A customer oriented approach to warehouse network evaluation and design

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Abstract

Cost or profit based optimisation with capacity restrictions is the most widely used method for distribution network design. This approach is based on production or company oriented logistics thinking. However, in the present competitive business environment, a more customer driven and holistic approach to supply chain management is required. In this paper, the focus is on warehouse network evaluation and design. The aim is to present a customer oriented approach to the evaluation and selection of alternative warehouse operators. The Analytic Hierarchy Process (AHP) is used for analysing the customer-specific requirements for logistics service and for evaluating the alternative warehouse operators. The AHP-based analysis results in a customer-specific priority for each alternative warehouse operator. This priority describes how well a certain warehouse operator is expected to satisfy a certain customer's performance requirements. The priorities are then entered to a Mixed Integer Linear Programming (MILP) -model which is used for maximising the overall service performance of the warehouse network under relevant restrictions. Thus, the warehouse network can be designed based on multiple quantitative and qualitative criteria instead of just costs or profits alone. \copyright 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The distribution center or warehouse location problem is a strategic level network design problem [1]. This means that the nature of the decision is long-term and the influence of the warehouse location decision on the profitability of the company will last for years. This partly explains the great interest of practitioners and scientists on the issue. Partly the same techniques and frameworks have been used for warehouse and plant location problems, although qualitative elements like business culture, financial subsidies and professional staff have a greater influence in the plant location problem. Because the same techniques are utilized,
these problems are often included in the facility location problem. For the basic theory concerning facility location problems, see e.g. Francis et al. [2].

Today, it is rather common practice for companies to outsource distribution logistics functions at least to some extent. Thus, ensuring that the distribution network achieves the requested performance level calls for analytical approaches for evaluating the alternative third party logistics service providers. Costs are often used as the major factor in selecting the service providers, whereas enough attention is not paid to the various quantitative and qualitative customer service elements.

In Section 2 of this paper, we discuss the benefits and problems related to logistics modelling. In Section 3, some approaches to supply chain optimisation are presented. In Section 4, we present an approach to warehouse network evaluation and design which is based on the integrated utilisation of the Analytic Hierarchy Process and Mixed Integer Linear Programming.

2. On the benefits and difficulties in logistics modelling

2.1. The utilization of mathematical models in logistics network design

In logistics literature, many practically oriented papers on the optimisation of logistics have been published since 1990. This is due to the improved power of the mathematical tools, improved availability of the basic data resources in companies, and managers' increased interest on utilizing the results of mathematical models. For example Baunack et al. [3] have predicted that in the case of Germany's construction industry the opening of two main depots and the closure of five sub-depots will increase the turnover of their case company by 5% and the profit by 20%. In a paper by van den Bruggen et al. [4] which deals with depot location and the client assignment to depots for a large oil company, the simulation study pointed out that the total logistics cost savings were in the range of 5–6% per year. These two examples give an idea of the potential savings through optimisation and simulation tools on logistics.

2.2. On problems of implementing logistics network design models

From some published papers we may conclude that there have been problems in implementing the results of logistics models in reality. For example, according to Mourits et al., many logistics support systems have the following shortcomings [5]:

- they focus on a subset of activities contained in the supply chain.
- they focus only on a subset of problems related to the development of distribution networks or
- they are difficult to apply to real cases due to the large data requirements.

Mourits et al. have even stated that the available support systems do not facilitate a coherent approach to all issues involved in the development of large-scale distribution networks.

LeMay et al., added to the problems of implementing logistics systems the poor understanding of logistics functions by system designers, accountants and top managers [6]. Solving this problem of poor understanding requires above all several negotiations and coordination between logistics specialists.

3. Different approaches to supply chain optimisation

3.1. The traditional approach

In the traditional supply chain network design problem the focus has been on achieving the minimum cost or maximum profit within given restrictions. This is mainly a consequence of the high strategic importance of the network structure for the delivering company which wants to achieve the best possible profit. Normally, companies determine the logistics structure, e.g. warehouse location, based on costs or profits by implementing quantitative elements as restrictions like minimum transportation time or distance, minimum safety
stock requirement or minimum delivery frequency. The values of these restrictions can be rated from internal knowledge of the customers’ behaviour or from performed customer surveys. However, due to the qualitative nature of these restrictions, they are very seldom taken into account in the objective value itself. According to Tampoe et al., until recently, most models used quantitative data and mathematical relationships, which limits the ability of the model to mimic reality [7].

In order to fully support the analysis of the performance of an integrated logistics chain, the traditional approach, in which the model is the starting point of the analysis and in which the data structure is derived from the model, is insufficient. In integrated logistics chain modeling the choice of suitable models should be determined by the information structure required and by the information technology available [8]. This means that the model designer must have knowledge on both the operational rules and tactics and on the information systems (data resources) of the target company.

3.2. Service-sensitive location problems

Ho and Perl have defined the Service-sensitive Warehouse Location Problem (SSWLP) as the problem of determining the number and locations of warehouses, and the allocation of markets to the established warehouses, so as to maximize total profit [9]. In the SSWLP, according to Ho and Perl, the demand generated by each market is dependent on two customer service elements: product availability and order cycle time. To product availability they have given a pre-specified minimum level, which cannot be exceeded at any warehouse, and to each market they have a maximum allowable order cycle time. They handle these two elements, product availability and order cycle time, as quantitative elements and exclude other qualitative aspects. From a customers’ point of view this can be considered as a shortcoming. Nevertheless, the formulation of the SSWLP is a step towards a more customer oriented, holistic and integrated logistics approach compared to the traditional approach.

4. An integrated approach to warehouse network evaluation and design

4.1. Proposed approach

In this paper, we propose an approach to evaluate and design a warehouse network for a company based on integrating the Analytic Hierarchy Process (AHP) and Mixed Integer Linear Programming (MILP). The basic premises for the proposed approach are the following: (1) warehousing activities have been outsourced, i.e. only “third party” warehouse operators are used, and (2) this approach is preceded by an analysis in order to define the best potential locations for the warehouses, to determine the feasible alternative warehouse operators and to gather extensive information on them. Thus, the objective for the proposed approach is to assist in deciding which warehouse operators of the feasible alternatives will be included in the distribution network of a company. By incorporating the AHP in the process, the individual customer’s requirements and preferences for logistics service can be analysed and prioritised, and the alternative warehouse operators can be analysed in a customer-focused manner. By using the results of the AHP-analysis, i.e. the priorities for each alternative operator from each customers’ point of view, as the basis for the MILP-optimisation, the warehouse network can be designed based on all relevant customer service elements instead of the costs only.

The warehouse network design process is a complex decision problem involving numerous quantitative and qualitative elements, and full information concerning these elements is not always available. In order to reach the decision under these circumstances, the available objective information has to be combined with subjective judgments. Therefore, the AHP is a suitable tool for assisting this decision process by allowing the utilisation of both subjective judgments and objective information.

The proposed approach is presented in Fig. 1, and it consists of the following steps:

4.1.1. Preliminary analysis

The first phase of the approach involves e.g. stating the objectives for the warehouse network
design problem, determining the best potential locations for the warehouses, and defining the alternative warehouse operators on the locations and gathering and analysing information concerning all aspects of their operations. The information can be gathered e.g. through direct visits to and meetings with the alternative warehouse operators.

4.1.2. Defining the final evaluation problem

This phase involves defining the alternative warehouse operators among which the final selection will be made. The most feasible alternative warehouse operators are defined based on the information gathered in the previous phase, i.e. the warehouse operators that do not satisfy the basic requirements set on e.g. customer service and cost level are eliminated from the final evaluation.

4.1.3. The AHP-based analysis

The following steps are included in the third phase: (1) representatives of each customer affected by the decision define the criteria they use for analysing the alternative warehouse operators, and determine their requirements concerning each criterion, (2) the criteria are structured into a customer-specific AHP-hierarchy, and (3) the representatives of each customer derive priorities for the criteria and the corresponding requirements. The structured AHP-models are then used for analysing the alternative warehouse operators, resulting in a preference priority for each alternative warehouse operator from each customer’s point of view. In the proposed approach, this preference priority is labelled “customer satisfaction priority” as it measures the overall estimated satisfaction provided by a certain warehouse operator. As the representatives of the customers normally do not have direct information or knowledge concerning the alternative warehouse operators, the representatives of the company conducting the analysis help them to evaluate the warehouse operators. Notably, the analysis of the warehouse operators is based on both factual information and subjective judgements, which is allowed for in the AHP-method.

4.1.4. MILP-based optimisation

MILP-based optimisation is based on maximising customer satisfaction while taking into account the relevant constraints. Instead of costs, customer satisfaction priorities are used as the basis for the optimisation, i.e. the objective function is to maximise the overall customer satisfaction provided by the warehouse network under the defined constraints (such as capacity limits).

4.1.5. Implementation and follow-up

After implementing the decided warehouse network in practice, the AHP-models can be used to support periodical reviews of the actual performance of the warehouse network. The MILP-based optimisation model can then be used to review the overall warehouse network. New alternative warehouses can also be included very easily in the analysis.
In this paper, we extend the work by Korpela and Tuominen [10] in which they used the AHP and benefit/cost-analysis for evaluating and selecting the warehouse operators. For earlier work on the utilisation of the AHP for the site selection problem, see also e.g. Hegde and Tadikamalla [11]. The AHP and linear programming have earlier been used together by e.g. Liberatore [12] for selecting R and D projects, by Korhonen and Wallenius [13] for formulating a marketing strategy, by Gass [14] for large-scale personnel planning models and by Olson et al. [15] for an export planning model for a developing country.

We demonstrate the utilisation of the proposed approach by a numerical, illustrative example.

4.2. Preliminary analysis and defining the final evaluation problem

The logistics network of process industry corporation A is shown in Fig. 2. The corporation operates worldwide, but most of the corporation’s production and customers are located in Europe.

The main flow of the corporation’s products is exported via loading and destination ports to market area warehouses, from where the products are delivered to the customers. The corporation is now restructuring the warehouse network. The potential locations for the warehouses have been defined and the potential warehouse operators have been mapped and analysed.

Based on the gathered information, the objective now is to determine which third party warehouse operators will be selected. In this illustrative example, there are five alternative warehouse operators and five customer companies of corporation A to be served. The service capabilities of the alternative warehouse operators will be analysed based on the requirements of each individual customer. In order to establish a warehouse network which matches the customers’ requirements as well as possible, the final selection of the warehouse operators to be used will be based on the customers’ requirements and preferences under relevant restrictions.

4.3. AHP-based analysis

The third step in our approach involves analysing the capabilities and characteristics of the alternative warehouse operators by using AHP-supported analyses. In order to achieve a strong
focus on the customers’ requirements, the alternative warehouse operators are analysed separately by each customer. Through this approach, an in-depth understanding can be created about the preferences set by each customer for the alternative warehouse operators and locations. In this section, we review the basis of the AHP and present an example analysis of the alternative warehouses.

The Analytic Hierarchy Process (AHP) is a systematic procedure for representing the elements of any problem in the form of a hierarchy [16]. The AHP supports executive decisions, communicates recommended decisions, applies knowledge, intuition and experience, derives priorities, and ranks alternatives [17]. The AHP is a theory of measurement for dealing with quantifiable and intangible criteria, which has been applied to numerous areas, such as decision theory and conflict resolution [18]. The AHP is based on the following three principles: decomposition, comparative judgments, and the synthesis of priorities [19]. The AHP starts by decomposing a complex, multi-criteria problem into a hierarchy where each level consists of a few manageable elements which are then decomposed into another set of elements [20]. The second step is to use a measurement methodology to establish priorities among the elements within each level of the hierarchy. The third step in using the AHP is to synthesise the priorities of the elements to establish the overall priorities for the decision alternatives. The AHP differs from conventional decision analysis methodologies by not requiring decision makers to make numerical guesses, as subjective judgements are easily included in the process and the judgements can be made entirely in a verbal mode [21].

According to the principles of the AHP, the first step in the analysis is to identify the criteria on which the analysis of the alternative warehouse operators is based. The criteria are then structured into a hierarchical form to represent the relationships between the identified factors. We will present an illustrative example of how the analysis is conducted by one of the customers involved in the warehouse selection process.

The representatives of the example customer identify three main aspects of warehouse performance to be included in the analysis: reliability, flexibility, and customer’s overall logistics costs. In order to reach an adequate level of detail in the analysis, reliability and flexibility are further divided into subelements. Reliability consists of the following subcriteria: the ability to deliver products to the customers according to the target schedule, in right quantities, and without damage. Flexibility refers to the ability of a warehouse to (1) arrange urgent deliveries when needed, (2) have flexibility in the frequency of deliveries, (3) conform to any special requests set by the customer, and (4) respond to changes in the warehousing capacity needs of a customer. The third main criterion, customer’s logistics costs, refers to the total logistics cost level for the customer if a certain warehouse operator is used. The criteria included in the analysis are structured into the form of a hierarchy as shown in Fig. 3.

The second step in using the AHP is to derive priorities for each element in the hierarchy. The priorities are derived by a pairwise comparison of each set of elements with respect to each of the elements on a higher level [20]. A verbal or a corresponding 9-point numerical scale can be used for the comparisons which can be based on objective, quantitative data or subjective, qualitative judgements. In a group setting, there are several ways of including the views and judgements of each person in the priority setting process. In a common objectives context where all members of the group have the same objectives, there are four ways that can be used for setting the priorities: (1) consensus, (2) vote or compromise, (3) geometric mean of the individuals’ judgements, and (4) separate models or players [22]. The primary method would be to try and achieve a consensus based on extensive debate and discussion. However, if a consensus cannot be established the geometric mean of the group members’ judgements would be used. The derived importance priorities for the subcriteria are presented in Fig. 4.

In a typical AHP-hierarchy, the alternatives to be analysed would be added to the lowest level of the hierarchy and would then be analysed in a pairwise manner with regard to each subcriterion in order to derive the overall priorities for the decision alternatives. However, in order to be able to analyse numerous alternatives and to be able to add
new alternatives flexibly, we use ratings instead of the actual decision alternatives at the lowest level of the hierarchy in our example. Ratings, in this case, are qualitative or quantitative descriptions of the characteristics of a certain warehouse operator with regard to the subcriteria. The rating scales are the following:

- **Delivery time**: the products are usually delivered within 2, 4, 6 or 8 h of the target delivery time;
- **Quantity**: the frequency of deliveries can be 3 times a week, 2 times a week, once a week, or once in two weeks;
- **Quality and Quantity of Deliveries**: the accuracy of the deliveries with regard to the quality and quantity of products is usually over 99%, 95–99%, 90–95%, or below 90%;
- **Urgent Deliveries**: urgent deliveries can usually be arranged within 1, 2–3, 4–5, or over 5 days of placing the order;
- **Frequency**: the frequency of deliveries can be 3 times a week, 2 times a week, once a week, or once in two weeks;
- special requests: the performance is at the preferred, acceptable or unacceptable level;
- capacity: the ability of a warehouse to conform to capacity changes is outstanding, above average, average, below average, or unsatisfactory;
- customer’s logistics costs: the customer’s logistics costs are at an outstanding, above average, average, below average, or unsatisfactory level.

In a classical weights and scores approach, the ratings would be given ordinal numbers, such as 1 for unsatisfactory and 5 for outstanding [23]. According to Forman et al., the classical approach violates the proper use of “scales of measurement” with the implicit and incorrect assumption that, for example, outstanding is five times better than unsatisfactory. The problem is avoided in the AHP-method by deriving the utility priorities for the ratings with regard to each criterion using pairwise comparisons. By deriving utility priorities for the ratings using pairwise comparisons, the customers can define what the real utility of each performance level is for them. An example of the utility priorities set for a ratings scale is presented in Fig. 5.

The actual analysis of the alternative warehouses is performed by relating a rating (and the corresponding utility priority) to each of the warehouses with respect to each subcriterion. As the customers do not necessarily have previous experience on the utilisation of the warehouse operators being evaluated, the evaluation of the expected performance levels of the alternative warehouse operators is a joint effort between the representatives of the customer and corporation A. Based on the preliminary analysis, the representatives of corporation A have enough analysed information on the warehouse operators in order to be able to support the evaluation of the expected performance levels. The evaluation of the alternative warehouses is presented in Table 1.

In our example, five alternative warehouse operators are included in the analysis. The results of the analysis can be approached in several ways: (1) by focusing on one warehouse at a time, a detailed insight can be gained about the logistics service performance of the warehouse in question, (2) by focusing on one subcriterion at a time, the differences between the different warehouses can be pointed out, and (3) by focusing on the columns labelled “total” and “%-max”, an understanding about the overall performance level of the different warehouses can be gained. As illustrated in Table 1, warehouse alternative 5 is the best alternative with a total priority of 0.550. The total priority represents the overall preference of a certain warehouse to the customer. As pointed out in the Section 4.1, the
total priority is called the “customer satisfaction priority”.

Correspondingly, all other customers included in this illustrative example evaluate the expected performance levels of the alternative warehouse operators based on their own sets of evaluation criteria, priorities and ratings. The overall outcome of the AHP-based analysis is a preference priority given by each customer for each alternative warehouse operator.

### 4.4. MILP based optimisation

By using a MILP model, the warehouse network is finally selected by maximising the overall customer preferences. Thus, the selection of the warehouse network is based on the customer satisfaction priorities derived by using the AHP instead of minimising the total distribution costs or maximising the total profits of corporation A. Maximising the preferences means that the objective is to try and use the most preferred warehouse operator for each customer under the relevant restrictions.

The MILP model is selected and needed as an analysing tool because it makes it possible to give a minimum throughput volume for each warehouse operator. The minimum throughput volume is a relevant restriction as e.g., an acceptable cost level cannot normally be ensured without a certain minimum volume commitment in the negotiations with a warehouse operator. Another practical reason for using the MILP model after the AHP analyses in the warehouse network selection process is the possible need for defining a maximum number of warehouses to be selected, the option of which is included in the following illustrative analysis.

In this phase it is noteworthy to bear in mind that the AHP preferences also include the delivery costs, which in this approach are variable costs, because only third party warehouse operators are used. Two illustrative analyses have been made on the warehouse network selection problem for corporation A:

1. Maximising customers’ preferences without giving the maximum number of warehouses
2. Maximizing customers’ preferences by giving the maximum number of warehouses

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Total</th>
<th>Logcost</th>
<th>Capacity</th>
<th>Frequency</th>
<th>Quality</th>
<th>Quantity</th>
<th>Reliability</th>
<th>Time</th>
<th>% Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse 5</td>
<td>0.590</td>
<td>0.1078</td>
<td>0.0587</td>
<td>0.0608</td>
<td>0.161</td>
<td>0.0894</td>
<td>0.0389</td>
<td>0.2951</td>
<td></td>
</tr>
<tr>
<td>Warehouse 1</td>
<td>0.521</td>
<td>0.1624</td>
<td>0.0894</td>
<td>0.0808</td>
<td>0.1661</td>
<td>0.1085</td>
<td>0.0587</td>
<td>0.2951</td>
<td></td>
</tr>
<tr>
<td>Warehouse 3</td>
<td>0.510</td>
<td>0.1661</td>
<td>0.0894</td>
<td>0.0808</td>
<td>0.1661</td>
<td>0.1085</td>
<td>0.0587</td>
<td>0.2951</td>
<td></td>
</tr>
<tr>
<td>Warehouse 2</td>
<td>0.481</td>
<td>0.1661</td>
<td>0.0894</td>
<td>0.0808</td>
<td>0.1661</td>
<td>0.1085</td>
<td>0.0587</td>
<td>0.2951</td>
<td></td>
</tr>
<tr>
<td>Warehouse 4</td>
<td>0.450</td>
<td>0.1661</td>
<td>0.0894</td>
<td>0.0808</td>
<td>0.1661</td>
<td>0.1085</td>
<td>0.0587</td>
<td>0.2951</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1** The analysis of the alternative warehouses by one customer

J. Korpela, A. Lehmusvaara/Int. J. Production Economics 59 (1999) 135–146
In both analyses the warehouse location problem is defined from the customer’s point of view by maximising the total customer preferences. In the second analysis the maximum number of warehouses to be selected is given in order to demonstrate a situation where the number of warehouses is limited for example because of operational reasons. The objective function of the preference maximisation MILP model can be defined as follows:

\[
\text{MAX } Z = \sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij} W D_{ij} \quad (1)
\]

s.t.

\[
\sum_{j=1}^{J} W D_{ij} = W_i, \quad (2)
\]

\[
\sum_{i=1}^{I} W D_{ij} = D_j, \quad (3)
\]

\[
W_i \geq a_i [W_i], \quad (4)
\]

\[
W_i \leq \sum_{j=1}^{J} D_j [W_i], \quad (5)
\]

\[
\sum_{i=1}^{I} [W_i] \leq N, \quad (6)
\]

where:

- \( p_{ij} \) the customer satisfaction priority of warehouse \( i \) as analysed by customer \( j \) in analysis 1.
- \( W D_{ij} \) the material flow from warehouse \( i \) to customer \( j \).
- \( W_i \) the throughput volume of warehouse \( i \).
- \( D_j \) the market demand of customer \( j \).
- \( [W_i] \) the 0/1 integer variable of warehouse \( i \).
- \( a_i \) the required minimum throughput volume to open warehouse \( I \).
- \( N \) the maximum allowed number of warehouses in the solution.

The results of the two illustrative examples are given in Tables 2 and 3. In Table 2 we have the results of case 1, where the total customer preferences are maximised. In Table 3, we have the results of the same problem, when the maximum number of warehouses is two.

Comparing the results of the cases one and two we can notice that warehouse three is used in both cases, and warehouse four is excluded in both cases. After giving the upper limit to the number of warehouses, warehouse one replaces warehouses two and five in the solution.

After the preference maximisation analyses we can compare their results to the outcome of the traditional cost minimisation and profit maximisation approaches. After these comparisons we get the difference which we would have to pay in costs or losses in profit from matching the customers’ preferences precisely.

4.5. Implementation and follow-up

After implementing the results of the analysis, the proposed approach forms a flexible procedure for the follow-up of the performance of the selected warehouse network. The present customers can be interviewed periodically, e.g. twice a year, in order...
Table 3
Material flow (tons) from the warehouse operators to the customers, when the customers’ preferences are maximised and the upper number of warehouses is limited to two

<table>
<thead>
<tr>
<th>Destination</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warehouse 1</td>
</tr>
<tr>
<td>Customer 1</td>
<td>20000</td>
</tr>
<tr>
<td>Customer 2</td>
<td></td>
</tr>
<tr>
<td>Customer 3</td>
<td></td>
</tr>
<tr>
<td>Customer 4</td>
<td></td>
</tr>
<tr>
<td>Customer 5</td>
<td></td>
</tr>
</tbody>
</table>

to update the AHP-analyses of the warehouse operators based on the experiences the customers have gained. The results of the updated analyses can be entered into the MILP model in order to periodically validate the selected warehouse network. Furthermore, new alternative warehouse operators can be evaluated flexibly, if needed. Correspondingly, new or potential customers can present their preferences for the alternative warehouse operators, and, consequently, the validity of the currently used warehouse network in serving the new or potential customers can be evaluated using the MILP model. Changes in the volumes demanded by the customers can be accounted for by up-dating the data and resolving the MILP model.

5. Conclusions

The proposed approach provides a systematic and flexible framework for selecting a warehouse network that maximises the preferences of the customers. Compared to the traditional, mainly cost-oriented approach, the utilisation of the Analytic Hierarchy Process enables the inclusion of both quantitative and qualitative factors in the decision process. The proposed approach is strongly customer-driven as the customers are provided with the possibility of presenting their preferences for the alternative warehouses in an analytic manner. Traditionally, warehouse network selection has been approached from the viewpoint of the supplier company, whereas the proposed approach focuses on the customer. Finally, the proposed approach forms a basis for organising the follow-up of the performance of the selected warehouse network.

References


