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The transport of hazardous materials by all modes is a major concern of the U.S. Department of Transportation. Estimates place the total amount of hazardous materials transported in the United States in excess of 1.5 billion tons per year. Highway, water, and rail account for nearly all hazardous materials shipments; air shipments are negligible. Fuels, such as gasoline and diesel, account for about half of all hazardous materials transported. Chemicals account for most of the remainder.

This report presents estimates of truck shipments of 1-butanol, one of the 147 large-volume chemicals that account for at least 80 percent of U.S. truck shipments of hazardous chemicals.

All of the reports in this series are based on the best available information at the time the research was conducted. The U.S. chemical industry, however, operates in an environment in which markets, production processes, and distribution requirements can change substantially from year to year. The information in this report on (a) chemical producers and their plant locations, (b) consuming plants and their locations, and (c) the estimated traffic flow from producers to consumers, is thus subject to change.

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PREFACE

The transport of hazardous materials by all modes is a major concern of the U.S. Department of Transportation (U.S. DOT). Estimates place the total amount of hazardous materials transported in the United States in excess of 1.5 billion tons per year.[1] Highways, water, and rail account for nearly all hazardous materials shipments; air shipments are negligible. Fuels, such as gasoline and diesel, account for about half of all hazardous materials transported. Chemicals account for most of the remainder.

Because of the intermixture of freight and passenger vehicles on the Nation's roads and highways, and because hazardous materials are frequently transported through residential and commercial areas, incidents involving truck movements of hazardous materials may pose a risk to the general population. The U.S. DOT has extensive data on highway incidents involving particular hazardous materials, but does not have comparable volume data with which to establish failure rates (i.e., the percentage of shipments involved in incidents). Moreover, little is known about the routes over which particular hazardous materials are transported. Consequently, Federal and state authorities lack critical information they need to formulate hazardous materials policies and programs regarding enforcement of regulations, training for dealing with hazardous materials incidents, etc.

This document is one of a series of reports being prepared on the transport of large-volume manufactured or processed non-fuel substances that together account for at least 80 percent of U.S. truck shipments of hazardous chemicals. It was sponsored by the Office of Hazardous Materials Safety, Research and Special Programs Administration (RSPA), U.S. DOT. The report was prepared by the Environmental Engineering Division, Volpe National Transportation Systems Center, U.S. DOT and TDS Economics, Menlo Park, California.

It should be emphasized that all of the reports in this series are based on the best available information at the time the research was conducted. The U.S. chemical industry, however, operates in a dynamic economic and technological environment in which markets, production processes, and distribution requirements can change substantially from year to year. The information in this report on (a) chemical producers and their plant locations, (b) consuming plants and their locations, and (c) the estimated traffic flows from producers to consumers is thus subject to change.

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1 Office of Technology Assessment, Congress of the United States, *Transportation of Hazardous Materials*, 1986 and Research and Special Programs Administration, U.S. Department of Transportation, *Truck Transportation of Hazardous Materials, A National Overview,* 1987.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

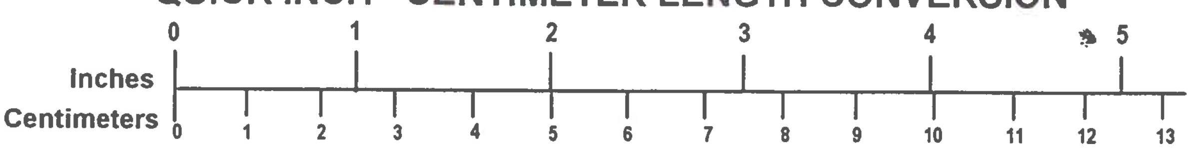
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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1. INTRODUCTION

The principal purpose of this report is to present estimates of truck shipments of 1-butanol, one of the 147 large-volume chemicals that account for at least 80 percent of U.S. truck shipments of hazardous chemicals. Appendix A lists these chemicals and their estimated 1987 production volumes.

The following sections of the report describe the physical characteristics of 1-butanol, its uses, and domestic producers and users. Because there is so little direct evidence on the specific routes over which 1-butanol is shipped, and in what quantities, this information is estimated by the use of models. Two widely used models of interregional commodity flows have been used: a gravity model and a linear programming model, each generating its own set of results. Both sets of results show quantities of 1-butanol flowing through individual states, and both are displayed graphically on flow maps.

Unfortunately, there are insufficient data on actual flows of 1-butanol to test the model results for accuracy or to determine which model provides the more reliable estimates. It is shown, however, that both sets of results are consistent with Research and Special Programs Administration (RSPA) data on incidents involving truck shipments of 1-butanol. More important, although the results of the two models are somewhat different, they agree in their identification of the major routes that carry 1-butanol, which is a major objective of this research.

2. CHARACTERISTICS OF 1-BUTANOL

1-butanol, which appears in the top one-third of the chemicals listed in Appendix A, is a low-boiling liquid. It is flammable, can irritate skin and eyes in the case of exposure, and is harmful if swallowed. The U.S. Department of Transportation's *Emergency Response Guidebook* recommends that emergency responders use its Guide No. 26 in the case of a spill of 1-butanol. See Table 1 for additional characteristics of this chemical.

3. USES OF 1-BUTANOL

1-butanol is used in the production of n-butyl acrylate/methacrylate (for surface coatings) and of n-butyl acetate and butyl glycol ethers (for solvents). In addition, it is used as a solvent for waxes, shellac, resins, gums, and varnishes. It is also used in hydraulic fluids, detergents, and plastics.

TABLE 1. CHARACTERISTICS OF 1-BUTANOL

Common Synonyms	Butanol n-Butanol Butyl alcohol Butyl hydroxide Butyric alcohol n-Butyl alcohol 1-Hydroxybutane n-Propylcarbinol
Formula	$CH_3(CH_2)_2CH_2OH$
UN Number	1120
IMCO Class	3.3
CAS Number	71363
DOT Hazard Class	Class 3 (Flammable and Combustible Liquids)
Description	Watery liquid Colorless Alcohol odor Flash point: 84 degrees F C.C. 97 degrees F O.C.

Sources: *CHRIS Manual*, June 1985; *Hazardous Commodity Handbook*, September 1987; *Hazardous Substances Resource Guide*, 1993.

4. PRODUCTION

U.S. production of 1-butanol in 1987 is estimated at 575,000 short tons, of which 450,500 short tons were available for shipment to off-site consumers. All production is in the Texas-Louisiana region, while consumption of the chemical is concentrated in the Chicago, New Jersey, and Los Angeles areas. There are six producers (five of which have terminals) and 67 major consuming plants.

1-Butanol is frequently used in the manufacture of other chemicals within the same plant. Intraplant use is termed "captive production." To calculate captive production, downstream chemicals produced within the same plant as 1-butanol are identified and the amount of 1-butanol needed in their production is estimated. The difference between total production and captive production defines the amount available for off-site shipments. It is the amount of production available for off-site consumption that is of interest to this study.

Table 2 shows net production available for off-site consumption by producing plant.

TABLE 2. MAJOR PRODUCERS OF 1-BUTANOL, 1987

Company	Plant Location	ZIP Code	Off-site Availability (Thousands of Short Tons)	Captive Shipments†
BASF	Freeport, TX	77541	17.5	yes
Celanese	Bay City, TX	77414	125.0	yes
Eastman Kodak	Longview, TX	75607	56.0	no
Shell	Deer Park, TX	77536	75.0	no
Union Carbide	Texas City, TX	77590	172.0	no
Vista	Lake Charles, LA	70669	5.0	no
Total off-site availability			450.5	

†Captive shipments are off-site shipments of the chemical from a producing plant to another plant owned by the same company. Companies with captive shipments are ones with corporate affiliations to net consumers listed in Table 3.

Sources: SRI International, *Study of Truck Transportation of Hazardous Chemicals*, SRI Project 8511, prepared for U.S. DOT, March 1993, and industry contacts.

5. CONSUMPTION

The net product requirement for any given plant can be calculated by subtracting the plant's total production from the plant's total requirements. Net product requirements for plants receiving 1-butanol by truck, barge, and rail are listed in Table 3. Note that 1987 net product requirements of 401.7 thousand short tons were less than the off-site availability of 450.5 short tons.

TABLE 3. MAJOR CONSUMERS OF 1-BUTANOL, 1987

Company	Plant Location	ZIP Code	Estimated Net Product Requirement (Thousands Short Tons)	Derivatives†
Consumers Receiving Shipments by Truck				
Air Products	Pensacola, FL	32592	1.7	BAM
AKZO	Columbus, OH	43211	1.0	AR
AKZO	Louisville, KY	40216	1.0	AR
American Cyanamid	Charlotte, NC	28201	0.5	AR
American Cyanamid	High Point, NC	27260	0.5	AR
American Cyanamid	Kalamazoo, MI	49003	0.5	AR
American Cyanamid	Mobile, AL	36601	0.5	AR
American Cyanamid	Wallingford, CT	06492	0.5	AR
American Cyanamid	West Memphis, AR	72301	0.5	AR
Albright & Wilson	Charleston, SC	29401	0.8	Misc.
BASF	Anaheim, CA	92801	6.1	DS
BASF	Detroit, MI	48200	5.5	AR,DS
BASF	Morganton, NC	28655	3.5	DS
Celanese	Bucks, AL	36512	0.7	BAM
Celanese	Portsmouth, VA	23703	0.7	BAM
Chemol	Greensboro, NC	27420	0.1	PL
Cheseborough-Ponds	Gallipolis Ferry, WV	25515	0.8	Misc.
CPHall	Chicago, IL	60638	0.4	PL
DuPont	Belle, WV	25015	1.5	BMCR
DuPont	Flint, MI	48502	1.4	DS
DuPont	Moberly, MO	65270	1.4	DS
DuPont	Mt. Clemens, MO	48043	1.4	DS
DuPont	Toledo, OH	43613	1.4	DS

TABLE 3. MAJOR CONSUMERS OF 1-BUTANOL, 1987 (Continued)

Company	Plant Location	ZIP Code	Estimated Net Product Requirement (Thousands Short Tons)	Derivatives†
DuPont	Tucker, GA	30084	1.4	DS
Emery	Cincinnati, OH	45202	0.1	PL
FMC	Nitro, WV	25143	0.8	Misc.
Guardsman	Grand Rapids, MI	49507	1.5	DS
Guardsman	High Point, NC	27261	3.7	DS
Guardsman	Southgate, CA	90280	3.7	DS
HATCO	Fords, NJ	08863	0.4	PL
INOLEX	Philadelphia, PA	19148	0.1	PL
Lilly	High Point, NC	27261	4.7	DS
Lilly	Montebello, CA	90640	4.7	DS
Monsanto	Cincinnati, OH	45001	1.5	AR
Monsanto	Springfield, MA	01151	1.5	AR
Morflex	Greensboro, NC	27403	1.2	Misc., PL
Nuodex	Chesterton, MD	21620	0.7	PL, Misc.
Pennwalt	Wyandotte, MI	48192	1.5	BAM
PPG	Cleveland, OH	44111	1.2	DS
PPG	Delaware, OH	43015	1.2	DS
PPG	Dover, DE	19901	1.2	DS
PPG	East Point, GA	30344	1.2	DS
PPG	Oak Creek, WI	53154	4.1	DS,AR
PPG	Springdale, PA	15144	1.2	DS
PPG	Torrance, CA	90509	1.2	DS
Reichhold	Carteret, NJ	07008	1.1	Misc., PL
Reliance	Brea, CA	92621	4.0	DS
Reliance	High Point, NC	27261	4.0	DS
Rhone Poulenc	St. Joseph, MO	64502	0.5	Misc.
Sybron	Birmingham, NJ	08011	0.4	Misc.
Union Camp	Dover, OH	44622	0.2	PL
Union Carbide	Institute, WV	25103	0.8	Misc.
Unitex	Greensboro, NC	27406	0.8	PL
Witco	Newark, NJ	07101	0.2	PL
Total truck shipments			83.2	

TABLE 3. MAJOR CONSUMERS OF 1-BUTANOL, 1987 (Continued)

Company	Plant Location	ZIP Code	Estimated Net Product Requirement (Thousands Short Tons)	Derivatives†
Consumers Receiving Shipments by Barge				
Cain	Bayport, TX	77000	17.0	GE
Celanese	Bishop, TX	78343	17.5	BACE
Celanese	Clear Lake, TX	77058	30.0	BACR
Rohm and Haas	Deer Park, TX	77536	92.0	BACR, BMC
Shell	Geismar, LA	70734	14.0	GE
Union Carbide	Seadrift, LA	77983	47.8	GE, Misc.
Union Carbide	Taft, LA	70057	35.0	BACR
Total barge shipments			253.3	
Consumers Receiving Shipments by Rail				
Aristech	Neville Island, PA	15225	2.2	PL, Misc.
BASF	Kearny, NJ	07032	3.8	PL
Dow	Midland, MI	48667	28.0	GE
Eastman Kodak	Kingsport, TN	37662	16.9	BACE, PL
ELCO	Hooven, OH	45033	2.3	Misc.
Monsanto	Bridgeport, NJ	08014	12.0	PL
Total rail shipments			65.2	
Total of all modes			401.7	

†Derivatives are chemicals that use 1-butanol in their manufacture. Listed below is the derivatives glossary for this table:

AR-Amino Resins	BACE-Butyl Acetate	BAM-Butylamines
BACR-Butyl Acrylate	BMCR-Butyl Methacrylate	DS-Direct Solvent
GE-Glycol Ethers	PL-Plasticizers	Misc.-Miscellaneous

Sources: SRI International, *Study of Truck Transportation of Hazardous Chemicals*, SRI Project 8511, prepared for U.S. DOT, March 1993, and U.S. Department of Transportation, HMIS database.

6. INTERNATIONAL TRADE

Imports of 1-butanol are negligible. Of the 450,000 short tons (Table 2) shipped in 1987, only 5,000 short tons (1.1 percent) were imported.[1] In 1987, a much larger amount (93,000 short tons) was exported. Of this amount, 93 percent departed directly from the Houston/Galveston area. Most of the exported 1-butanol is expected to require only minimal highway movement.[2]

7. DISTRIBUTION AND TRANSPORT

As shown in Table 3, 1-butanol is shipped by barge and rail, as well as by truck. In 1987, barge shipments exceeded shipments by rail and truck combined.

Information on barge, rail, and truck movements of 1-butanol was obtained for this report from telephone interviews with logistics managers of producer and consumer firms. Information on rail shipments was also obtained from the 1987 ICC Waybill Sample.

Most large-volume shipments of 1-butanol are made by barge on inland and coastal waterways. Waterborne shipments are especially important for shipping 1-butanol from four of the five large suppliers to the largest consuming plants located near navigable waterways. In most of these cases, the destination plants use 1-butanol to produce other chemicals.

Because 1-butanol is a liquid, bulk shipments are also delivered in tank trucks or rail cars. Non-bulk shipments (not investigated in this study) are typically carried by truck in drums or in smaller containers capable of holding liquids.

Rail is used for large-volume movements that do not follow navigable waterways. Rail rates charged on routes near waterways tend to be low because of the influence of competing barge rates.

Most producers of 1-butanol have terminals located at or near major consuming centers for the purpose of storing the chemical until it is sold to nearby customers. 1-butanol is generally shipped by rail or barge to these terminals and then distributed by truck to final customers. Table 4 lists the terminals by user and location.

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1 SRI International, *Study of Truck Transportation of Hazardous Chemicals*, SRI Project 8511, prepared for U.S. DOT, March 1993.

2 Ibid.

TABLE 4. TERMINALS USED BY 1-BUTANOL PRODUCERS

Parent Company	Terminal Location
BASF	Carteret, NJ Lemont, IL
Celanese	Carteret, NJ Lemont, IL Richmond, CA
Eastman Kodak	Carteret, NJ Lemont, IL Richmond, CA Kingsport, TN
Shell	Carteret, NJ Lemont, IL
Union Carbide	Carteret, NJ Lemont, IL Richmond, CA S. Charleston, WV
GATX Public Terminal†	Los Angeles, CA

†A public terminal is available to all producers on an as-needed basis. Use may change from year to year. It is likelky that all of the major suppliers with terminals in Richmond, CA also use the GATX public terminal in Los Angeles.

Source: Telephone conversations with producers.

Many truck movements are limited to short-haul (e.g., from a terminal to the end-user) shipments in drums. Companies using 1-butanol as a solvent have it delivered by truck in mixed shipments, using compartmented tankwagons (cargo tank trucks). Most tankwagon shipments originate from terminals located near major consuming centers.

Average net consumption of 1-butanol at plants receiving truck shipments is significantly lower than at plants receiving barge or rail shipments, as shown in Table 5. About four times as many consuming plants are served by truck as are served by barge and rail combined, indicating the important role of truck transport in the movement of 1-butanol.

TABLE 5. ESTIMATED AVERAGE ANNUAL VOLUME OF TRUCK VERSUS NON-TRUCK DELIVERIES OF 1-BUTANOL

	Number of Plants	Average Annual Consumption (Thousands of Short Tons)
Non-truck	13	50.38
Truck	54	1.54

8. USE OF MODELS TO ESTIMATE TRUCK FLOWS

The major producers of 1-butanol and their plant locations are identified in Table 2, along with the amounts of the chemical each has available to consumers. Table 3 lists consuming companies, their plant locations, and the amounts of 1-butanol each received by truck delivery in 1987. The terminals from which many truck shipments originate are listed in Table 4. This section explains how this information is used to identify the specific highways over which bulk shipments of 1-butanol are transported from producers to users and in what quantities.

Because there is so little readily available direct evidence on the flows of 1-butanol over the Nation's highways, the flows must be estimated. For this report, this was accomplished by the use of two widely used models of interregional commodity flows, a gravity model and a linear programming model. Using the data presented in Tables 2, 3, and 4, both models allocate truck flows from the producing plants and terminals to consuming plants. The basic features of these models are described in Appendix B.[3]

Both models have been adjusted to take into account some real-world features of the distribution of hazardous chemicals:

- Some shipments are made to captive consumers, that is, consuming plants that are owned by the same parent company that owns the producing plant.
- A producer may serve a consumer with shipments from either a production facility or a terminal.
- As a matter of company policy, some consuming plants do not purchase from certain producers.
- Regulations mandate the use of two drivers for trips that are over 230 miles in length.

There appears to be no consensus as to which model provides the more accurate estimates of routes used for truck shipments of hazardous chemicals. However, because the gravity model approach is clearly more inclusive in identifying routes over which commodities are transported by truck, its results are presented in the main body of this report, and the results of the linear programming model are presented in Appendix B. A key point to be emphasized, however, is that, although the two models yield somewhat different results, they agree in their identification of the major truck routes that carry 1-butanol.

9. GRAVITY MODEL ESTIMATION RESULTS

The gravity model results presented in this section are most clearly understood in the context of the distribution system within which 1-butanol is transported. The data in Table 3 indicate that only 21 percent of off-site shipments (measured in tons) move by truck. The remainder move by rail or barge. Most truck shipments originate at terminals rather than at manufacturing plants. A combination of rail or barge and truck transport is generally less expensive than truck transport alone, even though total miles of transport may be longer for the multimodal option. Only about nine percent

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3 A more detailed, technical explanation of the models is found in "Alternative Modeling Approaches for Allocating Truck Flows of Hazardous Chemicals," a draft report prepared for RSPA's Office of Hazardous Materials Safety by the RSPA/Volpe Center and TDS Economics, July 1994.

of truck movements are estimated to originate at manufacturing facilities, which leads to an average length of a truck haul of about only 360 miles.

The gravity model results for bulk shipments of 1-butanol are shown in Table 6.[4] According to those estimates, in 1987, the following eight states had the greatest highway exposure to 1-butanol in terms of both ton-miles and truck-miles (in descending order): Michigan, Virginia, North Carolina, Indiana, West Virginia, Illinois, Louisiana, and Texas.

It is not surprising that Texas and Louisiana are on this list, because they are the major producer states. Michigan and North Carolina are important consumer states. West Virginia has a Union Carbide terminal, and Illinois has terminals operated by BASF, Celanese, Eastman Kodak, Shell, and Union Carbide. Virginia lies between the terminal in West Virginia and consumer plants in North Carolina. Indiana lies between terminals in Illinois and consumers in Michigan.

The gravity model results shown in Table 6 are reflected on the maps in Figures 1 and 2, which show the major routes carrying truck shipments of 1-butanol.[5] The width of the blue lines is directly proportional to the quantity flowing over the routes, as indicated in the figure legends. The direction of flow is indicated by the position of the flow line relative to its route, shown in magenta. A blue flow line shown to the right of a north-south route indicates that the flow is northward. A blue flow line that lies above an east-west route line indicates that the flow is westward.

The national map, shown in Figure 1, shows a relatively small amount of 1-butanol being trucked from Texas to southern California. Within California itself, there appears to be substantial movement from terminals to consumer plants in the southern-most part of the state.

The majority of truck movements of 1-butanol occur in the eastern U.S. As shown in Figure 2, the largest flows are those (a) from terminals in Illinois to consumer plants in Michigan, (b) from a terminal in West Virginia across Virginia to consumer plants in North Carolina, and (c) from a terminal in Kingsport, Tennessee, to consumer plants in North Carolina. The map also depicts flows to North Carolina from terminals in New Jersey.

It should be noted that the maps in Appendix C, which depict the flows of 1-butanol according to the linear programming model, show that the consumer plants in North

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[4] The linear programming results are shown in Appendix C.

[5] The software used to generate the flow maps is described in Appendix D.

TABLE 6. GRAVITY MODEL ESTIMATES OF BULK TRUCK SHIPMENTS OF 1-BUTANOL BY STATE, 1987

State	Ton-miles (Thousands)	Truck-miles (Thousands)†
Alabama	727	36
Arizona	92	5
Arkansas	84	4
California	535	27
Connecticut	187	9
Delaware	179	9
District of Columbia	22	1
Florida	40	2
Georgia	262	13
Illinois	1,321	66
Indiana	1,706	85
Iowa	100	5
Kansas	0	0
Kentucky	330	16
Louisiana	1,318	66
Maryland	333	17
Massachusetts	10	0
Michigan	2,330	116
Mississippi	469	23
Missouri	155	8
New Jersey	670	34
New Mexico	38	2
New York	56	3
North Carolina	1,066	53
Ohio	776	39
Oklahoma	25	1
Pennsylvania	201	10
South Carolina	162	8
Tennessee	543	27
Texas	943	47
Virginia	1,320	66
West Virginia	1,588	79
Wisconsin	115	6
Total	17,703	885

†Truck miles are calculated by dividing the number of ton-miles by 20,000, the average size of a tank truck load.

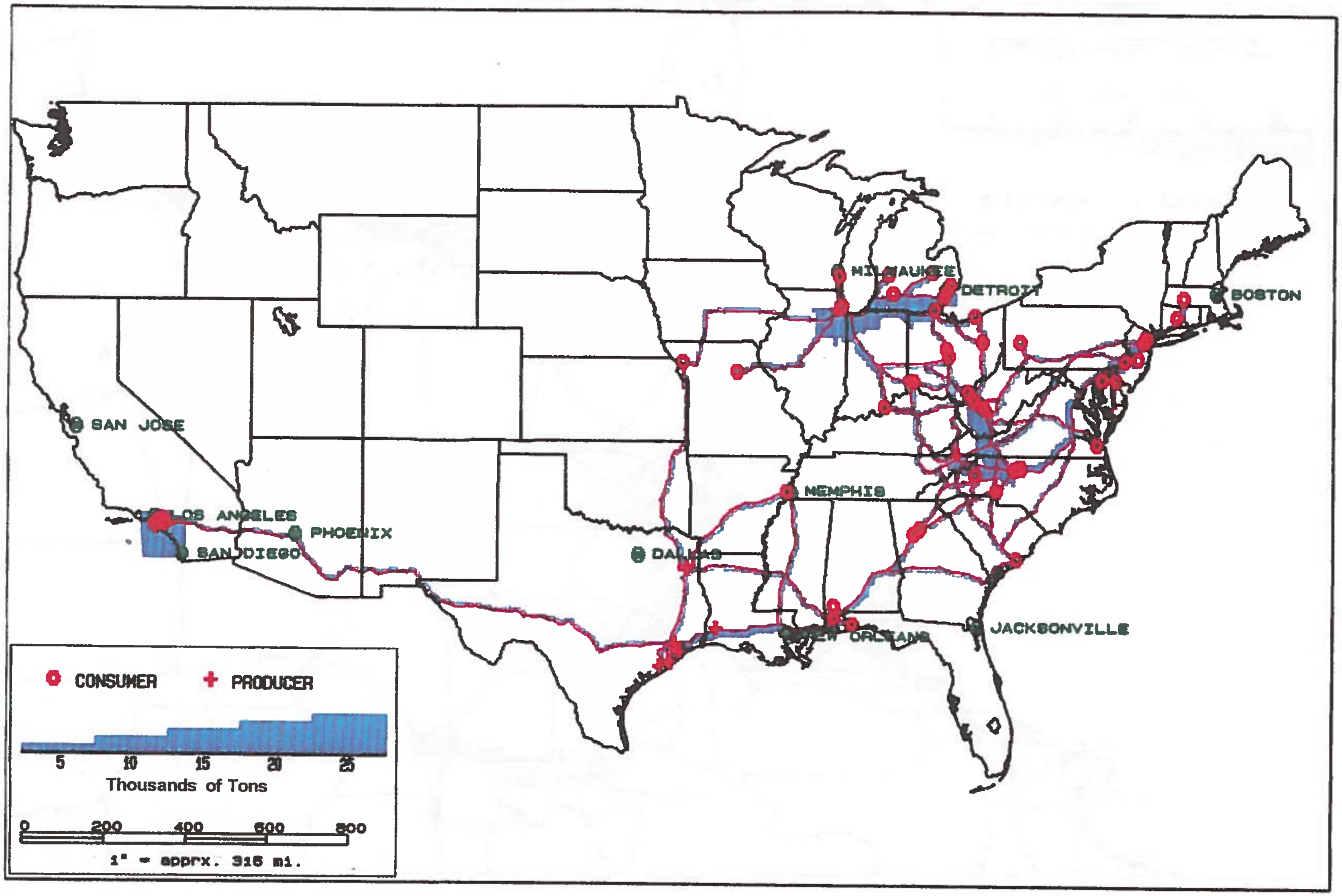

FIGURE 1. NATIONAL TRUCK FLOWS OF 1-BUTANOL (GRAVITY MODEL RESULTS)

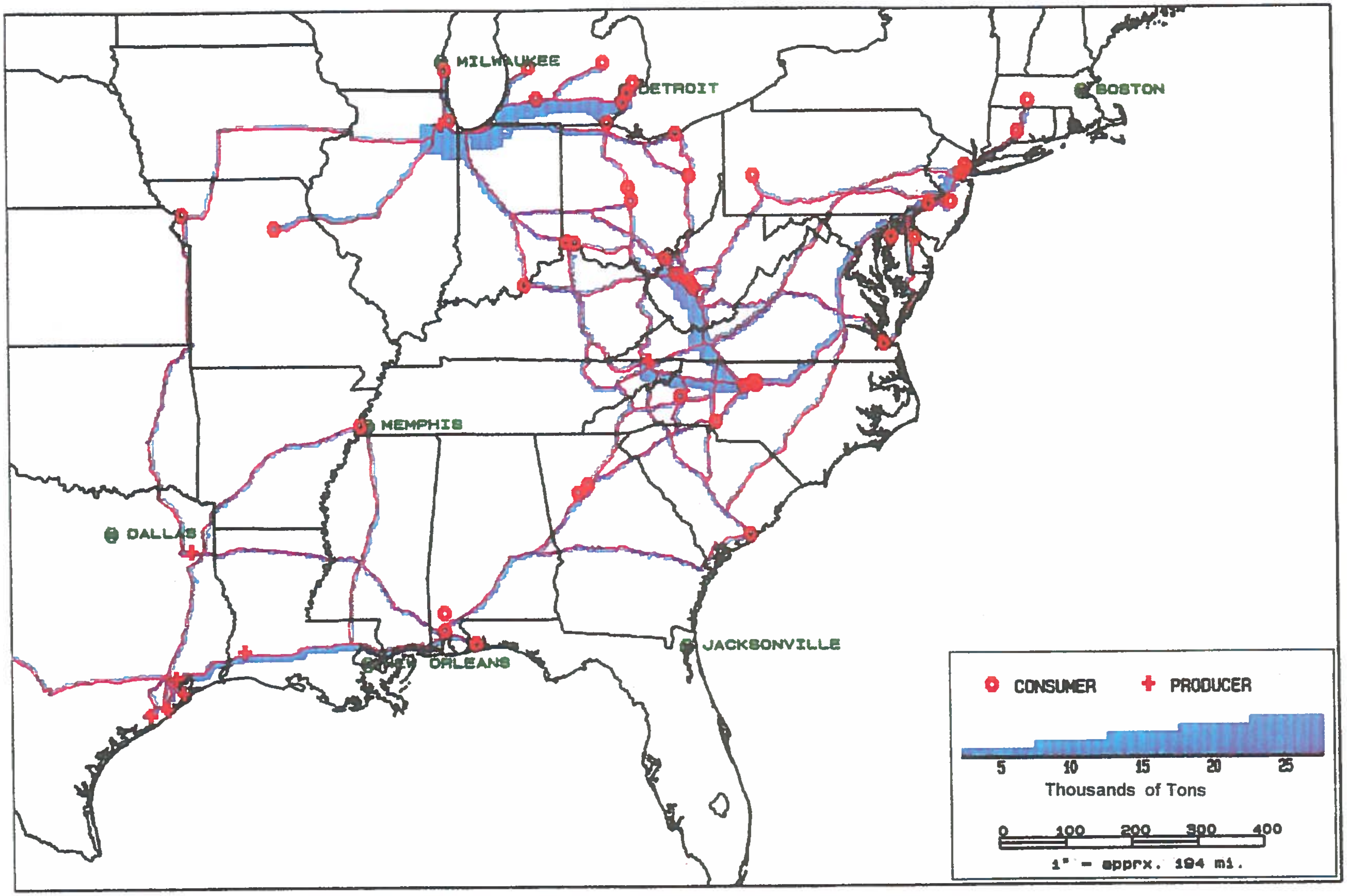

FIGURE 2. NATIONAL TRUCK FLOWS OF 1-BUTANOL: EASTERN U.S. (GRAVITY MODEL RESULTS)

Carolina are supplied solely by the terminal in Kingsport, Tennessee. Also, truck shipments from the terminal in West Virginia flow only northward, and not southward to North Carolina through Virginia.

10. COMPARISON OF MODEL RESULTS WITH INCIDENT DATA

Table 7 shows estimates of the expected annual number of truck accidents involving 1-butanol. These estimates, based on 1987 truck miles, are shown in the third column of the table. Given an RSPA estimate that about 15 percent of highway accidents result in a release or spill, the last column shows the expected number of years between spills for each state.

The estimates in Table 7 indicate that as of 1987, the states with the highest risk of both truck accidents and spills were Illinois, Indiana, Louisiana, Michigan, North Carolina, Texas, Virginia, and West Virginia. This is hardly surprising, since these states also rank highest in ton-miles and truck-miles of 1-butanol. The expected annual number of truck accidents involving 1-butanol for the nation was 1.6, and the expected number of years between spills was four.

Table 8 indicates that, from 1985 to 1987, there was only one incident caused by a highway accident for all types of butanol. Unfortunately, the U.S. DOT hazardous materials database combines incident data for 1-butanol, iso-butanol, and secondary butanol, making it impossible to isolate incidents involving only 1-butanol. However, even if the one highway accident in Table 8 did involve 1-butanol, the average number of highway accidents over the 1985-87 period would be only one-third of an accident per year, a lower rate than the estimate of 1.6 shown in Table 7.

It is noteworthy that the one highway accident during the three-year period occurred in Illinois, a state with one of the highest risks of accidents and spills. The remaining four incidents in Table 8, involving relatively small releases of 1-butanol, were caused by packaging failure, not highway accidents.

TABLE 7. ESTIMATED NUMBER OF TRUCK ACCIDENTS INVOLVING 1-BUTANOL, BY STATE, 1987

State	Ton-Miles† (Thousands)	Estimated Truck Miles† (Thousands)	Estimated Accidents‡	Estimated Years/Spill‡
Alabama	727	66	0.07	101
Arizona	92	8	0.01	833
Arkansas	84	8	0.01	833
California	535	49	0.05	136
Connecticut	187	17	0.02	392
Delaware	179	16	0.02	417
District of Columbia	22	2	0.00	3,333
Florida	40	4	0.00	1,667
Georgia	262	24	0.02	278
Illinois	1,321	120	0.12	56
Indiana	1,706	155	0.16	43
Iowa	100	9	0.01	741
Kansas	0	0	0.00	--
Kentucky	330	30	0.03	222
Louisiana	1,318	120	0.12	56
Maryland	333	30	0.03	222
Massachusetts	10	1	0.00	6,667
Michigan	2,330	212	0.21	31
Mississippi	469	43	0.04	155
Missouri	155	14	0.01	476
New Jersey	670	61	0.06	109
New Mexico	38	3	0.00	2,222
New York	56	5	0.00	1,333
North Carolina	1,066	97	0.10	69
Ohio	776	71	0.07	94
Oklahoma	25	2	0.00	3,333
Pennsylvania	201	18	0.02	370
South Carolina	162	15	0.02	444
Tennessee	543	49	0.05	136
Texas	943	86	0.09	78
Virginia	1,320	120	0.12	56
West Virginia	1,588	144	0.14	46
Wisconsin	115	10	0.01	667
Total	17,703	1,609	1.61	4

‡The number of accidents per year is calculated at one accident per one million truck miles; about 15 percent of these accidents results in a release or spill. These rules of thumb were suggested by RSPA's Office of Hazardous Materials Safety.

†Source: Table 6

TABLE 8. DATA ON BUTANOL BULK-SHIPMENT INCIDENTS, 1985 TO 1987

Origin State	Destination State	Spill State	Release Amount (Gallons)	Cause†	Type of Consignee‡	Highway Accident
IL	IN	IL	181.00	30	Chemical	yes
WV	UT	OH	55.00	20	Unknown	no
MO	KY	IL	3.00	20	Unknown	no
VA	OH	OH	1.00	20	Manufacturer	no
PA	KY	OH	1.00	20	Unknown	no

†Cause of release: 10 denotes human error; 20 denotes packaging failure; 30 denotes highway accident; and 40 denotes all other.

‡Chemical denotes a chemical, solvent, or related company or wholesaler; manufacturing denotes a manufacturing company; and unknown indicates that the company name was not given.

Source: "Hazmat" computerized incident database, RSPA, U.S. DOT, 1994.

APPENDIX A. LIST OF 147 LARGE-VOLUME CHEMICALS

Chemical	Production Volume, 1987 (Thousands of Short Tons)
Sulfuric Acid	39,235
Propane	26,896
Nitrogen	24,515
Oxygen	16,669
Ammonia	16,100
Calcium Oxide	15,733
Sodium Hydroxide	11,486
Chlorine Gas	11,019
Phosphoric Acid	10,685
Sulfur	10,321
Carbon Dioxide	8,307
Ethylene Dichloride	7,878
Ammonium Nitrate	7,612
Nitric Acid (100% HNO_3 Basis)	7,225
Benzene	5,904
Ethylbenzene	4,630
Vinyl Chloride	4,201
Styrene	4,007
Methanol	3,769
Toluene	3,223
Ethylene Oxide	2,921
Hydrochloric Acid (100%)	2,869
p-Xylene	2,578
Methyl t-Butyl Ether	1,757
Phenol	1,676
Acetic Acid, Synthetic	1,623
1,3-Butadiene	1,465
Ethanol (Synthetic)	1,434
Aluminum Sulfate	1,426
Carbon Black (Furnace Black)	1,362
Vinyl Acetate	1,253
Acrylonitrile	1,250
Formaldehyde	1,232
Cyclohexane	1,137
Propylene Oxide	1,105

APPENDIX A. LIST OF 147 LARGE-VOLUME CHEMICALS (Continued)

Chemical	Production Volume, 1987 (Thousands of Short Tons)
Acetone	1,048
Butyraldehyde	879
Acetic Anhydride	858
Adipic Acid	795
Isopropanol	685
Nitrobenzene	625
1-Butanol	575
Argon	560
Acrylic Acid	550
Hexamethylenediamine	543
Isobutylene	518
Hydrogen Cyanide	516
Methyl Methacrylate	514
Phthalic Anhydride	508
o-Xylene	470
Methylene Diphenyl Diisocyanate	467
Cyclohexanone	465
Barite	448
Aniline	430
Hexane	426
Phosgene	421
Linear Alkylate Sulfonate	399
Hydrogen	389
Carbon Tetrachloride	374
Acetaldehyde	363
Toluene Diisocyanate	357
Methylchloroform	347
Phosphorus	344
Methyl Ethyl Ketone	336
Sodium Chlorate	289
Tripropylene (Nonene)	275
Hydrofluoric Acid	274
Methyl Chloride	261
Methylene Dichloride	259
n-Butyl Acrylate	258

APPENDIX A. LIST OF 147 LARGE-VOLUME CHEMICALS (Continued)

Chemical	Production Volume, 1987 (Thousands of Short Tons)
Potassium Hydroxide	246
Perchloroethylene	237
1-Butene	231
Calcium Carbide	230
Sulfur Dioxide	229
Epichlorohydrin	225
Chloroform	224
Dodecene (Propylene Tetramer)	200
Maleic Anhydride	193
Dichlorodifluoromethane	184
Acetylene	182
Carbon Disulfide	180
Ethylene Glycol Monobutyl Ether	175
Bromine	168
Ethyl Acrylate	162
Hydrogen Peroxide	153
Chlorodifluoromethane	142
n-Pentane	142
Propionaldehyde	140
Ferric Chloride	137
Nonylphenol	137
Sodium Chromate/Dichromate	128
Chlorobenzene	123
Naphthalene	121
Monoethanolamine	116
Activated Carbon	109
Ethyl Acetate	107
Phosphorus Trichloride	102
n-Butyl Acetate	101
Isobutyraldehyde	99
Trichloroethylene	98
n-Propanol	93
Barium Sulfide	92
n-Heptane	89
Calcium Hypochlorite	88

TABLE B-1. PRODUCTION/CONSUMPTION FLOW MATRIX

nsumers oducers	Consumer 1	Consumer 2	Consumer 3	Total Available for Off Site Shipments
oducer 1	F_{11}	F_{12}	F_{13}	Production 1 $\geq \Sigma_j F_{1j}$
oducer 2	F_{21}	F_{22}	F_{23}	Production 2 $\geq \Sigma_j F_{2j}$
oducer 3	F_{31}	F_{32}	F_{33}	Production 3 $\geq \Sigma_j F_{3j}$
oducer 4	F_{41}	F_{42}	F_{43}	Production 4 $\geq \Sigma_j F_{4j}$
otal onsumption eceived by uck	Consumption 1 $\Sigma_i F_{i1}$	Consumption 2 $\Sigma_i F_{i2}$	Consumption 3 $\Sigma_i F_{i3}$	Total Shipped by Truck $\Sigma_{ij} F_{ij}$

s in the table indicate the flows to be estimated. For example, F_{21} indicates the om producing plant 2 to consuming plant 1. Note: if we sum the flows lly, they will equal the consumption listed across the bottom of the table. er, in general, the horizontal sums will be less than or equal to the production ies listed at the right, because some of the production will be used for other es or may travel by a mode other than truck.

Based on previous research, two models are used to estimate truck flows by state.[6] These models are described below.

Gravity Model

Gravity models provide a method for filling in the above table. They are widely applied and accepted models for freight allocation problems and have been shown to be reasonable predictors of freight movements.[7] They take their name from the mathematical form, which is analogous to Newton's Law of Universal Gravitation, but otherwise they have nothing to do with gravity.

Unless they are programmed otherwise, gravity models assign the largest commodity flows to those origin-destination pairs that (a) are closest in distance and (b) have the largest volumes of product available at the origin or demanded at the destination. Gravity models also provide a routing over the actual highway network for these flows. By their mathematical structure, they tend to assign flows in such a way that all of the F_{ij}'s are non-zero, although some may be quite small. Because, in reality, companies tend to buy in large quantities, such as truckloads, the model is modified to restrict the F_{ij}'s to be at least 20 short tons. Other adjustments, such as giving preferences to flows between producers and consumers owned by the same parent company, are incorporated into the model.

Linear Programming Model

Linear programming is the second model used for estimating the F_{ij}'s.[8] This particular application of linear programming models is part of the "Transportation Problem" in which the model tries to minimize ton-miles, truck-miles, or some other measure of transportation cost. The same input variables used in the gravity model are required for the linear programming model: information on production available for off-site consumption, demand for truck shipments by consumers, and estimated miles between each producer and consumer.

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[6] "Alternative Modeling Approaches for Allocating Truck Flows of Hazardous Chemicals," a draft report prepared for RSPA's Office of Hazardous Materials Safety by the RSPA/Volpe Center and TDS Economics, July 1994.

[7] Overgaard, K. Rask, "Traffic Estimating and Planning," *Acta Polytechnica Scandinavica*, Civil Engineering and Building Construction Series No. 37, 1966.

[8] Kwak, N., *Mathematical Programming with Business Applications*, McGraw-Hill, Inc., 1973.

The linear programming approach, however, is quite different from the gravity model approach in several respects. The linear programming model starts with an objective function, typically to minimize ton-miles or truck-miles traveled:

$$\text{Min } \Sigma_{ij} F_{ij}.$$

This model is ideally suited for the decision process of a single company interested in minimizing its transportation costs. It may be less applicable to modeling the decisions of multiple companies that are not all working together to minimize total industry-wide transportation costs.

Due to the mathematical nature of linear programming models, flows are assigned to only a few F_{ij}'s; many of the F_{ij}'s are zero. The same constraints as those used by gravity models on the flows--e.g., adjustments to favor flows between producers and consumers owned by the same company--are incorporated into the model to reflect the realities of the transportation decision making process.

Model Comparison

The two model types, gravity and linear programming, provide alternative methods for analyzing truck flows. The first tends to assign flows to most possible origin-destination pairs, while the other assigns flows to only a few pairs. The results of the two approaches show the range of possible outcomes, which are subject to many factors beyond simple mathematical modeling, such as fuel prices, corporate alliances, and the desire of purchasing companies to have multiple sources of supply.

APPENDIX C. LINEAR PROGRAMMING ESTIMATES OF BULK SHIPMENTS OF 1-BUTANOL BY STATE

This appendix reports the linear programming estimates of bulk shipments of 1-butanol and compares them with the estimates of the gravity model presented in the main body of the text. The linear programming results are shown in Table C-1.

As expected, the linear programming results reflect a greater concentration of trucking activity nationwide than do the gravity model results. This greater concentration is especially strong in some states, most notably North Carolina and Tennessee, where shipment estimates more than double. Shipment levels in Michigan, Indiana, and Illinois remain high, but flows in Virginia, West Virginia, Louisiana, and Texas are significantly lower than the gravity model estimates.

A comparison of Figures 3 and 4 with Figures 1 and 2 indicates the same high level of flows from terminals in Illinois to consumer plants in Michigan, and the same high concentration of trucking activity in southern California. Unlike the gravity model, however, the linear programming model does not indicate any flow from Texas to southern California. This is consistent with the gravity model's tendency to indicate small flows where none may exist, and the tendency of the linear programming model to not recognize small flows.

In contrast to the gravity model estimates, consumer plants in North Carolina are supplied solely by the terminal in Kingsport, Tennessee, and not from a terminal in West Virginia. Also, truck shipments from the terminal in West Virginia flow only northward, and not southward to North Carolina through Virginia.