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Special Programs
Administration**

Truck Transport of Hazardous Chemicals: Dodecene-1

Final Report
September 1995

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.

This report presents estimates of truck shipments of dodecene-1, one of the 147 large-volume chemicals (non-fuel) 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 percent 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. 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

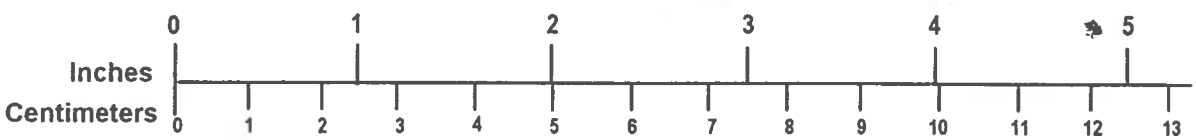
VOLUME (APPROXIMATE)

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 dodecene-1, one of the 147 large-volume chemicals (non-fuel) that account for at least 80 percent of U.S. truck shipments of hazardous chemicals. Appendix A lists these chemicals and their 1987 production volumes.

The following sections of the report describe the physical characteristics of dodecene-1, its uses, and domestic producers and users. Because there is so little direct evidence on the specific routes over which dodecene-1 is shipped, and in what quantities, the routes are 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 dodecene-1 flowing through individual states, and both are displayed graphically on flow maps.

Unfortunately, there are insufficient data on actual flows of dodecene-1 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 dodecene-1.

2. CHARACTERISTICS OF DODECENE-1

Dodecene-1 is a colorless, flammable, high boiling-point liquid. It is combustible, can irritate the skin and eyes in the case of exposure, and is harmful if swallowed. The *Emergency Response Guidebook* (DOT P 5800.5) recommends that emergency responders use its Guide No. 27 in the case of a spill involving dodecene-1. Additional information about dodecene-1 is given in Table 1.

3. USES OF DODECENE-1

Dodecene-1 is used primarily in the production of the following chemicals: dodecylbenzene (which is used as an emulsifier for agricultural chemicals), tridecyl alcohol (which is used in the production of plasticizers and surfactants), and dodecylphenol (which is used in the production of lubricating oil additives).

TABLE 1. CHARACTERISTICS OF DODECENE-1

Common Synonyms	Propylene tetramer Tetrapropylene
Formula	$C_{12}H_{14}$
UN Number	2850
IMCO Class	3.3
CAS Number	112414
DOT Hazard Class	Class 3 (Flammable and Combustible Liquids)
Description	Liquid Colorless Flash point: 120 degrees F C.C. 134 degrees F O.C.

Source: *CHRIS Manual*, June 1985; *Hazardous Commodity Handbook*, September 1987.

4. PRODUCTION

Dodecene-1, with an estimated 1987 U.S. production of 200,000 short tons, is in the middle third of the list of 147 chemicals given in Appendix A. The chemicals listed in this appendix account for over 80 percent (by volume) of truckload shipments of hazardous chemicals in the United States.

Production of dodecene-1 occurs in several places throughout the United States, including the Mid-Atlantic, Gulf, Great Lakes, and West Coast regions of the country. Dodecene-1 is frequently used in the manufacture of other chemicals at its producing plants. Intraplant use is termed "captive production." To calculate captive production, downstream chemicals produced within the same plant as dodecene-1 are identified and the amount of dodecene-1 needed in their production is estimated. The difference between total production and captive production of dodecene-1 defines the amount available for off-site consumption. This is the amount of production available for shipment.

Of the plants producing dodecene-1, four are identified as net producers that ship product by truck domestically, either directly from the plant or from terminals supplied by barge or other ocean-going vessels. These plants are listed in Table 2, which shows net production available for off-site consumption by producing plant.

TABLE 2. MAJOR PRODUCERS OF DODECENE-1 THAT SHIP BY TRUCK, 1987

Company	Plant or Terminal Location	ZIP Code	Off-site Availability (Thousands of Short Tons)
Chevron	Houston, TX†	77015	150.0
Coastal	Corpus Christi, TX	78403	10.0
Sun	Toledo, OH	43693	23.0
Unocal	Beaumont, TX	77704	10.0
Total off-site availability			193.0

†Location of terminal supplied by Chevron's Richmond, CA plant.

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

Producing plants that do not ship dodecene-1 by truck are eliminated from this analysis. Based on interviews with representatives of producing companies, it was determined that no truck shipments are made from:

- Exxon, Baton Rouge, LA: Exxon uses the dodecene-1 produced at this plant for on-site captive production of other chemicals.
- Chevron, Richmond, CA: Chevron ships dodecene-1 by water from its Richmond, CA plant to its overseas customers and to a terminal in the Houston area. (See Table 2.)

- Arco, Los Angeles, CA: The only U.S. consuming plant receiving dodecene-1 from Arco's Southern California plant is Monsanto's nearby plant that gets the product by pipeline.

5. CONSUMPTION

Thirteen plants are identified as net consumers of dodecene-1. Of those plants, eight are identified as receiving shipments by truck and are listed below in Table 3. Also shown is each consuming plant's estimated net product requirement of dodecene-1. The estimates are based on known production of other chemicals using dodecene-1 and any on-site production of dodecene-1 at each consuming plant. Note that total net product requirements are less than off-site availability; that is, total estimated demand for dodecene-1 is less than production capability.

6. DISTRIBUTION AND TRANSPORT

Shipments of dodecene-1 move by tank trucks, rail tankcar, ship, barge, or pipeline. Smaller shipments can be carried in drums or other containers capable of holding liquids. Only about 8 percent of total shipments (including exports) and 25 percent of domestic shipments move any distance by truck. Use of terminals served by water eliminates truck movements of dodecene-1 from the Chevron's California plant to Southern and East Coast consumers. No truck shipments are estimated for Western states because of the use of pipelines.

No entries for dodecene-1 under any of its names were available from the Interstate Commerce Commission's Waybill Sample for rail movements. However, rail shipments are reported by producers and consumers of dodecene-1. Because of the small size of these shipments, they may have been missed in the sample or included in an "all other" category.

None of the eight net consumers that receive truck shipments is a captive consumer; that is, one with a corporate affiliation with a net producing plant. Captive consumers of dodecene-1 reportedly receive their shipments by other modes of transport. Exports generally move directly from plant to ocean-going vessel and do not require the use of truck transport.

TABLE 3. MAJOR CONSUMERS OF DODECENE-1 THAT RECEIVE SHIPMENTS BY TRUCK, 1987

Company	Plant Location	ZIP Code	Estimated Net Product Requirement (Thousands of Short Tons)
Consumers Receiving Shipments by Truck			
Buffalo	Buffalo, NY	14240	0.6
Dixie	Bayport, TX	77062	0.6
GAF	Calvert City, KY	42029	1.0
Humphrey	North Haven, CT	06473	0.6
Lubrizol	Painesville, OH	44077	2.2
Milliken	Inman, NC	29349	0.6
Monsanto	Kearny, NJ	07032	6.0
Phillips	Borger, TX	79007	3.5
Total truck shipments			15.1
Total barge or rail shipments			59.5
Total all modes			74.6

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

7. USE OF MODELS TO ESTIMATE TRUCK FLOWS

The major producers of dodecene-1 that ship by truck 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 dodecene-1 each received by truck delivery in 1987. This section explains how this information is used to identify the specific highways over which bulk shipments of dodecene-1 are transported from producers to users and in what quantities. As stated in the Preface, this report is concerned with only bulk shipments. For dodecene-1, this means shipments primarily in tank trucks, each typically carrying twenty short tons of product.

Because there is little direct evidence available on the flows of dodecene-1 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 above, both models allocate truck flows from the producing plants to consuming plants. The basic features of these models are described in Appendix B.[2]

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

- 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, the gravity model, which is more inclusive in identifying routes over which commodities are transported, may well have identified a major dodecene-1 flow from Texas to New Jersey that does not, in fact, exist. The existence of this flow is in doubt, because the consuming plant in New Jersey could easily obtain all of its required dodecene-1 from the much closer Sun plant in Toledo, Ohio. For this reason the results of the linear programming model appear to be more reasonable. These are presented in the main body of this report, and the results of the

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[2] 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 Material Safety by the RSPA/Volpe Center and TDS Economics, July 1994.

gravity model are presented in Appendix C. A key point to be emphasized, however, is that, except for the questionable flow from Texas to New Jersey, the two models agree in their identification of the major truck routes that carry dodecene-1.

8. LINEAR PROGRAMMING MODEL ESTIMATION RESULTS

The linear programming results for bulk shipments of dodecene-1 are shown in Table 4. Of the estimated 11.6 million ton-miles of dodecene-1 moved by truck in 1987, 28 percent flowed through Pennsylvania, a state with neither production nor major consumption facilities for dodecene-1. Twenty-five percent of the ton-miles occurred in Ohio, which has a production facility in Toledo. Nearly 20 percent occurred in Texas, a major producing and consuming state. Because the volume of production and consumption of dodecene-1 is relatively small, terminal facilities (other than Chevron's terminal in Houston) have not been established to offset the cost of truck movements.

The linear programming model results shown in Table 4 are reflected on the maps in Figures 1 and 2, which show the major routes carrying truck movements of dodecene-1. 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, indicates that there are no truck shipments of dodecene-1 west of Texas. As shown in Figures 1 and 2, the linear programming model indicates that there are only two major routes. The larger flow goes from Toledo, Ohio, through Pennsylvania to the Monsanto plant in Kearny, New Jersey. The smaller flow goes from Chevron's terminal in Houston to the Phillips plant in Borger, Texas. It should be noted that the maps in Appendix C, which depict the flows of dodecene-1 according to the gravity model, show dodecene-1 being trucked from Texas through Louisiana, Mississippi, Alabama, Tennessee, Virginia, Maryland, and Pennsylvania to the Monsanto plant in Kearny, New Jersey. As indicated above, there is reason to believe that this flow may not, in fact, exist, given that the Kearny plant is able to purchase its required dodecene-1 from the Sun plant in Toledo, which is closer.

TABLE 4. LINEAR PROGRAMMING ESTIMATES OF BULK TRUCK SHIPMENTS OF DODECENE-1 BY STATE, 1987

State	Ton-miles (Thousands)	Truck-miles (Thousands)†
Connecticut	34	1.7
Kentucky	428	21.4
New Jersey	426	21.3
New York	58	2.9
North Carolina	53	2.6
Ohio	1,886	94.3
Oklahoma	959	48.0
Pennsylvania	2,125	106.2
South Carolina	8	0.4
Tennessee	76	3.8
Texas	1,503	75.2
Total	7,556	337.8

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

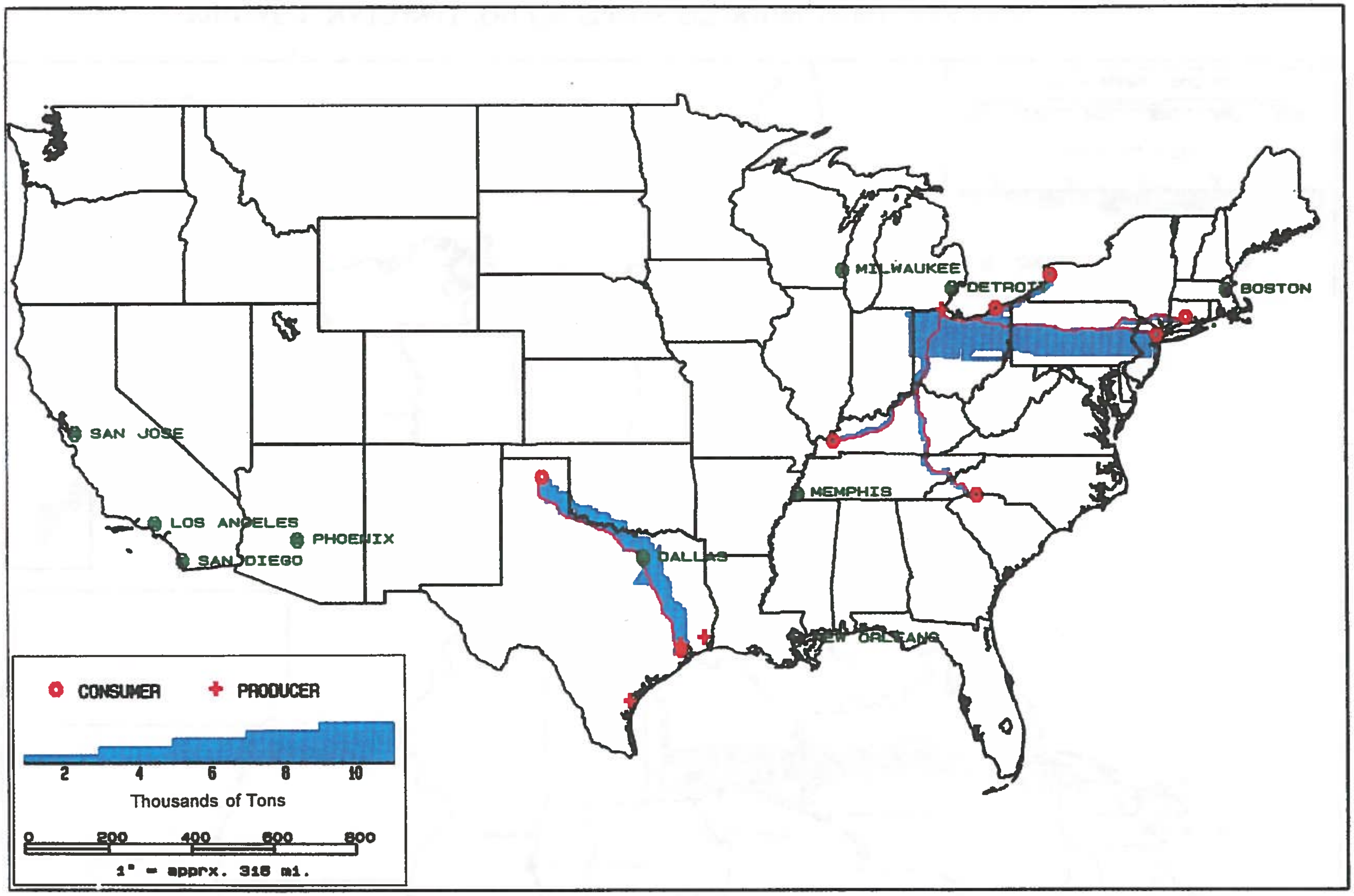

FIGURE 1. NATIONAL TRUCK FLOWS OF DODECENE-1
(LINEAR PROGRAMMING RESULTS)

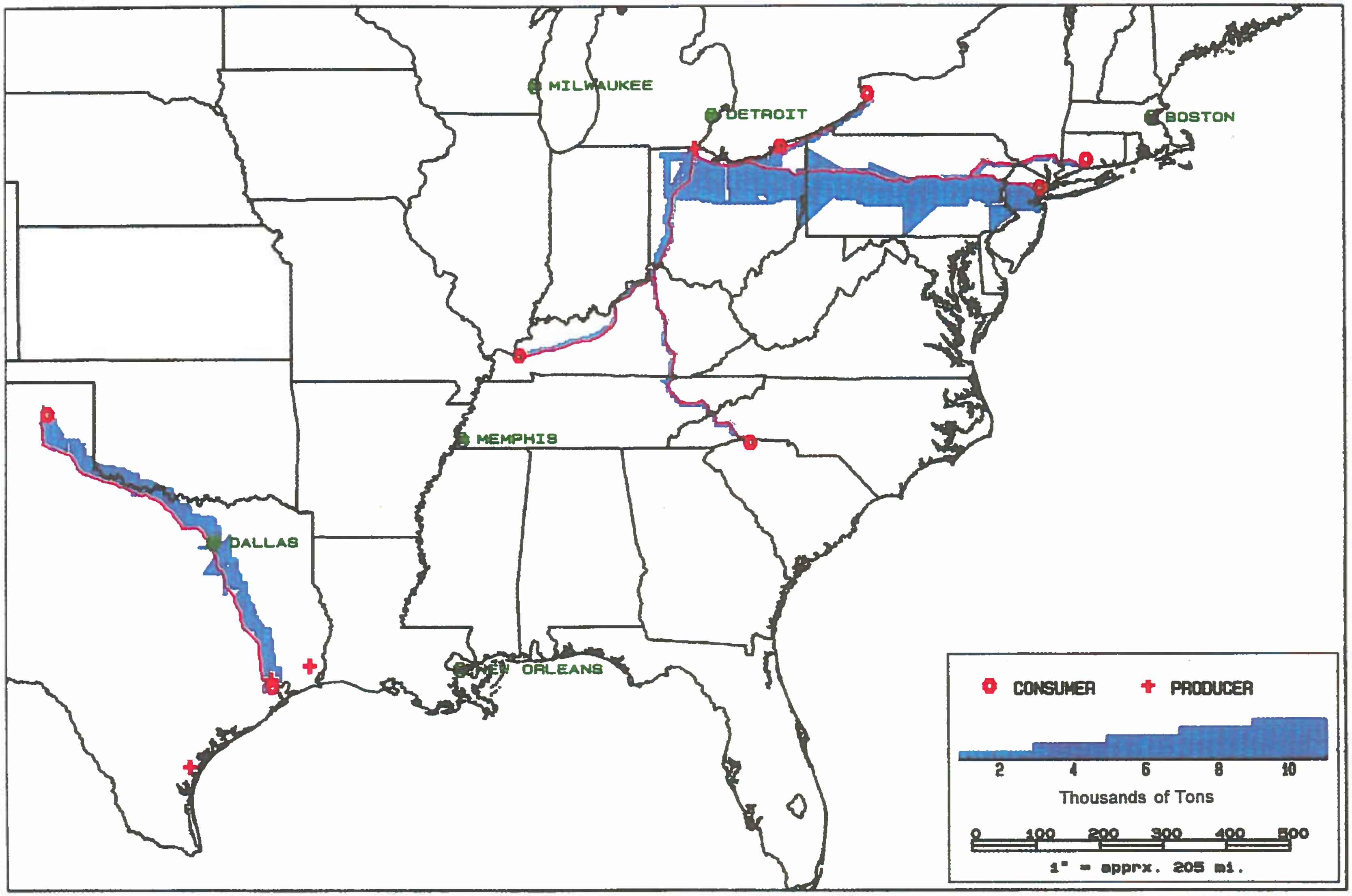

FIGURE 2. NATIONAL TRUCK FLOWS OF DODECENE-1: EASTERN U.S.
(LINEAR PROGRAMMING RESULTS)

9. COMPARISON OF MODEL RESULTS WITH INCIDENT DATA

Table 5 shows estimates of the expected annual number of truck accidents involving dodecene-1. These estimates, based on 1987 truck-miles, are shown in the third column of the table. Given that RSPA estimates 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 5 indicate that, as of 1987, the states with the highest risk of both truck accidents and spills were Pennsylvania, Ohio, and Texas. This is not surprising, since these states also rank highest in ton-miles and truck-miles of dodecene-1, as shown in Table 4 and in Figures 1 and 2. The expected annual number of truck accidents for the Nation involving dodecene-1 was 0.38, and the expected number of years between spills was eighteen.

Data from the U.S. DOT hazardous materials database were examined to determine if these results were consistent with actual experience for the years 1985 through 1992. However, given the low volume of truck movements of dodecene-1, the number of actual spills was expected to be negligible. The only dodecene-1 incident in the database involved a shipment carried by a small package carrier, and the total release was 0.13 gallons. There were no incidents involving bulk shipments (the subject of this report). This finding is consistent with the model prediction of 18 years between spills.

TABLE 5. ESTIMATED NUMBER OF TRUCK ACCIDENTS INVOLVING DODECENE-1, BY STATE, 1987

State	Ton-Miles† (Thousands)	Estimated Truck-Miles† (Thousands)	Estimated Accidents‡	Estimated Years/Spill‡
Connecticut	34	1.7	0.00	3,922
Kentucky	428	21.4	0.02	312
New Jersey	426	21.3	0.02	313
New York	58	2.9	0.00	2,299
North Carolina	53	2.6	0.00	2,564
Ohio	1,886	94.3	0.09	71
Oklahoma	959	48.0	0.05	139
Pennsylvania	2,125	106.2	0.11	63
South Carolina	8	0.4	0.00	16,667
Tennessee	76	3.8	0.00	1,754
Texas	1,503	75.2	0.08	89
U.S. Total	7,556	377.8	0.38	18

‡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 4

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

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

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

Chemical	Production Volume, 1987 (Thousands of Short Tons)
Sodium Cyanide	85
Isobutanol	83
Pinene	78
Sodium Hydrosulfite	78
Ethyl Chloride	77
Tetrahydrofuran	77
Methyl Isobutyl Ketone	76
Chloronitrobenzene	73
Sodium (Metal)	72
Phosphorus Pentasulfide	70
Hexene-1	61
Propionic Acid	59
Acrylamide	56
Chlorinated Isocyanurates	55
Isoprene	54
Zinc Sulfate	54
Ethylene Glycol Monoethyl Ether	53
p-Dichlorobenzene	52
Dicyclopentadiene	50
Hydrofluosilicic Acid	50
Benzoic Acid	48
Isobutyl Acetate	44
Atrazine	43
Ethylene Glycol Monoethyl Ether Acetate	42
Ethylenediamine Tetraacetic Acid	41
Furfural	40
Sodium Hydrosulfide	40
Ethylenediamine	39
Dimethylamine	37
Cupric Sulfate	36
Ethylene Glycol Monomethyl Ether	36
n-Propyl Acetate	35
Aluminum Chloride	33
Benzyl Chloride	33
Phosphorus Oxychloride	31

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

Chemical	ProductionVolume, 1987 (Thousands of Short Tons)
Ethylene Dibromide	30
Zinc Chloride	28
Isopropyl Acetate	27
Isopropylamine, Mono	27
Methylamine	26
Sodium Phosphate, Tribasic	26
Amyl Alcohol	25
Total for 147 Chemicals	288,792

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 20 short tons per year are set for any given origin-destination pair. This amount is approximately equal to the minimum requirement for inclusions in the U.S. DOT's Hazardous Materials Registration Program. It is also the capacity of a typical tank truck fully loaded with dodecene-1.

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

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

The models start with a set of plants that produce or have available, off-site shipments, varying in estimated quantities, the hazardous chemical under study. The quantities are typically measured in thousands of short tons per year, as listed previously in Table 2. Similarly, there are consuming plants buying or receiving estimated amounts of the chemical.

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.[3] 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.[4] 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 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.[5] 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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[3] "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.

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

[5] Kwak, N., *Mathematical Programming with Business Applications*, New York: 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--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 ESTIMATES OF BULK SHIPMENTS OF DODECENE-1 BY STATE

This appendix reports the gravity model estimates of bulk shipments of dodecene-1 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 dodecene-1 are shown in Table C-1.

Of the estimated 11.6 million ton-miles of dodecene-1 moved by truck in 1987, nearly 20 percent occurred in Texas, a major consuming and producing state. (See Table C-1.) About 10 percent of the ton-miles occurred in Ohio, which has a production facility in Toledo. About 14 percent of the ton-miles occurred in Pennsylvania, a state that has neither production nor major consumption facilities of dodecene-1. Other states with neither production nor consumption facilities that have relatively large percentages of ton-miles include Alabama, Louisiana, Mississippi, Oklahoma, Tennessee, and Virginia. Because the volume of production and consumption of dodecene-1 is relatively small, terminal facilities (other than Chevron's terminal in Houston) have not been established to offset the cost of truck movements.

The gravity model results shown in Table C-1 are reflected on the maps in Figures 3 and 4, which show the major routes carrying truck shipments of dodecene-1.[6] 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 3, indicates that there are no truck shipments of dodecene-1 west of Texas. As shown in Figures 3 and 4, the gravity model indicates that there are three major routes. First, there is a flow from Chevron's terminal in Houston to the Phillips plant in Borger, Texas. Second, dodecene-1 is trucked from Texas through Louisiana, Mississippi, Alabama, Tennessee, Virginia, Maryland, and Pennsylvania to the Monsanto plant in Kearny, New Jersey. The Monsanto plant in Kearny also receives truck shipments from Toledo, Ohio, by way of Pennsylvania. It should be noted that the maps in the main body of the text, which depict the flows of dodecene-1 according to the linear programming model, show that the Monsanto plant in Kearny, New Jersey is supplied solely by the Sun plant in Toledo, and that no dodecene-1 flows northward through Louisiana, Mississippi, Alabama, Tennessee, etc.

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

TABLE C-1. GRAVITY MODEL ESTIMATES OF BULK TRUCK SHIPMENTS OF DODECENE-1 BY STATE, 1987

State	Ton-miles (Thousands)	Truck-miles (Thousands)†
Alabama	871.9	43.6
Arkansas	338.0	16.9
Connecticut	34.2	1.7
Georgia	139.5	7.0
Illinois	23.8	1.2
Indiana	33.4	1.7
Kentucky	199.4	10.0
Louisiana	991.8	49.6
Maryland	33.2	1.7
Mississippi	509.6	25.5
Missouri	64.5	3.2
New Jersey	418.1	20.9
New York	58.2	2.9
North Carolina	13.2	0.7
Ohio	1,145.0	57.2
Oklahoma	919.8	46.0
Pennsylvania	1,664.0	83.2
South Carolina	36.6	1.8
Tennessee	791.4	39.6
Texas	2,264.4	113.2
Virginia	987.1	49.4
West Virginia	78.8	3.9
Total	11,615.9	580.8

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

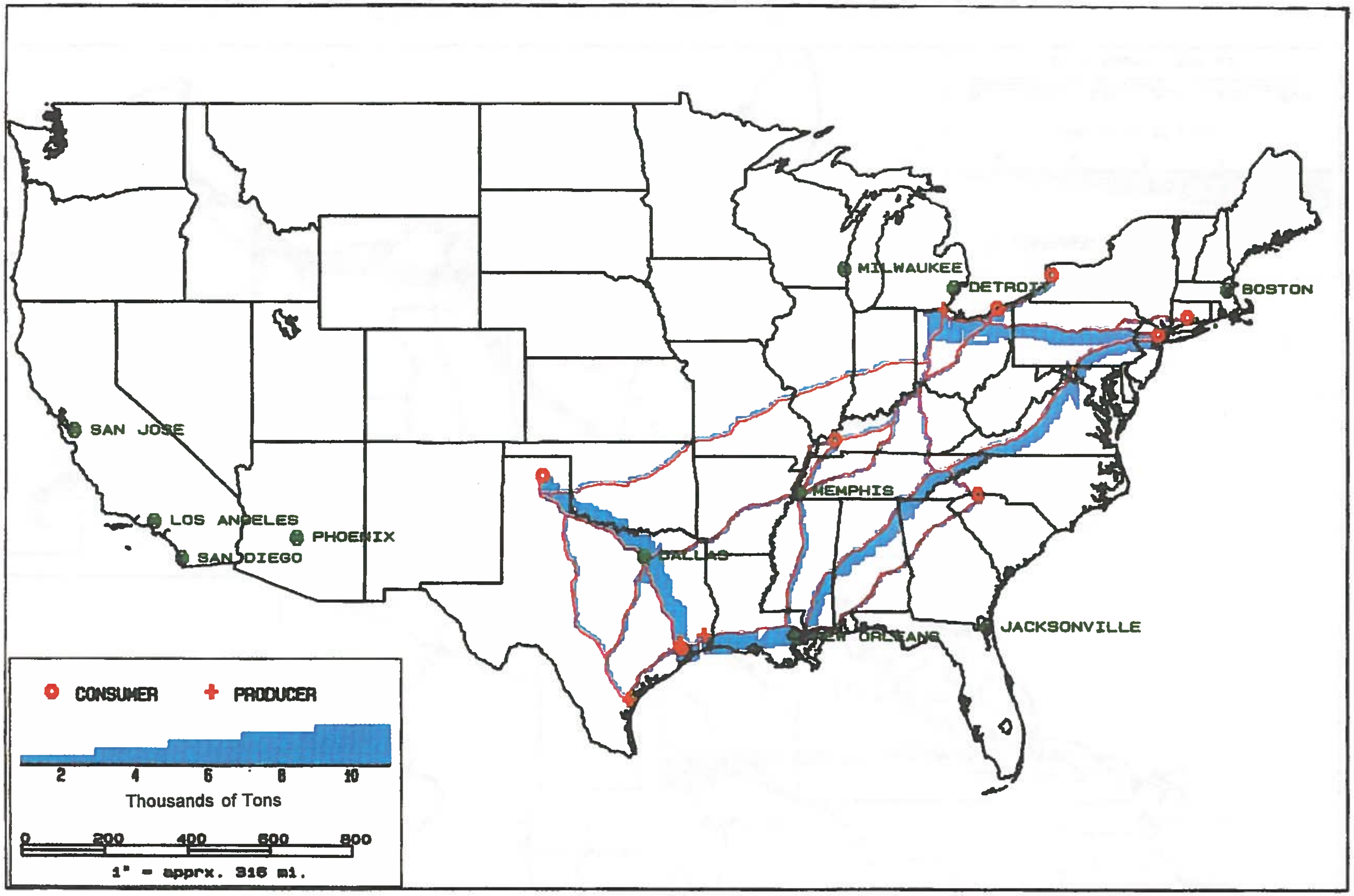

FIGURE 3. NATIONAL TRUCK FLOWS OF DODECENE-1
(GRAVITY MODEL RESULTS)

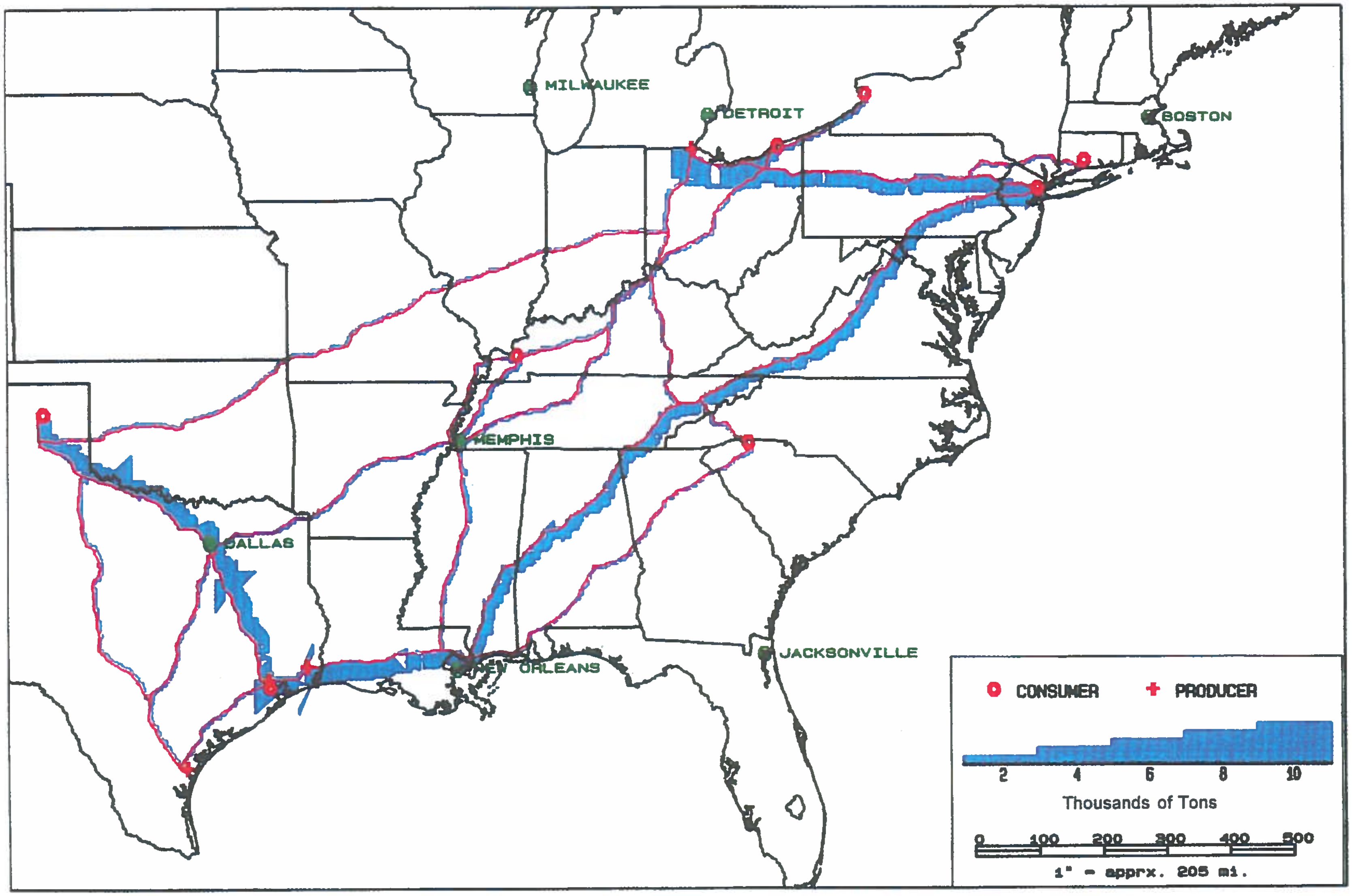

FIGURE 4. NATIONAL TRUCK FLOWS OF DODECENE-1: EASTERN U.S.
(GRAVITY MODEL RESULTS)

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.