A plot similar to Figure 8 would be useful in the initial selection of parameters for a system designed to provide a certain level of service. For instance, for a average container time in the system of 600 min, a processing time of 60 min would require a line speed of 55 mph. Reducing processing time to 30 min would reduce the required line-haul speed to 45 mph. A zero processing time would still require a line-haul speed of 38 mph. On the other hand, increasing the processing time to 120 min would require a line-haul speed in excess of 100 mph.

It is informative to plot curves of equal time in the system for various values of terminal processing time (P) and transit time across a line-haul segment D/V. (The use of the variable D/V instead of V versus P is useful because D/V and P are in the same units, i.e., time.) The data in Figure 9 show such curves for a specific combination of other system design variables. The lines in this figure are fairly straight and evenly spaced. This should not be surprising, as P and D/V are combined linearly in calculating time in the system and heavily influence the result.

The data in Figure 9 provide a means of rapidly determining the trade-off between D/V and P for any given level of service. The sections of the curves above P = 3 are unsubstantiated by LINET runs and are therefore indicated with dashed lines. It would be expected that, as the line-haul transit time (D/V) decreases, a breakdown point would occur at which the linear relation would no longer be valid. The curve should begin to bend down with decreasing D/V, which indicates that the terminal processing time (P) must decrease to avoid train queuing delays in the terminal.

The number of terminal platforms influences the size of the feasibility region (i.e., a system with 2 platforms/terminal has a larger feasibility region than a system with 1 platform/terminal). Once a system design is feasible, however, adding extra platforms to terminals has little effect on the average time a container spends in the system. Thus the number of platforms affects the ability of the system to satisfy the demand, but once the system is able to satisfy the demand, the number of platforms has little effect on system effectiveness.

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Network Analysis of Highway and Intermodal Rail-Highway Freight Traffic

ALAIN L. KORNHAUSER AND MICHAEL BODDEN

The analysis capabilities of the Princeton highway and intermodal rail-highway network models are described. These network models are extensions of the Princeton railroad network model and graphic information system and are based on a geocoded network representation of intermodal transfer locations and the U.S. highway system. The models contain efficient routing and traffic assignment algorithms, highway and rail cost models, and extensive network editing and computer graphic utilities. Examples of highway and intermodal routes and a graphic analysis of the railside flows of 1980 intermodal traffic based on the 1980 one percent waybill sample are presented.

Analysis of U.S. highway and intermodal (highway-rail) traffic has been difficult because precise and broad-based highway traffic data were lacking and because an efficient computer-based network representation of the U.S. highway system did not exist. The unavailability of these data is unexpected given the amount of planning and funding that has been expended on the U.S. highway system. One would have assumed that the FHWA would have sponsored the creation of such a network data system, or that the Interstate Commerce Commission (ICC) or the FHWA would have secured the authority to collect a sample of highway traffic movements similar to the 1 percent waybill sample collected for rail freight (1).

However, because the carrier portion of highway freight transportation is fragmented and some sections of highway transportation are not regulated, no national sample of origin and destination data for highway freight traffic exists. The best publicly available cross-sectional national sample of truck traffic is the 1977 Census of Transportation (2). Although beneficial, this data source is significantly inferior when compared to the rail freight waybill sample. The origin and destination data of the 1977 Census of Transportation are grossly aggregated to state levels or to metropolitan areas, and no revenue data are given. Similarly, there are little or no data available for intermodal traffic because no government agency collects it. (Because intermodal traffic is deregulated, there may not exist a public need to know.)

The rail freight waybill sample only reports rail interchange locations, and not the ultimate highway origin or destination of the traffic. Even the railroads have not maintained traffic data on the ultimate origin or destination of intermodal traffic. Highway traffic data do exist within large trucking companies and within the freight forwarders that perform much of the retailing of intermodal traffic. However, these data sources are not accessible to the public or to the research community.

One reason why origin and destination highway traffic data have not been collected may be that there did not exist a means by which such data could be used effectively. The sheer size and ubiquity of the U.S. highway system did not lend itself to network-type traffic analysis.

A literature search has not uncovered the existence of any publicly available geocoded U.S. highway network. There does exist some proprietary highway networks, such as

1. Lansdown's highway network, which includes some 60,000 nodes and links (3);
2. Rand McNally-TDS's "Mile Make I," which is based on household goods movement mileages (3);
3. Networks by Numerax and others for mileage and rating purposes (3); and
4. Highway networks by CACI, for which little description is available in the literature.

Because of the analytical and problem-solving successes of the Princeton railroad network model (PRNM) (4), construction of a link-node network data base of the U.S. highway system was undertaken. The highway network was coded for the following reasons:

1. A quantitative and computer graphic mechanism could be provided for describing and understanding current freight distribution patterns and options on a national, local, regional, and corporate basis.
2. Alternate highway routings could be assessed. The ubiquity of the U.S. highway system suggests that numerous, essentially equivalent, alternate routes exist between most points. Although this is often true, favored routes tend to emerge, especially when toll facilities, weight restrictions, and legal passage of hazardous materials are taken into account. Many bridges and tunnels ban the shipment of hazardous commodities; states have varying weight limits; and many communities ban the transportation of nuclear materials.
3. Alternate intermodal routes could be analyzed because the highway network was developed so as to be compatible with the U.S. railway network.
4. Highway market service areas could also be analyzed. There is a need to identify the areas served by various elements of the highway system (e.g., toll facilities or segments of Interstate and intermodal facilities). These analyses are accomplished by assembling either all origins (destinations) to (from) a common destination (origin) or both, so that the market service area for intermodal facilities can be assessed.
5. Operational pricing and policy analysis issues could be studied, including estimates of the quantitative effects of variation in the size of the market service areas with changes in the price of fuel, truck sizes and weights, speed limits on highways, tolls, intermodal train service, and intermodal ramp charges.
6. The strategic value of various segments of the highway system, especially bridges and tunnels, could be assessed.

Of the above analyses, only distrbution patterns require traffic (origin-destination) data. The others can be accomplished in a straightforward manner with network data, routing algorithms, and network editing and computer graphic utilities contained in the Princeton highway network model.

If origin-destination traffic data are available, then distribution patterns and opportunities can be studied by the following analysis capabilities:

1. Display of the volume of traffic by highway segment, direction, equipment type, and commodity;
2. Display of empty or loaded factor for weighted volumes by direction;
3. Display and analysis of optimum routing and reload opportunities as part of a vehicle management system;
4. Identification of where backhauls would be most beneficial; and
5. Evaluation of alternate locations of warehouse and terminal operations.

The above analysis capabilities serve as desirable primary goals of a highway and intermodal management information system because they act as basic inputs to a framework for highway policy and plan analysis, and because they aid in ongoing corporate distribution decision making.

HIGHWAY NETWORK DESCRIPTION

The Princeton highway network is a link-node data structure that is similar to the Princeton railroad network. It consists of 8,862 nodes and 14,796 links. Node attributes include x,y coordinates (longitude and latitude equivalent), place names and state, standard point location code, and intermodal ramp code (if applicable). Other geographic files relate highway nodes to counties, business economic areas, census zones, and zip codes.

Table 1. Highway network node and link attributes.

Item	Example
Node attribute	
Node number	1257
Coordinate location	Latitude and longitude
Name and state	Princeton, New Jersey
Standard point location code	194537
Intermodal ramp	Princeton TOFC
Link attribute	
A node	1257
B node	1263
Distance (tenth of miles)	126 (12.6 miles)
Route class (1, 2, 3, 4)	1 = toll facilities; 2 = Interstate, free; 3 = divided highway; 4 = undivided roadway
Route designation	I-95
Hazardous material restriction (yes/no)	Yes

Figure 1. U.S. highway network.

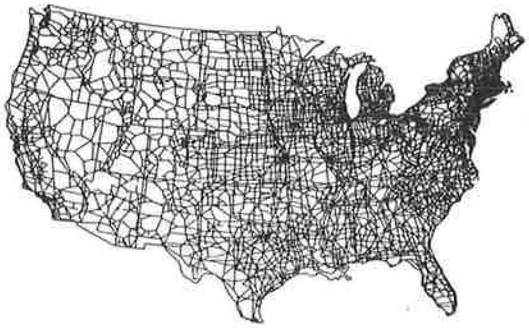


Figure 2. Highway network in vicinity of Mercer County, New Jersey.

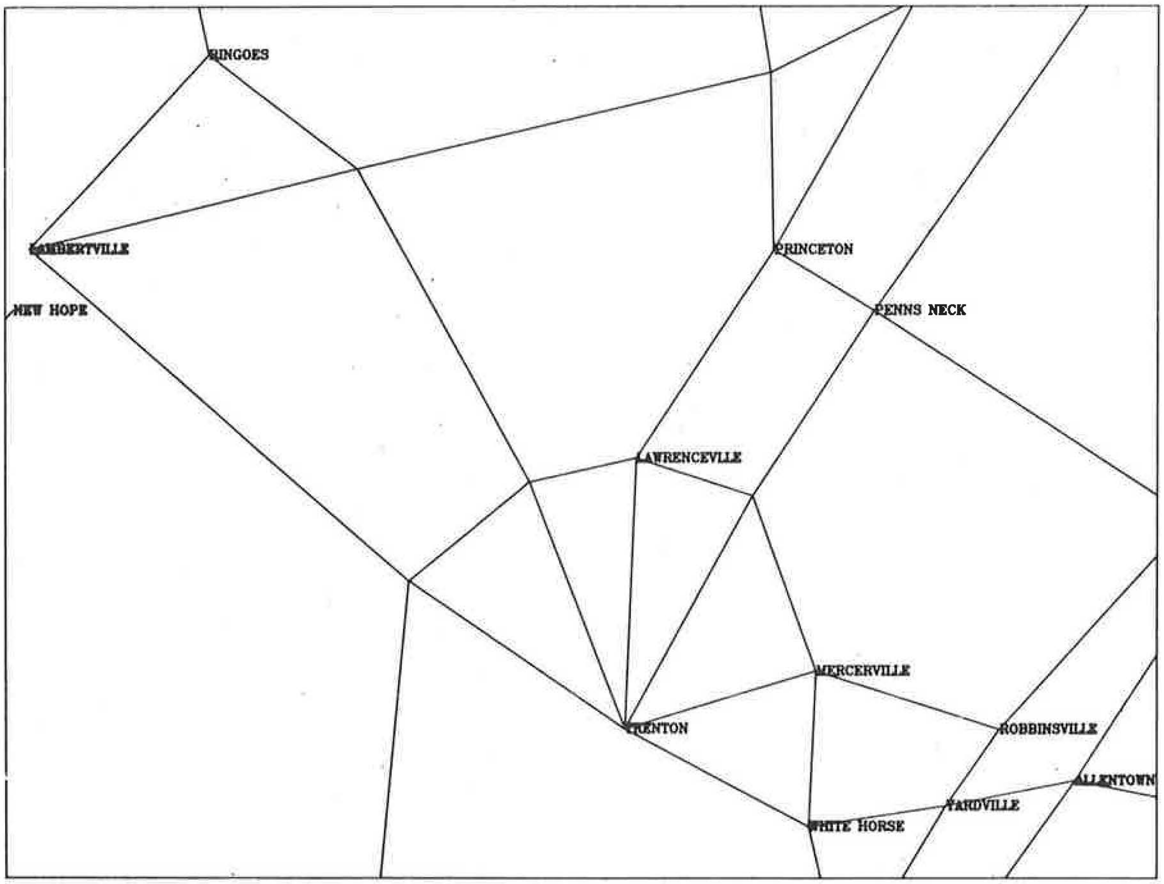
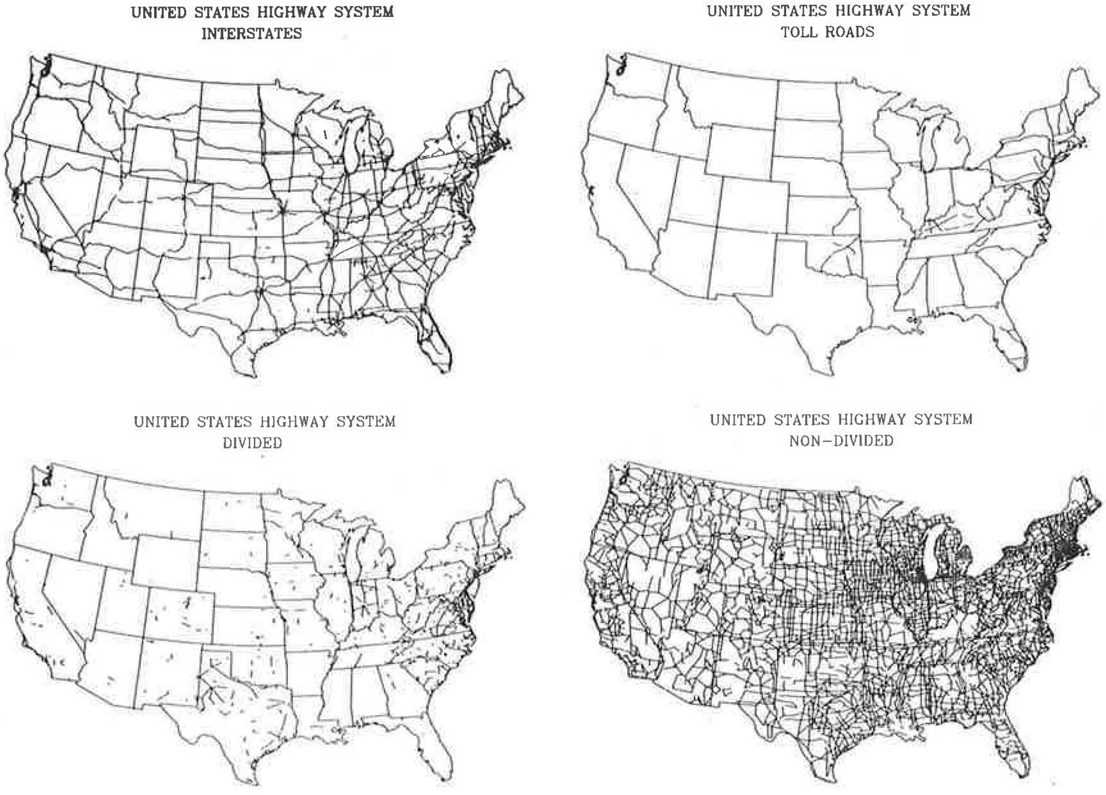


Figure 3. U.S. highway network divided by road type.


UNITED STATES HIGHWAY SYSTEM INTERSTATES

UNITED STATES HIGHWAY SYSTEM TOLL ROADS

UNITED STATES HIGHWAY SYSTEM DIVIDED

UNITED STATES HIGHWAY SYSTEM NON-DIVIDED

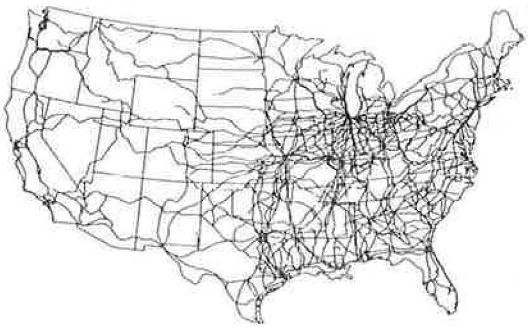
Link attributes include distance, hazardous material restriction, and route designation and type. Up to three route designations have been coded on each segment (i.e., Interstate, U.S. highway, and state highway). Four route types are coded, which include Interstates, toll roads, divided limited-access highways, and nondivided highways. Examples of node and link attributes are given in Table 1.

A geographic depiction of the Princeton highway network for the entire United States is shown in Figure 1. A close-up of a section of the highway network near Princeton, New Jersey, is shown in Figure 2. The network has been coded to an intermediate level of detail. All Interstates and federal roads, most state roads, and a few country roads (but no residential roads) have been coded (see Figure 3).

INTERMODAL NETWORK DESCRIPTION

The link-node network is a combination of the highway network and the subset of the Princeton railroad network that actively served intermodal traffic in 1980. This reduced railroad network contains 7,436 nodes and 8,406 links. Node and link attributes are the same as those for the entire railroad network, except that 1980 trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) link volumes, 1980 TOFC and COFC ramp volumes, and a ramp location code are added. A total of 855 ramps are coded. These ramps had significant (more than 1 car/day) activity during 1980. The Princeton TOFC rail network is shown in Figure 4.

Figure 4. Intermodal rail portion of network.

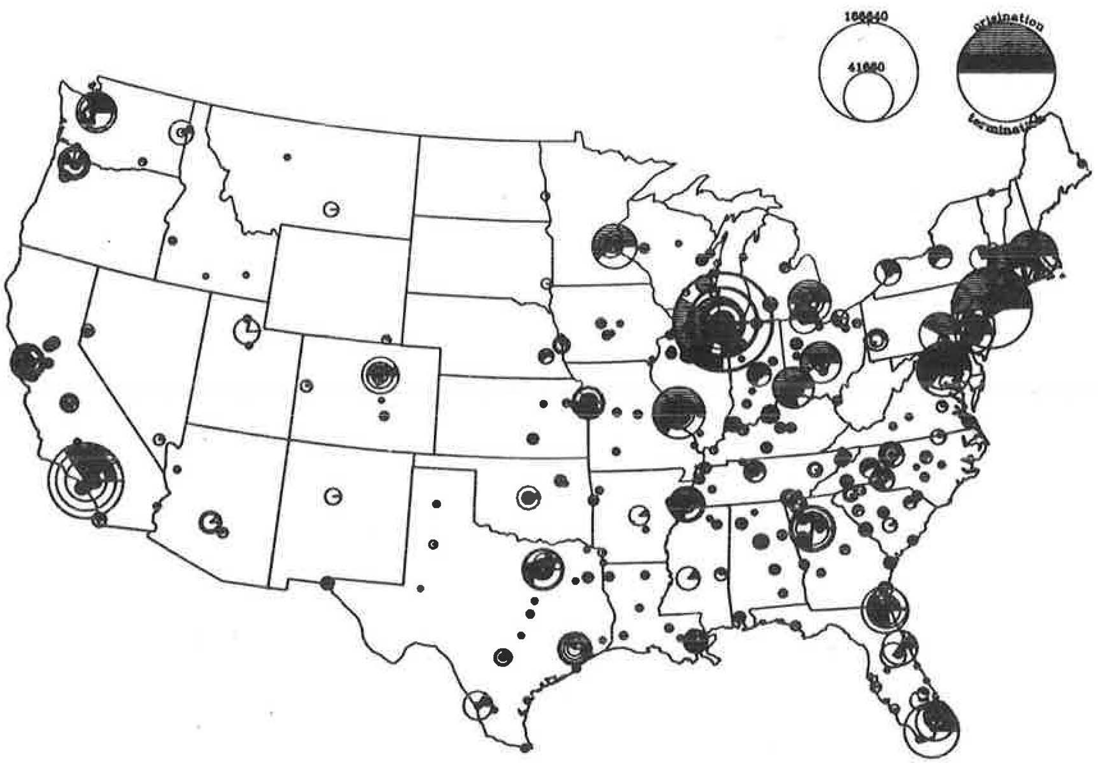


The TOFC ramp volumes for 1980 are shown in Figure 5. The area of the pies are proportional to the total carload volume of intermodal traffic interchanged between highway and rail at each location. The open slice is the highway-to-railway interchange volume, and the dark slice is the railway-to-highway volume.

The ramp volumes are not an accurate reflection of the rail origin and destination volumes of intermodal traffic because of the phenomenon of rubber interchange. This phenomenon principally occurs in Chicago and St. Louis, where intermodal traffic interchanged between railroads is achieved by off-loading the trailer from the flatcar, transferring of the trailer across town on highways to the other railroad's facility, and loading the trailer back onto a flatcar. Such movements are generally transacted by using individual waybills. As such they appear as double-counted rail movement rather than a single inter-railroad movement. Thus the activity represented in Figure 5 is only the rail-highway interchange activity and an overestimate of the amount of traffic that has rail originations or terminations in Chicago and St. Louis.

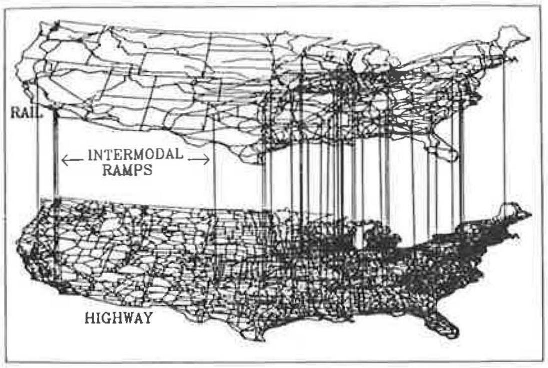
The Princeton intermodal network, which includes highway (without Interstate links), rail, and ramp

Figure 5. 1980 TOFC volumes from 1 percent waybill samples.



elements, is shown in Figure 6 in the quanta-net perspective (5). This view easily distinguishes the highway network (bottom plane) from the TOFC network (top plane). Also shown (by means of vertical lines) are the locations of intermodal ramp facilities. These vertical links permit traffic to be interchanged from the highway to the railway network and vice versa. With regard to network analysis, they represent the unit cost of transferring equipment from highway to rail. These costs can differ by ramp location due to varied operating practices and available equipment. The total intermodal network consists of 24,058 links and 16,298 nodes.

Figure 6. Quanta-net representation of intermodal network.



ROUTING MODEL

Routing of traffic on the Princeton highway or intermodal network is accomplished by using a minimum-cost, unconstrained, path-finding algorithm. It is the same algorithm that is used in the PRNM, except that it operates on highway or intermodal network data instead of railway network data (6). The routing algorithm accepts various cost functions for highway, rail, and ramp elements. The model contains a default cost function that is based on user-specified mileage rates for highway and rail portions as well as for rail form A type (7) ramp charges. Compensation is made for toll roads and divided and nondivided highways. Capabilities exist for the user to modify the link cost data or respecify the cost model, subject only to data availability and that the cost of a route is the linear sum of the cost to traverse each segment of that route.

Several examples of minimum-cost routes out of Princeton are shown in Figure 7. Note that the total distance to each destination is shown; although the routes are minimum cost, they are rarely minimum distance. The data in this figure indicate that the destinations of Scranton, Pennsylvania, and Boston are best reached by highway-only routes; however, the Philadelphia intermodal facility captures the rail portion of the best routes to other locations.

All of the destinations served by the Los Angeles TOFC ramp for intermodal traffic originating in Princeton are shown in Figure 8. The data in this figure reveal the market area served by the Los Angeles ramp vis-à-vis other (California) ramps for traffic from and to Princeton (and probably most points east of the Rocky Mountains). [Although Princeton does not generate much (if any) traffic, it has been used as an example. Any other city can also be analyzed interactively.]

EDITING AND GRAPHIC FUNCTIONS

The highway network model includes all of the network editing and display capabilities that have been developed for the PRNM. The figures used in this paper are examples of the various graphic capabilities of the model. Because the model operates in an interactive computer environment by using APL as the programming language, its editing utilities allow the user to easily correct or alter the network link and node data. These capabilities greatly simplify the mechanics of doing variational analyses.

HIGHWAY TRAFFIC FLOWS

In order to use the highway network for analysis purposes the highway portion of the 1977 Census of Transportation (2) was geocoded (i.e., encoded with highway network node numbers in place of the origins and destinations of metropolitan areas). A standard traffic assignment procedure was followed to accumulate traffic volumes of chemicals [standard transportation commodity code 28 (STCC28)] over the best highway routes between metropolitan areas. The

Figure 7. Optimal intermodal routings from Princeton.

Figure 8. Optimal routings from Princeton to the highway nodes of Los Angeles (using the TOFC ramp).

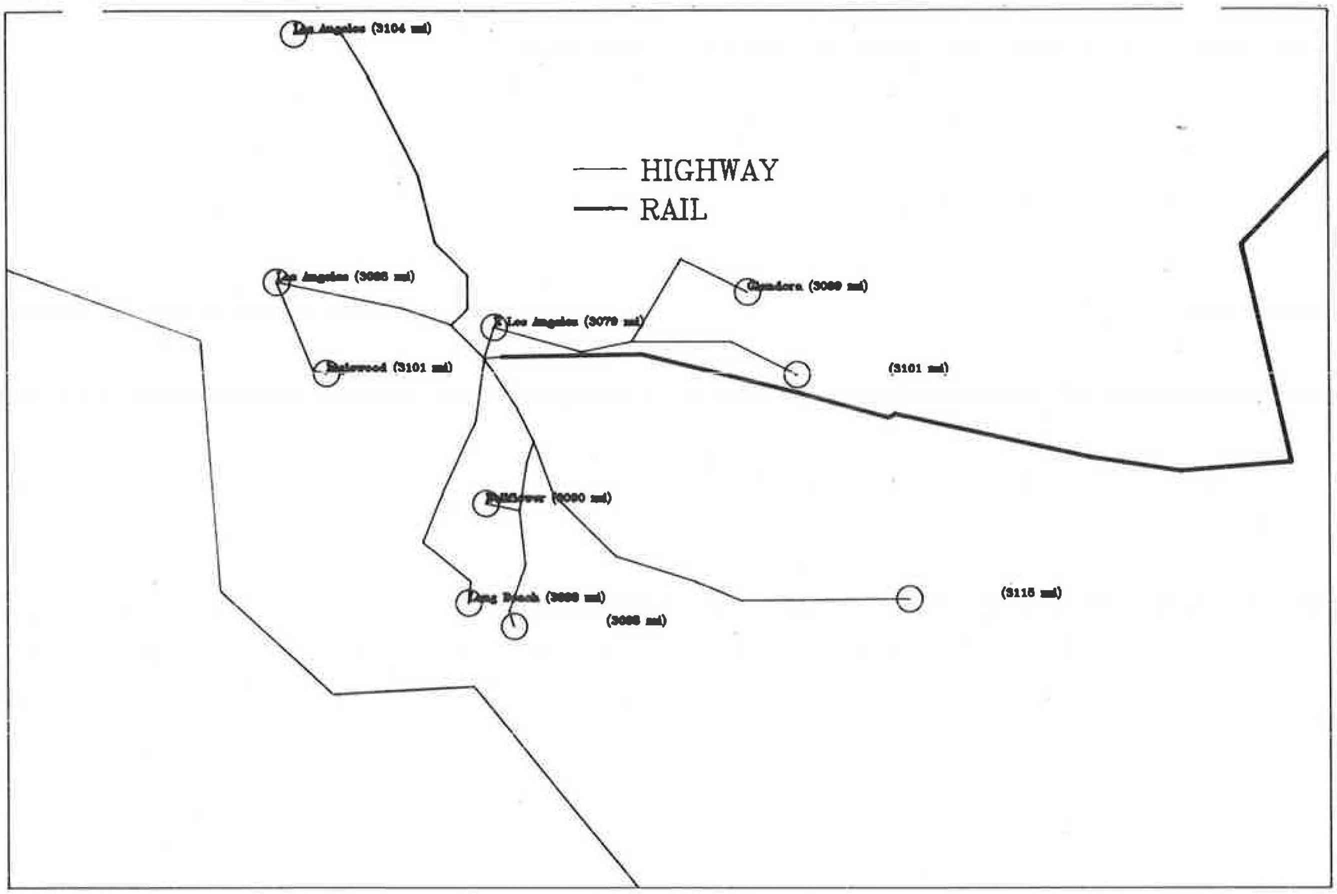
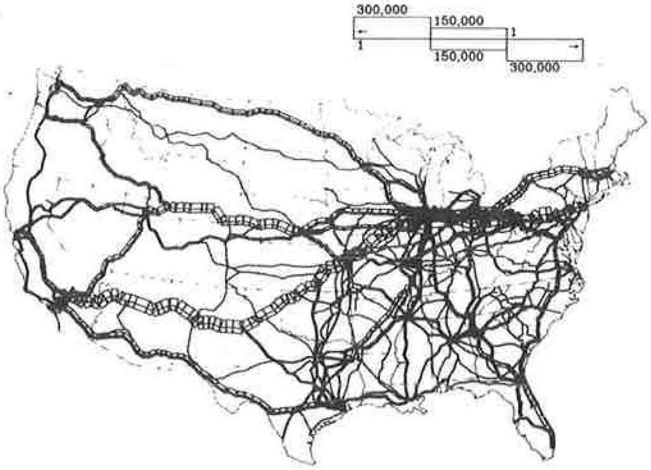


Figure 9. 1980 carload volumes for intermodal traffic (TOFC, COFC, and combinations).



resulting traffic densities were plotted (see Figure 9).

Figure 9 is believed to be the first computer-generated U.S. highway traffic density map. The information on the map reveals the following items:

1. The relative density of chemical traffic by direction over the U.S. highway system.
2. The New Jersey Turnpike is the most heavily traveled route for chemical traffic.
3. The next most heavily traveled highway corridor is the I-80 route across Pennsylvania [i.e., 800,000 net tons/year or about 40,000 trucks/year (an average of 150 trucks/day) travel on I-80].
4. The largest corridors are east-west between the Boston, New York, and Philadelphia areas to and from St. Louis and Chicago.
5. The Texas and Louisiana route to the northeast diagonal route is the next largest corridor.
6. Large westbound movements exist to the Los Angeles Basin and north and south between San Francisco and Los Angeles.
7. The rest of the highways in the United States serve relatively little chemical traffic.

A similar analysis can be performed for other commodities by using the Census of Transportation data. Other truck data bases can also be used.

ANALYSIS OF 1980 INTERMODAL TRAFFIC

Because no ultimate origin and ultimate destination intermodal traffic data base has been available, it is not yet possible to prepare intermodal traffic density charts that display the highway and rail portions. Nevertheless, the 1980 one percent waybill sample does describe the rail portion of intermodal traffic on a ramp-to-ramp basis. The data are coded on a carload (not trailer or container) basis and are specific as to plan and whether the flatcar carried trailers (TOFC), containers (COFC), or a combination (trailers and containers). These data

Figure 10. 1980 TOFC volumes.

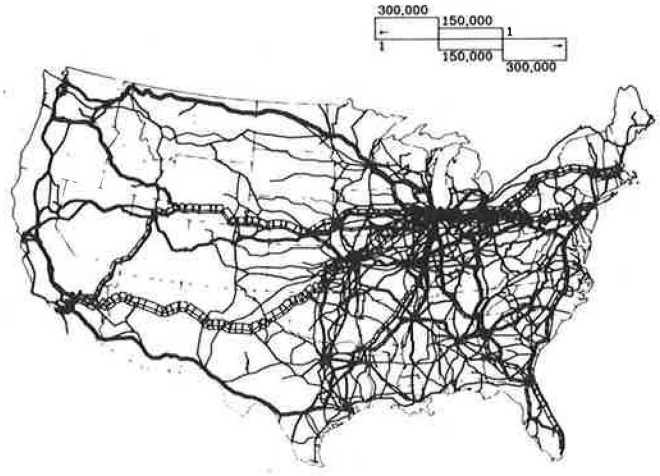


Figure 11. 1980 COFC volumes.

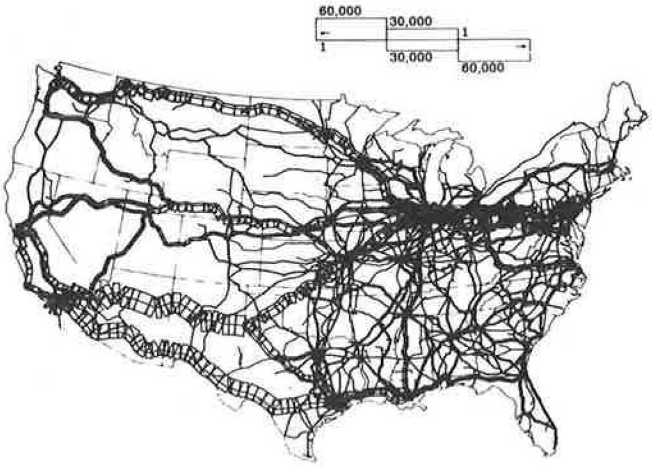
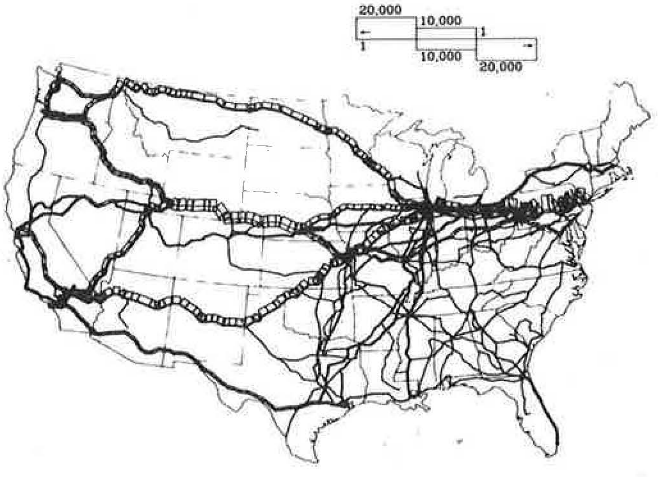


Figure 12. 1980 TOFC and COFC volumes combined.



were routed and accumulated (i.e., assigned) to the rail portion of the intermodal network.

The 1980 intermodal rail traffic indicated definite and distinct patterns. The traffic consists of TOFC traffic, COFC traffic, and traffic that mixes TOFC and COFC on the same car. The rail carload volumes of intermodal traffic are shown in Figure 9. TOFC makes up the majority of the traffic.

The rail carload volumes of TOFC traffic are shown in Figure 10. TOFC traffic volumes reveal major flows between southern California and Chicago. The Santa Fe Railroad handles the majority of this traffic, and the Union Pacific (UP) and Southern Pacific railroads also handle substantial traffic. Large volumes travel between Chicago and Boston and Newark and Elizabeth, New Jersey, over Consolidated Rail Corporation (Conrail) lines. Each of these major volume flows is well balanced directionally, i.e., the eastbound flow is comparable to the westbound flow.

Substantial volumes are shown moving south into Florida over the Family Lines System (FLS) and Southern Railway, and a large portion is taken to Ft. Lauderdale and Miami by Florida East Coast Railroad (FEC). Noticeable traffic volumes move between the Pacific Northwest and Chicago on the Burlington Northern (BN) or the UP. There is also a substantial flow of traffic between Texas and Chicago, where the Missouri Pacific Lines (MP) handle a large portion of the traffic.

The 1980 rail carload volumes of COFC traffic are shown in Figure 11. COFC traffic patterns demonstrate that containerized ocean freight is transhipped at ports to rail. The largest volumes were shown to be on Conrail to Port Elizabeth, New Jersey. Large volumes are shown to travel from Oakland and Los Angeles to the East through Chicago and to the Gulf ports of Galveston and New Orleans. Santa Fe and SP handle the majority of the traffic, and UP also carries substantial amounts. BN handles the majority of traffic between the Pacific Northwest and the East, and UP handles the remainder. Illinois Central Gulf (ICG) carries substantial traffic between New Orleans and various points north.

The combined TOFC and COFC traffic patterns were similar to those of the other two categories. Some differences were apparent in the balance of the flow. There was noticeably more traffic westbound to the West Coast on the BN, SP, and Santa Fe. The 1980 carload volumes of the combined TOFC and COFC traffic are shown in Figure 12.

SUMMARY

The first elements of a nationwide analysis of highway freight and intermodal (highway-rail) movement has been presented, and a newly available link-node network representation of the U.S. highway system and intermodal facilities has been used. The motivation for developing an analytical framework for quantifying U.S. highway freight issues was presented. The highway network was described, and how it has been integrated with the railway network has been discussed.

Examples of the use of the network model in generating minimum-cost highway and intermodal routes was presented. The highway routing capability was used to assign chemical traffic (STCC28) from the 1977 Census of Transportation (2) to the highway network, and the resulting traffic densities were described. Another analysis of the rail portion of highway-rail intermodal traffic was also presented. Nationwide statistics were displayed and described.

These analyses serve as examples of the value of the highway and intermodal network analysis capabilities. Their integration into a graphic information system provides capabilities for understanding distribution patterns and doing highway-freight-oriented strategic and policy studies.

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Intermodal Freight Transfer Facilities in California

NOREEN ROBERTS AND WILLIAM FELTS

The increase in international trade through California ports is creating transportation problems in the urbanized regions adjacent to these ports. Most intermodal freight transfer facilities are being planned or constructed as part of seaport expansion due to this increase in trade. Although these transfer facilities may alleviate some problems on the transportation system, they may also exacerbate others. Any modal shifts from truck to rail that result from the relocation of transfer facilities in closer proximity to the ports must be viewed in the context of the overall increase in rail traffic. The projected increase in container cargo and coal and grain exports equates to significantly higher volumes of rail traffic through highly urbanized areas. Although modal shifts may benefit highway truck traffic, increases in rail traffic could create severe problems, particularly at grade crossings in the Los Angeles area. The focus of this paper is on the role of the state, specifically the California Department of Transportation, in port access planning. The role of the state is reexamined in the light of increases in international trade through California's ports and the impact of these increases on the transportation systems that provide access to the ports. In addition, proposed intermodal freight transfer facilities are examined to determine if such facilities will have a significant effect on the problems associated with increased port traffic.

Intermodal freight transfer facilities in California play a key role in the efficient transportation of commodities. Most of the major new intermodal transfer facilities are being planned or constructed as a part of seaport expansion. This expansion is due, in large part, to increasing international trade through West Coast ports. The increased activity at the major seaports in California has had, and will continue to have, a significant impact on the transportation systems that provide access to the port complexes.

The focus of this paper is on the role of the state, specifically the California Department of Transportation (Caltrans), in port access planning. The role of the state is reexamined in the light of increases in international trade through California's ports and the impact of these increases on the transportation systems that provide access to the ports. In addition, proposed intermodal freight transfer facilities are examined to determined if such facilities will have a significant effect on the problems associated with increased port traffic.

CALTRANS' ROLE IN PORT ACCESS PLANNING

Caltrans is a multimodal transportation agency concerned with developing and maintaining a balanced, environmentally sound, and efficient transportation system within the state. This perspective should extend to intermodal freight and port-related transportation facilities and issues.

The rapid growth of international trade through California ports suggests that the Department should expand its capability for port transportation planning. In the past goods movement through California ports has increased at a manageable pace. However, if the anticipated increases in certain commodities occur, port development during the 1980s may result in significant impacts to the highway and other transportation systems in the state. By emphasizing port transportation planning, such impacts may be mitigated and goods movement may be facilitated.

Historically, California has not placed a high degree of state involvement in port activity. Most ports are quasi-public entities, and some are partly funded through taxation. However, unlike certain other states, there is no state authority over port development and operations.

Transportation planning has not been conducted on a port-specific basis. Port access facilities are analyzed on much the same basis as all other departmental projects. The state's role in port transportation planning should be developed on the premise that there are characteristics of port access that require a special planning approach.

Due to the multimodal aspects of port access facilities and the multiplicity of jurisdictions involved along the corridors through which facilities pass, planning and coordination at both the regional and state level is appropriate. However, in the absence of a constituency, much less a mandate, for such a state role, planning activities have been limited. Other priorities place higher claims on available state resources.

As a result, current Department responsibility in port planning focuses primarily on transportation impacts associated with port activity. This responsibility is carried out by (a) actions that implement Department policy, (b) the environmental review process, and (c) policy analysis and recommendation.