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Truck Transport of Hazardous Chemicals: Acetone

Final Report
March 1997

U.S. Department of Transportation
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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.

The principal purpose of this report is to present estimates of truck shipments of acetone, one of 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 frequently involve or expose 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 bulk shipments of large-volume manufactured or processed non-fuel substances that together account for at least 80% of U.S. truck shipments of hazardous chemicals. It was sponsored by the Office of Hazardous Materials Planning and Analysis, 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, with contract support from 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. Thus, 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 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 (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .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)

°C=5/9(°F - 32)

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 (km) = 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 (ha) = 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)

°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1			2			3			4			5
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13		

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 NIST 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 acetone, one of the 147 large-volume chemicals (non-fuel) that account for at least 80% of U.S. truck shipments of hazardous chemicals. Appendix A lists these chemicals.

The following sections of the report describe the physical characteristics of acetone, its uses, domestic producers and users. Because there is so little direct evidence on the specific routes over which acetone 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 acetone flowing through individual states, and both are displayed graphically on flow maps.

Unfortunately, there are insufficient data on actual flows of acetone 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 RSPA data on incidents involving truck shipments of acetone.

2. CHARACTERISTICS OF ACETONE

Acetone is a colorless, low boiling-point liquid. It is flammable and may be poisonous if inhaled or absorbed through the skin. The *1996 North American Emergency Response Guidebook* recommends that emergency responders use its Guide No. 127 (UN 1090) in the case of a spill involving acetone. Additional information about acetone is given in Table 1.

3. USES OF ACETONE

Acetone is used primarily in the production of acetone cyanohydrin, bisphenol A, and aldol chemicals. These chemicals are used, directly or indirectly, to produce a variety of products, including glazings, coatings, paints, resins, polymers, polyesters, lacquers, lube oil additives, solvents, rubber antioxidants, and specialty surfactants. Acetone is also used for a variety of solvent applications (e.g., as a thinner and wash solvent for surface coatings and in the pharmaceutical industry). Small quantities of acetone are used in a variety of other chemical syntheses and applications.

TABLE 1. ADDITIONAL INFORMATION ON ACETONE

Common Synonyms	Dimethyl ketone Methyl ketone 2-Propanone
Formula	CH_3COCH_3
UN Number	1090
DOT Hazard Class	Class 3 (Flammable and Combustible Liquids)
CAS Number	67-64-1
Description	Watery liquid Colorless Sweet odor Flash point: -9.4 degrees C O.C.

Sources: *CHRIS Manual, Vol. 1, A Condensed Guide to Chemical Hazards,* 1992; National Tank Truck Carriers, Inc., *Hazardous Commodity Handbook,* Tenth Edition, 1994; and Gale Research Inc., *Hazardous Substances Resource Guide,* 1993.

4. PRODUCTION

Acetone, with an estimated 1992 U.S. production of 1.33 million short tons, is in the top third of the list of 147 chemicals given in Appendix A. The chemicals listed in this appendix account for over 80% (by volume) of truckload shipments of hazardous chemicals in the United States.

Acetone is produced at twelve plants located in nine states. Texas (with about one-third of the total) and Pennsylvania together accounted for over half of total 1992 production. Other major producing states are Ohio, Indiana, Louisiana, and West Virginia.

Acetone is used in the manufacture of other chemicals at some of its producing plants. Intraplant use is termed "captive production." To calculate captive production, downstream chemicals produced within the same plant as acetone are identified, and the amount of acetone needed in their production is estimated. The difference between total production capacity and captive production requirements defines the amount available for offsite shipment. Table 2 shows net production available for offsite consumption by producing plant in 1992. Producers may ship to plants at other locations owned by the same parent company. These shipments are termed "captive shipments," and producers believed to have captive shipments are identified in Table 2.

TABLE 2. MAJOR PRODUCERS OF ACETONE, 1992

Company	Plant Location	Offsite Availability† (Thousands of Short Tons)	Captive Shipments‡
Allied-Signal	Frankford, PA	250.0	Yes
Aristech	Haverhill, OH	171.7	No
BTL	Blue Island, IL	26.5	No
Dow	Oyster Creek, TX	167.5	Yes
Eastman	Kingsport, TN	0.0	No
Georgia Gulf	Pasadena, TX	50.0	No
Georgia Gulf	Plaquemine, LA	135.0	No
Goodyear	Bayport, TX	7.5	No
Mt. Vernon (GE)§	Mt. Vernon, IN	170.0	Yes
Shell	Deer Park, TX	60.1	No
Texaco	El Dorado, KS	27.5	No
Union Carbide	Institute, WV	38.8	Yes
Total Offsite Availability		1,104.6	

†Offsite availability is the amount of the product available for shipment after intraplant consumption is accounted for.

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

§Mt. Vernon is now General Electric Company, GE Plastics.

Sources: Based on information from industry sources.

5. CONSUMPTION

Table 3 lists 107 plants identified as net consumers of acetone that receive bulk shipments by truck, rail, or water.[2] For each plant, the estimated net product requirement of acetone is shown. The estimates are based on the known production at the plants of other chemicals using acetone. None of the identified plants manufactures acetone. Note that total net product requirements are less than off-site availability; that is, total estimated demand for acetone is less than production capacity.

In Table 3, 91 consuming plants are identified as being likely to receive bulk truck shipments of acetone.[3] The annual volume of acetone received by plants using bulk truck shipments averages about 1,800 short tons, or about a tank truck once or twice a week. The other 16 consuming plants in Table 3 are identified as receiving shipments of acetone by rail or water.[4]

6. INTERNATIONAL TRADE

Imports and exports of acetone are small in comparison with domestic production and consumption. According to industry sources, in 1992, U.S. consumers imported 48 thousand short tons, primarily from South Africa (56%), Spain (24%), and Italy (14%). U.S. exports of acetone totaled 160 thousand short tons, with the largest volume of exports going to Taiwan (28%), Japan (23%), Mexico (8%), and the Netherlands (8%). The domestic transportation component of international shipments is not included in this study. It is unlikely, however, that shipments to or from these countries involve truck transportation, because most producers, consumers, and terminals are located adjacent to port facilities serving international trade or on rail lines linked to ports. There may be truck shipments to or from Mexico or Canada; these, however, are expected to be minimal.

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[2] Because of its use as a solvent, there are thousands of acetone consumers throughout the U.S. The vast majority, however, receive small volume, less than truckload (LTL) shipments. Since the focus of this report is on bulk shipments of acetone, these plants are excluded from consideration.

[3] Where specific information on modal selection by producers or consumers was unavailable, the following rules were used:

Estimated Annual Consumption	Mode
Less than 150 short tons	Less than truck load
150 to 350 short tons	Truck loads (drums)
350 to 7,500 short tons	Tank trucks
7,500 short tons and over	Rail or barge

Note that consumers may use more than one mode. For example, consumers generally use rail, but rely on truck deliveries if supplies unexpectedly run low.

[4] The production and consumption estimates given in Tables 2 and 3 were developed from industry sources, including telephone interviews with representatives of producer and consumer firms. Implied shipments based on these estimates were found to be consistent with origin and destination data contained in the 1992 Rail Waybill Sample and the Army Corps of Engineers Waterborne Commerce reports (barge or ship cargoes).

TABLE 3. MAJOR CONSUMERS OF ACETONE, 1992

Company	Plant Location	Estimated Net Product Requirement (Thousands of Short Tons)	Derivatives†
Consumers Receiving Truck Shipments			
3M	White City, OR	0.4	SOLV
3M	Hartford City, IN	0.7	SOLV
3M	Cordova, IL	1.4	SOLV
Abbott Laboratories	No. Chicago, IL	2.4	AB
Advanced Dielectrics	Fremont, CA	0.2	SOLV
Air Products	Calvert City, KY	1.5	ACAL
AKZO	Columbus, OH	5.4	SCS
Allied-Signal	Elizabeth, NJ	0.2	SOLV
Allied-Signal	Philadelphia, PA	0.4	SOLV
American Cyanamid‡	Hannibal, MO	0.6	AB
American Cyanamid‡	Pearl River, NY	0.6	AB
American Cyanamid‡	Westwego, LA	0.4	SOLV
American Cyanamid‡	Willow Island, WV	0.6	AB
Arco	Pasadena, TX	0.6	SOLV
BASF	Anaheim, CA	4.6	SCS
BASF	Detroit, MI	4.6	SCS
BASF	Greenville, OH	4.6	SCS
Biocraft Laboratories	Waldwick, NJ	3.3	AB
Burroughs-Wellcome	Greenville, NC	0.2	SOLV
Bristol-Meyers	Syracuse, NY	2.4	AB
Dupli-Color	Elk Grove Village, IL	0.2	SOLV
DuPont	Mt. Clemens, MI	1.5	SCS
DuPont	Flint, MI	2.4	SCS
DuPont	Fort Madison, IA	2.4	SCS
DuPont	Front Royal, VA	2.4	SCS
DuPont	Parlin, NJ	2.4	SCS
DuPont	Toledo, OH	2.4	SCS
Dupont	Axis, AL	4.0	CYAN
Eastman	Rochester, NY	1.0	SOLV
Eli Lilly	Indianapolis, IN	0.2	SOLV
Eli Lilly	Clinton, IN	1.2	AB
Eli Lilly	Lafayette, IN	2.8	AB
Fermtec	West Chester, PA	2.4	AB
Ganes	Pennsville, NJ	0.7	SOLV
GE Plastics	Waterford, NY	0.2	SOLV
Grow Group	Cleveland, OH	2.2	SCS
Grow Group	Louisville, KY	2.3	SCS
Guardsman	Grand Rapids, MI	1.3	SCS
Guardsman	High Point, NC	1.3	SCS
Guardsman	Little Rock, AR	1.3	SCS
Guardsman	South Gate, CA	1.3	SCS
Hercules	Kenvil, NJ	0.6	EXPS

TABLE 3. MAJOR CONSUMERS OF ACETONE, 1992 (CONTINUED)

Company	Plant Location	Estimated Net Product Requirement (Thousands of Short Tons)	Derivatives†
Hercules	Hopewell, VA	1.3	SOLV
Hickory Springs	Conover, NC	0.3	SOLV
Hoechst	Bishop, TX	2.5	ALD
Hoechst	Narrows, VA	4.9	CAS
Hoechst	Rock Hill, SC	4.9	CAS
Holliston Mills	Church Hill, TN	0.4	SOLV
Holston Army	Kingsport, TN	0.4	SOLV
ICI§	Huron, OH	4.6	SCS
ICI§	San Francisco, CA	4.6	SCS
ISP	Columbus, OH	0.2	SOLV
ISP	Calvert City, KY	0.5	SOLV
KalSec	Kalamazoo, MI	0.3	SOLV
Lilly Ind. Coatings	Dallas, TX	2.7	SCS
Lilly Ind. Coatings	Dothan, AL	2.7	SCS
Merck	Danville, PA	0.6	AB
Merck	Elkton, VA	0.6	AB
Merck	St. Louis, MO	0.6	AB
Monsanto	Nitro, WV	2.8	ETMQ
Morton International	Salem, OR	0.2	SCS
Pfanstiehl	Waukegan, IL	0.8	SD
Pfizer	Groton, CT	1.2	AB
Pfizer	Terre Haute, IN	1.2	AB
Pioneer Plastics	Auburn, ME	0.2	SOLV
PMC, Inc.	Kearny, NJ	0.4	SOLV
Polaroid	Waltham, MA	0.6	SOLV
PPG	Circleville, OH	3.5	SCS
PPG	Delaware, OH	3.5	SCS
PPG	Oak Creek, WI	3.5	SCS
PPG	Torrance, CA	3.5	SCS
Radford Army	Radford, VA	0.5	SOLV
Riverside Labs	Geneva, IL	0.3	SOLV
Senco Products	Cincinnati, OH	0.3	SOLV
Seymour	Sycamore, IL	0.2	SCS
Sherwin-Williams	Richmond, KY	0.9	SOLV
Smith Kline/Beckman	Conshohocken, PA	2.4	AB
Stanley Tools	Cheraw, SC	0.2	SOLV
Stone Container	Florence, SC	0.3	SOLV
Takeda	Wilmington, NC	3.2	VC
Union Carbide	Institute, WV	1.3	SOLV
Union Carbide	Texas City, TX	1.4	SOLV
Union Carbide	So. Charleston, WV	2.6	ALD
Uniroyal	Geismar, LA	2.4	R-PC
Upjohn	Portage, MI	0.6	SOLV
Upjohn	Kalamazoo, MI	2.9	AB

TABLE 3. MAJOR CONSUMERS OF ACETONE, 1992 (CONTINUED)

Company	Plant Location	Estimated Net Product Requirement (Thousands of Short Tons)	Derivatives†
Valspar	Baltimore, MD	2.7	SCS
Valspar	Rochester, PA	2.7	SCS
Vi-Jon Labs, Inc.	St. Louis, MO	0.5	NPR
W.M. Barr, Inc.	Memphis, TN	5.0	PVR+T
Warner-Lambert	Holland, MI	0.3	SOLV
Total Truck Shipments		152.2	
Consumers Receiving Shipments by Barge or Rail			
BF Goodrich	Akron, OH	9.6	DPA-A.TMQ
BP Chemicals	Green Lake, TX	32.1	ACH
Chesebrough-Ponds	Jefferson City, MO	7.9	NPR
CYRO	Avondale, LA	62.7	ACH
Dow	Freeport, TX	40.0	BPA
Dupont§	Beaumont, TX	36.4	ACH
Dupont§	Memphis, TN	133.8	ACH
Eastman	Kingsport, TN	36.0	ALD, CAS, MAK, MIBK
GE	Burkville, AL	22.2	BPA
Hoffman LaRoche	Belvidere, NJ	8.8	VC
Revlon	Phoenix, AZ	7.0	NPR
Rohm & Haas	Deer Park, TX	198.5	ACH
Sherwin-Williams	Baltimore, MD	7.9	SCS
Sherwin-Williams	Bedford Heights, OH	7.9	SCS
Sherwin-Williams	Chicago, IL	7.9	SCS
Uniroyal	Naugatuck, CT	9.6	DPA-A, TMQ
Total Rail and Barge Shipments 621.3			
Total, All Modes		773.5	

† Derivatives listed below are chemicals that use acetone in their manufacture.

AB	Antibiotics
ACAL	Acetylenic alcohols
ACH	Acetone cyanohydrin
ALD	Aldol chemicals
BPA	Bisphenol A
CAS	Cellulose acetate solvent
CYAN	Cyanazine
DPA-A	Diphenylamine-acetone condensates
ETMQ	1,2-Dihydro-6-ethoxy-2,2,4-trimethylquinoline
EXPS	Explosives solvent
MAK	Methyl n-amyl ketone
MIAK	Methyl isoamyl ketone
MIBK	Methyl isobutyl ketone

(Derivatives list is continued on next page)

TABLE 3. MAJOR CONSUMERS OF ACETONE, 1992 (CONCLUDED)

† Derivatives (Continued)

NPR	Nail polish remover	SOLV	Solvent use
PVR+T	Paint and varnish remover and thinner	TMQ	1,2-Dihydro-2,2,4-trimethylquinoline
R-PC	Rubber-processing chemicals		
SCS	Surface coatings solvent	VC	Vitamin C
SD	Sugar derivatives		

‡ American Cyanamid is now Cytec Industries.

§ These DuPont plants are now owned by Zeneca; ICI is now Zeneca.

Note: Totals may not add due to rounding.

Sources: Based on information from industry sources and the U.S. Department of Transportation's HMIS Database.

7. DISTRIBUTION AND TRANSPORT

Producers deliver acetone directly to the largest consuming plants using ships, barges, or rail. Truck transport is used for smaller shipments. Producers also use company-owned and public terminals to facilitate the distribution of acetone. Table 4 lists public and private terminals known to be used by acetone producers. There are, however, numerous other public terminals available that could be used for acetone distribution.

Terminals on navigable waterways receive bulk shipments primarily by barge and ship, but rail can be used if waterborne commerce is interrupted for some reason. Terminals not on navigable waterways receive bulk and, in some cases, carload or truckload drum shipments of acetone by rail or truck. Shipments to consumers from both types of terminals are typically made by truck. The use of terminals helps to minimize the road transport of acetone. Truck movements from distribution points to final consumers are generally short distance.

Some acetone is marketed to smaller consumers through distributors that maintain bulk storage, drumming, and drum storage facilities throughout the country. Typically producers ship bulk quantities of acetone to distributors by rail or barge. The distributors may make some truck deliveries in bulk quantities from their facilities to consumers (including delivery of more than one chemical using mixed tank trucks with two or more separate tanks). These shipments, however, tend to be limited because producers prefer to serve large customers directly. The principal business of distributors is the drumming of acetone received from producers and the shipment of LTL quantities of drums to customers. Table 5 lists some major distributors of acetone and their terminals.

Because truck shipments are used by small volume consumers, the average annual net consumption of acetone at plants receiving truck shipments is smaller than that of plants receiving rail and water shipments. In 1992, the average annual net consumption of acetone at plants receiving truck shipments was approximately 1,700 short tons per year, compared with approximately 39,200 short tons per year for plants receiving shipments by rail and water. Plants receiving rail or waterborne shipments are located in Texas and other southern states, the Mid-Atlantic states, and the Great Lakes states.

TABLE 4. TERMINALS USED BY ACETONE PRODUCERS

Producing Company	Terminal Location
Allied Signal	Chicago, IL Cincinnati, OH Forest View, IL Houston, TX St. Louis, MO
Aristech	Houston, TX
Dow	Joliet, IL Long Beach, CA Pittsburg, CA
Georgia-Gulf	Carteret, NJ Lemont, IL St. Louis, MO
Mt. Vernon† (GE)	Carteret, NJ East Liverpool, OH Houston, TX Wilmington, NC
Shell	Argo, IL Atlanta, GA Richmond, CA Sewaren, NJ
Union Carbide	Carteret, NJ Forest View, IL South Charleston, WV Texas City, TX Torrance, CA

†Mt. Vernon is now General Electric Company, GE Plastics.

Note: Public terminals are available to all producers on an as-needed basis. Use may change from year to year.

Sources: Industry contacts and literature.

TABLE 5. TERMINALS USED BY ACETONE DISTRIBUTORS

Distributor	Terminal Location
Ashland Chemical	About 50 locations having bulk storage tanks, including:
	Argo, IL
	Columbus, OH
	Dallas, TX
	Doraville, GA
	Englewood/Sheridan, CO
	Newark, CA
	St. Louis, MO
	Santa Fe Springs, CA
	Willow Springs, IL
Chemcentral	32 locations having bulk storage facilities, including:
	Forest View, IL
	Louisville, KY
Great Western	Portland, OR
	Richmond, CA
	Torrance, CA
Univar Corp., Van Waters & Rogers Subsidiary	106 locations, many of which have bulk storage facilities, including:
	Knoxville, TN
	Portland, OR
	San Jose, CA

Sources: Industry contacts and literature.

8. USE OF MODELS TO ESTIMATE TRUCK FLOWS

The major producers of acetone 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 estimated amounts of acetone each received by truck delivery in 1992. The terminals known to be used in the distribution of acetone are listed in Tables 4 and 5. This section explains how this information is used to identify the specific highways over which bulk shipments of acetone are transported from producers to users and in what quantities.

Because there is little readily available direct evidence on the flows of acetone over the Nation's highways, the flows must be estimated. For this report, this was accomplished by the use of two widely accepted models of interregional commodity flows, a gravity model and a linear programming model. Using data presented previously, 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.[5]

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, to 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 may not purchase from certain producers or may purchase only from a given supplier.
- Regulations mandate the use of two drivers for trips 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. The linear programming results, however, are consistent with extensive industry use of terminals to minimize road transport of acetone, whereas the gravity model results indicate a number of long-haul truck routes that may, in fact, not exist. For these reasons, the linear programming results are presented in the main body of the report. The results of the gravity model are presented in Appendix C.

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5 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 RSPA/Volpe Center and TDS Economics, July 1994.

9. LINEAR PROGRAMMING MODEL ESTIMATION RESULTS

The linear programming results for bulk truck shipments of acetone are shown in Table 6. Of the estimated 22.8 million ton-miles of acetone moved by truck in 1992, 22% flowed through Ohio, a state that both produces and consumes acetone. Ten percent occurred in Illinois, which also produces and consumes acetone. Other states with at least five percent of the Nation's ton-miles were Kentucky, Michigan, West Virginia, Texas, Indiana, North Carolina, and Pennsylvania.

The linear programming model results shown in Table 6 are reflected on the map in Figure 1, which shows the major routes carrying truck movements of acetone. The width of the blue lines is directly proportional to the quantity flowing over the routes, as indicated in the figure legend. The direction of flow is indicated by the position of the flow line relative to its route, shown in red. 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.

As can be seen in Figure 1, there is a concentration of truck shipments of acetone in the Ohio, Indiana, and West Virginia section of the country. In Ohio, the Aritech plant provides acetone to a number of consuming plants in that state. Likewise, the Mount Vernon (G.E.) plant in Indiana and the Union Carbide plant in West Virginia are in close proximity to a number of consuming plants. It should be noted that the map in Appendix C, which depicts truck flows of acetone according to the gravity model, also shows a heavy concentration of acetone movement in the same three-state area of the country.

TABLE 6. LINEAR PROGRAMMING MODEL ESTIMATES OF BULK TRUCK SHIPMENTS OF ACETONE, BY STATE, 1992

State	Producer, Terminal, or Consumer Located in State	Ton-miles (Thousands)	Truck-miles† (Thousands)
Alabama	Consumer	291.4	14.6
Arkansas	Consumer	566.9	28.3
California	Consumer, Terminal	515.2	25.8
Connecticut	Consumer	229.1	11.5
Delaware		121.9	6.1
Illinois	Consumer, Producer, Terminal	2,303.2	115.2
Indiana	Consumer, Producer	1,167.6	58.4
Iowa	Consumer	58.6	2.9
Kentucky	Consumer	1,566.5	78.3
Louisiana	Consumer, Producer	1,076.9	53.8
Maine	Consumer	11.3	0.6
Maryland	Consumer	418.8	20.9
Massachusetts	Consumer	62.7	3.1
Michigan	Consumer	1,537.4	76.9
Mississippi		554.3	27.7
Missouri	Consumer, Terminal	543.2	27.2
New Hampshire		2.9	0.1
New Jersey	Consumer, Terminal	572.1	28.6
New York	Consumer	335.5	16.8
North Carolina	Consumer, Terminal	1,151.3	57.6
Ohio	Consumer, Producer, Terminal	4,955.1	247.8
Oregon	Consumer, Terminal	17.0	0.9
Pennsylvania	Consumer, Producer	1,135.8	56.8
Rhode Island		9.2	0.5
South Carolina	Consumer	92.4	4.6
Tennessee	Consumer, Producer	39.9	2.0
Texas	Consumer, Producer, Terminal	1,286.5	64.3
Virginia	Consumer	758.2	37.9
West Virginia	Consumer, Producer, Terminal	1,357.4	67.9
Wisconsin	Consumer	109.7	5.5
Total		22,848.0	1,142.6

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

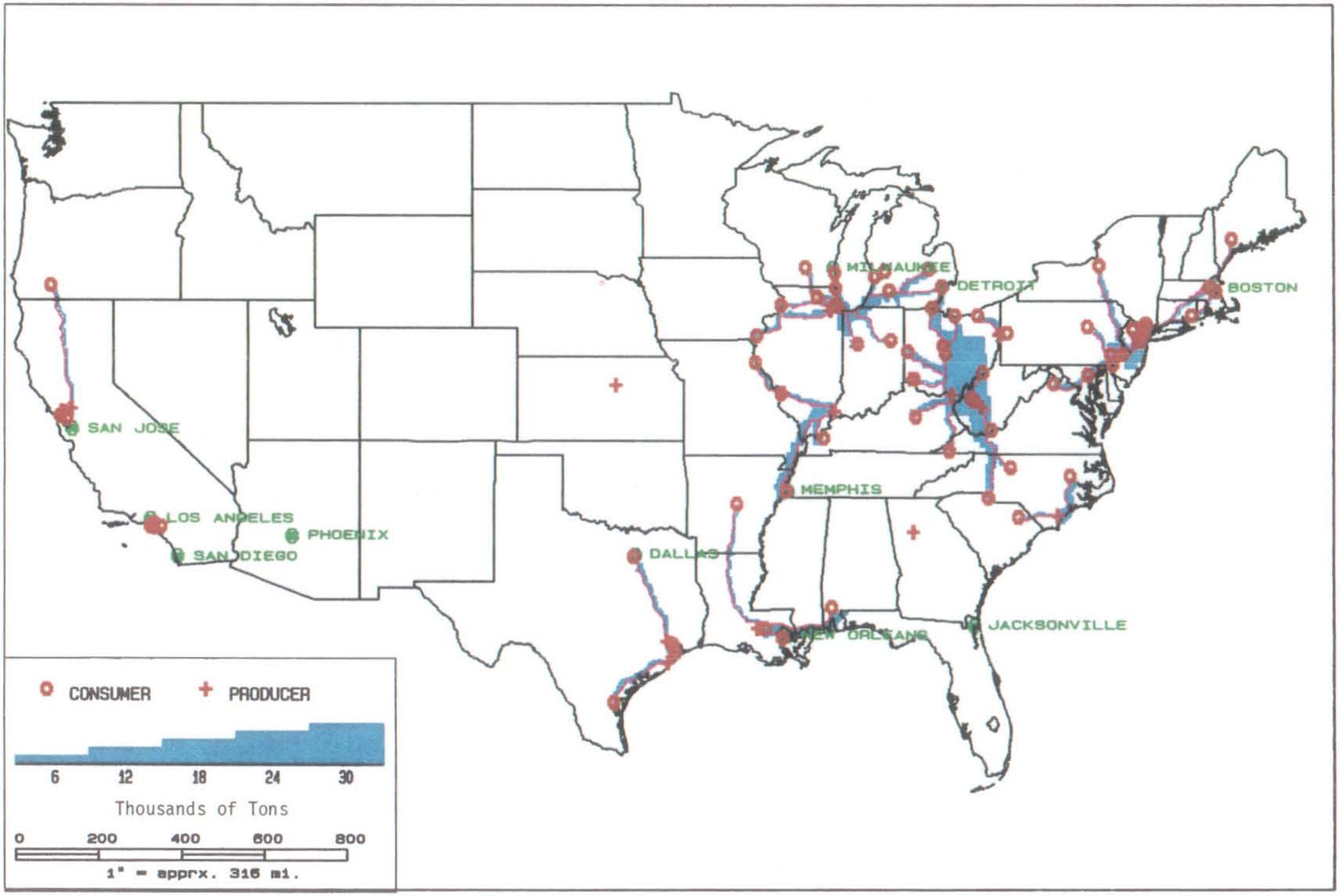

FIGURE 1. NATIONAL TRUCK FLOWS OF ACETONE
(LINEAR PROGRAMMING RESULTS)

10. COMPARISON OF MODEL RESULTS WITH INCIDENT DATA

Table 7 shows estimates of the expected annual number of highway truck accidents involving acetone in 1992, by state. These estimates, based on 1992 truck-miles, are shown in the "Estimated Accidents" column of the table. Using an RSPA estimate that about 15% of highway accidents result in a release or spill, the "Estimated Years/Spill" column shows the expected number of years between spills for each state.

The estimates in Table 7 indicate that, in 1992, the states with the highest risk of both truck accidents and spills were Illinois, Indiana, Ohio, Texas, and West Virginia. This is not surprising, since these states rank highest in ton-miles and truck-miles of acetone. The expected annual number of truck accidents for the nation involving vehicles carrying acetone was 1.82, and the expected number of years between spills was four.

Data from the U.S. DOT hazardous materials incident database were examined to determine if these results were consistent with the actual incident experience for the years 1985 to 1993. In the database, 38 acetone highway bulk-shipment incidents were reported for the nine-year period (see Table 8[6]). Of these, three involved chemical wastes, which are not covered by this study.[7] Another involved exports to Mexico from a distributor located in the greater Los Angeles area. Of the remaining 34 incidents, 4 involved highway accidents. This result generally agrees with the model estimate that about two-and-one-half highway accident incidents were likely to occur during a nine-year period.

Of the other 30 incidents, 9 were caused by human error, 20 were caused by packaging failure, and 1 is attributable to other causes. Many of these incidents occurred at the origin or destination point. Highway accident incidents tend to have the largest releases, generally over 1,000 gallons, while incidents involving packaging failure or human error tend to have releases of under 100 gallons.

Shipment information included with the incidents in the U.S. DOT hazardous materials incident database appears to substantiate the finding that truck shipments tend to be short distance movements. Most of the origin-destination pairs identified in the database are in the same state or in adjacent states. Less than 10 of the 38 incidents involved routes that passed through several states, and many of these involved truckload shipments of drums, rather than tank trucks carrying bulk liquids.

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[6] The data provided in Table 8 represent reported acetone highway incidents involving shipment sizes of 3,500 gallons or greater for the nine-year period from 1985 to 1993.

[7] Chemical wastes are used chemicals that are shipped back to a producer or to a special facility for recycling or other uses. Chemical wastes are not contained in the hazardous chemicals category, but rather in the hazardous wastes category.

TABLE 7. ESTIMATED NUMBER OF HIGHWAY TRUCK ACCIDENTS INVOLVING ACETONE, BY STATE, 1992

State	Estimated Accidents‡	Estimated Years/Spill‡	State	Estimated Accidents‡	Estimated Years/Spill‡
Alabama	0.05	130	Nebraska	0.01	554
Arizona	0.04	171	Nevada	0.02	437
Arkansas	0.03	266	New Hampshire	0.00	45,977
California	0.08	80	New Jersey	0.03	214
Colorado	0.02	439	New Mexico	0.02	421
Connecticut	0.01	582	New York	0.02	375
Delaware	0.01	753	North Carolina	0.06	114
DC	0.00	11,111	Ohio	0.25	26
Georgia	0.01	679	Oklahoma	0.00	2,705
Illinois	0.12	54	Oregon	0.00	7,843
Indiana	0.13	51	Pennsylvania	0.10	71
Iowa	0.01	551	Rhode Island	0.00	14,493
Kansas	0.02	409	South Carolina	0.02	325
Kentucky	0.10	70	Tennessee	0.03	238
Louisiana	0.07	93	Texas	0.17	39
Maine	0.00	11,799	Utah	0.02	408
Maryland	0.03	195	Virginia	0.07	98
Massachusetts	0.00	2,127	West Virginia	0.10	66
Michigan	0.08	79	Wisconsin	0.01	1,209
Mississippi	0.04	153	Wyoming	0.01	612
Missouri	0.04	174	US	1.82	4

‡The number of highway 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.

TABLE 8. DATA ON ACETONE BULK-SHIPMENT INCIDENTS, 1985 TO 1993

Incident State	Origin State	Destination State	Release Quantity (gallons)	Cause†	Capacity (gallons)	Shipper Type
AL	GA	AL	1,000	20	7,800	Unknown
AL	TN	AL	30	10	8,000	Unknown
AR	PA	TX	2	20	6,500	Plant
CA	CA	CA	30	10	7,000	Terminal
CA	CA	CA‡	5	10	6,500	Distributor
CA	CA	OR	2	20	7,250	Terminal
CA	CA	OR	200	20	6,700	Terminal
IL	IL	IL	0	20	6,500	Waste
IL	IL	IL	3	20	9,000	Terminal
IL	IL	IL	20	20	7,000	Plant
IL	IL	MI	187	20	5,510	Distributor
IL	NE	IL	40	20	4,400	Waste
IN	IL	IN	5,544	30	7,500	Terminal
IN	IL	KY	1	20	7,000	Distributor
KS	KS	IA	8	10	8,500	Plant
KY	IN	KY	5	20	6,900	Plant
KY	OH	TN	2	20	6,500	Plant
KY	OH	TN	6,000	30	7,797	Plant
KY	OH	TX	0	20	6,500	Plant
KY	PA	KY	25	20	6,700	Plant
MD	PA	WV	1	20	6,668	Plant
MO	KS	IL	120	40	9,500	Plant
MO	KS	MO	950	30	9,200	Plant
NJ	NJ	ME	13	20	6,900	Terminal
NJ	PA	NJ	2	10	7,500	Plant
NJ	PA	NJ	150	10	7,500	Plant
NY	PA	NY	1	20	5,187	Plant
OH	OH	KY	0	20	7,250	Unknown
OH	OH	OH	1	10	9,000	Distributor
OR	OR	OR	5	10	7,600	Distributor
PA	PA	OH	20	20	6,700	Plant
PA	PA	PA	150	10	6,900	Plant
SC	NJ	SC	2	20	7,000	Terminal
TN	OH	TN	20	20	6,739	Plant
TN	TN	AL	20	10	7,000	Distributor
TN	WV	TN	1,000	30	6,300	Terminal
TX	TX	TX	2	20	9,500	Unknown
WI	IL	WI	75	30	6,800	Waste

† Cause 10 indicates human failure, 20 indicates packaging failure, 30 indicates a highway accident, and 40 other cause.

‡ Shipment for export to Mexico, change of carrier at the San Ysidro border crossing.

Source: U.S. Department of Transportation HMIS Database

APPENDIX A. LIST OF 147 LARGE-VOLUME CHEMICALS

Chemical	1994 Production (Thousands of Short Tons)	Chemical	1994 Production (Thousands of Short Tons)
Acetaldehyde	174	Chloroform	565
Acetic Acid, Synthetic	1,992	Chloronitrobenzene	65
Acetic Anhydride	na	Copper Sulfate	53
Acetone	1,331	Cyclohexane	982
Acetylene	>140	Cyclohexanone	552
Acrylamide	58	p-Dichlorobenzene	39
Acrylic Acid	575	Dichlorodifluoromethane (F12)	63
Acrylonitrile	1,491	Dicyclopentadiene	na
Activated Carbon	158	Dimethylamine	na
Adipic Acid	900	Epichlorohydrin	253
Aluminum Chloride	na	Ethanol (Synthetic)	324
Aluminum Sulfate (w/17% Al_2O_3)	1,316	Ethyl Acetate	163
Ammonia	17,256	Ethyl Acrylate	182
Ammonium Nitrate	8,517	Ethylbenzene	5,378
Amyl Alcohol	23	Ethyl Chloride	na
Aniline	632	Ethylenediamine	45
Argon	800	Ethylenediamine Tetraacetic Acid	6
Atrazine	na	Ethylene Dibromide	13
Barite	643	Ethylene Dichloride	8,380
Barium Sulfide	na	Ethylene Glycol Monobutyl Ether	195
Benzene	>7,110	Ethylene Glycol Monoethyl Ether	29
Benzoic Acid	60	Ethylene Glycol Monoethyl Ether Acetate	
Benzyl Chloride	na		23
Bromine	215	Ethylene Glycol Monomethyl Ether	20
1,3-Butadiene	1,689	Ethylene Oxide	2,928
1-Butanol	739	Ferric Chloride (100%)	225
Butene-1	483	Formaldehyde (37%)	4,082
n-Butyl Acetate	155	Furfural	43
n-Butyl Acrylate	412	n-Heptane	60
Butyraldehyde	1,097	Hexamethylenediamine	626
Calcium Carbide	244	Hexane	170
Calcium Hypochlorite	92	Hexene-1	na
Calcium Oxide	>16,314	Hydrochloric Acid (100%)	3,734
Carbon Black	1,625	Hydrofluoric Acid	200
Carbon Dioxide	12,547	Hydrofluosilicic Acid	55
Carbon Disulfide	na	Hydrogen	862
Carbon Tetrachloride	124	Hydrogen Cyanide	514
Chlorinated Isocyanurates	68	Hydrogen Peroxide	318
Chlorine Gas	12,187	Isobutanol	70
Chlorobenzene, Mono	109	Isobutyl Acetate	42
Chlorodifluoromethane (F22)	153	Isobutylene	1,539

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

Chemical	1994 Production (Thousands of Short Tons)	Chemical	1994 Production (Thousands of Short Tons)
Isobutyraldehyde	264	Pinene	na
Isoprene	310	Potassium Hydroxide (100%)	27
Isopropanol	726	Propane	31,492
Isopropyl Acetate	28	n-Propanol	625
Isopropylamine, Mono	na	Propionaldehyde	182
Linear Alkylate Sulfonate	305	Propionic Acid	94
Maleic Anhydride	239	n-Propyl Acetate	44
Methanol	5,387	Propylene Oxide	1,850
Methylamine	na	Propylene Tetramer (Dodecene)	155
Methyl t-Butyl Ether	5,515	Sodium (Metal)	na
Methyl Chloride	500	Sodium Chlorate (100%)	559
Methylchloroform	335	Sodium Chromate/Dichromate	132
Methylene Dichloride	na	Sodium Cyanide	142
Methylene Diphenlyene Diisocyanate	535	Sodium Hydrosulfide	117
Methyl Ethyl Ketone	600	Sodium Hydrosulfite	90
Methyl Isobutyl Ketone	70	Sodium Hydroxide	12,555
Methyl Methacrylate	659	Sodium Phosphate, Tribasic	22
Monoethanolamine	198	Styrene	5,455
Naphthalene	101	Sulfur	12,677
Nitric Acid (100% HNO_3 Basis)	8,611	Sulfur Dioxide	229
Nitrobenzene	720	Sulfuric Acid	44,813
Nitrogen	31,515	Tetrahydrofuran	126
Nonylphenol	na	Toluene	>2,895
Oxygen	25,045	Toluene Diisocyanate	419
n-Pentane	na	Trichloroethylene	na
Perchloroethylene	123	Tripropylene (Nonene)	328
Phenol	2,065	Vinyl Acetate	1,518
Phosgene	na	Vinyl Chloride	6,924
Phosphoric Acid (P_2O_5 Basis)	12,792	o-Xylene	457
Phosphorus	255	p-Xylene	3,114
Phosphorus Oxychloride	36	Zinc Chloride	<10
Phosphorus Pentasulfide	61	Zinc Sulfate	43
Phosphorus Trichloride	158		
Phthalic Anhydride	480	**Total**	>349,004

Notes:

(1) The acetylene production numbers include production for chemical use only.
(2) The calcium oxide, benzene, and toluene production numbers do not include production from all sources;
(3) The zinc chloride production number includes the zinc content of zinc ammonium chloride.

Sources:

(1) List of Chemicals: C. Starry, K. McCaleb, and W. Stock, "Study of Truck Transportation of Hazardous Chemicals," Prepared by SRI International for the U.S. Department of Transportation, 1993.
(2) 1994 Production Numbers: U.S. International Trade Commission, *Synthetic Organic Chemicals, United States Production and Sales, 1994*, USTIC Publication 2933, June 1995; U.S. Geological Survey, *Minerals Yearbook, 1994*; *Chemical & Engineering News*, June 24, 1996, pp. 41-43; U.S. DOE/EIA, *Petroleum Supply Annual, 1995*, Vol. 1; other industry sources; and Volpe estimates based on industry source projections of chemical production or consumption, or on the relationships between the quantities of selected inputs and the quantities of finished chemical product outputs.

APPENDIX B. MODELING TRUCK FLOWS

Models are used to allocate truck flows from the various producing plants and terminals to consuming plants that receive shipments by truck. The models are designed to estimate likely origin-destination pairs based on a variety of considerations, as described below:

(1) The shorter the distance between an origin-destination pair, the greater the likely cargo flow between them.

(2) The larger the production or consumption of the chemical at the origin or destination, the greater the cargo flow.

(3) Corporate affiliations are sufficiently strong that if a producing and a consuming plant are both owned by the same company, the effective distance between them is treated as equivalent to one-third the actual distance.

(4) Minimum shipment volumes of approximately 10 short tons per year are set for any given origin-destination pair. This amount is approximately equal to 3,500 gallons, the minimum required for inclusion in the U.S. DOT's Hazardous Materials Registration Program.

(5) Available supply at each origin is set equal to the net production available for off-site truck shipments.

(6) The total amount supplied to each destination is set equal to its estimated net product requirement specified for truck delivery.

(7) Due to regulations, two drivers are required for trips that are over 230 miles in length. An additional driver is estimated for this study to increase the cost per mile by 33 percent.[8,9]

The models start with a set of plants that produce or have available, off-site shipments, varying in estimated quantities, of the hazardous chemical under study. The quantities are typically measured in thousands of short tons per year. Similarly, there are consuming plants buying or receiving estimated amounts of the chemical. Terminals (see Tables 4 and 5) are included as possible routing opportunities for producers. Each origin-destination pair may be served directly from a producing plant or via a terminal.

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[8] Jack Faucett Associates, "The Effect of Size and Weight Limits on Truck Costs," Working Paper Prepared as Part of the Truck Size and Weight and User Fee Policy Analysis Study, U.S. Department of Transportation, Federal Highway Administration, Revised October 1991.

[9] Leon Witconis And Ken Stadden, "Cost Per Mile: A View From The Top," *Owner Operator*, September/October 1988.

The models estimate the quantities of chemicals, termed flows, moving from the producing plants to the consuming plants. The flows can be arrayed in a two-dimensional table (see Table B-1).

TABLE B-1. PRODUCTION/CONSUMPTION FLOW MATRIX

Consumers Producers	Consumer 1	Consumer 2	Consumer 3	Total Available for Off Site Shipments
Producer 1	F_{11}	F_{12}	F_{13}	Production 1 $\geq \Sigma_j F_{1j}$
Producer 2	F_{21}	F_{22}	F_{23}	Production 2 $\geq \Sigma_j F_{2j}$
Producer 3	F_{31}	F_{32}	F_{33}	Production 3 $\geq \Sigma_j F_{3j}$
Producer 4	F_{41}	F_{42}	F_{43}	Production 4 $\geq \Sigma_j F_{4j}$
Total Consumption Received by Truck	Consumption 1 $\Sigma_i F_{i1}$	Consumption 2 $\Sigma_i F_{i2}$	Consumption 3 $\Sigma_i F_{i3}$	Total Shipped by Truck $\Sigma_{ij} F_{ij}$

The F's in the table indicate the flows to be estimated. For example, F_{21} indicates the flow from producing plant 2 to consuming plant 1. Note that if we sum the flows vertically, they will equal the consumption listed across the bottom of the table. However, in general, the horizontal sums will be less than or equal to the production quantities listed at the right, because some of the production will be used for other purposes or may travel by a mode other than truck.

Based on previous research, two models are used to estimate truck flows by state.[10] 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.[11] They take their name from their mathematical formulation, which is analogous to that of Newton's Law of Universal Gravitation; 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 10 short tons (approximately 3,500 gallons).[12] 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.[13] 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.

The linear programming approach, however, is quite different from the gravity model approach in several respects. The linear programming model starts with an objective

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[10] "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.

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

[12] For the purposes of this report, the minimum quantity carried in a truckload shipment of acetone is assumed to be 10 short tons. The typical quantity carried in a truckload shipment is assumed to be 20 short tons.

[13] Kwak, N., *Mathematical Programming with Business Applications*, New York: McGraw-Hill, Inc., 1973.

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--for example, 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. GRAVITY MODEL ESTIMATION RESULTS

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

Because consumption of acetone is so widespread, the gravity model estimates that large-volume truck shipments of acetone occur in 41 of the 48 contiguous states, plus the District of Columbia. The gravity model estimates bulk truck flows at over 35 million ton-miles per year. Ohio has the greatest number of estimated ton-miles, followed by Texas, Indiana, and Illinois. West Virginia, Kentucky, Pennsylvania, Michigan, Louisiana, and North Carolina, California, Virginia, and Alabama are shown to have over a million ton-miles per year. All of these states have consuming plants, and most also have production facilities or terminals.

The gravity model results shown in Table C-1 are reflected on the map in Figure 2, which shows the major routes expected to be carrying truck shipments of acetone. The width of the blue lines is directly proportional to the quantity flowing over the routes, as indicated in the figure legend. The direction of flow is indicated by the position of the flow line relative to its route, shown in red. 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.

Figure 2 shows a concentration of bulk highway movements of acetone in the Ohio-Indiana-West Virginia area. This concentration is consistent with the findings of the linear programming approach, as a comparison of Figure 1 with Figure 2 shows.

Total estimated ton-miles of bulk truck shipments of acetone is considerably larger with the gravity model than with the linear programming model. The gravity model results show ten more states (plus the District of Columbia) through which acetone moves by truck in bulk than the linear programming results show. For most states, ton-miles of acetone with the gravity model increase or remain approximately the same compared with the linear programming model results. The increases are significant in several states. Almost all of the states that are shown to have bulk truck flows by the linear programming model have a consumer, terminal, or production facility, but this is not the case for the gravity model. Average length of haul for bulk truck shipments is about 240 miles with the gravity model, while it is about 150 miles with the linear programming model.

It should be recognized that some of the routes shown in Figure 2 may not exist. The gravity model has a tendency to indicate small flows where none may exist. Alternatively, there is a tendency for linear programming results to not recognize small flows, so there may be more routes than are shown in Figure 1.

TABLE C-1. GRAVITY MODEL ESTIMATES OF BULK TRUCK SHIPMENTS OF ACETONE, BY STATE, 1992

State	Producer, Terminal, or Consumer Located in State	Ton-miles (Thousands)	Truck-miles† (Thousands)
Alabama	Consumer	1,056.5	52.8
Arizona	---	936.7	46.8
Arkansas	Consumer	502.0	25.1
California	Consumer, Terminal	1,691.9	84.6
Colorado	---	88.1	4.4
Connecticut	Consumer	228.9	11.4
Delaware	---	175.4	8.8
DC	---	12.0	0.6
Georgia	Terminal	195.8	9.8
Illinois	Consumer, Producer, Terminal	2,354.1	117.7
Indiana	Consumer, Producer	2,282.9	114.1
Iowa	Consumer	90.2	4.5
Kansas	Producer	124.8	6.2
Kentucky	Consumer	1,926.2	96.3
Louisiana	Consumer, Producer	1,418.6	70.9
Maine	Consumer	11.3	0.6
Maryland	Consumer	674.5	33.7
Massachusetts	Consumer	62.7	3.1
Michigan	Consumer	1,468.3	73.4
Mississippi	---	860.2	43.0
Missouri	Consumer, Terminal	1,031.3	51.6
Nebraska	---	228.9	11.4
Nevada	---	234.8	11.7
New Hampshire	---	2.9	0.1
New Jersey	Consumer, Terminal	622.5	31.1
New Mexico	---	489.5	24.5
New York	Consumer	355.5	17.8
North Carolina	Consumer, Terminal	1,171.5	58.6
Ohio	Consumer, Producer, Terminal	5,683.5	284.2
Oklahoma	---	221.1	11.1
Oregon	Consumer, Terminal	17.0	0.9
Pennsylvania	Consumer, Producer	1,367.0	68.4
Rhode Island	---	9.2	0.5
South Carolina	Consumer	409.9	20.5
Tennessee	Consumer, Producer	568.8	28.4
Texas	Consumer, Producer, Terminal	3,486.1	174.3
Utah	---	152.9	7.6
Virginia	Consumer	1,331.0	66.6
West Virginia	Consumer, Producer, Terminal	1,973.0	98.7
Wisconsin	Consumer	110.3	5.5
Wyoming	---	207.8	10.4
Total		35,835.6	1,791.7

† Truck-miles are calculated by dividing the number of ton-miles by 20 short tons, or the typical size of a tank truck load.

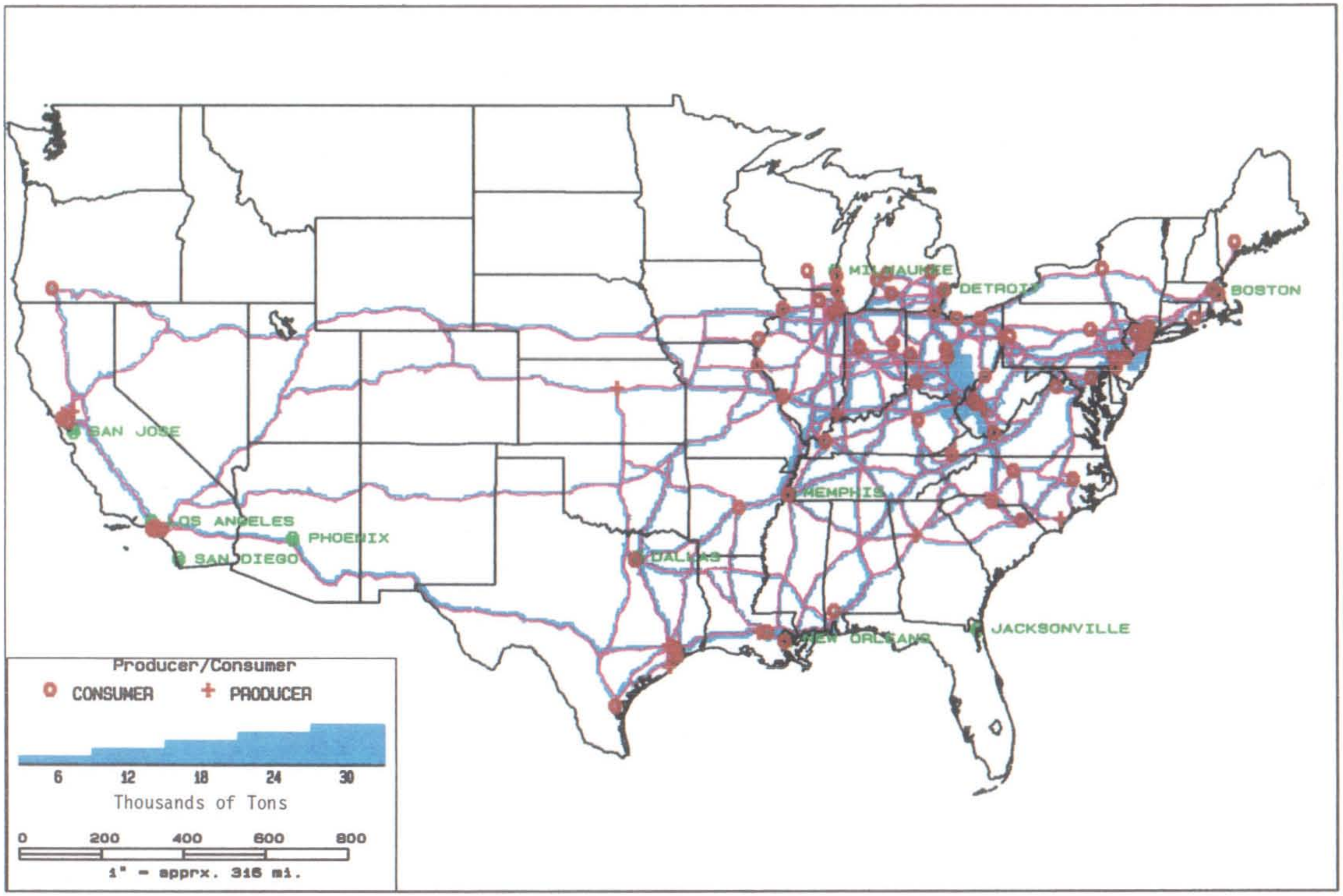

FIGURE 2. NATIONAL TRUCK FLOWS OF ACETONE
(GRAVITY MODEL RESULTS)

APPENDIX D. TRANSCAD© MAP DISPLAY PROGRAM

TransCAD© mapping software, developed by the Caliper Corporation of Newton, Massachusetts, was used to prepare the maps in this report, which depict the results of the gravity and linear programming results. The software enables users to construct national, regional, and local maps on IBM-compatible personal computers. Three kinds of input data are used to produce the maps: point (node), link (flow), and area files. For this study, point and link data are used. TransCAD© input data files are the output files from the gravity and linear programming models described in Appendix B. The point data file provides the ZIP code location and descriptors for each of the producing and consuming plants. The link file provides the estimated flow (tonnage) of chemicals moving from each producing plant to each consuming plant.

TransCAD© has an auxiliary database that contains descriptors of each of the Nation's roads and highways. The descriptors include such items as local, state, or federal control; paved or unpaved; all year or seasonal operating conditions; and height or weight restrictions on vehicular traffic. The software can be modified to ensure that hazardous chemicals are not moved on certain types of roads, including restricted, unpaved or seasonal roads. It tends to select larger, interstate routes and de-selects smaller, winding roads, although the model is not prevented from selecting such roads.