INTEGRATING ECOLOGICAL ASPECTS INTO THE SIMULATION AND PLANNING WAREHOUSE LOCATIONS

Barbara WEIGEL
Dipl.Wirtsch.-Ing.
Locom Consulting GmbH
Karlsruhe - Germany

INTRODUCTION

In the past, when determining the best number of warehouses and their locations, procurement and distribution logistics mainly evaluated transportation, warehouse, and inventory costs. These types of costs are typically degressive: Rationalization and automation decrease warehouse costs per ton for large warehouses, for example. Transport costs per ton decrease as shipment quantities and distances increase. When turnover and the related number of customers increases, the stock of a particular warehouse need only be increased by approximately the root of the turnover ("square root law") to secure the same service quality, since the larger number of customers balances fluctuation in sales.

The degression of these types of costs leads to solutions which are more economic, the fewer warehouse locations are needed to maintain logistic services. Higher transportation costs contrast with reduced stock and warehouse costs. The more valuable the wares in stock are, the greater the costs can be minimized by centralization. The development of the European Common Market will strengthen the trend towards centralizing warehouses and distribution systems across national borders. Simplified customs procedures, for example, will make it possible to guarantee delivery times which previously were achieved only by maintaining national warehouses.

This method of evaluating and planning procurement and distribution systems is largely limited to the types of degressive costs mentioned above. Strategic decisions, however, should preferably also reflect additional factors.

In the future the time factor will gain importance when planning logistic systems. Presently overloaded traffic networks, night regulations, and roads where certain types of trucks are prohibited make it difficult to guarantee delivery times. Particularly when wares can be substituted easily, it is hardly possible to maintain a 24-hour delivery service and customer proximity with - for example - only five warehouse locations Europewide.

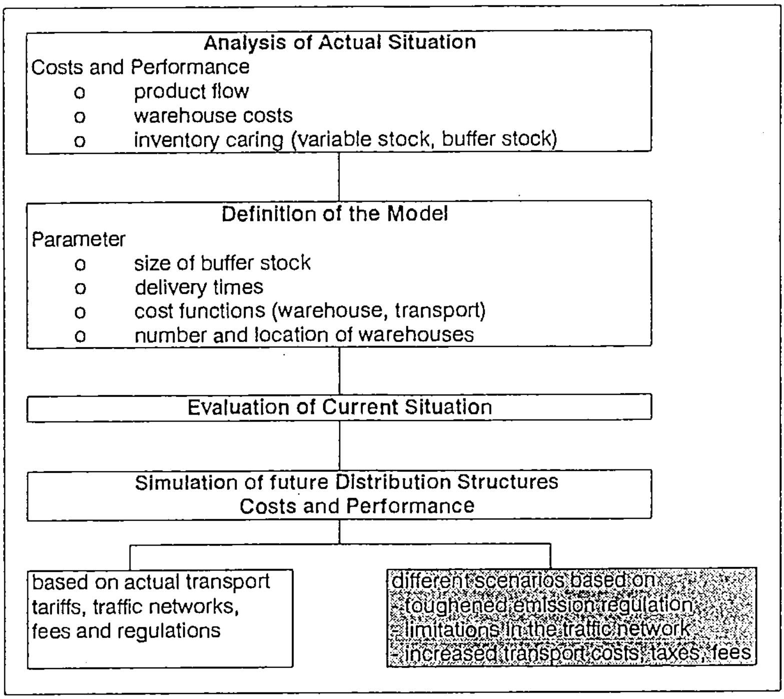
Environmental problems and consequently tougher emission regulations will continue to raise transportation costs in the future. Adding the so-called "external" costs of transportation (air pollution, noise, landscape disfiguration, accidents) to the traditional costs in the form of taxes considerably changes the ratio between stock and warehousee costs on the one hand and transportation costs on the other.

The calculation of environmental burdens, future traffic delvelopments and energy consumption has usually been limited to specific economic sectors or regions, such as estimating the emissions of truck transportation for the Federal Republic of Germany for the year 1990. However, when planning and evaluation various distribution systems, it is wise to consider scenarios at a micro-economic level for future developments in emission and traffic laws: These scenarios are an aid to decision-making, which cover more than traditional costs.

1. PROCEDURE

In order to plan a logistic system for procurement and distribution it is necessary to 1) analyze the current situation, 2) define a model, 3) copy the current situation onto the model, and 4) plan and evaluate various future systems (cf. Graph 1).

Graph 1



Source: Locom Consulting 1991

The parameters of the model include the amount of buffer stock in warehouses, delivery times demanded by the market, and cost functions for warehouse maintenance and transportation. In Germany transportation costs are determined by tariffs, which will need to be modified by empirical data or replaced by vehicle total costs in Europe-wide planning. The cost function for warehousing is generated by the approximation of the customer's data for the current situation. The resulting model simulates the current situation and provides a check on the quality of the model itself.

The simulation of various systems can be made for existing locations, as well as for optimized warehouse locations. For existing locations, customers can be allotted to the warehouse which is optimal in terms of transportation costs, or according to assignment criteria such as nationality, geography, delivery times, etc.

Optimizing warehouse locations is done with a cluster-analytic heuristic method. The initial data are the warehouse location coordinates and the coordinates of the demand locations, the total quantity per demand location, the number of transports (dependent on demanded delivery times), the quantity of individual wares groups and the locations of production sites. In the first phase an initial solution is set up, which determines demand concentrations as candidates for possible locations. The customers are assigned to location either with the Euclidean distance function or with a distance function which approximates transport costs. Through gradual improvement phases the location is determined by partial enumeration of the demand locations and consideration of the production locations.

Ecological factors can be accounted for when defining the distance function: The time factor, for example, can be included with the Euclidian distance, the actual road distance or the degressive transport costs. Another method is to include time and ecology in sensitivity studies:

- How much turnover is made in a zone of 500 to 600 km around the warehouse location and can no longer be serviced in 24 hours if the traffic situation becomes worse?
- How much more does a distribution system cost if external traffic costs accounted for?

2. DATA BASE

2.1 Structural Data and Flow Data

The European data base includes approximately 5000 cities and the attributes coordinates, number of inhabitants, purchasing power and the distances between these cities in the form of a distance matrix.

The structural data comprise the addresses of customers, delivey times, and article data such as weight, volume, packaging and production sites.

The flow data needed for planning are the deliveries from a warehouse to a certain customer within a certain period in terms of quantity, volume, shipment date, product or product group, etc. The quantity of ware flow from the production sites to the existing warehouses can also be considered. Turnover and growth can be calculated for a defined prognostic period on a customer or product base.

2.2 Cost Data

2.2.1 Warehouse Costs

The storage costs for the various warehouses in the current distribution system are collected, checked for plausibility and functionally related to the flow and turnover of each particular warehouse. Data from experience are substituted for missing or unplausible cost data. Generally warehouse costs drop as warehouse flow decreases, whereas the warehouse costs per ton drop with increasing througput. The following warehouse function, based on approximated current data, is an example of a warehouse cost function, whose degression can be weakened with additional location fixed costs:

Warehouse costs per month = 1000 * month flow [tons] exp 0.8

2.2.2 Stock Costs

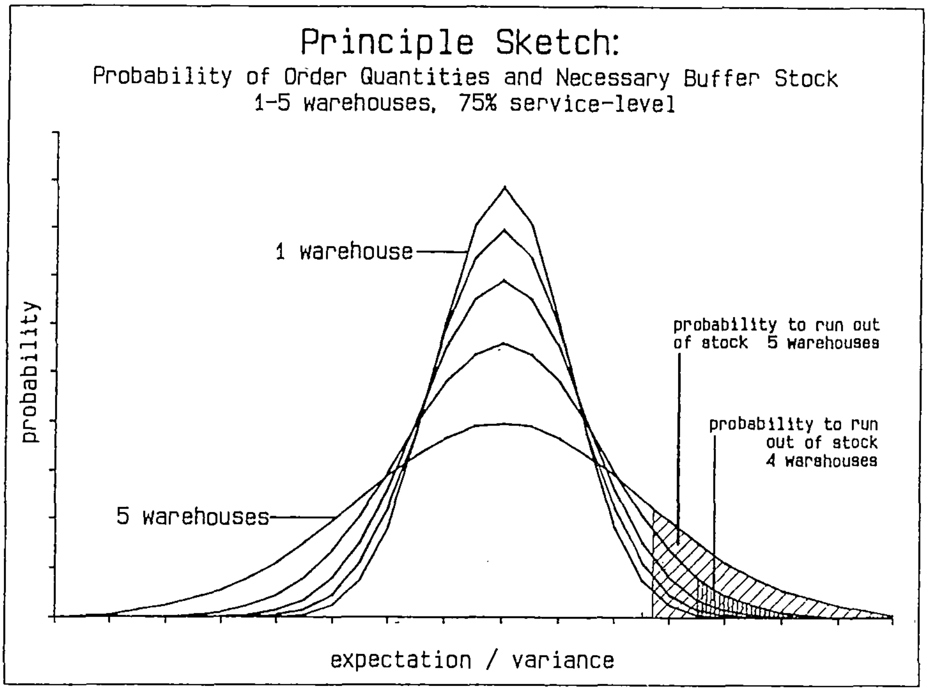
The degree of the service defines the percentage of orders which can be supplied from a warehouse. A service degree of 95% means that 95% of all orders can be supplied directly from the warehouse stock and 5% are backorders. In a decentrally organized distribution system with a limited number of regional warehouses a defined degree of service must be guaranteed by the buffer stock of each individual warehouse. In contrast, centralizing warehouses means a reduction of buffer stock, since the total demand comprises the demands of several smaller warehouses. *Ceteris paribus* demand fluctuations can be smoothed and the probability of not being able to supply is lessened. Graph 2 shows the connection of ordered quantity and supply ability for a service degree of 75% with 1 to 5 warehouses.

A rule of thumb for the functional relationship between turnover and quantity of buffer stock in a distribution system is the so-called "square root law", that means, that the total buffer stock of a distribution system increases with the root of numer of warehouses multiplied with the buffer stock of one warehouse.

Total Buffer Stock = # of Warehouses exp 0.5 * Buffer Stock of one Warehouse

Centralizing the inventory of all European sales companies provides another problem. Caused by different safety standards etc. only a portion of the products is saleable allover Europe. Also "fast movers" (A-Items in an ABC-Pattern) should not be stored centrally, for it could provide disadvantages in the market position of a product. Assuming a portion of 30% inventory of pure national products and about 40% inventory of "fast movers" the rule for centralized bufferstock can only be used for roughly 40% (0.7*0.6) of the stored products. In case of centralization from 10 to 5 warehouses it is necessary to store national products and the fast movers in small warehouses e.g. leaded by forwarding agents.

Graph 2

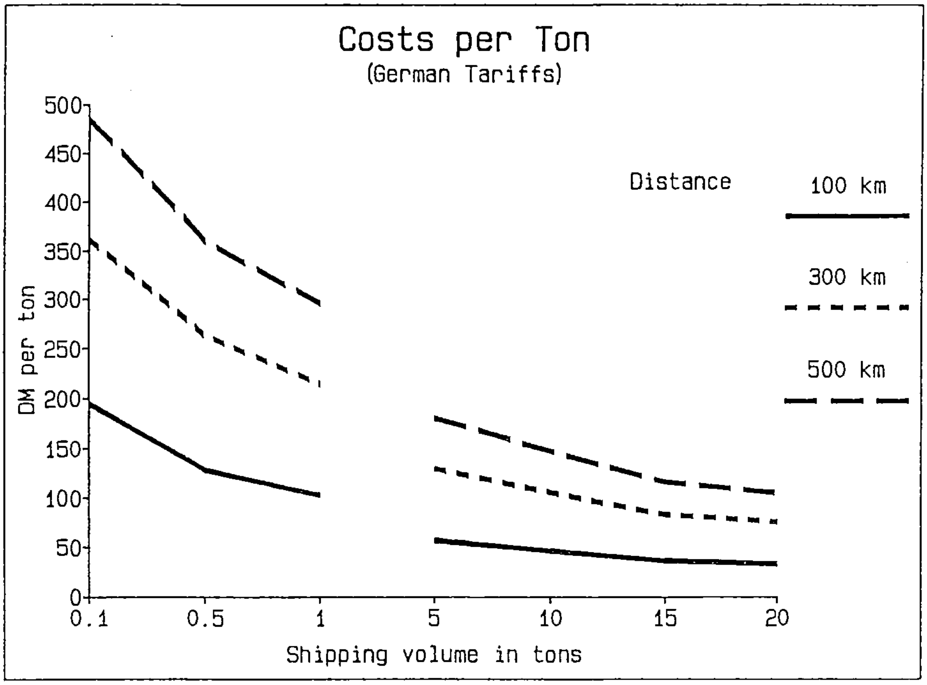


Source : Locom Consulting 1991

2.2.3 Transport Costs

The transport cost calculation are based on the present valid tariff for goods traffic in Germany (GFT). This tariff is reduced by distance- and weight-dependent margins in orde to come closer to European cost rates, which are up to 20% lower. The German tariff is a function which includes the weight of the shipment and the distance. The degression of this transport cost function is shown in Graph 3. Lighter shipments (e.g. up to 100 kg) cost five times as much per ton as shipments from the heaviest class.

Graph 3



Source: Locom Consulting 1991

2.2.4 External Costs

As traffic increases we must ask whether everyone involved should include all of the economic traffic costs in their calculations. Market prices reflect the social costs of ressources incompletely where it is difficult to separate individual rights to ressources or where legislature refrains from defining these rights. External costs are a part of the social costs which are not considered in decisions made by the market [1]. Environmental burdens due to traffic, such as noise, fumes, earth and water pollution, landscape misuse, etc. reflect a loss in the quality of goods with a collective nature and are examples of external costs. The problem of quantifying this loss can be solved in a variety of ways. If environmental burdens can be avoided through preventive measures, they can be evaluated on the basis of preventive costs: Noise, for example, costs as much as the construction of noise absorbing walls and noise reflecting windows would cost. Unavoidable damage can be quantified by its damage costs. A study on external costs completed in 1990 for the German Railway [2] estimated between DM 0.04 and DM 0.05 per ton/km (depending on the function) external costs for freight traffic. These costs include air pollution (without CO_2), earth and water pollution, noise accidents not covered by insurance and landscape loss due to roads.

Another study made in 1989 by an institut for environmental problems and forecasts in Germany [3] using different methods of quantifying estimates the external costs per ton/km from DM 0.17 (minimum) up to DM 0.39 per ton/km (maximum).

3. PLANNING AND SIMULATION

3.1 Analyze the Current Situation

The current situation is simulated with the model described above in terms of quantity flow, warehouse costs and stock quantity. The total costs calculated for logistics are divided into transportation costs, warehouse costs and stock costs. For very valuable goods (in the example approx. 60 TDM per ton) the total costs split up into 52% stock costs, 19% warehouse costs and 31% transportation cost.

3.2 Optimizing Locations and Simulations

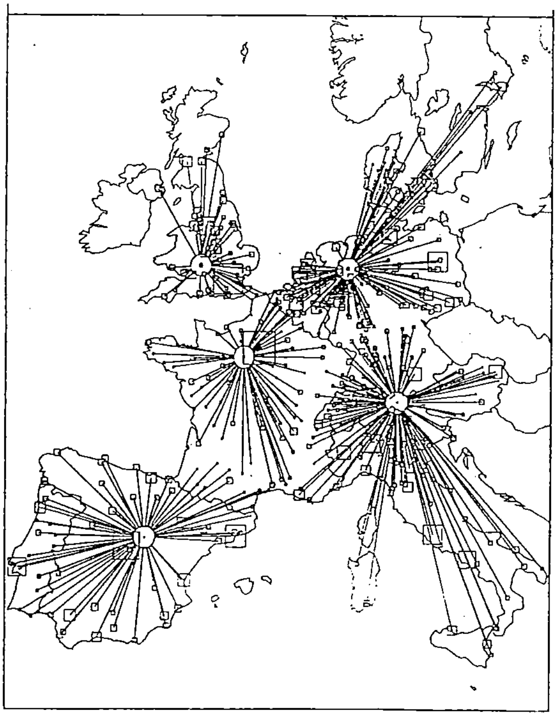
Based on the same assumptions concerning the amount of buffer stock, warehouse costs, delivery times and transportation costs, simulations can be made for three to nine warehouse locations in Europe. For a given number of warehouses a cluster analysis is used to calculate the optimal location in terms of transportation costs. Experience has shown that due to the demand concentration in highly populated areas in Europe (Rhine-Ruhr Area, Northern Italy, Paris, Southern Great Britain) one warehouse location is calculated for each of these. The follwing table shows the results of the simulations for three to nine warehouse locations. The total costs of every model are based on 100% of the current logistics costs. Reducing from ten to three warehouse locations decreases logistic costs by ca. 8%; the extra costs for transportation are contrasted with the savings in stock costs and warehouse costs.

Table 1

	Logistic Costs			
# Locations	Inventory Caring [%]	Warehouse Costs [%]	Transport Costs[%]	Total Costs [%]
Current Situation (10 Warehouse)	51,6	18,8	29,5	100
3	48,3	17,5	34,1	92
5	50,0	17,9	32,1	94
7	50,8	18,1	31,0	97
9	51,3	18,6	30,0	99

The percentage of stock costs within the total distribution costs drops from 52% to 48%, while the transportation costs rise by ca. 4,6% due to greater distances. The optimal locations for these three warehouses are Reading in Southern England, Cologne in Germany and Annecy near Geneva. The logistics costs are at a minimum with only one warehouse in Europe. Warehouses of this size, however, are not advisable, for safety and handling reasons and they cannot meet delivery time needs. To secure a 24-hour delivery service for 65% of all European customers, at least five warehouse locations are needed in Europe. Graph 4 shows the locations of five warehouses in Europe and the assignment of customers to these warehouses.

Graph4



Source: Locom Consulting 1991

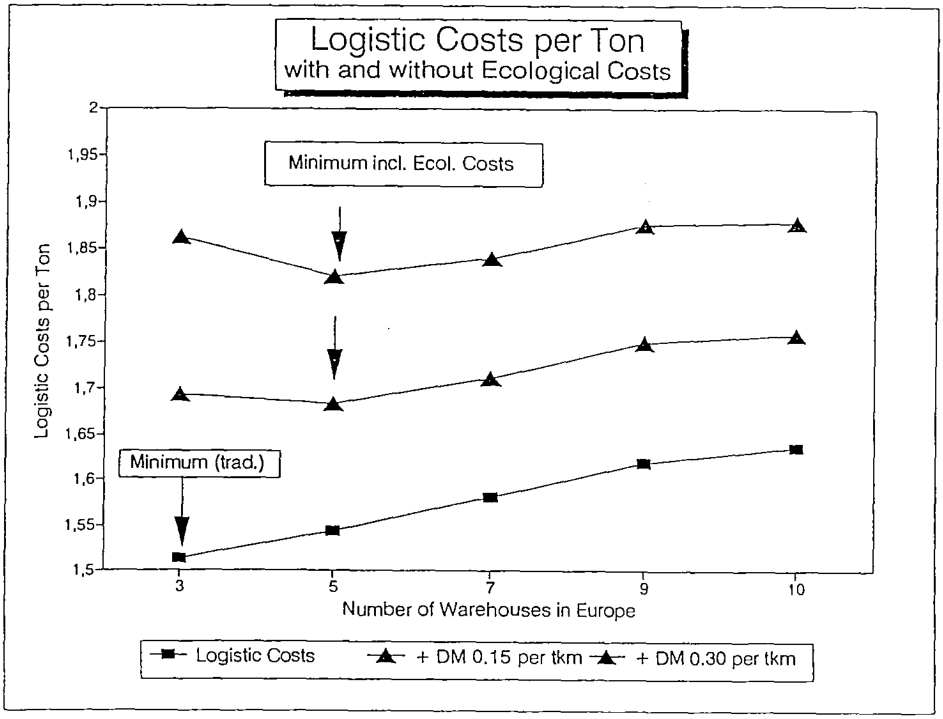
3.3 Sensitivity Analyses

The individual plans for a European distribution system can now be examined and evaluated with sensitivity analyses. Costs can be simulated for a 48-hour service instead of a 24-hour service for all or for some groups of customers. Turnover percentages and/or weight percentages can be stated for particular distance ranges. In addition, various distribution systems can be examined in terms of higher transportation costs (due to mineral oil tax increases, truck taxes, highway tolls, etc.).

3.3.1 Sensitivity Analysis for Transportation Costs

The total logistics costs in the example of an European distribution system shown above are DM 1640 per ton and year with transportation costs of 29,5%. Graph 5 shows the sensitivity anylsis of an increase of transportation costs by external costs ceteris paribus. The traditional way of calculating the logistic costs leads to the cost minimum with only 3 warehouses in Europe. Including external costs into the distance function of the cluster analysis this trend to centralization is economically less favorable. The middle line shows the logistic costs per ton with added external costs of DM 0.75 per km, representing an average delivery of 5 tons with DM 0.15 per tkm only for long haul traffic, not for local delivery. The mimimum is reached with a distribution structure of 5 warehouses in Europe and the savings by centralization drop from 8 % to ca. 4 %. Doubling the external costs up to DM 1,50 per km the effect of centralization is lessened more and more. The total costs of procurement and distribution in Europe increase by ca. 7% including the external costs of DM 0.15 per tkm.

Graph 5



Source: Locom Consulting 1991

3.3.2 Sensitivy Analysis for Delivery Times

In the main areas of Europe the market today generally demands a 24-hour delivery service. Assuming the time schedule of a "distribution day", the order comes in on Day A and the delivery to the customer must be fulfilled by the end of Day B. If the truck departs from the warehouse at 7.00 pm and reloading at the turnover point for regional and local distribution occurs between 4.00 and 9.00 am on the next morning, nine hours remain for long haul transportation. On the average a truck can cover 60 to 65 km per hour, which means in the remaining time it can reach up to 500 km, not taking into account the time for customs clearance and waiting periods at the border. Table 2 shows weight and turnover percentages in various distance zones between customers and warehouses for various numbers of locations in the distribution systems. For ten warehouse locations 81% of the turnover lies within a range of 500 km. This portion is reduced to 65% for five and three locations; the percentage of customer turnover within a range of 800 km and more doubles from 9 to 18%.

Table 2

Distance	percentage of netsales in the supplied area number of warehouses			
Customer <-> Warehouse	10	7	5	3
< 500 km	81	67	65	65
500 - 600 km	4	6	5	7
600 - 700 km	3	6	6	6
700 - 800 km	2	5	6	5
> 800 km	9	16	18	18

With increasing traffic problems and traffic jams in the future it is rather unfavourable to do 30% worth of business in a geographical zone which can't be reached in 24 hours.

4. OUTLOOK

Another way to plan warehouse locations is to employ graph theory. In this case Europe is described as a graph with cities, border crossing points, motorway intersections etc. as the nodes of the graph and intersections of the traffic net as the edges. These edges can describe motorways, waterways or railway lines. The attributes of the edges can be speed, capacity, distance, fees, emission or a combined cost function of different attributes. Thus traffic jams on defined intesections of European motorways can be simulated by decreased average speed.

With this cost functions as valuation of edges also time, emission, and other external costs can be taken into account for optimizing locations and warehouse-customer relations.

Caused by the tremendous variety of possibilities using graph algorithms for warehouse location problems the cluster analysis is used to find a starting solution. Based on this starting solution algorithms of graph theory can be used to improve the solution and to find the shortest geographical distance between customer and warehouse as well as the time-shortest relation between customer and warehouse.

Notes

/1/ Planco 1990, Page 1
/2/ Planco 1990, Page 22
/3/ UPI 1989, Page 62

Bibliography

Planco Consulting GmbH, editor(1990), Externe Kosten des Verkehrs - Zusammenfassung, Planco Consulting GmbH, Essen

Späth, H.(1975), Cluster -Analyse-Algorithmen, Oldenbourg Verlag , München-Wien

UPI , (1989), Gesellschaftliche Kosten des Straßengüterverkehrs; Heidelberg