Estimating Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients

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ABSTRACT

This study uses commodity flows from the 1993 Commodity Flow Survey (CFS) together with Input-Output (I-O) coefficients to generate truck flows for the state of Wisconsin. Production and attraction rates in tons, for the heavy truck mode only, were derived at the county level using employment for 28 economic sectors. The CFS, a joint product of the Bureau of Transportation Statistics and the U.S. Bureau of the Census, together with a private database developed for the state, TRANSEARCH, was used to derive the trip production rates. Economic-based I-O software was used to derive the I-O coefficients at the state level in order to develop trip attraction rates. Annual tons at the county level were converted to daily truck trips using an average tons-per-vehicle load and a days-per-year factor. The resulting trips were disaggregated to the Traffic Analysis Zone (TAZ) level using zonal population as a disaggregation factor. Truck trips for four trip types were derived: Internal-to-Internal, Internal-to-External, External-to-Internal, and External-to-External to the state. In order to assess the accuracy of the generation procedure, another more comprehensive study distributed and assigned the estimated trips to

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the state network following the traditional four-stage Urban Transportation Planning modeling process. The results of comparing the estimated truck flows to ground counts for selected network links show that the overall model performed well, indicating that the generation procedure produced a reasonable estimation of statewide truck trips.

INTRODUCTION

This research deals with the forecasting of freight at the statewide level. The forecast of goods in urban areas has been extensively explored, and some forecasts employ computer modeling programs that are relatively well developed. The recently released *Quick Response Freight Manual* (Cambridge Systematics 1996) is a good example of such development in the forecasting of urban truck trips. On the other hand, at the state level many truck forecasting models in the United States were developed by state departments of transportation following state planning proposals, often including passenger forecasting.

Many states use trend line analysis to estimate and forecast statewide truck travel (Park and Smith 1997). These studies will not be fully detailed here because most rely on traffic counts and the base year Annual Average Daily Traffic (AADT) to estimate future traffic growth factors (Huang 1998). It is believed that the demand for freight is better explained when derived from economic activities rather than from traffic counts and projections. In addition, interaction between links is ignored when a trend line approach is applied to statewide truck travel estimations.

To forecast truck flows, other states use standard travel demand models, such as the four-stage and network-based models. These models, however, require costly Origin-Destination (O-D) survey data for calibration. Oregon and Wisconsin have developed network-based models. The TRANSLINKS 21 project developed for Wisconsin (TRANSEARCH 1996) explored commodity flow data to forecast freight demand in an intermodal feasibility study. Growth factors were used to estimate future truck traffic flows.

The problem of the cost of O-D survey data can be mitigated if a direct O-D trip matrix estimation is applied. Models based on the principles of information minimization and entropy maximization (Van Zuylen and Willumsen 1980) can be used to estimate the direct O-D trip matrix from traffic counts. Solution of the entropy maximization model involves, however, a nonlinear programming formulation.

Data availability is the most critical factor in developing a statewide truck demand model. Techniques that can be used as analytical tools also have some drawbacks. The simple trend line analysis and growth factor models are costly and cannot effectively estimate future traffic for long-range planning purposes. Entropy maximization techniques may be useful for small networks but require an initial trip table for estimation of the direct O-D trip matrix, and the forecasting of future travel demand is limited to a simple Fratar expansion. Adapted Urban Transportation Planning models provide the most effective approach for statewide truck forecasting if truck trip productions and attractions can be easily estimated.

The Commodity Flow Survey[1] (USDOC 1996b) shows that local transportation of freight is important to the economy of Wisconsin since in 1993 roughly 35% of the value and 70% of the weight of the total shipments from the state were shipped to destinations within the state. In addition, the survey shows that most commodities originating in Wisconsin were moved specifically by truck: about 84% of the value and 88% of the weight.

Current research in freight relies on a limited source of data for truck forecasting, based mainly on either expensive and time-consuming truck traffic surveys or inefficient truck traffic counts. In the latter case, the studies fail because trend analysis using traffic counts shows little relationship between the growth of truck traffic and possible explanatory variables. The Minnesota Department of Transportation study (MinDOT 1985), the New Mexico Department of Transportation procedure (Albright 1985), the methodology developed for the Maryland Department of Transportation (Sirisonponsilp and Schonfeld 1988), and the comprehensive Michigan Statewide Travel Demand Model (Nellet et al. 1996)

[1] The Commodity Flow Survey is a joint program of the Bureau of Transportation Statistics and the U.S. Bureau of the Census. Additionally, the Federal Highways Association provided financial support for the 1993 edition.

provide examples of methods that use trend line and growth factors based on Annual Average Daily Traffic (AADT) to estimate and to forecast truck travel. A better way to generate truck trips is to use a commodity-based approach together with, for example, Input-Output (I-O) coefficients.

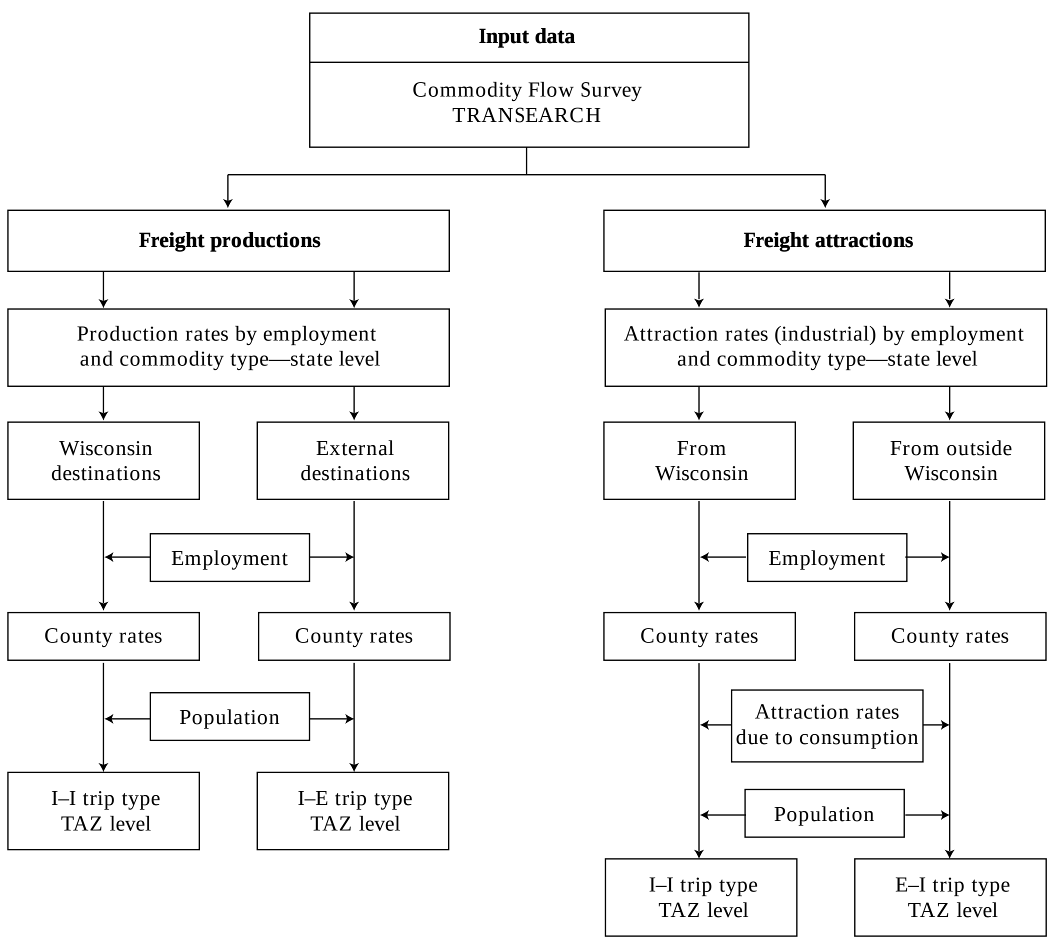
The National Cooperative Highway Research Program (NCHRP 1983) addressed the need for a freight-oriented planning process with one of the main requirements being the preparation of the freight components of statewide master plans. Also, the resulting freight model should use vehicle or commodity flow data as major inputs rather than vehicle count or frequency data alone. Thus, freight traffic projections should be based on economic activity instead of trend extrapolation.

The resulting technique mainly utilizes commodity and employment data together with I-O coefficients in order to improve the truck trip generation process. The procedure was used in the four-stage model. As a result, the state may have a forecasting model that can be applied in the state planning process when heavy truck trips for major commodities need to be estimated. The overall algorithm followed in this study is shown in figure 1.

FREIGHT GENERATION

Freight generation and distribution are normally separate phases when simulation techniques, such as the I-O technique, are used to estimate commodity flow data. In this study, the I-O technique will be used to estimate freight attractions for Wisconsin for 1992. Freight production will be estimated through use of the 1993 Commodity Flow Survey (USDOC 1996c) with complementary data from a private database, TRANSEARCH. TRANSEARCH, which has been produced annually by Reebie Associates since 1980, provides ori-

FIGURE 1 Production and Attractions Rates



gins and destinations of commodity flows for all 72 counties in Wisconsin and for another 70 external zones, including some Canadian zones. The database has been used extensively by the Wisconsin Department of Transportation (WisDOT) since then. Also, the database has a strong relationship with the Commodity Flow Survey in terms of commodity classification and truck type studied. The overall procedure for deriving production and attraction of truck flows is detailed in the following sections.

FREIGHT PRODUCTION MODEL

Freight production can be inferred from various measures of economic activity, such as monetary measures and employment data by economic sector. Monetary values are converted to physical units, tons, with commodity attributes files (NCHRP 1983), provided that an average value-per-ton of each commodity is known. Employment data from the Census are used to convert state production in tons, stratified by the Standard Transportation Commodity Classification (STCC) (two-digit level in the CFS) first to production rates by sector at the state level (tons per employee) and later to the county level in tons. County tons by sector are further disaggregated to the Traffic Analysis Zone (TAZ) level using population as a disaggregator since at the TAZ level there are no reliable employment data available.

For this study, the 1993 CFS database provided information on 23 economic sectors out of the 28 under study. Table 6 in the CFS report (USDOC 1996c) for Wisconsin provides monetary values, tons, and percentage shipped for the state by private and for-hire truck modes.

Table 1 shows the 28 economic sectors analyzed in this study. The sectors were mainly manufacturing sectors, chosen by data availability, if they were hauled by truck, and if they matched the sectors used by the IMPLAN software in the attraction model. According to the CFS report (USDOC 1996c), sectors 09, 13, 27, and 38 did not meet publication standards, and sector 10 had its figures withheld so as to avoid disclosing data of individual companies. Thus, production tons for these five sectors were borrowed from the TRANSEARCH database.

TABLE 1 Selected Economic Sectors

SIC–STCC[1]	Sector	Tons per truck[2]
01	Farm products	24
08	Forest products	13
09[a]	Fresh fish and other marine products	06
10[a]	Metallic ores	24
13[a]	Crude petroleum, natural gas, and gasoline	14
14	Nonmetallic minerals	19
19	Ordinances and accessories	24
20	Food and kindred products	18
21	Tobacco products, excluding insecticides	05
22	Textile mill products	05
23	Apparel and other finished textile products	03
24	Lumber and wood products, excluding furniture	15
25	Furniture and fixtures	03
26	Pulp, paper, and allied products	16
27[a]	Printed matter	09
28	Chemicals and allied products	22
29	Petroleum and coal products	19
30	Rubber and miscellaneous plastic products	04
31	Leather and leather products	03
32	Clay, concrete, glass, and stone products	23
33	Primary metal products	19
34	Fabricated metal products	24
35	Machinery, excluding electrical	09
36	Electrical machinery, equipments, and supplies	08
37	Transportation equipment	12
38[a]	Instruments, photographic and optical goods	05
39	Miscellaneous products of manufacturing	02
40	Waste and scrap materials	16

[1] SIC = Standard Industrial Classification
STCC = Standard Transportation Commodity Classification
[2] Source: TRANSEARCH database (TRANSEARCH 1996)
[a] Sectors with production tons from the TRANSEARCH database (TRANSEARCH 1996)

Table 2, column 3, shows the total freight production rates in tons per employee for the state of Wisconsin. Annual tonnage shipped by the private and for-hire truck modes by the 28 sectors for 1992 was obtained from the CFS and the TRANSEARCH database. Employment data by sector, column 2, were provided by the *County Business Patterns* (USDOC 1994) from the Census.

The CFS CD-ROM (USDOC 1996c) gives information on commodities transported from state of origin to state of destination for all 50 U.S. states. Tons are stratified by commodity type and by all modes of transportation, including truck, rail, air, water, and pipeline. The truck share from the CFS (USDOC 1996c), table 6, was applied to derive truck tons. In a later step, this procedure was used to derive the freight production table for

TABLE 2 Freight Production Table for the State of Wisconsin

STCC	(1) Employment (1992)	(2) Total production (tons/employee)	(3) Destination inside state (tons/employee)	(4) Destination outside state (tons/employee)
01	67,959[a]	104.95	59.12	45.82
08	149	7,159.53	7,159.53	0.00
09	11	13.27	0.00	13.27
10	90	5.12	0.00	5.12
13	90	0.51	0.00	0.51
14	2,749	13,050.93	12,337.73	713.20
19	1,005[b]	5.17	0.00	5.17
20	53,244	476.15	241.85	234.30
21	1,109[c]	15.90	15.04	0.86
22	2,965	50.25	26.74	23.51
23	6,404	36.70	10.43	26.26
24	26,751	461.07	347.22	113.85
25	14,468	28.13	5.70	22.43
26	44,677	212.03	92.37	119.67
27	49,717	13.29	8.89	4.40
28	11,119	402.91	230.26	172.65
29	297	65,343.43	54,190.82	11,152.62
30	25,927	44.97	15.04	29.93
31	7,106	22.09	4.48	17.62
32	9,072	1,451.83	1,254.88	196.94
33	22,997	163.28	78.04	85.24
34	52,700	40.65	17.20	23.45
35	94,271	16.43	4.16	12.27
36	40,447	22.84	7.15	15.69
37	27,725	78.09	7.52	70.56
38	16,351	3.68	0.61	3.07
39	11,005	33.08	6.63	26.44
40	2,490[d]	1,022.49	698.26	324.23
Sum	**592,895**			

[a] Farms from Census of Agriculture (USDOC 1996a)
[b] SIC 348
[c] From wholesale trade (SIC 5194)
[d] From wholesale trade (SIC 5093)

the state with destinations within the state, the Internal-to-Internal trip type (I-I), and for external destinations, the Internal-to-External trip type (I-E). Table 2, column 4 shows freight production rates in tons per employee for Wisconsin, with only Wisconsin destinations which was used to derive the I-I trip type. Table 2, column 5 shows freight production rates in tons per employee for Wisconsin with only destinations outside the state used, to derive the I-E trip type.

Employment data from the *County Business Patterns* report (USDOC 1994) were used to derive and disaggregate the tons produced from the state level to the county level. Production rates in table 2 multiplied by the number of employees for each sector in each county produced 72 tables, one for each county in Wisconsin.

Table 3 shows the 1993 production tons with destinations internal and external to Wisconsin. The county figures in table 3 do not match the state figures in table 2 because the employment data for counties are not added to the state total in the *County Business Patterns* report. This is because much of the employment information for counties is presented in ranges of employees (e.g., B = from 20 to 99 employees) to avoid the identification of individual firms. For this reason, an average value was applied in this study. The tonnages in table 3, however, are close to the state total.

The next step is to disaggregate the production tons from the county level to the TAZ level so that the estimated truck flows can be compared to ground counts. Employment is a more reliable factor for the disaggregation, but there is no information available on employment by economic sector

TABLE 3 County Production Table (Wisconsin Internal and External Destinations)

STCC	Internal destinations (tons)	External destinations (tons)
01	4,017,881	3,114,119
08	2,641,867	0
09	0	1,062
10	0	359
13	0	36
14	35,273,562	2,039,040
19	0	4,320
20	12,844,193	12,443,527
21	17,088	980
22	77,798	68,387
23	66,825	168,175
24	9,297,398	3,048,590
25	81,573	320,982
26	4,059,096	5,258,696
27	443,712	219,870
28	2,621,081	1,965,288
29	18,208,115	3,747,279
30	386,842	770,028
31	32,572	128,118
32	11,001,576	1,726,616
33	1,823,547	1,991,868
34	930,246	1,268,536
35	392,229	1,157,461
36	289,247	634,479
37	209,308	1,963,111
38	9,764	49,257
39	72,617	289,399
40	1,967,009	913,345
Sum	**106,765,145**	**43,292,928**

at the TAZ level. Consequently, population was used as the disaggregation factor. After the disaggregation, 624 tables resulted, showing the tons produced by each of the 28 sectors at each of the 624 TAZs in the state.

The TRANSEARCH database has information on tons per truck by commodity type. The annual tons at each TAZ divided by the tons per truck from TRANSEARCH resulted in the annual truck trips generated at each TAZ. Yearly truckloads were then divided by 312 (6 days per week multiplied by 52 weeks per year) to estimate daily truck trips. Tons per truck by commodity for the 28 two-digit STCC code sectors are shown in table 1.

DERIVATION OF FREIGHT ATTRACTIONS

Deriving freight attractions is not as straightforward as deriving freight productions. Considered final demand, the consumption of commodities by processing industries and by consumers equals freight attractions. Freight is also attracted by physical distribution centers. This study used the Input-Output analysis to derive the industrial and consumption attractions. The procedure for deriving I-O coefficients, county level attractions, and TAZ level attractions follows.

THE BASICS OF INPUT-OUTPUT ANALYSIS

The Input-Output (I-O) model has had a substantial theoretical and empirical appeal as a tool for national and regional economic analysis since its development in 1936 by Wassily Leontief. Input-Output analysis attempts to quantify, at a point in time, the economic interdependencies in an economy, such as a nation, state, or county. All economic activity is assigned to one of two types of sectors: production or final demand. Production sectors (e.g., agriculture, manufacturing, services, trade, etc.) represent all establishments in the region producing a specific product or service. Final demand may include households, government, foreign trade, or inventory. These are sectors where the level of activity is assumed to be determined by forces external to the model, such as a government policy (Otto and Johnson 1993).

The most important assumption made in I-O analysis is that the inputs used in production are proportional to the output. The amount of a product (good or service) produced by a given sector in the economy is determined by the amount of that product purchased by all users of the product. Users include other industrial sectors using the product as input in the production of their own products, collectively referred to as intermediate demand, as well as sectors that use the product in its final form, collectively referred to as final demand. The flow of products between sectors is measured in monetary values and referred to as transactions between the various sectors (Otto and Johnson 1993).

It is necessary to establish an I-O model specific to the region in order to use the I-O framework for regional analysis. Three prescribed tables (or matrices) form an I-O model: the transactions table, the direct requirements table, and the total (direct, indirect, and induced) requirements table. The transactions table shows the interaction between the various sectors in an economy, providing a snapshot of all the economic activity in the economy at a point in time. The data from the transactions table can be used to derive the direct requirements table, which shows how much of each input is required to produce one monetary value of output. From the direct requirements table, a table of total requirements can be determined, showing the impact of a change in any particular sector or combination of sectors on the entire economy.

Industries producing goods and services for final users (final demand) purchase goods and services (direct purchases) from other producers. These other producers, in turn, purchase goods and services as well (indirect purchases). The induced effects are due to the effects of household expenditures, and they can be obtained from a set of multipliers as a result in the total requirements table. This buying of goods and services continues until leakages from the region (imports) stop the cycle. Therefore, purchases for final use drive the I-O model.

A tremendous amount of data is required to create regional I-O models. The cost of surveying industries within each region to obtain the list of commodities purchased in order to derive the production function of the model is often prohibitive. However, since many times we are only interested in a specific economic sector or industry, the data requirement problem is mitigated. In addition, computer software packages, such as the IMPLAN Professional, provide a database for the development of I-O models at the national, state, and county levels. Therefore, given the necessary amount of data, the I-O models can be used for both forecasting and economic impact analysis. Figure 2 shows the I-O production functions.

The basic Leontief production function can be represented analytically as in equation (1):

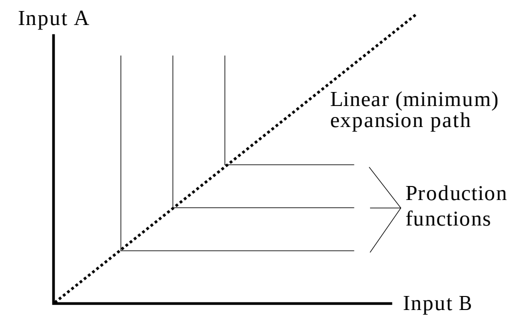
$$Z_{ij} = a_{ij} X_j \tag{1}$$

where:

Z_{ij} = interindustry sales from sector i to sector j,
a_{ij} = technical coefficients, and
X_j = total output of sector j in monetary value terms.

The model revised in matrix format is shown in equation (2):

FIGURE 2: Input-Output (Leontief) Production Function



$$X = AX + Y \tag{2}$$

where:

X = output matrix,
A = technical coefficients matrix, and
Y = final demand vector.

A change in percentage in final demand creates changes in other sectors. Other sectors change their output through increases in input, creating further changes of a diminishing magnitude. The revised final matrix format representing the changes follows:

$$\Delta X = (I–A)^{-1}\,\Delta Y \tag{3}$$

where:

I is the identity matrix.

DERIVATION OF THE INPUT-OUTPUT TABLES

The IMPLAN Professional software package was used to derive the transactions, direct, and total requirements tables for the state of Wisconsin using the 1994 database, the year closest to the 1992 base year of this study. The model initially had 528 sectors to be aggregated by sector of interest (see table 1). In this study, the final number of sectors, aggregated at the two-digit Standard Industrial Classification (SIC) codes, was 41, with 38 having data available for the state. A type II multiplier[1] option was chosen in order to obtain

[1] When households are included in a closed I-O model, output multipliers include induced, as well as direct and indirect, effects. Output multipliers, which include induced effects, are termed type II multipliers, in distinction to type I multipliers, which include only direct and indirect effects.

the direct, indirect, and induced effects, and this default multiplier was chosen as a requirement to run the IMPLAN software. In this study, only the direct coefficients were computed when deriving freight attractions.

The model must be run first with the 528 IMPLAN sectors. These sectors are enumerated with the SIC codes. A bridge with the four-digit 1987 SIC codes is provided in the software manual, facilitating future aggregation. Only 28 sectors, out of the 38 sectors with available data, were selected because not all the sectors generate commodity movement. In addition, sectors such as coal (SIC 11) do not have information on the value or tons of commodities shipped by truck in the 1993 CFS and, for this reason, were not selected. Most of the 28 sectors selected for the analysis were manufacturing sectors, with the exception of sectors such as farm and forest products.

Components of the IMPLAN database are part of the social accounts of the region under study. Social accounts show the flow of commodities to industry from producers and institutional consumers (household, government). Also shown is the consumption of factors of production, that is, workers, owners of capital, and imports from outside the region. From the social accounts, the model is converted to the industry-by-industry formulation of I-O accounts and ultimately to the predictive multipliers.

The I-O accounts use two classification systems: one for industries and the other for commodities. In the industry classification system, output represents the total output of establishments (defined as a single, physical location), regardless of whether the commodities produced are primary (composing the largest proportion of the output of the establishment) or secondary (primary to another industry) to the industry. In the commodity classification system, output represents the total output of the product or service, regardless of the classification of the establishment where it is produced (USDOC 1991).

In order to create a regional I-O model, the regional database is combined with the national structural matrices to form the regional multipliers. The initial data set is the "use" of commodity by industry and the "make" of commodities by industry, which are flows from the national I-O table. The regional study area file is created by combining the states or counties selected by the user. From the initial study area, the national structural matrices are regionalized by eliminating industries that do not exist in the region.

Imports are then estimated through the Regional Purchase Coefficients (RPC). An RPC represents the proportion of the total supply of a good or service not locally produced that is required to meet a particular demand of an industry. For example, an RPC value of 0.80 for the commodity fish means that 80% of the demand for fish is provided by local fishermen. The remaining 20% is imported. IMPLAN generates RPCs automatically with a set of econometric equations.

The regional final demands and use matrices are multiplied by the resulting RPC coefficients, creating a set of matrices and final demands free of imports. The regional use matrix and final demands are converted from a commodity to an industry basis, providing for the development of the I-O accounts. The subsequent inversion of the I-O accounts provides an import-free matrix of multipliers.

The direct requirement matrix derived in this study was generated from the regional transactions table and is import-free, meaning that it will be used to derive attractions for the Internal-to-Internal (I-I) trip type. In this matrix, the direct coefficients for each sector are added to the value-added and to imports in order to have a total direct coefficient close to one for the state. Imports and value-added were provided by the industry summary report in the IMPLAN social accounts.

Another regional industry-by-industry coefficient matrix, including imports by sector, was also generated by adding imports from outside the state. The import coefficients were derived from the industry balance sheet report from the IMPLAN Social Accounts by subtracting the regional inputs from the gross inputs for each sector and dividing the results by the total industry output.

The total consumption of a commodity is composed of two parts: industrial and personal. Industrial consumption is simply the amount purchased by an industry in order to produce its own goods. Personal consumption is the amount purchased by consumers, both household and government. The final demand report from IMPLAN provides the monetary values spent by households and government for each sector under analysis. Households tend to buy little directly from industries, other than via retail trade. However, in an I-O table purchases made by individuals for final consumption are shown as payments made directly to the industry producing the goods. Government expenditures are made up of federal, state, and local government. Federal purchases are divided by military and nonmilitary use, whereas state and local government are divided by public education and noneducation. RPC coefficients were applied to provide the proportion of consumption used to purchase goods from inside and from outside the state as imports. Then, a final regional industry-by-industry coefficient matrix includes purchases by industries and consumption, since a type II multiplier was selected when the model was run.

DERIVATION OF INDUSTRIAL FREIGHT ATTRACTIONS

Input-Output direct coefficients for the state of Wisconsin were used to derive freight attractions. These coefficients are defined as the monetary amount of one product used in making one monetary unit's worth of another product. In other words, it is the amount and type of commodity purchased by each industry in order to produce its output. Thus, it is necessary to derive a table for each of the 28 sectors that shows all the inputs required to produce the output of that particular sector. Table 4 shows the annual industrial attrac-

TABLE 4 Industrial Freight Attractions Table for Sector 1—Farm Products

(1) Input commodity STCC	(2) I–O direct coefficient	(3) Input ($)	(4) 1992 value ($/ton)	(5) Total tons 1992
01	0.2360000	1,211,328,034	1,270	953,802
08	0.0010800	5,545,249	4,075	1,361
09	0.00E+00	0	3,415	0
10	2.32E-09	12	17,605	0
13	1.79E-06	9,171	224	41
14	0.0007610	3,897,274	98	39,768
19	1.38E-07	707	192,046	0
20	0.0726000	372,235,275	1,442	258,138
21	2.10E-10	1	19,268	0
22	0.0004440	2,273,687	5,385	422
23	0.0003020	1,547,682	16,655	93
24	0.0017800	9,130,461	1,123	8,130
25	3.08E-06	15,781	5,132	3
26	0.0025700	13,177,619	2,406	5,477
27	0.0003710	1,898,400	5,414	351
28	0.0279000	142,904,539	3,869	36,936
29	0.0031600	16,205,274	838	19,338
30	0.0017300	8,887,548	4,652	1,910
31	0.0001490	761,983	12,704	60
32	0.0001130	576,655	1,751	329
33	0.0001640	837,971	4,201	199
34	0.0008770	4,493,804	7,612	590
35	0.0043300	22,176,516	14,660	1,513
36	0.0018000	9,199,189	14,403	639
37	0.0012100	6,191,039	62,439	99
38	0.0001120	573,855	80,036	7
39	0.0001530	785,237	21,035	37
40	0.00E+00	0	514	0

(1) Standard Transportation Commodity Classification—STCC code
(2) I-O direct coefficient from the I-O direct requirements table
(3) = (2) × $5,123,703,613 (farm products output from IMPLAN)
(4) 1992 value per ton. From 1977 MIT research inflated to 1992 using Producer Price Indices (NCHRP 1983)
(5) = (3) ÷ (4)

TABLE 5 Total Industrial Freight Attractions for the State of Wisconsin

(1) Input commodity STCC	(2) Total tons	(3) Truck tons	(4) Employment (1992)	(5) Tons/ employee
01	4,784,196	3,382,426	67,959	49.77
08	93,917	82,459	149	553.42
09	25,215	22,138	11	2,012.59
10	9,267	8,136	90	90.40
13	879,696	772,373	90	8,581.92
14	1,431,163	1,379,641	2,749	501.87
19	28	18	1,005	0.02
20	2,539,964	2,207,229	53,244	41.45
21	19	17	1,109	0.02
22	126,360	119,284	2,965	40.23
23	14,099	11,632	6,404	1.82
24	1,680,314	1,529,086	26,751	57.16
25	35,108	33,669	14,468	2.33
26	1,798,056	1,454,627	44,677	32.56
27	136,524	119,868	49,717	2.41
28	1,018,087	869,446	11,119	78.19
29	233,900	201,388	297	678.07
30	497,706	465,355	25,927	17.95
31	13,411	12,553	7,106	1.77
32	399,471	363,119	9,072	40.03
33	1,117,205	1,081,455	22,997	47.03
34	422,650	406,167	52,700	7.71
35	246,185	218,366	94,271	2.32
36	217,216	197,015	40,447	4.87
37	28,555	4,793	27,725	0.17
38	4,357	2,963	16,351	0.18
39	5,308	4,560	11,005	0.41
40	196,400	147,890	2,490	59.39
Total	**17,954,377**	**15,097,672**	**592,895**	

(1) STCC code
(2) Total freight inputs for all modes of transportation
(3) Truck tons obtained by applying the truck proportion from the CFS (USDOC 1996c)
(4) Total state employment from the County Business Patterns Table 1b (USDOC 1994)
(5) = (3) ÷ (4)

tions for farm products (sector 01) for the state of Wisconsin. Industrial attractions for the other 27 sectors are derived with the same procedure. Direct I-O coefficients for imports-only were used to derive the freight attractions table for inputs from outside the state. Similarly, coefficients without imports were used to derive the freight attractions table for inputs coming inside the state (domestic attractions).

Adding the inputs from all sectors produces the total freight attractions table for the state of Wisconsin together with the import-only and the internal attraction tables. Results are in tons per employee, which can be disaggregated from the state to the county level using employment for each sector. Table 5 shows the total industrial freight attractions table for the state of Wisconsin.

Freight attractions are disaggregated from the state to the county level using employment data as a disaggregation factor. It is assumed that all counties in the state will have the same state productivity in tons per employee. This assumption may be relaxed if an I-O direct table is derived for each of the 72 counties in the state through the use of the IMPLAN county database. However, application at this level of detail is beyond the scope of this study and should be a topic of future research. Also, counties with no employment in a specific sector do not have tons attracted to that sector. Table 6 shows the total industrial freight attractions in tons for Dane county. Industrial attractions for the other 71 state counties were derived with the same procedure.

TABLE 6 Total Industrial Attractions Table for Dane County

(1) STCC	(2) Employment (1992)	(3) Tons/ employee	(4) Tons
01	2,639	49.77	131,347
08	0	553.42	0
09	0	2,012.59	0
10	0	90.40	0
13	10	8,581.92	85,819
14	156	501.87	78,292
19	14	0.02	0
20	3,698	41.45	153,300
21	156	0.02	2
22	156	40.23	6,276
23	58	1.82	105
24	411	57.16	23,493
25	2,088	2.33	4,859
26	417	32.56	13,577
27	3,758	2.41	9,061
28	845	78.19	66,074
29	0	678.07	0
30	2,188	17.95	39,272
31	0	1.77	0
32	540	40.03	21,614
33	606	47.03	28,498
34	1,412	7.71	10,882
35	2,005	2.32	4,644
36	1,078	4.87	5,251
37	1,101	0.17	190
38	2,545	0.18	461
39	337	0.41	140
40	155	59.39	9,206
Total	**26,373**		**692,365**

(1) STCC code
(2) County employment from the County Business Patterns Table 1b (USDOC 1994)
(3) Tons per employee from table 5, column (5)
(4) = (2) x (3)

CONSUMPTION DERIVATION

Consumption by each sector was derived in the same way as industrial derivation, although in this case the disaggregation factor used was population instead of employment. The IMPLAN final demand report provides the monetary value expenditure for households and the government. First, tons per inhabitant must be derived for the truck mode at the state level. Then, disaggregation to the county level is done using county population. Table 7 shows the derivation for the total consumption attractions for the state of Wisconsin.

Regional Purchase Coefficients (RPCs) for each sector from IMPLAN were used to derive the consumption from inside the state (domestic consumption) and from outside the state (imports). The results are tons per inhabitant for the state by sector.

Disaggregation to the county level is done using county population. Tons per population from the state is applied to the county population. Again, it is assumed that all the counties will follow the same pattern in terms of consumption per inhabitant. This assumption could be relaxed if RPCs were derived for each of the 72 Wisconsin counties using the IMPLAN model, also an issue for future research. Table 8 shows the disaggregation of the total freight attractions due to consumption from the state to the county level for Dane County.

Adding freight attractions from the industrial and the consumption derivation gives the total freight attractions for each county by economic sector. The next step will be to disaggregate the total attraction tons from the county level to the TAZ level. Again, employment is a more reliable factor for the disaggregation of industrial attractions, but there is no information available on employment by economic sector at the TAZ level. Consequently, population was used as a disaggregation factor. After the disaggregation, 624 tables resulted showing the tons attracted by each of the 28 sectors at each TAZ in the state.

The TRANSEARCH database provides information on tons per truck by commodity type. The annual tons at each TAZ divided by the tons per truck from TRANSEARCH resulted in the annual truck trips generated in each zone. Yearly truckloads were then divided by 312 (6 days per week, multiplied by 52 weeks per year) to estimate daily truck trips.

MODEL EVALUATION

The Gravity Model (GM) function in TRANPLAN was used to distribute the three trip types: Internal-to-Internal (I-I), Internal-to-External (I-E), and External-to-Internal. The Fratar Growth Factor model was applied for distributing the External-to-External (E-E) trip type. Huang's trip length frequency distributions (1998) were used in the GM calibration.

The four trip types were merged and assigned to the state highway network. A Selected Link Analysis (SLA) iteration procedure in TRANPLAN must be undertaken in order to calibrate the trip

TABLE 7 Total Freight Attractions for the State of Wisconsin Due to Consumption

(1) Input STCC	(2) PCE commodity million $)	(3) Government expense (million $)	(4) Total consumption (million $)	(5) 1992 value ($/ton)	(6) Total tons 1992	(7) Truck tons 1992	(8) Tons/ inhabitant 1992
01	387.2	13.9	401.1	1,270	315,839	223,298	0.04565
08	168.4	10.8	179.2	4,075	43,976	38,611	0.00789
09	58.7	0.8	59.4	3,415	17,401	15,278	0.00312
10	0	0	0	17,605	0	0	0.00000
13	0	0	0	224	0	0	0.00000
14	1.9	8.5	10.4	98	106,526	102,691	0.02099
19	32.6	43.1	75.7	192,046	394	256	0.00005
20	5,441.6	311.5	5,753.1	1,442	3,989,675	3,467,028	0.70875
21	469.9	0	469.9	19,268	24,390	21,414	0.00438
22	211.4	8.0	219.4	5,385	40,744	38,462	0.00786
23	1,758.5	98.2	1,856.7	16,655	111,478	91,969	0.01880
24	52.7	5.4	58.1	1,123	51,740	47,084	0.00963
25	415.3	95.7	510.9	5,132	99,554	95,473	0.01952
26	254.4	123.4	377.9	2,406	157,058	127,060	0.02597
27	629.9	186.2	816.1	5,414	150,742	132,351	0.02706
28	1,786.2	298.9	2,085.1	3,869	538,934	460,250	0.09409
29	1,495.2	280.3	1,775.5	838	2,118,769	1,824,260	0.37292
30	323.3	62.1	385.4	4,652	82,841	77,456	0.01583
31	324.5	5.2	329.7	12,704	25,950	24,289	0.00497
32	124.0	18.2	142.2	1,751	81,219	73,828	0.01509
33	2.1	6.2	8.3	4,201	1,970	1,907	0.00039
34	160.9	94.8	255.7	7,612	33,591	32,281	0.00660
35	142.1	227.6	369.7	14,660	25,221	22,371	0.00457
36	1,129.3	140.7	1,270.0	14,403	88,176	79,975	0.01635
37	2,712.7	1,275.9	3,988.7	62,439	63,881	35,564	0.00727
38	271.2	320.0	591.2	80,036	7,387	5,023	0.00103
39	762.1	66.4	828.5	21,035	39,385	33,831	0.00692
40	527.0	0	528.0	514	1,027,201	773,482	0.15812
Total	**19,644.2**	**3,701.8**	**23,346.0**		**9,244,041**	**7,845,493**	

(1) STCC code
(2) PCE—Personal Consumption Expenditure from IMPLAN Final Demand report
(3) Government expenditures (federal + state & local) from IMPLAN Final Demand report
(4) = (2) + (3)
(5) Value/ton from table 4, column (4)
(6) = (4) ÷ (5)
(7) Truck tons obtained by applying the truck proportion from the CFS (USDOC 1996c)
(8) = (7) ÷ 4,891,769 (state population from 1990 Census of Population and Housing (Census of Population 1991))

table so that the assigned truck trips provide a reasonable match to the actual truck volumes. Evaluation of the SLA is accomplished by checking if the ratio between actual truck volumes and estimated volume approaches 1.0 for most of the 40 selected links in the state network. Adjustment factors for productions and attractions are also checked in each iteration to see if they approach 1.0, indicating that TAZ productions and attractions do not need further adjustments.

Evaluation measures are needed to determine if the GM is calibrated and to what extent improvements are obtained from the SLA. The overall performance of the truck travel demand model is measured by the Root Mean Squared Error (RMSE) by comparing the model-generated link volumes with single-day ground counts collected by WisDOT. A percentage RMSE (%RMSE) by aggregation volume group is also computed by dividing the RMSE by the ground count. Changes in the RMSE and the %RMSE from the initial GM through the second iteration of the SLA are shown in table 9 for the 40 selected links in this research.

The RMSE declines between the initial GM and the second iteration. The overall performance of the SLA was good, with the overall %RMSE declining from 65% to 42%. The first iteration produced a 22.4% reduction in the RMSE, and for

TABLE 8 Total Freight Attractions for Dane County Due to Consumption

(1) Input commodity STCC	(2) Tons/inhabitant 1992	(3) Total tons 1992
01	0.04565	16,757
08	0.00789	2,897
09	0.00312	1,146
10	0.00000	0
13	0.00000	0
14	0.02099	7,706
19	0.00005	19
20	0.70875	260,170
21	0.00438	1,607
22	0.00786	2,886
23	0.01880	6,901
24	0.00963	3,533
25	0.01952	7,164
26	0.02597	9,535
27	0.02706	9,932
28	0.09409	34,538
29	0.37292	136,895
30	0.01583	5,812
31	0.00497	1,823
32	0.01509	5,540
33	0.00039	143
34	0.00660	2,422
35	0.00457	1,679
36	0.01635	6,001
37	0.00727	2,669
38	0.00103	377
39	0.00692	2,539
40	0.15812	58,043
Total		**588,736**

(1) STCC code
(2) Tons per inhabitant from table 7, column (8)
(3) = (2) x 367,085 (county population from the 1990 Census of Population and Housing [Census of Population 1991])

the second iteration the reduction was 16.8%, less than the 20% threshold used in this research.

Regional volume biases were also checked through screenlines and functional highway classes, as measured by the link volume-ground count comparison and by the RMSE measure. Table 10 shows the five screenlines created to identify any bias in the estimation of truck trips moving across different sections of the state.

Some biases exist, as shown in table 10, with overestimation of 25% for the Eastern screenline and underestimation of 23% for the Western screenline. However, the model estimated truck trips very well for the other three screenlines, where the link volume almost matched the ground count.

For the functional highway class evaluation, 4 interstate highways with a total of 32 checkpoints, U.S. highways with 34 checkpoints, and 38 state highway checkpoints were analyzed. The results showed that underestimation occurred for the link volume-ground ratios, ranging from 0.69 for state highways, 0.89 for interstate highways, and 0.95 for U.S. highways.

A final overall measure of the goodness of fit of the truck travel demand model is provided by calculating vehicle-miles of travel (VMT) for the model and comparing that single number with the independent estimate of VMT for heavy trucks computed annually by WisDOT. This research produced an estimated 2.814 billion VMT, close to the 2.954 billion from the TRANSLINKS 21 report (TRANSEARCH 1996). The estimated VMT was 23% less than WisDOT's estimate.

SUMMARY AND CONCLUSIONS

This study derived freight productions and attractions for the state of Wisconsin using commodity flow data and Input-Output coefficients. The derivation process forms part of the trip generation

TABLE 9 RMSE and %RMSE by Iteration and by Volume Group for 40 Selected Links

Initial data and iteration	RMSE[1]	Total	Volume group: Under 1,000	1,001–2,000	2,001–5,000	Over 5,000
Links		40	18	8	6	8
Average GC[2]		2,495	363	1,490	3,369	7,641
Initial GM[3]	1,609	65%	61%	52%	32%	44%
1st iteration	1,247	50%	60%	38%	33%	33%
2nd iteration	1,038	42%	57%	36%	27%	27%

[1] Root Mean Squared Error
[2] Average ground count truck volume for 40 selected links
[3] Initial gravity model results

TABLE 10 Goodness of Fit Summary for Screenline

Goodness of fit measure	Screenline: Eastern	Western	Southern	Central	Northern
Ave. GC[1]	1,237	1,213	4,306	3,055	782
LV/GC[2]	1.25	0.77	0.97	1.01	1.00
%RMSE[3]	71	55	41	19	37

[1] Average ground count truck volume
[2] Link volume to ground county ratio
[3] Percent Root Mean Squared Error

stage when traditional four-stage Urban Travel Demand Model is adapted to the statewide level. It was found in the full study (Sorratini 1999) to provide improvements in the estimation of daily truck trips. Compared with two other studies developed in the University of Wisconsin—Madison, Park 1995 and Huang 1998, the full study was found to provide a better match between the estimated truck traffic counts and the ground counts than the other studies. It is believed that commodity flow data from the most recent commodity flow survey (USDOC 1996b), applied with insights from an Input-Output model developed for the state, produce better estimates of truck flows.

Daily truck trips for four trip types, Internal-to-Internal, Internal-to-External, External-to-Internal, and External-to-External, were derived first at the county level and later at the Traffic Analysis Zone (TAZ) level. The disaggregation to the TAZ level was done in order to compare the estimated truck flows to the actual ground counts. The four trip types were analyzed in an attempt to study all the trips separately since they have different characteristics in terms of trip length frequency.

Productions and attractions developed in this study were used as inputs to a more comprehensive research (Sorratini 1999). In that research, trips generated were later distributed and assigned to the state network using the TRANPLAN transportation planning software package. Link volumes estimated for the heavy truck mode were compared to actual ground counts at five screenlines and multiple links for three functional classes of highways in order to test the accuracy of the generation process. Performance measures, such as the Root Mean Squared Error, were used to evaluate the model's ability to forecast heavy truck trips at the state level.

The first results showed that productions and attractions derived in this study were underestimated when compared to truck traffic counts and had to be adjusted to better match the actual ground count volumes. This was expected since not all truck movement was accounted for in this research; empty truck movement serves as one example. This study analyzed the heavy and the private and for-hire truck types only, which also contributed to the underestimation. Also, sectors beyond the 28 considered in this study could generate some truck flows. However, an iterative process, through the use of the selected link analysis in TRANPLAN, was applied when adjusting productions and attractions, helping to mitigate the underestimation of flows. The overall performance of the models was found to be reasonable, when compared with previous, similar studies, thanks to a better derivation of productions and attractions, such as the one proposed in this study.

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