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**A GIS BASED INTELLIGENT
TRAILER MANAGEMENT SYSTEM**

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A GIS BASED INTELLIGENT TRAILER MANAGEMENT SYSTEM

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CHAPTER 1 – INTRODUCTION

This research develops a framework for modeling the tactical trailer management problem of moving full and empty trailers (both owned and rented) to maximize expected profit over a given time horizon. The research includes a prototype GIS (geographic information system) based DSS (decision support system). The main goal of the research is to develop a model and DSS that are “intelligent” in that they can provide useful answers based on limited available data.

The research report has three main parts. First, the literature survey summarizes recent work on strategic, tactical, and operational trailer management problems. Second, the mathematical model chapter details the tactical trailer positioning problem. Third, the DSS chapter provides a summary functional specification of a GIS-based decision support system, and describes a simple prototype.

CHAPTER 2 – LITERATURE REVIEW

This chapter reviews selected literature related to trailer management. The objective is to detail recent and significant material, not to provide an exhaustive review. This survey is based largely on literature surveys presented by Rajapkar (1997) and Crainic and Laporte (1997).

2.1. Hierarchical Decision Taxonomy

Management problems and decisions can be classified according to their scope as strategic, tactical, or operational. Strategic problems have the widest scope. Typically, strategic decisions have effect over several years, involve large expenditures, and are hard to reverse. Tactical decisions have effect over a single year and are less far-reaching than strategic decisions. Operational decisions deal with day-to-day problems and issues. This taxonomy is only a rough guide, as the various decisions levels obviously interact.

2.2. Strategic Trailer Management

Strategic management considers long term decisions that involve large capital expenditures. In a trailer management context, the decision whether to maintain a private fleet or outsource transportation activities is a strategic decision. Rajapkar (1997) summarizes recent fleet-sing literature. Strategic decisions are made at the upper-management level and are relatively infrequent.

Crainic et al. (1989) present a model in which strategic location/allocation decisions depend, in part, on the need to balance flows of containers from depots to

customers and empty containers from customers to depots. While trailers are not exactly analogous to containers, it is apparent that trailer movements could similarly affect location/allocation decisions for freight terminals.

Cole (1995) presents a strategic distribution network design model with interacting decisions on warehouse location/allocation, inventory, and transportation mode choice. The basic objective in his model is to minimize total cost. Insofar as it affects transportation cost, trailer management could affect the overall strategic model. Cole does not dwell on this, since transportation cost was only one of several factors considered in his model.

2.3. Tactical Trailer Management

Tactical management decisions affect operations over the course of year or so, and are often made by middle managers. Tactical decisions typically comprise generating basic rules and policies for how to operate a given system. Crainic and Laporte (1997) list the following main issues considered at the tactical level of freight transportation planning.

- empty balancing (repositioning of empty vehicles to meet forecasts)
- service network design (route choice and frequency)
- traffic distribution (routing specification for each origin-destination pair)
- terminal policies (general rules)
- crew and motive power scheduling

Although each of these can be related to trailer management, the issue of empty balancing is the most directly related.

Rajapkar (1997) presents a model for moving loaded and empty trailers so that profit (revenue from loaded trailers – cost of empty trailers) is maximized. His model is expanded later in this research report.

2.4. Operational Trailer Management

Operational management deals with day-to-day decision issues. Operational decisions follow guidelines set during tactical planning. Crainic and Laporte (1997) list the following operational issues encountered in freight transportation:

- empty vehicle positioning
- crew scheduling
- real-time resource allocation

Each of these issues is also faced at the tactical level. The difference is that operational decisions must usually be made in (near) real-time and must be specific. For example, operational-level empty vehicle positioning must specify where to send each specific empty trailer. On the other hand, tactical-level empty vehicle positioning does not differentiate between two similar trailers located at the same terminal.

Crainic and Laporte (1997) and Dejax and Crainic (1987) present thorough literature reviews on the operational aspects of empty vehicle positioning.

2.5. Decision Support Systems

Shen and Khoong (1995) present a DSS and network optimization model for multi-period distribution of empty containers for a shipping company. They break the problem into three levels: terminal planning, inter-regional planning, and intra-regional planning. Decisions are made at each level based on minimum cost network flow solutions. They solve their model using AMPL (a mathematical programming language).

Goeschalckx, et al, (1994) discuss the development of a graphical-based computer system for designing logistics networks. They developed their own simple GIS (geographic information system) and used a flat file database.

ESRI provides MapObjects™, a simple geographic information system that can be easily integrated in a user-defined Microsoft Visual Basic™ program. GIS programs such as this are significant in that they enable researchers to develop quality prototypes rapidly and inexpensively.

Fourer, et al. (1993) describe AMPL, an algebraic mathematical modeling language. AMPL enables the rapid development and debugging of models that can be easily hooked to commercial database programs. Such capabilities are very important since the design of decision support system is an ongoing process subject to revisions dictated by users.

Slats, et al. (1995) caution that logistics network analysis that starts with the mathematical model can be inadequate. Instead, they suggest starting the analysis with a view to data availability. They also stress the need to be able to rapidly develop new models and extend old ones when working with real-world logistics systems.

CHAPTER 3 – MATHEMATICAL MODEL

This chapter details a mathematical model for the tactical management of trailer flows (see Rajapakar (1997) and Mohsinuddin (1997)) for earlier versions of the model). The model is tactical in that it deals with aggregated, average-case data. Section 3.1 lists some basic assumptions. Section 3.2 covers the mathematical notation. Section 3.3 presents the mathematical formulation in traditional form. Section 3.4 discusses computation issues.

3.1. Assumptions

The problem is formulated as multiperiod, deterministic, capacitated multicommodity network model. The network comprises nodes (terminals) and arcs (connections between arcs). Each period, there is a forecasted demand within each terminal region and between terminal regions. Trailers (either owned or rented) are used to satisfy these demands so that profit (revenues – costs) is maximized over the time horizon.

3.2. Notation

Sets and Indexes

i,j,k terminals

p periods

Superscripts

r = rented

o = owned (or long term lease)

Parameters

C_{ij} cost to move an empty trailer from i to j

Cap_{ijp} maximum number of trailers (loaded + empty) that can be moved from i to j in period p

D_{ijp} forecast demand for loaded trailers from i to j in period p

$FacilityCap_j$ maximum number of trailers (loaded + empty) that can be handled at j in a single period

R_{ijp} average net revenue generated by moving a loaded trailer from i to j in period p

Independent (Decision) Variables

e_{ijp} empty trailers to be moved from i to j in period p

l_{ijp} loaded trailers to be moved from i to j in period p

3.3. Mathematical Formulation

Maximize

$$\sum_i \sum_j \sum_p [R_{ijp}^o l_{ijp}^o - C_{ij}^o e_{ijp}^o] + \sum_i \sum_j \sum_p [R_{ijp}^r l_{ijp}^r - C_{ij}^r e_{ijp}^r] \quad (1)$$

Subject to

$$\sum_i (l_{ijp}^o + e_{ijp}^o) = \sum_k (l_{jk(p+1)}^o + e_{jk(p+1)}^o) \quad \forall j, p \quad (2)$$

$$l_{ijp}^o + e_{ijp}^o + l_{ijp}^r + e_{ijp}^r \leq Cap_{ijp} \quad \forall i, j, p \quad (3)$$

$$\sum_i (l_{ijp}^o + e_{ijp}^o + l_{ijp}^r + e_{ijp}^r) \leq FacilityCap_j \quad \forall j, p \quad (4)$$

$$l_{ijp}^o + l_{ijp}^r \leq D_{ijp} \quad \forall i, j, p \quad (5)$$

$$l_{ijp}^o, l_{ijp}^r, e_{ijp}^o, e_{ijp}^r \geq 0, \text{ integer} \quad \forall i, j, p \quad (6)$$

The objective function (1) states that the goal is to maximize total profit over the time horizon. Profit is equal to net revenues from loaded trailer flows less cost of empty trailer flows. Note that owned and rented trailers can have different revenue and cost parameters.

Constraint (2) states the conservation of flow of owned trailers. In this model, owned trailers can neither be sold nor purchased. Note however that there is *no* conservation of flow constraint for rented trailers.

$$\sum_i (l_{ijp}^r + e_{ijp}^r) = \sum_k (l_{jk(p+1)}^r + e_{jk(p+1)}^r) \quad \forall j, p \quad (7)$$

The model assumes that trailers can be rented and/or returned at any region during any period. In this respect, rental trailers are more flexible than owned trailers.

Constraint (3) states the limited capacity for moving trailers between terminals, due to a limited number of tractors, for example. If the terminal subscripts are identical, the constraint limits the number of trailers in a region. If the constraint were modified slightly to count only empty trailers, then it could be used to enforce space capacity at the terminal.

Constraint (4) states that the number of trailers that flow through a terminal may not exceed the terminal's handling capacity.

Constraint (5) states that the total loaded flow over channel cannot exceed the associated demand. The model chooses which demands to satisfy in order to maximize total average profit.

Constraint (6) states that the loaded and empty flow variables can only take nonnegative integer values. Fractional trailers are not allowed, even if a region's demand requires only a fraction of a trailer's capacity.

3.4. Computation

The time required to solve an uncapacitated problem is often directly related to the problem size. Let I be the number of terminals and P be the number of time periods, then the problem size is approximately:

Number of integer variables: $4 * I * I * P$

Number of constraints: $2 * I * P + 2 * I * I * P$.

Several small test cases were run in which the model was programmed using the AMPL modeling language and solved via XLSOL. Solution times were less than a few minutes. For large, capacitated problems, solution times can be expected to be longer and much more variable. This is an area for future researchers to examine.

CHAPTER 4 – DECISION SUPPORT SYSTEM

Figure 1 shows the conceptual framework for the DSS (decision support system). The user interacts with the GIS (geographic information system) which functions as a graphical user interface. In the prototype software the GIS is ESRI MapObjects™, an add-on to Microsoft Visual Basic™. The GIS provides an interface to the database, in this case Microsoft Access™. When the data are organized, the GIS interfaces to the math model, in the form of AMPL™. AMPL™ in turn calls the solver, XLSOL™ in the prototype.

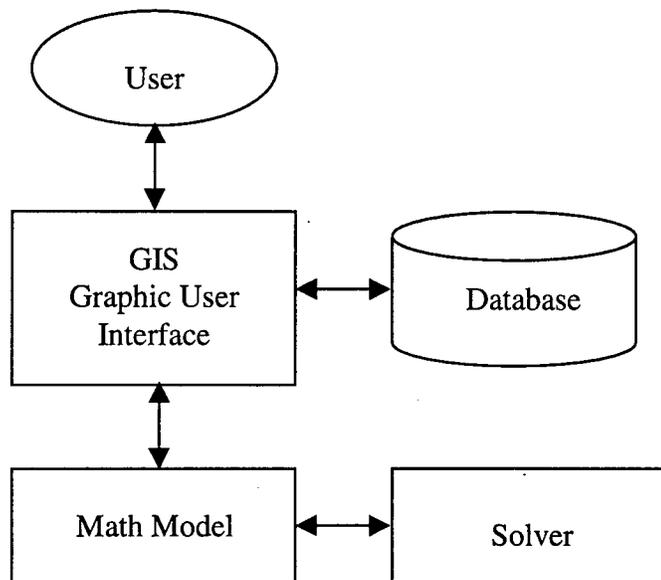


Figure 1. Conceptual Framework for Decision Support System

4.1. Geographic Information System

The GIS program is based on moView, a sample application program that is included free with ESRI MapObjects. Figure 2 shows the main screen. The user is

able to click on a city (or pair of cities for channels) to input or edit data.

Communication with AMPL is effected via the menu.

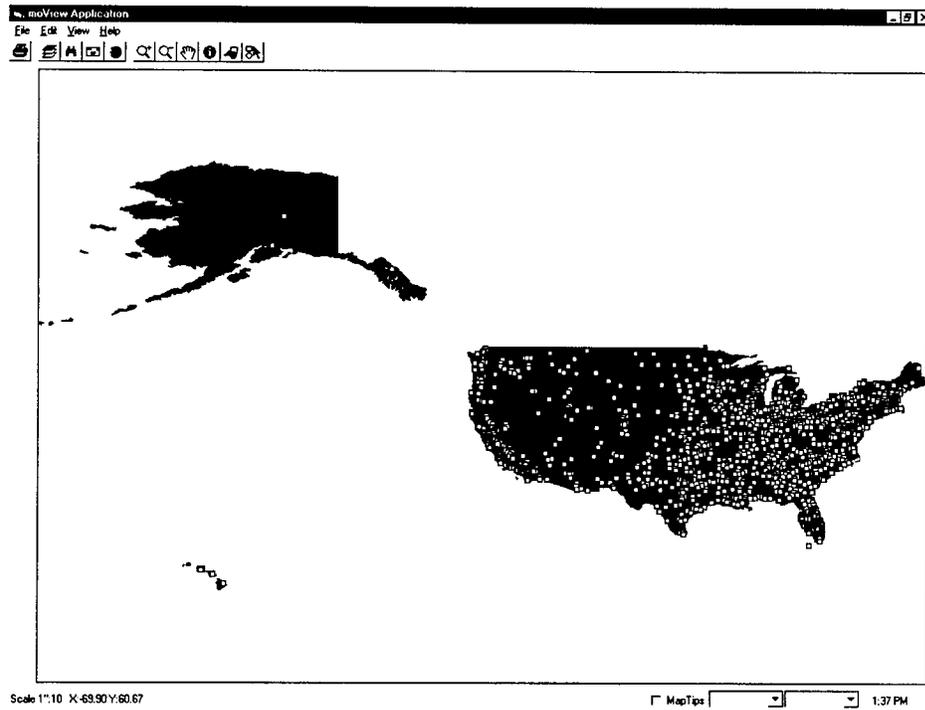


Figure 2. GIS Main Screen

Figure 3 shows a sample dialog box that pops up when the user clicks on a city. The dialog box enables the user to query the database and edit the database with respect to the node-related data tables. Similar dialog boxes are used to edit the channel data table.

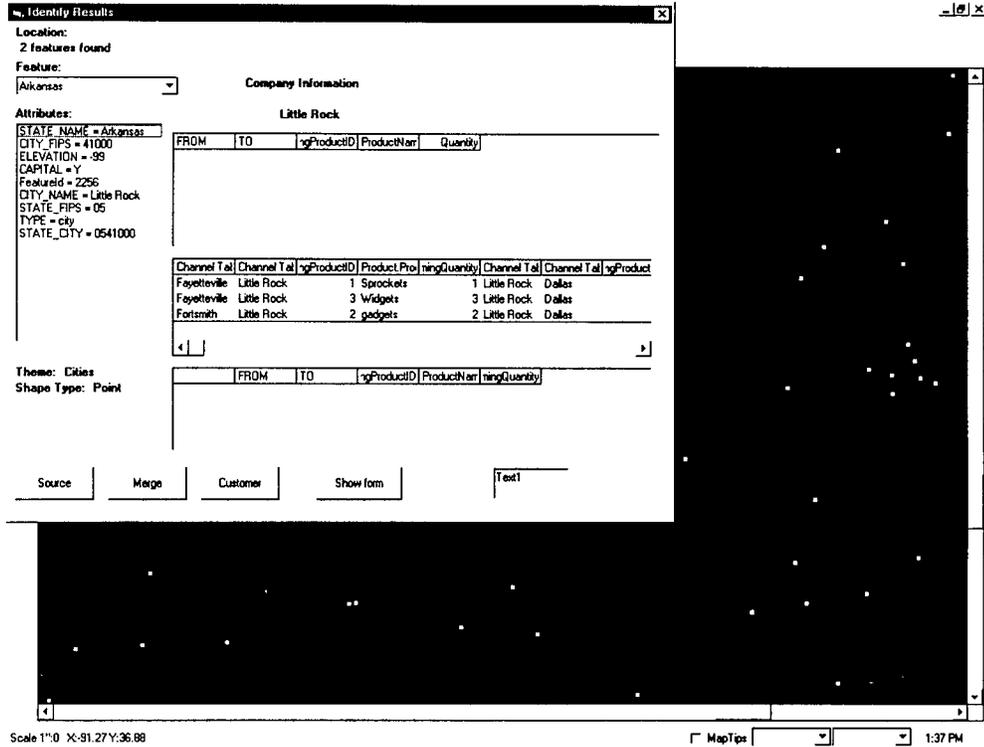


Figure 3. Sample Dialog Box

4.2. Database

The database should comprise the following tables: Terminal, Channel, and Flow. The Terminal and Channel tables are for inputs (parameter values), while the Flow table is for outputs (decision variable values). In general, each table is keyed to a unique name. For instance, the Terminal table is keyed to unique terminal names and the Flow table is keyed to unique channel names (or numbers).

Table 1 lists the fields of the Terminal data table.

Table 1. Terminal Table

Name
Location (zip code)
Capacity

Table 2 lists the fields of the Channel table.

Table 2. Channel Table

Name
Origin Terminal
Destination Terminal
Empty flow cost
Demand (by period)
Capacity (by period)
Loaded revenue (by period)

Table 3 lists the fields of the Flow table.

Table 3. Flow Table

Channel Name
Empty flow (by period)
Loaded flow (by period)

4.3. Solution Package

The solution package used in the prototype comprised AMPL+ (a mathematical modeling language) and XLSOL (a solver).

CHAPTER 5 – CONCLUSIONS

This research developed a simple mathematical model and decision support system for tactical trailer management.

Future research should include a full parametric analysis of the model to determine how sensitive solutions are to the various parameters. Future research should concentrate on extending the model to account for capacities, additional costs, and different cost structures (e.g., economies-of-scale). Future research should also consider modeling the system dynamically using simulation or multi-period network models. Researchers are advised to keep their models parsimonious since data collection can be a real challenge.

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