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Optimal location of intermodal terminals in Europe: an evaluation model

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Abstract

The goal of the EMOLITE project is to develop a selection and evaluation model for the location of intermodal terminals. The model will allow an accurate evaluation of potential sites for the development of freight and passenger terminals according to both internal and external requirements, considering the dynamic and continuously changing environment of freight and passenger transport. Specifically we will create a decision support system designed to be used at a strategic level, which includes a simulation module using Fuzzy Logic.

Keywords: freight transports, fuzzy logic, intermodal transportation networks

1. Introduction

Freight transport services have evolved substantially in the last decade and encountered a continuously increasing demand for speed, reliability, reduced transportation costs and value added services. The road haulage sector was able until now to benefit the most from the need for tailor made services. To minimize the potential negative effects on the environment as a consequence of the expected increase of commercial transport, the development of environment friendly transport concepts such as intermodal transport is required. In order to fully develop European intermodal transportation networks, intermodal transhipment centers have to be developed at strategic locations and the necessary supply and demand requirements identified. Conventional location models are either too complex or too general to provide "real life" solutions.

The goal of our project is the development of an alternative selection and Evaluation Model for the Optimal Location of Intermodal Terminals in Europe (EMOLITE). EMOLITE provides a simulation model developed by using fuzzy logic techniques and object-orientation. The end-result is intended for decision-makers, i.e., managers that need to choose optimal intermodal existing terminals to be used during the transportation of their goods. Their decision is based on general basic information and project specific information. General information may be divided into: national information (e.g., growth national product); site information (e.g., condition of the soil, capacity of the ground); terminal information (e.g., capacity of a terminal, types of cranes, type of transportation).

The project specific information is the relevant conditions and criteria used by the manager to make his decision. The EMOLITE software will allow that criteria to be weighted (i.e., we can add weights to some attributes so that we can decide whether an attribute is more important than other for the decisor). Moreover, we can also add conditions to the project specific information. For example, we may want to guarantee that the attribute cost can never be higher than a certain value.

The EMOLITE is composed of three main modules:

- a conceptual data model and a data dictionary defining the structure of a relational database. We will follow Yourdon's notation and symbology for the entity relationship diagram and data dictionary [Yourdon, 90].
- the interfaces to access to the database. The idea of wizard will be used to define the steps required to access to the database.
- the simulation module, in terms of two main processes, (a) a pre-selection of terminals, according to the user specific needs and (b) a multicriteria analysis to rank those terminals, according to the user preferences (weights).

The conceptual model of the database was obtained by using structured analysis techniques [Yourdon 91] and the implementation for the prototype was achieved using ACCESS. The simulation module will be obtained using fuzzy multiple attribute (criteria) concepts [Ribeiro, 96]. The analysis model will be built using the method proposed by Rumbaugh *et al.* [Rumbaugh *et al.* 91] and the code will be written in C++ [Stroustrup 91].

2. The project specification

2.1 EMOLITE general structure

The general structure of EMOLITE is depicted in Figure 1.

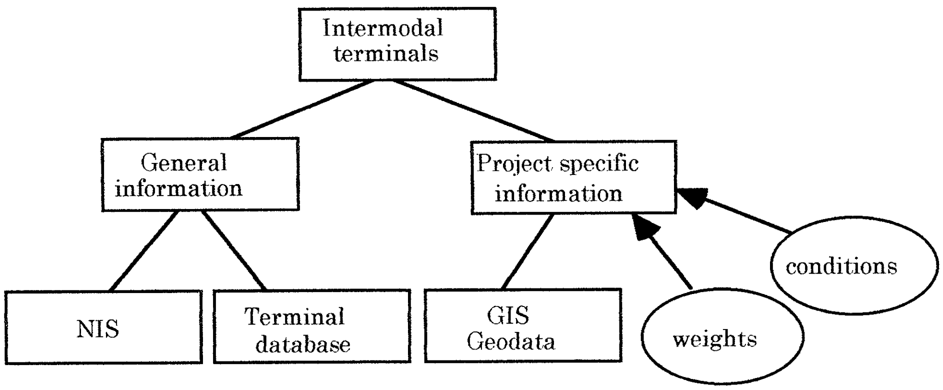

Figure 1: General structure

The database containing the general information can access both the data in the NIS database and the data in a terminal database. The database containing the project specific information can access the geographical database GIS/Geodata. The project specific information database contains the decision maker criteria that will be weighted and that will constitute the conditions of the decision support system.

A simple prototype of our project will be: when we run emolite command, the program displays EMOLITE main window. A manager will enter the initial requirements necessary to define the transportation framework. Then, the program will display a window listing the conditions that can be selected by the manager. The manager specifies his/her conditions and the program continues by selecting all the terminals that satisfy those conditions. After this, the program lists the criteria for the manager to choose and give the weights (preferences). Finally the program runs the simulation module and ranks the selected terminals. The results are presented in a decreasing mode, from the best to the worst choice.

2.2. Interface module

The interface module allows the user both to update and retrieve information from the EMOLITE's internal database and to connect to external databases.

The interface will be based on the idea of MDI (Multiple Document Interface), that is, a main window which visually contains child windows. Child windows will display different types of information such as project specific parameters, maps, reports and charts. Wizards will be part of the application to enable the user to perform some operations in an easy and friendly manner (e.g., entering data required by the simulation module, accessing databases, getting help).

2.3. Database

The information for EMOLITE is structured as shown in Figure 2:

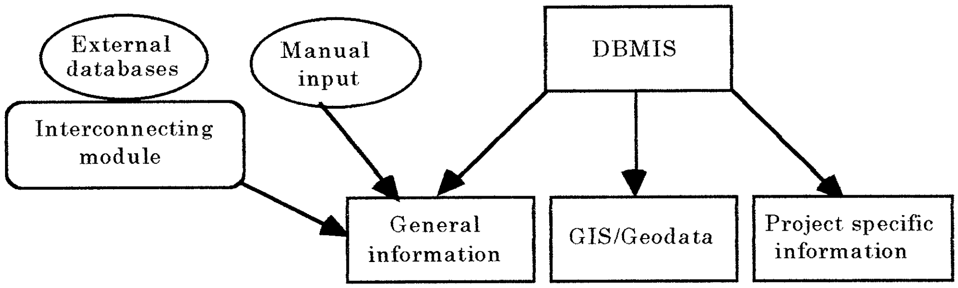

Figure 2: general data base structure

Some of this information is held in flat files, some other is stored in a relational database. Our concern here is to identify the data elements which are better dealt with in a database.

The database developement will include a conceptual data model and the data dictionary, defining the structure of a relational database. We will follow Yourdon's notation and symbology for the entity relationship diagram and data dictionary [Yourdon, 90].

2.4. Simulation module

The simulation model is a module of the EMOLITE decision support system which handles the selection and classification of terminals to recommend to the manager. This model follows the main structure found in fuzzy multiattribute models [Ribeiro, 96]. It includes two main tasks: (a) a pre-selection of terminals, according to user specific requisites and (b) a multicriteria analysis to rank those terminals, according to the user preferences (weights). The general description is shown in Figure 3.

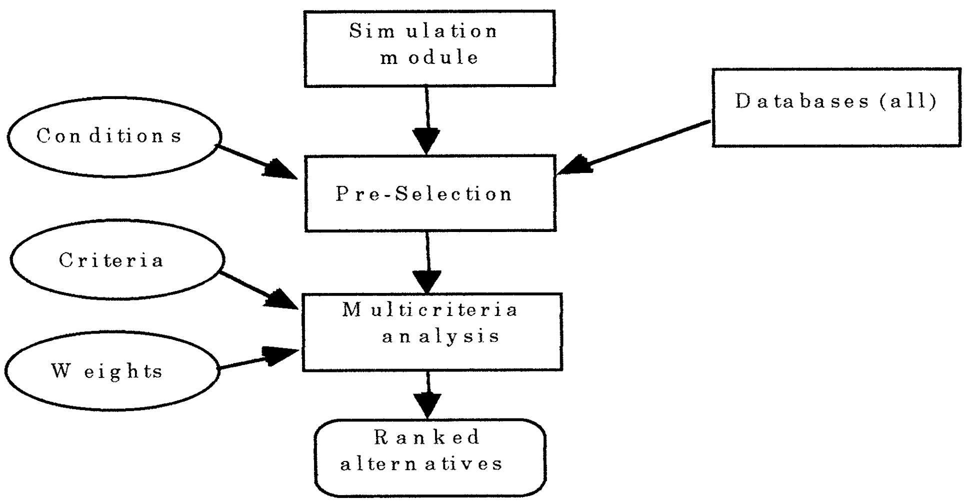

Figure 3: The simulation module

The transportation framework specifies the initial set of requirements that includes the intermodal terminals, the conditions, the criteria and the weights (or preferences). This information is given in the project specific information wizard which will drive the user through the process of entering the necessary data for defining the transportation framework. The information needed to perform the pre-selection is extracted both from the users and the databases. The users provide the conditions they need for the transportation of their goods and the system matches them with existing terminals which fulfill those needs. From this process a set of possible alternatives is passed to the multicriteria analysis. In the multicriteria analysis, users select the criteria they want to optimize the terminal selection and provides the weights for those criteria. With this information a multicriteria analysis, using fuzzy logic, is performed to rank the terminals. The ranking is presented in decreasing order of importance with a classification for each terminal.

The main features of the EMOLITE multicriteria analysis model will be: (1) it accepts and manipulates both types of criteria, crisp and fuzzy; (2) it is interactive and user-friendly in the sense that all dialogue with the user is guided by scroll-bar menus and dialogue-boxes, from the 'construction' of specifications to the manipulation and selection of query-types; (3) it is a flexible system in terms of the handling of criteria and weights, such as new insertions and modifications of their respective values. (4) it incorporates simulation facilities, providing an efficient way for the user to change preferences-weights, enabling the tuning of the system and the verification of the variables sensitivity; (5) it provides various types of inferencing, since the user may employ more than one type of reasoning. The fuzzy multicriteria model to be used in the simulation module is based in the MAF-DSS (Multiple-Attribute Fuzzy Decision Support System) developed by [Ribeiro, 93].

In order to achieve an optimal ranking of terminals, fuzzy set theory [Zadeh, 65] will be used because this problem involves many imprecise criteria such as stability, prices, index of infrastructure and so forth. Consider for example the problem of representing the criteria price "high", how can "high" be represented?. Fuzzy set theory is a suitable tool to represent these imprecise concepts. Fuzzy set theory main objective is to solve problems in which descriptions of activities and observations are imprecise, vague and uncertain. It is a theory of graded concepts where everything is a matter of degree. For example the criteria stability can be expressed as "good", "average" and "bad". Formally, if **X** is a collection of components denoted generically by **x** then a fuzzy set **A** in **X** is a set of ordered pairs $\mathbf{A} = \{\mathbf{x}, \mu_{\mathbf{A}}(\mathbf{x}) \mid \mathbf{x}, \mathbf{X}\}$, where $\mu_{\mathbf{A}}(\mathbf{x})$ is called the membership function or grade of membership of **x** in **A**. Another important aspect of decision making is the reasoning process that takes place when a decision is made. When in the presence of imprecise concepts this reasoning is usually denoted as approximate reasoning [Zadeh, 75].

The main entities to be considered in the multicriteria model are alternatives, criteria, sub-criteria and weights. Alternatives are the set of existing terminals. Criteria are the features used to classify the terminals, such as reliability, flexibility and cost. Sub-criteria are the criteria elements, that can be either crisp or fuzzy, as for example unions, social status and stability of criteria reliability. Weights are the preferences the user expresses for each criteria and sub-criteria. By default the weights are considered equivalent.

After presenting the main entities of our decision making multicriteria model a brief introduction to the decision making algorithm is needed. The mathematical formalisation to be used is:

Assuming there is set of decision alternatives $A = \{A_1, A_2, \ldots, A_n\}$ and a set of crisp and fuzzy criteria, $\mathbf{C} = \{\mathbf{C}_1, \mathbf{C}_2, \ldots, \mathbf{C}_\mathbf{m}\}$. Let $\mathbf{R}_{\mathbf{ij}}$ be a numerical rating (membership value of each alternative **i** assessed by criteria **j** and $\mathbf{W}_\mathbf{j}$ the weight of the respective criteria **j**. Then the general decision algorithm is:

$$\mathbf{D} = \underset{\mathbf{i}}{\mathbf{Max}} \left\{ \sum_{\mathbf{j}=1}^{\mathbf{m}} \mathbf{W}_\mathbf{j} * \mathbf{R}_{\mathbf{ij}} : \mathbf{A}_\mathbf{i} \right\}$$

where for $\mathbf{D} = \mathbf{A}_\mathbf{k}$ chose $\mathbf{A}_\mathbf{k}$ such that $\sum_{\mathbf{j}} \mathbf{W}_\mathbf{j} * \mathbf{R}_{\mathbf{kj}} \geq \sum_{\mathbf{j}} \mathbf{W}_\mathbf{j} * \mathbf{R}_{\mathbf{ij}}$ for $\forall$ **i**.

The reasoning process in the multicriteria analysis will probably also use the evidential logic rule of Baldwin [Baldwin, 94], which formally is,

$$D_{ev\log}(A_i) = S\left(\sum_j W_j * C_j(A_i)\right) \quad \text{where } \sum W_j = 1 \text{ and } S:[0,1]\times[0,1].$$

The weighting coefficient **Wj** for criterion **Cj** is the relative importance of each criterion in the selection process. Since the weighted rating **Devlog (Ai)** is not a conjunction (intersection) it might be said that it is true if *most* of the weighted criteria are true, where the *most* is a fuzzy linguistic truth function modification [Zadeh, 87]. Then the final decision support for the evidential logic rule **Devlog** obtained for each alternative **Ai** is given by passing the weighted average linear function through the function **S** which is the mapping shown in the formula. As can be observed this rule is a special case of the weighted average formula of the general decision making algorithm.

Our weighting system will be based on the conclusions of Alreck and Settle [Alreck, 85] in terms of questionnaire design. Importance represents the relative merit of a specific criteria or sub-criteria. Weights or importance are context-dependent and therefore they should be defined at run time. The choice about which technique must be used to define the relative merit of the criteria should be left to the decision makers. They should be presented with a significative range of possibilities to select from. For example, the transportation costs could be an interval where the values closer to the user needs will have a greater impact in the ranking process. The fuzzy scale for the criteria preferences (weights) will be: EI (Extremely important), VI (Very important), I (Important), N (Neutral), I (Irrelevant) and NI (Not important). The manager can either give weights only to the three main criteria or to each particular component.

3. Conclusions

EMOLITE joins efforts from several different experts (e.g. transports and logistics, computing science) to produce an evaluation model to identify the optimal location of intermodal terminals in Europe. The project has been developed following a rapid prototyping approach. We started building the user interfaces during the requirements analysis phase. This helped us understanding the requirements and having a tool to communicate within our team.

The development techniques used come from classical structured techniques, such as structured analysis, to artificial intelligence concepts, such as fuzzy set theory. For the initial prototype we decided to use relational databases to hold all the information and to implement the fuzzy algorithms using C++. The decision of using structured techniques, and not just an object-oriented development, is due to the lack of reliable object-oriented databases. Therefore, on the one side, we have a relational database able to link to existing external databases, such as the geographical database GIS/Geodata. On the other side, we have the simulation model, build using new technologies, such as object-oriented approaches and fuzzy set theory. These two modules of EMOLITE are integrated and form the required evaluation model.

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