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SIMULATING THE IMPACT OF CHANGES IN A STATEWIDE FREIGHT SYSTEM

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This model of the Michigan Freight Transportation System simulates the decision processes of shippers for freight movements in the state of Michigan. Given an origin and destination, the model will produce appropriate routes for shipments of a specified commodity, and will allocate the shipments of that commodity on a percentage basis to those routes, according to the freight rates, transit times, and variability of transit times for those routes. The model can be used to examine the effect of changed circumstances on the shipments of that commodity. These can include changes in the physical network system, its ownership or operating policies, or underlying economic parameters. For either single mode or multimodal routes, the model generates the variable costs associated with these routes, the applicable tariffs, the expected transit times, and the variability of times in transit. These data are used by a probabilistic model which computes the expected "market share" for each of the generated routes.

1. INTRODUCTION

Planning for the future needs for freight transportation in a state can be complex. Questions arise in planning for freight transportation systems which involve determining the effects of fuel price changes, labor wage rate changes, or changes in physical facilities or operating policies within the freight system. The latter changes could include the addition of trackage rights, elimination of rights-of-way, or adding shipping facilities. A conceptualization of the transport system which can provide information regarding the consequences of changes in the physical network, or in the costs and parameters which affect its operations, is very useful in attempting to answer these questions. This paper describes the application of a particular variety of network model to these problems. The model operates over a detailed Michigan network representation embedded within an appropriate skeletal representation of the rest of the U.S. and Canada.

There are two kinds of questions that can be addressed by these models. The first variety loads freight flows onto links of a network to determine congested links or bottlenecks. The second variety concerns the consequences of changes in the physical system. This is primarily the question addressed by the present model.

1.1 Previous Approaches to Freight Network Models

The earliest freight network model was probably the National Intercity Modeling System (NIMS) (Swerdloff 1971). Other similar models are the Great Lakes/St. Lawrence Seaway model (Kearney 1976) and the Inland Navigation System Analysis model (CACI 1976). Recent work has also been accomplished by CACI, Inc. (Bronzini 1979) and by Alain Kornhauser (1980).

Early modeling efforts utilized minimum time path algorithms to identify least cost routes between specific origins and destinations. This approach has the disadvantages that only one route is generated for each origin/destination pair, and that the railroad routes generated do not consider rail company practice. Early efforts to represent actual railroad routes did not work well because the rail nets of different companies were not given as separate networks, and because simple time or distance minimization is often inconsistent with practical operating considerations.

There is a further difficulty with some models in which the individual physical rail links have been condensed into a "sparse" network so that individual railroad companies are not identified. Instead, a single link between two cities is used to represent all railroads serving that city pair. Under such circumstances, a computer-produced minimum time or minimum distance algorithm uses links from many railroad systems with little regard for actual practice. This will usually generate very unrealistic rail routes.

The identification of only a single "best" route from one point to another ignores the possibility that several routes may equally share the freight traffic between two cities because the routes are nearly equivalent in all important respects. Consider two highway routes from Los Angeles to Chicago, one through Oklahoma City, and the other through Salt Lake City. These routes are nearly identical with respect to road distance and travel time. It seems obvious that neither route is so attractive that it would draw all of the traffic from the other. Instead, depending on road conditions, the two routes would draw nearly the same level of traffic.

For applications which "load" commodity flows onto network links, the choice of "best" routes has important implications since the entire tonnage for an origin/destination move is assigned to only one, rather than a number of routes. This can produce "lunging" from just small changes in the network, so that the former "best" route between two points is now assigned none of the traffic while the former "second best" route is assigned it all.

2. THE STRUCTURE OF THE MODEL

The work reported in this paper has been developed in two separate efforts. The first of these was the development of a regional network model for the U.S. Department of Energy (Bushnell <u>et al</u>. 1978). The second effort resulted in a radically rewritten model developed for the State of Michigan, to be used in evaluating the effects of changes on the port system of Michigan. The first program included only highway and rail nodes and no intermodal routes. The present version includes water, highway and rail networks as well as intermodal routes.

The model embraces three separate areas of calculation: (1) generation of routes, (2) calculation of the costs, tariffs and times associated with each route, and (3) determination of route split through the application of an empirically derived route-split model. Each of these areas will be addressed in turn.

2.1 Pathfinding Modules

The original version of the model was limited to rail and truck transportation and used separate pathfinding algorithms for each mode. However, the generation of intermodal routes is greatly facilitated by the use of a single algorithm for all modes of transportation. The current model utilizes a highly-modified Ford-Fulkerson algorithm to generate rail, highway, water and multimodal routes.

<u>Rail Pathfinding</u>
The original version of the model used a relatively simple algorithm to generate railroad routes which approximated the actual practice of shippers and railroads in the U.S. The basic thrust of the method was to utilize the minimum number of railroad companies to move from the origin to the destination.

It was felt that railroads tend to move freight which originates on their own lines relatively expeditiously, while the transfer of freight from one railroad to another involved substantially greater delays than a route which could avoid such transfers. Therefore, if a one-railroad route could be found to connect the origin and destination, the rationale was that it would only be in competition with other one-railroad routes, with some exceptions. These exceptions to the minimum railroad theorem were dealt with as special cases, and usually arose because of close cooperation between certain railroads in order to provide competitive service to routes which involved fewer railroads. The overall procedure was to seek routes which involved the least number of railroads needed to reach the destination.

In the latest version of the model, this procedure has given way to one in which a highly-modified Ford-Fulkerson algorithm is used to minimize the elapsed time needed to reach the destination. An ordinary path-minimization algorithm would tend to produce very unrealistic railroad routes because of the tendency to switch railroads at any convenient intersection, whether this was appropriate or not.

The modifications made to the current version produce not only the minimum time railroad path which makes sense to those knowledgeable about actual routes used, but will <u>also</u> produce the next "n" most desirable routes. An analysis of this sort will often show that there are several nearly equivalent paths which will share the railroad traffic between a specific origin and destination.

<u>Highway Pathfinding</u>
The original version of the model used a strict time minimization algorithm to generate truck routes between origins and destinations. Because of the limiting nature of the algorithm used, only <u>the</u> best route between each origin and destination was found. It was felt originally that this would be sufficient because it was expected that truckers would usually use this route almost exclusively.

However, after implementation of the improved version it was found that paths exist which have very nearly identical distances and travel times, even though the paths may run hundreds of miles apart. An example is the set of routes between Chicago and Los Angeles. Like the rail procedure, the improved version of the truck path-finding procedure allows the specification of the best "n" routes, which are reported in order of their desirability. This section also uses the Ford-Fulkerson algorithm mentioned above.

<u>Water Pathfinding and Intermodal Routes</u>
The water pathways through the Mississippi River System and through the St. Lawrence and the Great Lakes are sufficiently sparse that no special problems are encountered. Except for the important case of bulk commodities which are loaded from bulk deposits near a waterway and directly off-loaded to consumption locations on the waterway, most waterborne shipments must rely on other modes to complete their journey.

For intermodal shipments, the nature of the facilities at the transfer point between modes is fundamentally important. For the bulk commodities, the facilities available at a transfer point depend on the commodity being shipped. Little grain can be shipped where there are no elevators. Coal cannot be handled efficiently without a coal dock. Perhaps most important, the maximum size ship that can call on a port is constrained by the dimensions of the port. Therefore, it is necessary to have available to the algorithm the size restriction of the port as well as the availability of special facilities.

It is apparent that intermodal routes differ for various commodities because of the requirements for special transfer facilities. Furthermore, the trade-off in attractiveness to shippers between the transit times and costs for certain routes will depend on the commodity shipped. The trade-offs appropriate for grain will be different from those for coal.

As an added complication, it may be that the set of logical intermodal routes for a given commodity will include some routes which are entirely single mode, and yet are quite reasonable. However with this algorithm we can trace the alternative combinations of highway or railroad with water routes. Shipments from Michigan to Europe, for instance, can go by the Great Lakes and Seaway, by the Canadian rail system to ports at Montreal or Newfoundland, or by rail to many of the East Coast ports, and then to Europe.

2.2 Timing Algorithms

The attitude adopted for this model is that time-in-transit is a combination of two factors: travel time and handling time. Travel time for any mode is treated as a deterministic variable, with all stochastic considerations treated as a type of non-deterministic handling time. Therefore, even though the language is awkward, the time a ship spends passing through a lock is regarded as "handling time." Certainly the times that truck trailers spend loading and unloading, as well as their drop off and pick up times by various tractors at relay yards, can be considered as handling times.

The railroad timing algorithm is based on the detailed operating knowledge of each of the railroads operating in Michigan as to the manner in which the freight cars are collected and moved through intermediate yards to their destination. These yards have been characterized as to the number of "tricks" (shifts) required to process a freight car under different circumstances. Based on work by the MIT railroad reliability group (Belovarac and Kneafsey 1972) (Falk 1972) (Lang and Martland 1972) (Martland 1972) and by E. R. Petersen (1978), we have assumed that handling time distributions may be treated as members of the Erlang family whose frequency function is given in Equation (1).

(1) $$f(x) = \frac{a^n}{(n-1)!} x^{n-1} e^{-ax}$$

This family has the parameter "a" set to 3 and the parameter "n" set to specific values as required. The desirable characteristic of this distribution is that sums of Erlang distributions with same parameter "a" yield an Erlang distribution with the same parameter "a" but with the "n" parameter equal to the sum of the "n" parameters of the summed distributions. Since railroads usually work three tricks (shifts) per day, and the expected value of the distribution is "b/a," the name "number of tricks" is used for the parameter "n." Use of the Erlang distribution thus provides a means of dealing with handling times as the stochastic component of time-in-transit, and can be used to obtain a measure of variability of time-in-transit.

2.3 Cost Modules

Costs for each of the shipment modes in the model are derived by using a very detailed engineering-based cost model applicable to shipments of the specific commodity using that mode. The intent is to generate realistic costs of operation for each specific shipment route. Typical costs included are:

1. Labor costs for vehicle operation.
2. Capital recovery costs for equipment.
3. Terminal costs.
4. Yard costs.
5. Switching costs.
6. Fuel costs.
7. Maintenance costs.
8. Costs for operating supplies.
9. Other costs of specific shipment mode.

The cost models take into account the operating characteristics of the vehicle used for that commodity, as well as the characteristics of the specific route which would affect the costs incurred and the fuel used.

The cost models are derived from various sources. The railroad cost model is taken from the work of John F. Murphy of the U.S. Transportation Systems Center (1976). The truck model is patterned, with substantial modifications, on a model developed by William R. Martin of the Association of American Railroads (1976). The waterborne cost model is based on a series of models developed by the Department of Marine Engineering of The University of Michigan (Elste 1978).

2.4 Rate Modules

Models in this area have taken two approaches to the variable utilized as the price or cost variable. The Great Lakes/St. Lawrence Seaway study used rates directly supplied by freight bureaus, obtained through the Corps of Engineers which has a mandated responsibility to monitor freight tariffs. The Inland Navigation System Analysis and later CACI models used computed costs on the grounds that rates will follow costs.

The present model assumes that changes in costs will generate changes in rates, but that rates are the relevant variable perceived by shippers. Therefore, the model calculates both costs and rates, and the spread or "margin" between them. The model could be used to compute new rates resulting from a change scenario as equal to the new cost plus the old minimum margin (difference between rate and cost) for the mode.

Rail tariffs are developed on the supposition that for all except some "specific" tariffs (meaning a tariff for a "specific" commodity between two "specific" locations), all regular, class, column, and commodity rates could be identified as percentages of first class (100%) tariffs. Therefore, the U.S. is divided into geographic subdivisions corresponding to rate bureau jurisdictions for each transportation mode. The first class rate tables which apply for shipments within each jurisdiction and between each pair of jurisdictions are stored. The proper rate tables were determined by a freight rating firm. For example, for the railroads there are three rate bureau jurisdictions: Official, Southern and Western. This implies nine tables: one within each jurisdiction and one for the flows between jurisdictions in each direction. Each of these tables has an associated percentage constant called an "ex-parte" constant which serves to adjust it for across-the-board increases. For each of a wide variety of commodities, there is then a set of percentages (for rail there are nine such for each commodity) which is the appropriate percentage of first class to be used for that commodity with each table.

Truck tariffs were originally calculated like rail tariffs. However during recent years (1978 to 1980), the trucking industry has been operating in some respects as though unregulated. Contacts with some sources give the impression that a large number of owner-operators are willing to deliver on just a bill of lading without any clear tariff or authority, and that these "violations" are seldom prosecuted. In addition, each freight bureau regularly publishes almost any rate requested. Therefore, although the situation could not be characterized as "perfect competition," it bears a close enough resemblance that tariffs can be approximated by costs. A percentage is added to the calculated costs to account for the "margin". Such an approximation, it is recognized, fails to take certain factors into account. These factors include supply and demand conditions such as business cycles and seasonality, and whether the destination for the shipment will be a likely source of back haul business.

Water rates are developed from the waterborne cost models as the long term average cost which would have to be paid by a vessel owner-operator.

2.5 Route-Split Modules

The route split analysis is comprised of two parts, a model of choice and a method for inferring part-utilities. It has been documented further in Wiley and Colberg (1980). The additive part-worth model assumes that a utility score may be calculated as an additive function of a number of part-utilities, each multiplied by a quantitative performance level of service. The tool used is a particular variety of conjoint analysis known as trade-off analysis (Johnson 1973, 1974). This method treats utility as a linear form and permits the estimation of part-utilities due to different levels of different characteristics on the route.

The variables utilized for this model were dollar cost, time-in-transit and variability (variance) of time-in-transit. Interviews were conducted in which traffic decision-makers were given the opportunity to rank different conjectural routes representing different combinations of levels of the different route characteristics. The (normal) distribution of part-utilities for each characteristic was calculated from these observations. With this set of distributions, the distribution of the utility of any given route, with any given levels of different service characteristics can be computed.

To establish route split, it is assumed that the utility scores of all the alternative routes are distributed joint normally. Thus the proportion of traffic gained by a route will be the probability that the value of a given route's utility score is greater than or equal to the utility scores of all other routes. This could be difficult to compute. However, following a suggestion by Bock and Jones (1968), if the correlations between utilities are all assumed equal to one half, then the probability may be calculated by using the marginal distributions of the multivariate logistic distribution.

3. THE NETWORK DATA

The network data for Michigan is available in machine readable form from the Michigan Department of Transportation. Each of the link elements contains a variety of information pertaining to that link. For many purposes the links available are more detailed than required. Hence a number of network condensing programs were developed. These programs are of two varieties, link combining and node combining. In the link combining program, nodes having only two links are eliminated, and the two links are replaced by a macrolink. In the node combining program, nodes within a specified distance of each other are combined and any duplicate links thereby created are eliminated. By this means, suburbs and central cities can be reduced to a single place, or neighborhood places collapsed into a town name. The first procedure is applicable to all networks, while the second applies only to highway networks. The Michigan network is embedded in a skeleton of a national network developed by the authors.

One of the features of the present model is that virtually every parameter or data element may be individually changed between machine runs. Among the variety of data files used by the model are parameter files, link files and node files. Parameter files in tabular form cover all the variables used in cost, tariff and timing calculations. A separate disk file is used for each mode. These files may be edited between runs of the model, with the newly updated information being immediately utilized. Alternatively, the contents of a different file may be substituted in entirety for the previously specified file. Alterations in these files enable one to study changes in costs, wages, or prices.

A separate file of links for each transport mode contains the link-specific data. These data may be directly modified through the file editor. Links may be created, destroyed, or modified. With the proper instruction after such changes, the model program will completely reconstruct the internal network from the external network data. Such modification of data would permit the study of rail line abandonment or alternative subsidy plans. Since the ownership of rail lines may be changed on the file, the impacts of rail mergers may also be investigated.

The node file identifies which activities are permitted at each node, what facilities are available and which modes and/or companies may interconnect with each other at that node. Altering this file permits one to investigate the effect of building or creating a new facility or closing an old one. This file, for example, contains the specifications of the port dimension and facilities, as well as the ramps and the rail yards available. All of these data may be altered between runs and the new data utilized immediately.

Experience with the data in Michigan shows that utilizing rather standardized procedures, one can convert existing data bases into usable form. There is nothing immutable about such a data base. Using the computerized procedure described earlier, the existing state data was consolidated several times into a number of appropriate model data files, each emphasising a different aspect. Since all data used by the model is in tabular form, the programs should need little or no alteration in order to be adapted to a new data base.

4. CONCLUSION

Statewide data can be used in a large scale network model in order to allow the simulation of changes in system composition or operation. The use of such a model has the potential to provide transportation planners with improved insights into solutions for freight transportation problems at the state level.

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