{IACi} \times P_{IACi}) + \sum_{i=1}^n (V_{OACi} \times P_{OACi}) \\ \sum C_B &= \sum_{i=1}^n (V_{IBCi} \times P_{IBCi}) + \sum_{i=1}^n (V_{OBCi} \times P_{OBCi}) \\ \sum C_D &= \sum_{i=1}^n (V_{IDCi} \times P_{IDCi}) + \sum_{i=1}^n (V_{ODCi} \times P_{ODCi}) \end{aligned}$$

The site for distribution centre's location to be chosen (A, B or D) will thus satisfy the following:

$$\begin{array}{l} \left( \begin{array}{c} \Sigma VD_A \\ \Sigma VD_B \\ \Sigma VD_D \end{array} \right) \longrightarrow \text{MIN} \\ \text{Or} \\ \left( \begin{array}{c} \Sigma C_A \\ \Sigma C_B \\ \Sigma C_D \end{array} \right) \longrightarrow \text{MIN} \end{array}$$

The above mathematical model is designed to calculate the integration of total distance transport with given relevant volumes of cargo (VD) or total transport cost ( $\Sigma C$ ) associated with a specific site in the simple case when there is a single seaport or airport to be used. In practice, there may be several alternative seaports and airports to be used as the gateways for seaborne and airborne cargo flows. There are several scenarios:

- (1) The distribution centre may be used for seaborne or airborne cargo flows: in this scenario, the VD and  $\Sigma C$  associated with each alternative site is calculated in table 3.

Table 3: The matrix of site selection when there are several seaports

Seaports \ Sites	Site A	Site B	.....	Site N
SP/AP 1	$VD_{1A}/\Sigma C_{1A}$	$VD_{1B}/\Sigma C_{1B}$	.....	$VD_{1N}/\Sigma C_{1N}$
SP/AP 2	$VD_{2A}/\Sigma C_{2A}$	$VD_{2B}/\Sigma C_{2B}$	.....	$VD_{2N}/\Sigma C_{2N}$
.....	.....	.....	.....	.....
SP/AP M	$VD_{MA}/\Sigma C_{MA}$	$VD_{MB}/\Sigma C_{MB}$	.....	$VD_{MN}/\Sigma C_{MN}$

Source: The Authors

Note: SP= Seaport, AP=Airport

- (2) The distribution centre will be used for both seaborne and airborne cargo flows: in this scenario, the integration of total distance transport with given relevant volumes of cargo (VD) or total transport cost ( $\Sigma C$ ) associated with a specific site is calculated as the summation of respective VD or  $\Sigma C$  associated with seaborne and airborne cargo flows. For instance:



$$VD_A = VD_A \text{ (of seaborne cargo flows)} + VD_A \text{ (of airborne cargo flows)}$$

$$\sum C_A = \sum C_A \text{ (of seaborne cargo flows)} + \sum C_A \text{ (of airborne cargo flows)}$$

Suppose that there are M number of alternative seaports and P number of airports to be used as gateways for seaborne and airborne cargo flows to/from the distribution centre, it can be seen that there will be (M x P) number of integrated solutions of seaports and airports used. In this case, the (VD) and ( $\sum C$ ) associated with a specific site for distribution centre's location will be calculated in (M x P) solutions. This is illustrated in table 4.

Table 4: The matrix of site selection when there are several seaports and airports

<b>SP – AP</b>	<b>Sites</b>	<b>Site A</b>	<b>Site B</b>	<b>.....</b>	<b>Site N</b>
<b>Seaport 1/Airport 1</b>		$VD_{11A}/\sum C_{11A}$	$VD_{11B}/\sum C_{11B}$	.....	$VD_{11N}/\sum C_{11N}$
<b>Seaport 1/Airport 2</b>		$VD_{12A}/\sum C_{2A}$	$VD_{12B}/\sum C_{12B}$	.....	$VD_{12N}/\sum C_{12N}$
<b>.....</b>		.....	.....	.....	.....
<b>Seaport 2/Airport 1</b>		$VD_{21A}/\sum C_{21A}$	$VD_{21B}/\sum C_{21B}$	.....	$VD_{21N}/\sum C_{21N}$
<b>Seaport 2/Airport 2</b>		$VD_{22A}/\sum C_{22A}$	$VD_{22B}/\sum C_{22B}$	.....	$VD_{22N}/\sum C_{22N}$
<b>.....</b>		.....	.....	.....	.....
<b>Seaport M/Airport P</b>		$VD_{MPA}/\sum C_{MPA}$	$VD_{MPB}/\sum C_{MPB}$	.....	$VD_{MPN}/\sum C_{MPN}$

*Source: The Authors*

In each scenario above, a specific alternative site will be selected as the location for the distribution centre if its associated (VD) or ( $\sum C$ ) is the minimum in either the matrix table (3) or (4) above respectively.

#### 4. CASE STUDY

Through the last few decades, the European market has expanded not only to the East but also to the North and therefore placed Nordic countries such as Sweden and Denmark in the primary geographical position for international companies planning their current and future regional distribution set-up for the whole region. In fact, the introduction and development of the European Union (EU) into a unified market has created a regional-based market structure where the Northern part of the EU is always seen as one region (Nordic region) in not only economic but also cultural and social perspectives. In turn, this regionalisation of markets has created a demand for a centralised distribution system in each of these regions. The Northern region of Europe, or the Nordic region, is one of the most interesting and quickest developing regions in Europe.

One of the main tendencies of logistics and distribution globally today is the regional consolidation of distribution centres. Schenker International is a global freight forwarding company, sending freight by air and sea as well as related services. The range of its services includes customised logistics projects that meet special demands of exchanging goods on a global scale. It is the freight forwarding arm of Schenker AG which comprises European Land Transport, Logistics and Freight Forwarding activities. The company had a number of distribution centres in Denmark, Sweden, Norway and Finland to serve local demand. In 2001, the company considered the trend to regionalise its distribution networks in the Nordic region, by combining all distribution centres into one, for the sake of maximising long-term profit, optimising transport and minimising the total logistics cost with given levels of customer service. The aim was to bring about competitive advantages for the company. The basic question was where to locate such a regional distribution centre.

The three-stage approach was applied. At the first stage, the CoG principle was utilised to shape the general geographical area for the future distribution centre's location. In this stage, the population distribution and population growth of the Nordic region was analysed to identify the arrangement of population 'weights'. This helped to reveal that the Southern Sweden - Copenhagen region is the general geographical area for the future distribution centre's location. When considering other factors such as geographical location, population and labour force, economic indicators (such as GDP, PPP), transport infrastructures for logistics (especially, the impacts of the newly constructed Öresund Fixed Link which connects Sweden and Denmark) and education, research and development, the general geographical area was further narrowed down. The result was that the Öresund region, as the combination from the Skåne region in Southern Sweden and the Greater Copenhagen region, was considered as a good general geographical area for Nordic regional distribution centre.

In the second stage of the selection, the qualitative approach (Weighed Marking Method) as described in the previous parts was applied to identify several alternative sites for the distribution centre's location and alternative seaports and airports to be used as the gateways for seaborne and airborne, inbound and outbound cargo flows of the company. As a result, the following sites, which are located in the Öresund region, were identified as the alternative ones: Göteborg, Stockholm, Malmö, Copenhagen, Jönköping, Borås, Alvesta, Anderstorp, Norrköping, Helsingborg, Kungälv, Nässjö, Motala, Skövde, Kolbäck, Billingsfors,

Halmstad, Svenljunga, Trelleborg, Trollhättan and Linköping. Moreover, the port of Göteborg, Copenhagen-Malmö Port, Landvetter airport (in Göteborg) and Copenhagen airports were also identified as the gateway seaports and airports for cargo flows from and to the Nordic regions. This laid the background for the third stage of the selection process as the mathematical model of optimising the integration of total distance transport with given relevant volumes of cargo was designed using EXCEL software. There were four solutions of alternative using gateway seaports and airports:

- Solution 1: Both sea-freight and airfreight flows going through Göteborg (port of Göteborg and Landvetter airport).
- Solution 2: Both sea-freight and airfreight flows going through Copenhagen (Copenhagen-Malmö Port and Copenhagen airport).
- Solution 3: Sea-freight flows going through Göteborg (port of Göteborg) and airfreight flows going through Copenhagen (Copenhagen airport).
- Solution 4: Sea-freight flows going through Copenhagen (Copenhagen-Malmö Port) and airfreight flows going through Göteborg (Landvetter airport).

The simulation of comparing the integration of total distances transport with relevant given volumes of cargo among alternative gateways was done based on these four solutions used and the formula (3) described earlier. The following extract illustrates:

Supposing that the future regional distribution centre is placed in Malmö, and the choice of seaport used is through Göteborg and the airport used is through Copenhagen (solution 3). Now the integration of total distances transport with relevant volumes (both sea-freight and airfreight) and in both directions of inbound and outbound from the seaport and airport through the gateway in Malmö and then to customer's location in Borås and vice versa should be calculated.

The following data, as provided by the company, was available and used for the calculation:

- Distance from Copenhagen airport to the distribution centre in Malmö is about 20 Km.
- Distance from the port of Göteborg to the distribution centre in Malmö is about 279 Km.
- Inbound airfreight volume to Borås is 182.25 CBM.

- Inbound sea-freight volume to Borås is 3645 CBM.
- Outbound airfreight volume from Borås is 8.4 CBM.
- Outbound sea-freight volume from Borås is 168 CBM.
- Distance from the distribution centre in Malmö to customer's location in Borås is about 288 Km.

The integration was calculated as follows:

$$VD_{Malmö} = \{ (20 \times 182.25) + (279 \times 3645) + (182.25 + 3645) \times 288 \} + \\ + \{ (8.4 + 168) \times 288 + (8.4 \times 20) + (168 \times 279) \} \approx 2,220,691 \text{ (CBM.Km)}$$

Taking into consideration all customers' locations of both sea-freight and airfreight, inbound and outbound flows, the integration for the regional distribution centre placed in Malmö with solution 3 of seaport/airport used was:

$$\Sigma VD_{Malmö} \approx 19,026,702 \text{ CBM.Km}$$

The same principle was applied for calculating the integration of other alternative sites for distribution centre's location and in four solutions of seaport/airport used. Upon completion of calculating the integration of total distances transport with relevant volumes for both sea-freight and airfreight, in both inbound and outbound directions, in all four solutions of airport/seaport used, for all the alternative gateways, the findings of the best three alternative sites in each solution of seaport/airport used are presented in the ranking table 5.

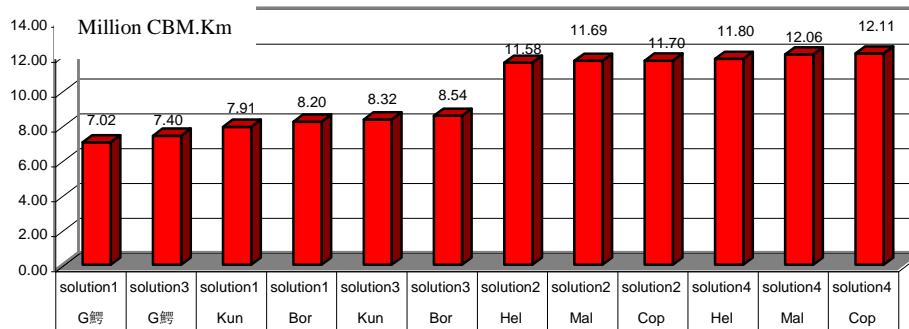
Table 5: Ranking of the best three alternative sites in each solution

SOLUTIONS			ALTERNATIVE SITES		
No.	Seaport	Airport	1	2	3
1	GÖTEBORG	GÖTEBORG	GÖTEBORG	KUNGÄLV	BORÅS
2	COPENHAGEN	COPENHAGEN	HELSINGBORG	MALMÖ	COPENHAGEN
3	GÖTEBORG	COPENHAGEN	GÖTEBORG	KUNGÄLV	BORÅS
4	COPENHAGEN	GÖTEBORG	HELSINGBORG	MALMÖ	COPENHAGEN

It was clear that if either solution 1 or 3 is taken, then Göteborg is the best place for the regional distribution centre for Schenker International; if either solution 2 or 4 is taken then the best location is Helsingborg. In order to have a clearer view of the difference among these best alternative locations, the quantified indicator is needed. In terms of value of the

integration of total distance transport with relevant volumes (CBM.Km), findings in table 5 were presented in figure 4.

Figure 4: Distribution of best alternative sites under various solutions



*Source: The Authors*

This figure shows that G 罇teborg and its surrounding cities (Kung 罇lv and Bor 罇s) are the best places for the regional distribution centre in that sea-freight flows go through the port of G 罇teborg and airfreight flows go through either Copenhagen or G 罇teborg-Landvetter airports. Helsingborg, Malm 罇 and Copenhagen would be the best places when both the port and airport of Copenhagen are used, yet this solution returns higher CBM.Km than the previous solutions.

## 5. CONCLUSION

This paper discusses the conceptual framework for site selection of distribution centre's location in logistics operations of logistics service providers, using the example of a Nordic case study. The study provides a systematic approach and combines both quantitative and qualitative perspectives. Further research is needed to explore, for instance, more comprehensive modification of the mathematical model to include detailed modelling of other cost factors beyond transport cost, in order to make it more complete.

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