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Authors
Munshi, Kaivan
Sullivan, Edward C.

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Kaivan Munshi
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**The University of California
Transportation Center**

University of California
Berkeley, CA 94720

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A Freight Network Model For Mode and Route Choice

Kaivan Munshi
Visiting Fellow
Indira Gandhi Institute of Development Research

Edward C. Sullivan
Department of Civil and Environmental Engineering
Cal Poly State University

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The University of California Transportation Center
University of California at Berkeley

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1. Background and Summary

As California has become increasingly congested, the importance of addressing freight transportation as a public concern has grown. Most visible in our urban areas is the competition for road capacity between trucks and personal vehicles, especially during commute hours, and the public health and safety concerns associated with the transport of hazardous materials. These issues, along with California's role as a principal transhipment point for trade between the U.S. and the other Pacific Rim nations, combine to create a freight transportation problem of immense proportions, one which is aggravated by the difficulty of implementing new infrastructure improvements.

With the goal of providing an analytical capability to help evaluate future infrastructure investments, proposed abandonments, and operational problems related to freight, a research effort has been underway for several years at Berkeley to create a statewide freight network model and associated commodity flow data base. A rudimentary network model has been created, and most recently has been used in a study of freight costs and accessibility to rural communities along the Pacific Northwest coast. The current study, described in this report, is a continuation of this work. It involves the development and testing of a new form of mode and route choice model which can be applied to analyze transportation networks in which services are represented by explicit routes and schedules. Such a model is appropriate for many freight network planning applications, and is equally useful in other areas, such as urban public transportation planning.

The work plan followed in the conduct of this research set out to accomplished the following:

- Select two regions in California as a case study, which would provide two origin-destination pairs for which representative commodity flow data could be obtained to test the new mode and route choice model specification. After attempting and failing to obtain suitable data on perishable agricultural commodities, a data base was created containing flows of lumber products between two locations in Northern California, and San Diego.
- With the help of contacts in selected carrier and shipper organizations, obtain detailed information on truck and railroad routes, schedules, and tariffs for the freight services operating in the corridor of interest. Also, obtain processing times and related level of service information for the relevant pickup and intermodal transfer activities.
- Develop a model formulation which determines the share of traffic using each mode (and route) based on the notion that traffic splits among the different available services on the basis of prevailing costs, travel times, and service frequencies. The split occurs because, during the course of a time period such as a week, the variations in travel and access times cause the services

provided by different modes to dominate during different portions of the overall time period.

- Evaluate the performance of the model against actual data and describe the implications of that evaluation for future model application, and/or future research.

This remainder of this report contains six sections. The next section provides additional background information about the current state of the art in freight network modeling generally, and provides additional insight as to why this research has followed the particular course that it has. Section 3 then presents, in general terms, the conceptual design of the new model. Section 4 describes the data collection process followed to develop the data set used in model testing. Section 5 describes the application of the model to the data set. Because of the simple network and data set employed, this testing was performed manually. The final two sections discuss, in detail, the outcomes of model evaluation, the implications of the study results, and suggestions for future work.

2. Review of Previous Related Work

Much of the previous freight network modeling work which has been done at Berkeley has utilized the Princeton Transportation Network Model. (Kornhauser and Bodden, 1983) It is among the most advanced systems of its kind, both in the size and quality of its network data base and in the usefulness of the associated software (the Graphic Information System). The PTNM/GIS is the result of over a decade of model development and refinement work initially conducted for Congress and the Federal Railroad Administration (FRA) by Princeton University, and more recently advanced by ALK Associates, a Princeton NJ consulting firm. Under the auspices of ALK Associates, the PTNM/GIS has been used extensively by many U.S. railroads, large shippers, and government agencies.

The full PTNM rail network of approximately 23,000 links is a refinement of the original Federal Railroad Administration (FRA) network model developed during the 1970's. The highway and waterway networks were coded originally by Princeton University research staff. Over the years, these networks have undergone considerable refinement and updating.

However, the PTNM/GIS is, by no means, the only antecedent of the freight network modeling work at Berkeley. Papers by Friesz, Tobin, and Harker (1983, 1984) and an earlier article by Bronzini (1980) provide a clear picture of the state of the art in large-scale freight network modeling. In addition to the Princeton model, there are three other comprehensive and up-to-date U.S. network models oriented to freight analysis: the CACI multimodal Transportation Network Model (TNM), the University of Pennsylvania/Argonne Lab. Freight Network Equilibrium Model (FNEM), and the Generalized Spatial Price Equilibrium Model (GSPEM) developed by Patrick Harker in his Ph.D. dissertation at the University of Pennsylvania. An NCHRP report by Creighton Associates and a paper by Kim and Hinkle also suggest that the UTPS (the U.S. DOT's Urban Transportation Planning System) can be utilized for statewide freight traffic planning, largely on the grounds of convenience to state DOT's; (Memmott, 1983; Kim and Hinkle, 1982) however the practicality of this controversial and seemingly naive approach has not, to our knowledge, been demonstrated. Furthermore, several experienced freight transportation analysts have cautioned strongly against trying to force freight transportation to fit an analytical framework designed for modeling intra-urban personal travel.

The most important characteristics of the three principal freight modeling approaches are described briefly below.

The CACI Transportation Network Model has a rather long and complex history which in many ways parallels that of the Princeton Model. The TNM evolved from a multimodal network model created in the mid 1970's for the Inland Navigation Systems Analysis (INSA) project of the U.S. Corps of Engineers. The original INSA rail network was obtained by aggregating the 19,000 link FRA network to about 3,000 links; the original waterways network contained about 400 links. Later work sponsored by the U.S. DOT Transportation Systems Center, in connection with a national freight energy use study, refined the original INSA model and added an aggregated 1,300 link version of the 4,500 link FHWA national highway model as well as about 100 pipeline links. (Bronzini, 1979, 1980) The last improvements to the CACI TNM were sponsored by the Electric Power Research Institute (EPRI), and have emphasized energy resource shipments by rail. (Bronzini and Sherman, 1983)

The CACI TNM is distinctive in two respects: its use of non-linear travel impedance (time and/or cost) functions to represent link service characteristics, its inclusion of energy use, and its traffic assignment logic. (The PTNM and the derivative California model use constant link impedances which do not vary with traffic.)

The link impedance functions of the TNM appear as either increasing or U-shaped average cost curves. The most recent version of the TNM employs a Frank-Wolfe type of equilibrium assignment procedure with special adjustments in the rail network to account for carriers' aversion to handing over traffic to other railroads before absolutely necessary, even if the total travel impedance is thereby increased. The use of equilibrium traffic assignment and non-linear impedance functions closely parallels UTPS-like methods, except in the use of U-shaped average cost functions. Unfortunately, these U-shaped functions result in a non-convex mathematical program, leading to the likelihood that the "equilibrium" traffic assignment is a local rather than a global user-optimum, which makes the physical significance of the traffic pattern that is found unclear.

The Freight Network Equilibrium Model was developed by researchers at the University of Pennsylvania and the Argonne National Laboratory with U.S. Department of Energy sponsorship. So far, it appears that the model has been implemented only for a 15,000-link network model of the national rail and waterway systems, with no highway applications.

The FNEM traffic assignment method is a clever hierarchical procedure which explicitly models shipper behavior as distinct from the behavior of carriers. In the shipper model, there apparently exist demand functions by commodity and by origin-destination pair. Shipper traffic is assigned to a very abstract and aggregate network, employing a Frank-Wolfe type of algorithm to find a user-optimum assignment in broad corridors which represent the carriers' service areas. The outcome of the shipper assignment provides the amount of traffic utilizing each carrier's services, in the form of origin-destination matrices, by commodity, for each carrier under consideration.

The carrier model then uses the carrier-specific origin-destination matrices to determine the system optimum traffic routing patterns within each carrier's service area, using a detailed link-node representation of the actual transportation infrastructure. The premise is that once the shipper has selected the sequence of carriers to provide the origin to destination service for a particular shipment, the responsibility is then left to the carrier to choose the actual route to use within that particular carrier's sub-network. Each carrier's route choice decisions are made on the basis of minimizing the total cost of the carrier's operation.

Patrick Harker's Generalized Spatial Price Equilibrium Model extends the FNEM logic in several important directions. (Harker, 1984) In particular, the GSPEM "closes the loop" in the sense that the shippers' equilibrium solution depends on the carriers' routing decisions, at the same time that carriers' routing decisions depend on the shippers' choices among carriers. These two decision-making processes are therefore consistent, unlike in the FNEM where the dependency only goes in one direction. Also, the GSPEM includes a trip distribution model in the sense that the demand for transportation between each origin-destination pair is determined using spatial price equilibrium theory, based on commodity demand and supply curves at each production and consumption node. To date, this model has been applied with some success to replicate the shipping patterns of eastern coal, using the Argonne Laboratory's 15,000 link rail and waterway network.

The notion of multiple equilibria, which results from the separate actions of the two major actors in freight transportation, the shippers and the carriers, is a very appealing feature of both the FNEM and Harker's GSPEM. Unfortunately, both of these models are very demanding of input data in terms of economic (supply and demand) relationships. Also, to our knowledge, neither has yet been applied to truck transportation. Both models are research tools which emphasize regional economics as much if not more than transportation issues. Furthermore, these models, like the CACI TNM, are afflicted by the problem of non-convex link costs which may result in the presence of local optima if U-shaped average link cost functions are used. Neither the CACI TNM nor the two University of Pennsylvania models are suited to certain classes of freight transportation problems where explicit routes and service frequencies are of concern, or where unusual "cost" functions must be defined as in the case of hazardous material transportation.

However, despite the practical drawbacks of the models, many of the concepts developed through the CACI and University of Pennsylvania work warrant further consideration for possible later incorporation in this research.

In addition to the major national network models described above, there are several related studies which may prove useful in this work. These include the seminal modeling research for Colombia performed by Kresge and Roberts (1971), as well as the freight network algorithms specified by Peterson and Fullerton (1975) and by Lansdowne (1981). All of this previous work is nicely summarized in the aforementioned paper by Friesz et al. (1983)

In addition to past network modeling efforts, there have been several studies to create commodity flow data sets which can serve as models for the work proposed here. Unfortunately, none of the existing commodity flow data sets exists at a sufficiently desegregate level to be used directly in this work. Virtually all of the existing commodity flow data sets were assembled from the same group of specialized primary data sources, including the Railroad Waybill Sample, the Corps of Engineers Waterborne Commerce Statistics, the various economic censuses, and the Commodity Flow Survey conducted by the U.S. Census Bureau.

Notable among the available commodity flow data sets are the national statistics and projections maintained by Reebie Associates in their Transearch data base. This ongoing work maintains national commodity flow data organized in an 183x183 matrix tied to the Business Economic Areas (BEA) of the U.S. Census Bureau, described at the 5-digit Standard Transportation Commodity Code (STCC) level and categorized by seven transport modes (rail carload, TOFC, truckload, less than truckload, private/exempt truck, air, and water). Recently, the Transearch data base was expanded to include forecasts of commodity flow patterns in addition to actual statistics. Although an excellent data source for national applications, the amount of aggregation in the BEA zonal system (eight zones for all of California) is problematic.

Another study which is interesting in its similarity to what might be appropriate commodity flow data for California is the 1979 freight forecasting work performed by Peat, Marwick, Livingston (now Mitchell) and Co. for the Florida Department of Transportation. (Middendorf, et al, 1982) Using several of the above data sources, as well as U.S. and Florida Agriculture Dept. statistics, they developed commodity origin-destination matrices for 13 commodity groups for flows among 67 Florida counties and 49 external locations. A growth factor approach based on the Fratar Model was used to forecast the future freight traffic volumes.

A similar database was established several years earlier for freight transportation planning in a 1,100 mile corridor stretching from Kansas City to Georgia. (Mullens, et al 1978) In this case, researchers relied heavily on commodity flow data from the National Transportation Plan. (Schuessler and Cardellichio, 1976) Origin-destination matrices were developed for 173 BEA areas (similar to Transearch) and for 47 commodity groupings.

Another significant study of freight transportation demand data was performed in the early 1970's at the M.I.T. Center for Transportation Studies. These researchers developed tables of standardized physical characteristics for commodities defined by STCC codes. The data are still useful for establishing the physical commodity characteristics needed, among other things, for calibrating freight demand models. (Samuelson and Roberts, 1975)

Finally, during the past two decades, there has been a rather large number of efforts to develop empirical models of freight transportation demand. Such models may be useful in suggesting clever ways of representing transportation levels of service for the models to be developed and tested in this research. A full complement of freight generation, distribution, and mode choice models are well represented in the literature and are too numerous to characterize here. A recent article by Winston (1983) does a good job of documenting the current state of the art.

3. Conceptual Background for the Model

Tariffs and transportation time are typically assumed to be the only attributes (costs) of a mode when studying the freight transportation mode choice decisions made by shippers. The transportation time may be further subdivided into an arrival delay (time that the carrier takes to arrive at the firm after being informed that a shipment is ready), a loading time and a line-haul time. The total transportation cost may be estimated as a generalized function of the form:

$$g = k \cdot m + T$$

where,

g = general cost in time units
k = the reciprocal of the value of time
m = freight tariff
T = transportation time

In reality, the generalized function for each mode is not constant over time. This is mainly due to the variance in the arrival delay. If this delay is uniformally distributed (equal probability of any delay occurring within the range of the variation), then the arrival delay experienced by the shipper over time may be considered analogous to the wait delay experienced by individuals arriving at a transit stop, at a uniform rate, for a bus service with a constant headway (equal to the maximum range of the variation described above). Extending this analogy further, the sum of the remaining general cost components (loading time, the line-haul time, and the time value of the tariff) which is roughly constant, may be assumed to be equivalent to the travel time for the transit line. In addition, the shipper is informed of the arrival delay by the various freight transport operators (for all modes) as soon as a load is ready for shipping. This would be equivalent in the analogous problem to a traveller arriving at a transit-stop with complete knowledge of the next scheduled arrival of all transit lines. Consequently, for the remainder of the report, all modes will be referred to as <u>lines</u>, which are characterized by headways, routes, and travel times. The shipment of products over time will be represented in the same way as the arrival (at a constant rate) of travellers, with a perfect knowledge of line schedules, at a transit-stop. The model considers a time period which is equal to the least common multiple of all the line headways, henceforth referred to as a "cycle". The sequence of arrivals in a cycle comprises a complete and distinct set of arrivals that completely defines the schedules of all the lines, repeating over time. The results of the model may thus be extended over multiple cycles without any loss in generality.

The traveller arriving at a particular point in the cycle would be aware of the expected wait delay at the transit-stop for each line, as well as the travel time, and would thus choose the line that minimized his general cost. However, while each line will have a unique and constant headway and travel time, its arrival delay would vary over a cycle. Hence, it is conceivable that multiple modes would be chosen over the course of an entire cycle. As the individuals are assumed to arrive at the transit-stop at a constant rate, the proportion of the cycle in which a given mode is preferred would be equivalent to its mode share over time. This may be contrasted with conventional deterministic mode choice models which propose an all-or-nothing allocation in which the mode characterized by the lowest average general cost is always chosen.

4. Data Collection

Ideally one would be interested in determining the headway and travel time by each mode for a single firm shipping its product to a particular destination. The actual mode shares would also be required, to verify the results of the model. However, mode shares are only available from secondary data sources for flows between aggregated geographic areas. Consequently, it is necessary to determine the modal characteristics that are representative of the entire aggregated area. Furthermore, multiple origin-destination pairs were considered (for additional verification of the model) while operationalizing the model, resulting in a simple freight transportation network. As a simplification, the data for the model was collected for shipments of a single commodity, within California, and included rail and truck modes only. The rail share was determined for a period of one year (1985).

The first task that presented itself was to select a suitable commodity. The set of origin-destination pairs to be studied was chosen next, defining the freight network described earlier. The data collection process was completed by determining the headway and travel time (considering all available routes) by each mode for all origin-destination pairs.

Choice of commodity

There is no constraint on the choice of commodity except that a significant mode share for both truck and rail be demonstrated. It may be recalled that tariffs and transportation time were the only modal attributes considered in the model. Consequently, the value of transportation time must be significant, for the model to have reasonable predictive power.

In general, bulk goods with low time values tend to be shipped by rail, while fragile finished products and perishables are transported by truck. To satisfy the requirements mentioned earlier, one would ideally choose perishable bulk commodities. While researching potential commodities it was noticed that there were serious discrepancies between the various secondary data sources. The one percent railroad waybill sample was taken as the definitive data source for the verification of data used in determining feasible commodities and subsequently, origin-destination pairs. Detailed information on the waybill sample may be obtained from the user guide produced by the Association of American Railroads or from Wolfe (1986). Appendix A lists the computer code that was written to process the 1985 railroad waybill tape (the description of the variables may be obtained from the user guide mentioned earlier).

Bulk food products such as potatoes, wheat and rice satisfy all the commodity requirements listed earlier, and hence were investigated first. Production figures by county were obtained from the California County Agricultural Commissioners Reports (1985), while consumption figures were available for major cities from the Fresh Fruit and Vegetables Arrivals in Western Cities (1985) data made available by the U.S. Department of Agriculture.

It is a relatively simple task to create total commodity flows between the production counties and the consumption centers if we assume that the share of the total flow to a consumption center for any origin county is equal to its corresponding share of the total production.

$$f_{i,j}/\Sigma_i f_{i,j} = P_i/\Sigma_i P_i$$

$$\Sigma_i f_{i,j} = C_j$$

where,

$f_{i,j}$ = flow from origin county i to destination center j
P_i = total production in origin county i
C_j = total consumption of products from all the origin counties in the consumption center

However, the mode shares for the movement of food products between the geographic areas of interest were unavailable. In addition, rail shipments of these food products were not observed in the waybill sample, causing them to be discarded from further consideration.

From the list of commodities observed in the waybill data, lumber and wood products, sawmill and planing mill products (STCC code 242) was then chosen as the next best alternative. As lumber is quite durable, the value of the time spent in transportation would not be as high as for food products, reducing the effectiveness of the model considerably, as will be seen later.

Choice of Origins and Destinations

As described above, the flow of a commodity between any origin-destination pair may be approximately derived if the corresponding production and consumption figures are known. For the specific case of lumber and wood products while production data by county were available (see Howard and Ward 1988), consumption figures could not be obtained from standard secondary data sources. The TRANSEARCH data-base (1989) which provides commodity flows at the BEA zone level was thus purchased. It may be recalled that the model is formulated as a mode-choice process over time for a single firm (sawmill in this case). Consequently, one would expect significant aggregation error in comparing the mode shares obtained from the database and the model. To minimize this error, it is preferable to choose origin and destination zones that are as geographically compact as possible. Consequently, San Diego was designated as the consumption center for the model (after duly verifying from the waybill data that it received lumber shipments by rail, from within California, in 1985).

The criteria for choosing origin BEA zones was that the total flow to San Diego be substantial with a significant mode share for both rail and truck. The BEA zones chosen were characterized by a single dominant lumber producing county to minimize the aggregation error mentioned above. The transportation network was built, and information on modal characteristics obtained for 'point' origins (specific lumber production centers). Redding in Shasta County (Redding BEA zone) and Ukiah in Mendocino County (San Francisco-Oakland BEA zone) were ultimately chosen as the origin locations.

Table 1 describes the flow of lumber by rail and truck in tons/year in 1985 as obtained from the TRANSEARCH data. The share of the dominant county (described above) in the total production and the rail share (considering hired carriers only) are also provided for each BEA zone.

Table 1
Lumber Flows and Mode
Shares to San Diego for Selected
Origin BEA Zones in California (ton/year in 1985)

Origin BEA zone	County (share)	Flow of lumber				Rail share
				Truck		
		Total	Rail	Private	Hire	(hire only)
S.F.-Oak.	Mendocino (0.88)	52909	14999	22315	15595	0.49
Redding	Shasta (0.43)	54976	14120	24792	16064	0.47

Transportation Network

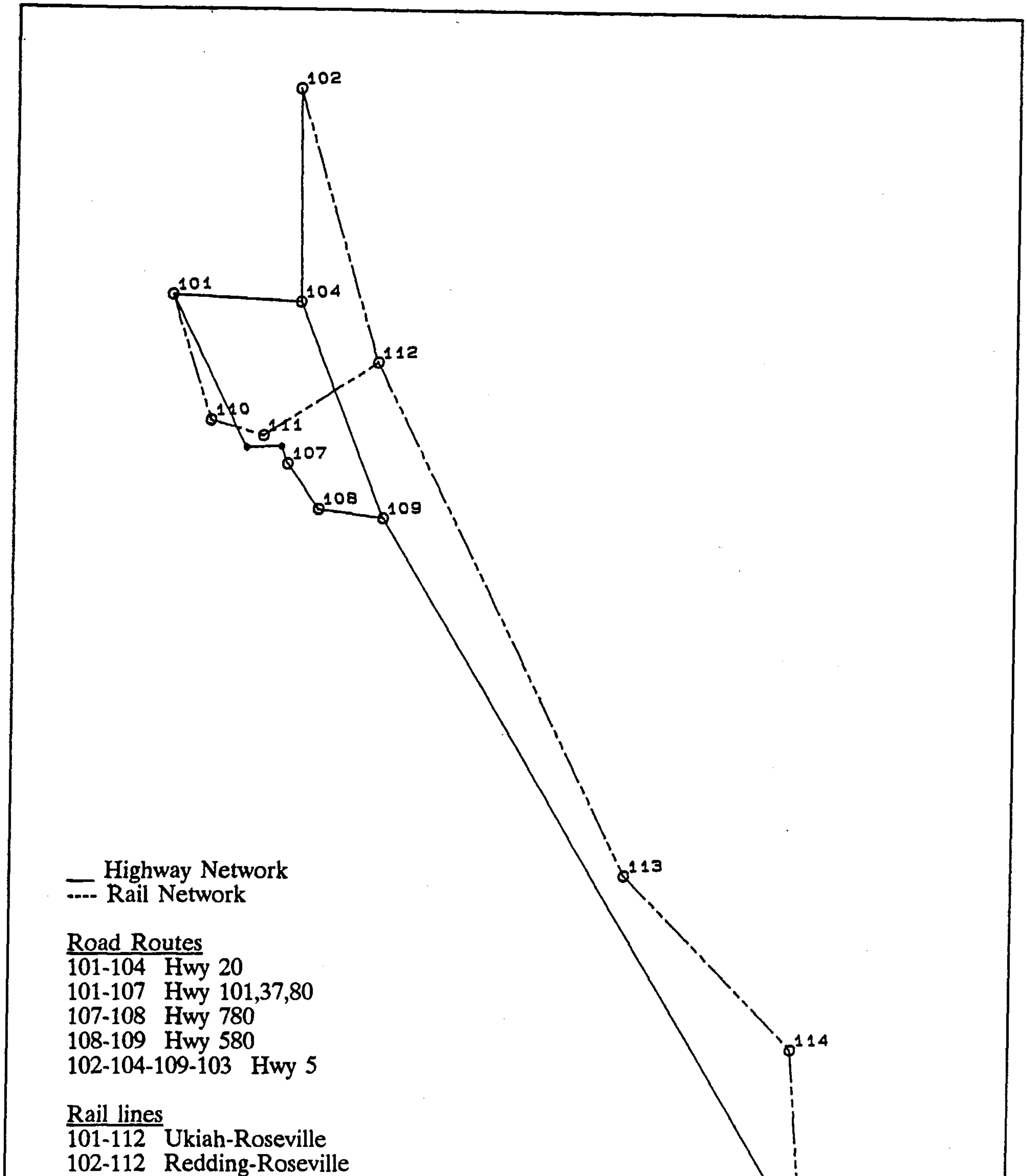
As described above, a major lumber producing center was selected as being representative of each origin BEA zone to permit the creation of a transportation network, with which to study the service provided by each mode to San Diego. The required time and tariff information was obtained directly from the railroads, the trucking companies, and the sawmills in Redding and Ukiah. The transportation network is relatively simple as there is considerable overlap of routes from the two origins to San Diego.

By road, the fastest route from northern California is along Interstate Highway 5. The route from Redding is thus straightforward. However, from Ukiah, there are two possible ways to connect with Highway 5 - along State Highway 20 (slower but more reliable) or successively along Highways 101, 37, 80, 780, and 580 (faster in general, but subject to Bay Area congestion).

The rail network is owned almost entirely by Southern Pacific. However, for the last section of the trip to San Diego, the lumber is shipped from W. Colton/San Bernadino onward by Santa Fe. Details of the route were obtained directly from the railroads. As in the road network, the routes from Ukiah and Redding overlap. From Appendix B, it is observed that shipments from Ukiah and Redding merge at Roseville and then continue along the Southern Pacific track to West Colton. At that point, shipments are interlined to the Santa Fe Railroad at the adjacent San Bernadino station for the final leg into San Diego. These connections are illustrated in Figure 1, which shows the coded network.

The Service

The rail service is based on fixed schedules and is, hence, fairly straightforward. Details of the truck operations, however, were not obtained as easily. The large number of independent truck companies operating in the area, together with the variability in service, made it difficult to arrive at a single perception of the



— Highway Network
---- Rail Network

Road Routes

101-104	Hwy 20
101-107	Hwy 101,37,80
107-108	Hwy 780
108-109	Hwy 580
102-104-109-103	Hwy 5

Rail lines

101-112	Ukiah-Roseville
102-112	Redding-Roseville
112-113	Roseville-Bakersfield
113-114	Bakersfield-W.Colton
114-103	San Bernadino-San Diego

MULTI-MODAL FREIGHT NETWORK
Figure 1

level of service actually provided. It may be recalled that the attributes of a transportation mode are headway and travel time (includes loading delay, line-haul time, and the time value of the tariff). The specific approach taken to estimate these data for both rail and truck transport is detailed in the following paragraphs.

1. Railroads: Information on rail services was obtained from a telephone survey conducted with sawmills in Ukiah and Redding. (For more details about the survey, refer to Appendix C.) The Southern Pacific and Santa Fe railroads were also contacted.

Typically, lumber is transferred to the rail yard from the sawmill by rail or truck, depending on whether the mill has a rail spur. The origin delay consists in general of the arrival delay of the truck or rail car in reaching the sawmill, and the loading delay (includes loading time at the sawmill, the time required to transfer the load to the rail yard, and the sorting delay at the rail yard).

The railroad delivers the rail cars within one day. There appears to be less pressure at the sawmill to load the cars than for trucks (as described later), since they may remain at the mill for up to one week without incurring any additional costs. The loading operation typically takes about two days. The loaded car is then transferred to the rail yard and is ready for the haul to San Diego in approximately twenty-four hours. The loading delay is thus roughly 3.5 days. Since a train leaves both Ukiah and Redding every day, the headway for the rail mode is one day.

The corresponding delays at sawmills without rail spurs are of the same magnitude. For sawmills that hire private trucks for this transfer (instead of using their own trucks), such trucks arrive within one day. While the trucks are loaded on the same day, there is a larger sorting delay at the rail yard than in the previous case (up to three days). In addition, the cost per truckload (50,000 lbs.) for the trip from the mill to the railyard is $127.

The rail trip takes 3.1 or 4.1 days from Ukiah and 2.5 or 3.5 days from Redding, depending on the day of departure (as seen in Appendix B). The rail service from Northern California to San Diego may be represented by a sequence of rail lines. For a more complex network, computer algorithms are available to determine which line will be chosen at various points along the way. However, in the present model, the rail network is simple enough to be represented as a single rail line with two possible line-haul times as described above. From Appendix B, there is an equal probability of either the longer or shorter trip occurring. The expected value of the line-haul times is then 3.64 and 2.95 days, respectively.

The rail tariffs quoted by the Southern Pacific Railroad Rates Department in Portland, Oregon are $2,947/rail car for box-cars (150,000 lbs.) and $2,038/rail car for flat-cars (up to 160,500 lbs.). The rate is the same for both Ukiah and Redding.

2. Trucks: Information on trucking services was obtained as in the case of the railroads, from a telephone survey conducted with sawmills and trucking companies in Ukiah and Redding (see Appendix C). There appears to be a considerable discrepancy between the service that the trucking companies claim to provide and the service that the sawmills claim to receive.

In general, the service is quite unreliable. Although there is an attempt in some cases to coordinate the pickup by ordering a truck in advance, the typical procedure is for a sawmill to order for transportation only after an order is completed. The arrival delay was stated by the sawmills as being anywhere between one and seven days, while the corresponding figure provided by the truckers was one to three days. Taking a conservative estimate, the headway will be assumed to be seven days (implying an equal probability of occurrence of any delay up to seven days). Once the truck has arrived, however, the loading delay is quite small (roughly 0.5 days). The travel time may be estimated quite easily. Since it is mandatory for truckers to rest for twelve hours after each eight hour drive, the total travel time from either location would be twelve hours more than the driving time. From the Rand McNally Road Atlas, the driving times for the two possible routes from Ukiah are 13.18 and 12.95 hours. The corresponding time from Redding is 12.35 hours. The expected (mean) travel time is therefore estimated as 1.04 days for Ukiah and 1.01 days for Redding.

The cost per shipment is also straightforward since the Public Utilities Commission rates (based on distance) must be applied by the trucking company. The tariff from Ukiah is $820/truckload and, from Redding, $825/truckload (the weight per truckload is 50,000 lbs.).

5. The Structure of the Model

The model considers the mode choice decisions made by sawmills in Ukiah and Redding shipping lumber to San Diego. As a simplification, the model assumes that all sawmills have rail spurs and that all truck transportation is by hired private carrier. It should be noted that, in general, all the assumptions and simplifications tend to favor a higher rail share. This will serve to emphasize the results of the model, as described later. The service provided by the carriers for each mode, as described in the previous section, are summarized in Table 2 below.

Table 2
Modal Attributies

	Ukiah		Redding	
	Truck	Rail	Truck	Rail
headway	7.00	1.00	7.00	1.00
loading delay	0.50	3.50	0.50	3.50
line-haul time	1.04	3.64	1.01	2.95
tariff	825	831	820	831

Times are measured in days and the tariff is in $/50,000 lbs.

As the tariffs are roughly the same for both modes, for both the origins, they will be discarded from the model (notice that this assumption strengthens the bias toward a higher rail share in the model, because the truck tariffs are actually slightly less than the corresponding rail tariffs). The travel time is then simply the sum of the loading delay and the line-haul time. One may then imagine the mode choice problem to be analogous to the choice made by an individual faced with two transit lines with known schedules; one faster with longer headways (truck) and the other slower with shorter headways (rail). Since the truck headway is a multiple of the shorter rail headway, it defines a single cycle. If the individual shipment is ready early in the cycle (shortly after the previous truck departed) it uses the railroad. However, after a certain cut-off point in the cycle, the shipment switches to truck. The portion of the cycle in which rail is favored is equal to the rail share as derived from the model.

Figure 2 shows the total transportation time (delay) for each mode at all points in a cycle. The terms in the Figure are defined as follows:

Maximum truck delay = $D_T + t_T + h_T$

Minimum truck delay = $D_T + t_T$

Maximum rail delay = $D_R + t_R + h_R$

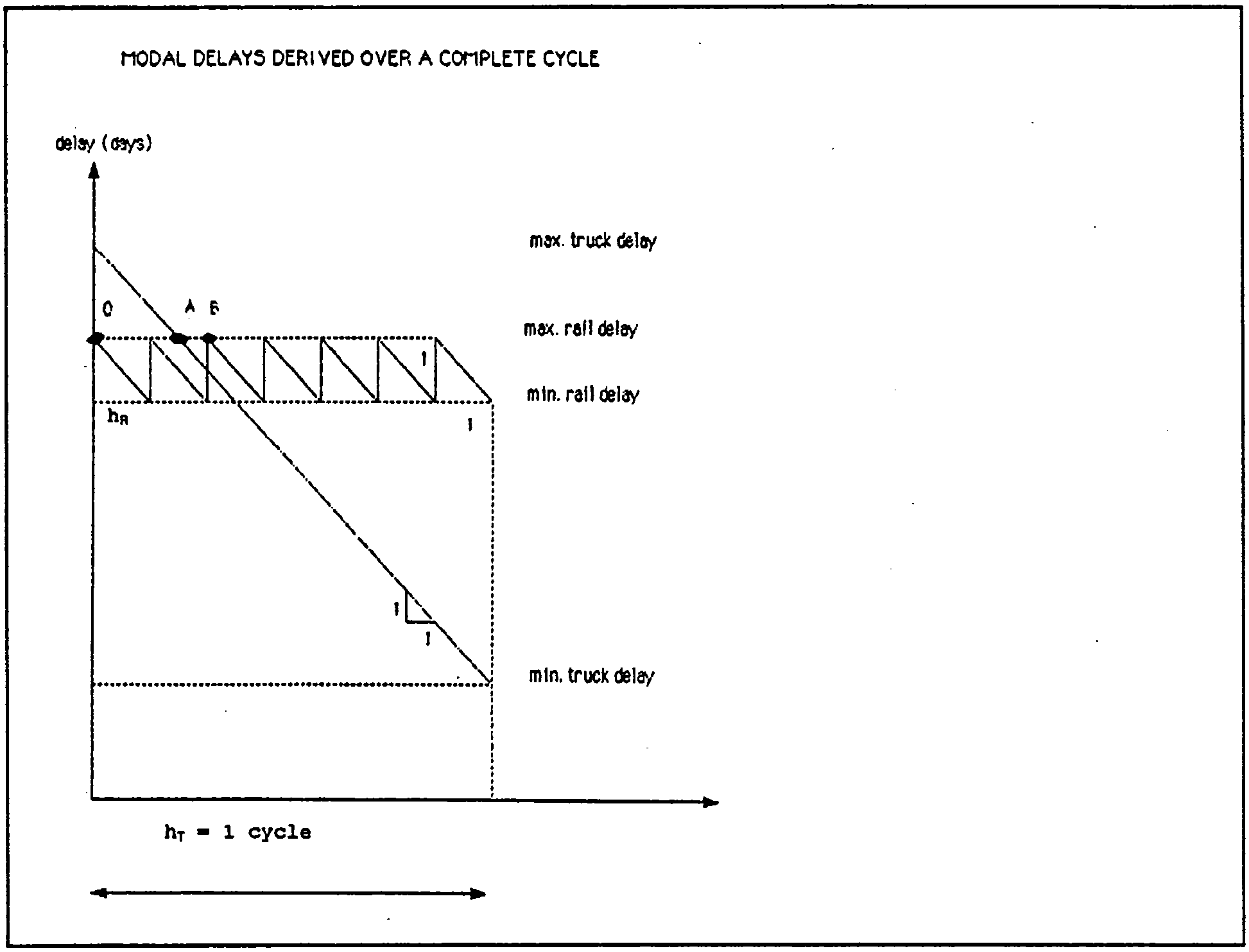


Figure 2

Modal delays during a single complete cycle

Minimum rail delay = $D_R + t_R$

where:

D_T= truck loading delay

t_T= mean truck line-haul time

h_T= truck headway

D_R= rail loading delay

t_R= expected rail line-haul time

= $\Sigma_i P_i . t_i$

P_i = probability of line-haul time t_i occurring

t_i = line-haul time

h_R= rail headway

The shipment would switch to truck beyond the point at which the truck delay and the rail delay curves intersect (this is necessarily a multiple of the rail headway, which is one day and hence an integer in our problem). The cut-off point is defined as the smallest multiple of the rail headway (OB) greater than the point at which the truck delay becomes less than the maximum rail delay (OA).

From Figure 2, the general expression for OA is found as;

$OA = [(D_T + t_T) + h_T] - [(D_R + t_R) + h_R]$ ---------- (1)

where,

OA = point at which truck delay is equal to maximum rail delay

Remaining notation is as defined earlier.

$S_R = OB / h_T$ ---------- (2)

where,

S_R = rail share
OB = smallest multiple of h_R greater than OA (h_R = rail headway)

Remaining notation is as defined earlier.

The data in Table 2 may be substituted into Equations 1 and 2 to obtain the rail share for both Ukiah and Redding.

For Ukiah $S_R = 1/7 =$ **0.14** (OA = 0.4)

For Redding $S_R = 2/7 =$ **0.28** (OA = 1.06).

6. Evaluation of Results

The rail shares obtained from the model are observed to be significantly less than the corresponding "for hire" shares obtained for the BEA zone from the TRANSEARCH database (see Table 1). The model shares are generally less than but much closer to the rail of total traffic, however. This is a particularly interesting result since all the simplifications and assumptions in the model described earlier would tend to increase the rail share. The aggregation error associated with the comparison of actual zonal mode shares with the shares for a single firm (based on travel time and tariffs only) may be assumed to be evenly divided over all modes. Consequently, there appears to be a set of factors other than tariffs and transportation time that cause sawmills to ship a higher proportion of their products by rail.

The following reasons have been suggested to explain the anomaly in mode share. The schedules and blocking department of the Santa Fe Railroad claimed that lumber is often transferred unsold on the rail line, to be bought by brokers as it travels southward, as and when a demand for the shipment arises. The rail line thus serves as a "moving warehouse" for the product. In addition, in situations where a load is ordered in advance by a buyer in San Diego, it becomes important to deliver the finished goods by a particular date. The trucking company informs the sawmill of the arrival delay when contacted after completion of a job. While the model assumes that the trucker adheres to this schedule, in reality the load is picked-up whenever a truck becomes available. Consequently, the sawmill may choose the slower but more reliable railroad for such jobs, adjusting its production schedule to accommodate the longer transportation times involved. Finally, sawmills that have traditionally shipped <u>all</u> their products by rail may be unaware of the quality of service provided by the trucking companies, increasing the aggregate rail share for the area.

While transportation time and tariffs are clearly not the only determinants of the rail share, they may be considered to be the only variables within the control of the transport operators (truckers and railroad companies). The subsequent analysis will study the effect of changes in the above variables on the rail share. As the nature of the difference between the model results and the actual rail share is not determined, we can only assume that the changes in the rail share observed in the simulation would roughly approximate the changes in the actual rail share, from changes in the service variables.

The variables specifically considered in the simulation are the loading time and the line-haul time for rail, and the headway for trucks. All the other variables in the rail share expression (Equations (1) and (2)) are maintained constant. It was mentioned earlier that truck tariffs are fixed by the Public Utilities Commission. As the railroads appear to set their rates based on the competing truck tariffs, these rates may be assumed to be roughly equal in general, and are thus neglected from the subsequent analysis. The derivation of the sensitivity of the rail share with respect to the variables is quite straightforward if we assume OA ≈ OB (refer to Equations (1) and (2)) as a simplification. In that case, the expression for the rail share is obtained as,

$$S_R = (K + h_T - D_R - t_R)/h_T \qquad \text{----------} \quad (3)$$

where:

$K = D_T + t_T - h_R$ (constant)

Remaining notation is as defined earlier.

While the function for S_R obtained in Equation (3) is continuous for changes in the defined variables, it must be noted that, in reality, the term OB in Equation (2), which is the numerator of the S_R function, must assume integer values, resulting in a step-function for S_R. However, the general trends described in the subsequent analysis may be assumed to be valid. Furthermore, since all the variables are measured in the same time units (days), it would be possible to compare the changes in the rail share for unit changes in truck headway, rail loading time, and rail line-haul time.

From Equation (3),

$\delta S_R/\delta h_T = (1 - S_R)/h_T$ ---------- (4)

$\delta S_R/\delta D_R = -1/h_T$ ---------- (5)

$\delta S_R/\delta t_R = -1/h_T$ ---------- (6)

The sensitivity of the rail share to changes in the modal service variables may be assumed to be a measure of the ability of the relevant transport operators to alter the existing rail share. As the tariffs on all modes are assumed constant in the model (based on PUC rates), the change in modal share would in turn reflect the change in revenue. As cost functions for the transportation modes are not determined in the model, the cost increase associated with a service improvement cannot be explicitly obtained. However, in general we may assume that for conditions in which the sensitivity is large, the increased revenues derived from a service improvement will outweigh the accompanying cost increases.

From Equations (4),(5), and (6), it is observed that the sensitivity of the rail share is inversely related to the cycle-length (equivalent to h_T in our model). This is because a unit change in any modal service variable would impact a greater share of the cycle, for smaller cycles. It is also seen that the rail share is more responsive to improvements in the rail service than to corresponding improvements for trucks, for a given cycle-length (h_T).

In the present condition, there is little incentive for transport operators of either mode to improve their service as the cycle-length (h_T) is large. This situation can only be altered if h_T is reduced by the truckers (which in turn would result in a reduction in S_R). The marginal change in S_R (sensitivity) increases as h_T and S_R get smaller (see Equation (4)), providing an increasingly greater incentive to the truckers to improve their service. However, it may be recalled that for any h_T, the railroad always has the potential to capture a greater share of the market than do the truckers. Consequently, while the trucking companies would obtain an increasing share of the total shipments by reducing h_T (assuming that the railroad did not improve its service), such an action would also provide a greater incentive to the railroad to improve its service (see Equations (5) and (6)), resulting possibly in less of a gain in truck market share than a priori might be expected. This could have a detrimental effect on trucking industry profitability.

In the present situation, there is little incentive for the railroad to improve its service. The truckers would probably behave in a similar manner, rather than improve performance and risk the effect described above. The only policy solution available to an external agency interested in improving the freight service is to encourage the entry of additional truck operators into the market, thus creating more competition within the truck mode itself, which would presumably lead to the decreased truck headways desired. On the other hand, the result of such a policy could be a generally less healthy trucking industry.

7. Suggestions for Future Research

The most obvious weakness in the present approach is that a micro-economic model is operationalized using aggregate data. The structure of the model is also quite simplistic with two modal attributes, tariffs and transportation time, being considered. It may be mentioned here that if two variables only are still to be used in future research, then it is particularly important that a commodity with a high value of time (such as food products) be modelled.

Apart from the general aggregation error that would be expected, there also appears to be a systematic error (possibly derived from factors not included in the model) that causes the model to underestimate the rail share.

The above discussion suggests a detailed study of the firm's (individual sawmill's) mode choice decision as the most effective area for future research. Apart from providing more accurate data for the variables presently considered, one would also obtain insights into the qualitative factors and perceptions involved in the mode choice decision. Included among these are the influence of variability in pickup time and the effect of the "moving warehouse" phenomenon described previously.

Finally, it is desirable to implement a practical computer algorithm which incorporates the mode choice estimation method utilized in this work. Such an algorithm would be of direct applicability in the analysis of any network representing transportation services with explicit routes and schedules, such as a public transit network. The development of such a computerized algorithm was initiated during the course of this study, and is expected to be completed during the coming year.

APPENDIX A: SAS Routine for Processing the 1985 Carload Waybill Statistics Tape

```
TAPMOUNT AC4328 * NL 1
CMSDISK WRITEPW MUNSHI
FILEDEF RAIL TAP1 (PERM RECFM FB LRECL 844 BLOCK 16036
EXEC SAS KAIVAN5
COPY KAIVAN5 LISTING A = = D

DATA  TRANSPT;
CMS FILEDEF RAIL TAP1 (PERM RECFM FB LRECL 844 BLOCK 16036;
INFILE RAIL;
INPUT TYR 21-22 WGHT 61-69 AWGHT 70-78 STCC 323-329
     OST$625-626 OFIP 653-657 TFIP 658-662
       OCN $ 788-802 TCN $ 803-817;

IF OST EQ 'CA'  AND TYR EQ 85;
     IF TCN EQ 'SAN DIEGO';

PROC SORT;
BY OCN ;

PROC PRINT;
VAR TYR STCC OST OFIP TFIP TCN OCN WGHT AWGHT;
BY OCN;
```

APPENDIX B: Rail Schedules

Line	**Headway (days)**	**Arrival**		**Departure**	
		time	**day**	**time**	**day**
Ukiah - Roseville	1				
Ukiah				7:30 P.M.	1
Petaluma		3:00 A.M.	2	10:00 A.M.	2
Suisun		2:30 P.M.	2	5:00 P.M.	2
Roseville		11:30 P.M.	2		
Redding - Roseville	1				
Redding				12:00 noon	2
Roseville		6:00 P.M.	2		
Roseville - Bakersfield	2				
Roseville				4:00 A.M.	3
Bakersfield		1:00 P.M.	3		
Roseville - Bakersfield	2				
Roseville				12:00 noon	3
Bakersfield		9:00 P.M.	3		
Bakersfield - W.Colton	1				
Bakersfield				6:00 P.M.	3/4
W.Colton		3:00 A.M.	4/5		
San Bernadino - San Diego	1				
San Bernadino				2:45 P.M.	4/5
San Diego		10:45 P.M.	4/5		

APPENDIX C: Telephone Survey

(Relevant portions were addressed to lumber manufacturers and trucking companies)

We are studying the shipment of lumber from Ukiah/Redding to San Diego. I'm calling to obtain some specific information about the transportation you use.

1. Your name and your position in the company.
2. Do you on occasion ship lumber to San Diego? We will use that city as the shipment destination for all upcoming questions.
3. How do you transport lumber to your customers in San Diego? Do you use both trucks and railroad?
   - trucks
   - railroad
   - other

RAIL

How do you transport lumber to the railyard? Do you have a rail spur or do you use trucks?

- rail spur
- trucks

Spurs

1. How often will the railroad pick-up at your spur? What is the lead-time (i.e. how much in advance do you have to notify them)?
2. Is there any extra cost for the pick-up?
3. How long does the rail car remain at the siding?

4. What is the sorting time at the railyard?

Trucks to railyard

1. Do you use your own trucks or do you hire outside truckers?
2. How long in advance do you need to arrange for a shipment to the railyard?
3. What is the loading time?
4. How long does it take to get to the railyard?
5. What is the cost per truckload?
6. How much in advance of the train departure must the shipment arrive at the yard? Who transfers it, what is the cost (was this included in the cost you provided earlier)?

TRUCKS TO SAN DIEGO

1. Do you use your own company trucks or do you hire outside truckers to haul to San Diego?
2. How long in advance do you need to arrange for a shipment?
3. What is the cost per truckload?
4. How long does it take to load the truck once it has arrived?

List of Respondents

<u>Lumber Carriers in Ukiah</u>
Wilson Trucking
Lyly and Sons
KVS Trucking Inc.
Cooper and Sons Trucking Inc.
Louisiana Pacific Corporation
North Cal. Wood Products Inc.

<u>Lumber Manufacturers in Ukiah</u>
Masonite
Burgess Lumber
Agwood Mill and Lumber

Lumber Carriers in Redding
Hurd Fritz and Sons Inc.
Kenny Knowles Trucking
Cattanach Trucking
Redding Lumber Transport Inc.

Lumber Manufacturers in Redding
Sierra Cascade Timber Products
Roseburg Forest Products
Redding Power Company, Sawmill Division
Wisconsin-California Forest Products Inc.
Girvan Lumber Company Inc.
Hyampom Lumber Company
Redding Pallet Inc.
Sound Stud
Sierra Pacific Industries
Lance Forest Products
L and B Lumber and Milling Company Inc.
Elam Lumber and Millwork

Other Respondents
Louisiana Pacific Corporation in Red Bluff
Joe Costa Trucking Company in Arcata

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Personal Information

1. Harry Balance, District Superintendent, Oakland, Southern Pacific Railroad.
2. Jim Chavez, Assistant Director, Schedules and Blocking, The Atchison, Topeka and Santa Fe Railway Company.
3. Rates Department, Southern Pacific Railroad Company, Portland,Oregon

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