Energy Demand Forecast for Motor Freight Transportation in Taiwan: An Application of the Dynamic Interregional Input-Output Model[1]

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Abstract

The structure of energy demand for motor freight transportation in response to industrial development and changes in the industrial structure in Taiwan is evaluated for various forecast years. An inter-industry interdependence model is used to estimate the total amount of freight transport for various transportation modes. This dynamic structure is characterized by mutual effects among industries between regions and also by an analytical equilibrium, due to the capability of capturing the progress of fast economic growth and global industrial development. A dynamic interrgional input-output model is appropriate for estimating the total amount of freight transport by mode and its corresponding end-user energy demand by vehicle type.

1. Introduction

Taiwan is very deficient in domestic energy resources. Energy consumption for motor freight transportation has increased rapidly, due to rapid economic development during the past two decades. Thus, a strategic model is needed for forecasting the energy demand of motor freight transportation in response to economic development and changes in the industrial structure. In this paper, a dynamic interregional input-output model, which could be characterized by regional inter-industry, interdependence and analytical equilibrium within a global economic system, is used to estimate the total amount of freight transport by transportation mode.

Meyer (1971) introduced the concept of an interregional input-output model for transport planning. Sakashita (1973) applied this concept to road investment and regional allocation in Japan. Generally, most previous research applied multiple regression techniques [e.g., Kaya (1983)] and econometric analysis [e.g., Daughty (1979), Winston (1983) and Zlatoper et al (1989)] to examine the relationship between gross domestic product (GDP), the total amount of freight transport and energy demand. A major disadvantage of this forecasting technique is that it identifies static relationship between variables and ignores global end-user industrial energy demand. To overcome these disadvantages, the structure of energy demand for motor freight transportation in response to industrial development and changes in the industrial structure are evaluated for various forecast years.

2.   Model Formulation

Four stages are described in preparing an energy demand forecast for motor freight transportation. During the first stage, commodity flow modeling is done by using a dynamic interregional input-output model [e.g., Chardson (1972), Hewings (1986) and Leontief (1986)] for regional commodity flow. At the second stage, a relationship is developed between product value and delivery weight in each sector to transform the regional commodity flow from product value units (NT$) into delivery (tons) units. The third stage encompasses a mode-split model for allocating transportation flow Q_j^{rs} by modes that depend on the characteristics of commodities and delivery distances and for estimating total ton-kilometers for each commodity. Finally, at the fourth stage, an energy-use model is constructed to estimate fuel demand for motor freight transportation based on the total number of vehicle-kilometers from ton-kilometers for truck utilization factors, such as usable loading capacity and actual loading, empty truck ratio, and fuel efficiency for each truck type and commodity.

2.1.   Commodity flow modeling

The principal purpose of an interregional input-output model is to analyze input, output, final demand by regions and industries and their relationships. Final demand by regions and industries can then be determined. Financial flow can also be determined based on the quantification of transactions. The framework for commodity flow modeling is illustrated by the dynamic interrelationship between input-output and final demand, as shown in Figure 1. Major steps for modeling this process are as follows:

1. Transportation facilities in the last period $(k-1)$ are assumed to be an exogenous input variable; i.e., cost or travel time between regions by transportation mode is used to quantify transportation facilities.

2. Freight distribution shipped via each transportation mode represents a potential demand for corresponding transportation facilities. Therefore, this factor could be used to verify the capacity of transportation facilities respectively.

3. Average transportation costs between regions for commodities is determined by using the distribution ratio as a weighted factor.

4. Regional transaction coefficients are determined by using regional average transportation costs.

5. Final demands in the present period (k) are determined based on value-added components in each industry for the last period $(k-1)$.

6. Inter-industrial interdependence is determined by using transaction coefficients, input and final demand.

7. Total amount of production, value-added components and transactions by regions and industries are then determined using the inter-industrial interdependent input-output table.

8. The total amount of freight transported by industry is forecasted.

9. An iterative process is used to estimate the total amount of freight transported by industry during the various forecast years.
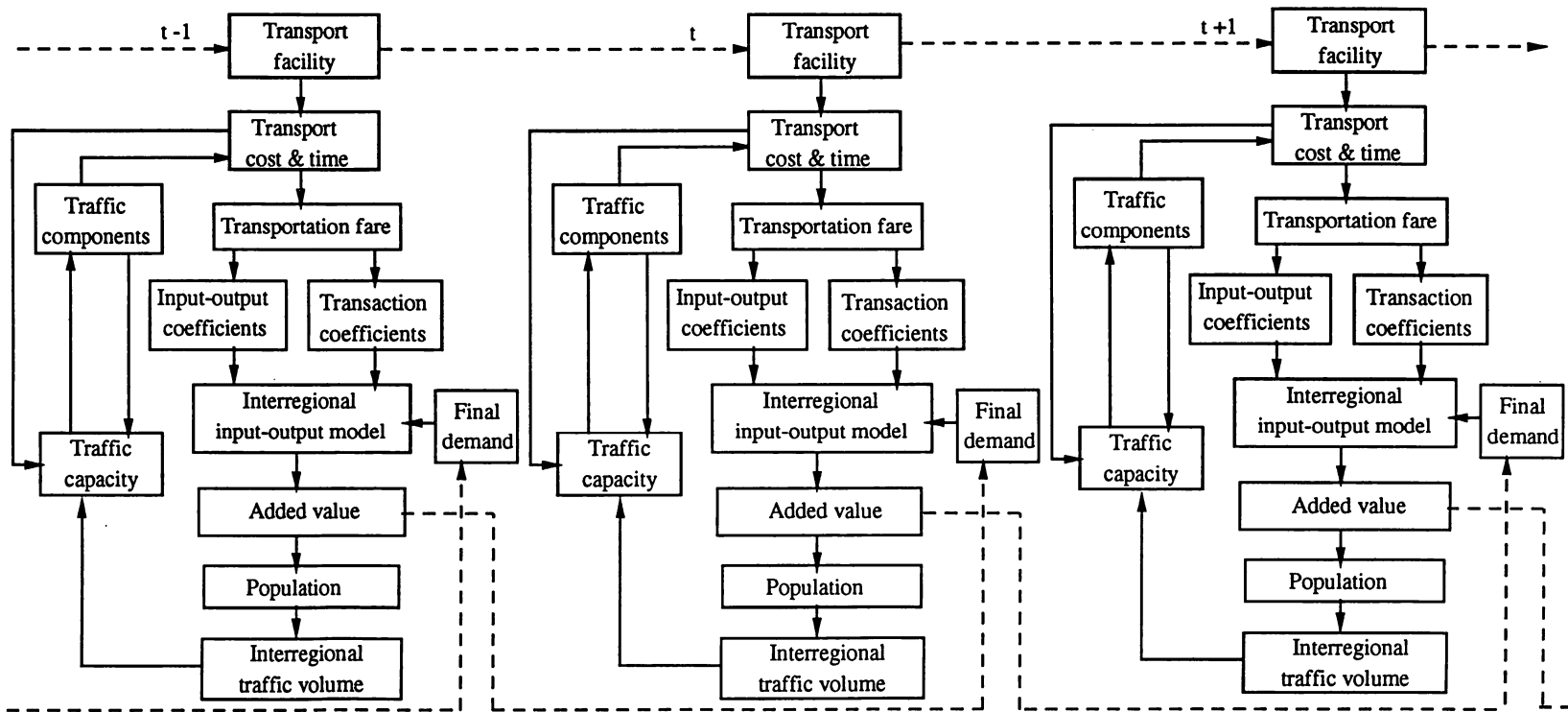
Figure 1 Dynamic interregional input-output model

The fundamental formulation for a competitive transfer-in model is shown below:

On the demand side

$$
\begin{aligned}
D_i^k(k) &= ID_i^r(k) + TD_i^r(k) + FD_i^r(k) \\
&= \sum_j a_{ij}^r(k)X_j^r(k) + \sum_s t_i^{rs}(k) + FD_i^r(k)
\end{aligned}
\tag{1}
$$

where

$D_i^k(k)$: total demand of ith sector (industry) in r^{th} region at time k;

$ID_i^r(k)$: intermediate demand of ith sector in r^{th} region at time k;

$TD_i^r(k)$: transfer out of ith sector in r^{th} region at time k;

$FD_i^r(k)$: final demand of ith sector in r^{th} region at time k;

$a_{ij}^r(k)$: direct I-O coefficient $(a_{ij}^r(k) = X_{ij}^r(k)/X_j^r(k))$; i.e., the technical coefficient (including transportation cost and technology) for industry i to industry j of region r at time k; and $(a_{ij}^{rs}(k) = X_{ij}^{rs}(k)/X_j^s(k), X_j^s(k) = \sum_i \sum_r X_{ij}^{rs}(k)$; $X_{ij}^{rs}(k)$ denotes the production (output) value of jth sector in s^{th} region by input value from i^{th} sector in r^{th} region at time k;

$X_j^r(k)$: total production (output) value of jth sector in r^{th} region at time k;

$t_i^{rs}(k)$: regional transaction coefficient; i.e., i^{th} sector in r^{th} region share, it is the ratio of total demand of ith sector in s^{th} region from r^{th} region input to s^{th} region at time k,

$$t_{ij}^{rs}(k) = \sum_j X_{ij}^{rs}(k) / \sum_j X_{ij}^s(k) = X_i^{rs}(k)/X_i^s(k)$$

On the supply side

$$
\begin{aligned}
S_i^r(k) &= X_i^r(k) + TI_i^r(k) + M_i^r(k) \\
&= X_i^r(k) + \sum t_i^{sr}(k)D_i^r(k) + M_i^r(k)
\end{aligned}
\tag{2}
$$

where

$S_i^r(k)$: total supply of ith sector r^{th} region at time k;

$TI_i^r(k)$: transfer-in of ith sector in r^{th} region at time k;

$M_i^r(k)$: import of ith sector in r^{th} region at time k;

$X_i^r(k), t_i^{rs}(k), D_i^r(k)$: the same definition as those in equation (1) at time k.

The equilibrium of the demand side and supply side

It is clear that at equilibrium, demand and supply must be equal for each product and each region from equation (1) and (2), i.e.

$$
D_i^r(k) = S_i^r(k)
\tag{3}
$$

This implies that the following equation must hold:

$$
(1 + \sum_s t_i^{sr}(k))X_i^r(k) = \sum_j a_{ij}^r(k)X_i^r(k) + \sum_s t_i^{rs}D_i^s(k) + FD_i^r(k) - M_i^r(k)
\tag{4}
$$

Assuming that the vector of total production value $X(k)$ satisfies demand $D(k)$, equation (4) can be shown in matrix form with R regions and I sectors:

$$X(k) = [(I + IT(K) - A(k) - T(k)]^{-1}[FD(k) - M(k)] \qquad (5)$$

where $IT(k)$ is a diagonal matrix at time k whose i^{th} sector r^{th} region component is

$$\sum_{s} t_i^{sr}(k) \;\; \text{and} \;\; M(k) = \begin{bmatrix} M^1(k) \\ \vdots \\ M^r(k) \\ \vdots \\ M^R(k) \end{bmatrix}_{RI \times 1}, X(k) = \begin{bmatrix} X^1(k) \\ \vdots \\ X^r(k) \\ \vdots \\ X^R(k) \end{bmatrix}_{RI \times 1}, A(k) = \begin{bmatrix} A^1(k) \\ \vdots \\ A^r(k) \\ \vdots \\ A^R(k) \end{bmatrix}_{RI \times RI}$$

$$FD(k) = \begin{bmatrix} F^1(k) \\ \vdots \\ F^r(k) \\ \vdots \\ F^R(k) \end{bmatrix}_{RI \times 1}, T(k) = \begin{bmatrix} T^1(k) \\ \vdots \\ T^r(k) \\ \vdots \\ T^R(k) \end{bmatrix}_{RI \times RI}, D(k) = \begin{bmatrix} D^1(k) \\ \vdots \\ D^r(k) \\ \vdots \\ D^R(k) \end{bmatrix}_{RI \times 1}$$

Further, the total production value ($X_j(k)$) for each sector is equal to the input from other sectors and the value-added ($V_j(k)$) of its own:

$$X_j(k) = \sum_{i} a_{ij}(k) X_j(k) + V_j(k) \qquad (6)$$

where national I-O coefficient $a_{ij}(k) = X_{ij}(k)/X_j(k)$; $X_{ij}(k)$ denotes the production value from i^{th} sector (input) to j^{th} sector (output) at time k and $X_j(k) = \sum_i X_{ij}(k)$. In this model, we assume I-O coefficient $a_{ij}^{rs}(k)$ and transacation coefficient $t_i^{rs}(k)$ are constants in time k (i.e., in the short-run), because $a_{ij}^{rs}(k)$ and $t_i^{rs}(k)$ are exogenous variables depending on government policy and social behavior, due to improving transportation costs, developing new technologies, and so on. Based on human behavior, the building of dynamic final demand $F_j(k)$ at time period k is influenced by total value-added $V(k-1)$ at previous time period $k-1$. Thus we can estimate final demand $F_j(k)$ by using the regression between final demand $F_j(k)$ and total value added $V(k-1)$ at previous time period $k-1$, as shown in equation (7).

$$F(k) = f(V(k-1)) \qquad (7)$$

where

$$V(k-1) = \sum_{j} V_j(k-1)$$

Based on this model, the regional commodity flow $X_{ij}^{rs}(k)$ over year k can be obtained by the given initial value added $V_j(k-1)$ and the coefficient of $a_{ij}^{rs}(k)$ in each period k. This iterative process may result in chaotic movements under certain specification, according to Dendrinos and Sonis (1990).

2.2.   Relationship model between value unit and quantitative weight

By using empirical survey data, the regression relationship can be obtained between the commodity flow of product value ($X_j(k)$) and the commodity flow of delivery weight (M_j); i.e.

$$M_j(k) = f(X_j(k)) \tag{8}$$

Then the total ton-kilometers of transportation flow $(Q_j^{rs}(k))$ in each sector can be estimated, i.e.,

$$Q_j^{rs}(k) = d_j^{rs} \times M_j^{rs}(k) \tag{9}$$

where

d_j^{rs} : delivery distance between r and s in i^{th} industrial sector;
$X_j^{rs}(k) \rightarrow M_j^{rs}(k)$ by using equation (8).

2.3.   Model split model

The model split model also uses empirical behavior data to calibrate the allocations of transportation flow $Q_j^{rs}(k)$ by modes (m). The modal share P_{jm}^{rs} in each sector is dependent on the characteristics of commodities and delivery distribution and is estimated by using empirical survey data:

$$TK_{jm}(k) = \sum_r \sum_s P_{jm}^{rs} Q_j^{rs}(k) \tag{10}$$

2.4.   Energy-use model

Truck demand is, in general, a function of the total amount of commodities carried and utilization factors, such as efficiency, the loading factor, and the percentage of empty trucks. In reality, truck fuel consumption is affected both by exogenous variables and human factors. These factors may include road slope, pavement material, vehicle velocity and the road condition, and driving habits. In this subsection, fuel demand for motor freight transportation is estimated using the total number of ton-kilometers carried by truck and truck utilization factors. Equation (10) is used for this purpose.

$$Q_{jm}(k) = \frac{TM_{jm}(k)}{LT_m \times ALF_{jm} \times FE_{jm}(k) \times (1 - ER_{jm})} \tag{11}$$

where
$Q_{jm}(k)$:   fuel demand in forecast year for m^{th} truck mode used by j^{th} commodity type at time k;

$TM_{jm}(k)$:   delivered quantity at forecast year for m^{th} truck type use by j^{th} commodity type at time k;

LT_m: the average usable loading capacity (ton) of mth truck type;

ALF_{jm}:   the average loading factor (%) for m^{th} truck type carrying j^{th} commodity type (excluding empty trucks);

$FE_{jm}(k)$:   the average fuel efficiency (km/liter) for m^{th} truck type carrying j^{th} commodity type at time k;

ER_{jm}:   percentage of empty truck for m^{th} truck type carrying j^{th} commodity type.

3.   Empirical Study and Discussions

In this section, an empirical test of the above models is carried out for Taiwan. To simplify the usage of existing data, Taiwan is divided into northern, central, southern, and eastern regions (R=4); industrial uses are classified into 30 categories (I=30); and trucks are classified into 4 types (m=4): private and business light trucks, and private and business heavy trucks.

3.1. Data description and analysis

A. Structure of freight transportation and industry

National input-output tables from 1971 to 1984, five-year regional input-output tables (1966, 1971, 1976, and 1981) and monthly industrial production statistical data were collected. Data analysis reveals that manufactured products constitute the mainstream of the domestic economy in Taiwan. Compared with the industrial structure in developed countries, in which profit is mainly derived from marketing, the ratio of the GDP in services in relation to that for all industries is low in Taiwan. Between 1976 and 1984, the ratio of the real GDP for civil industries, such as food, textile, lumber and furniture, and printed products, to that for all industries decreased, while the proportion of the real GDP in high-technology industries, such as information, electronic and automatic products increased significantly. This phenomenon may have resulted from the government's encouragement of investment in high-technology. In the export sector, the total amount of metal products, such as non-metallic, transportation equipment, and information, electronic and automatic products increased significantly over this period. High value-added, technology-intensive industries, such as information, electronic and automatic products and machinery, will probably continue to grow under government policy. The industrial structural changed gradually from agricultural to manufacturing between 1963 and 1973. Completion of six five-year economic plans, resulted in the growth of business and industrial establishments, as well as shipping. Bulk commodities, such as lumber, grain, fertilizer and coal, are transported by railroad and smaller size and high-value commodities are transported by road. The advantages of accessibility in motor freight transportation and the high density of freeways allows this mode of transportation to advance hand in hand with the promotion and adjustment of the industrial structure.

B. Vehicle operation characteristics of motor freight transportation

O-D data on the characteristics of motor freight transportation include delivery value (NT dollars) delivery quantity (tons), model split rates, deliver-distance distribution , usable loading capacity (tons) and actual loading (tons), empty truck ratio (%), and fuel efficiency for each truck type and commodity. All these variables were included in a special survey carried out jointly by the Department of Statistics of the Ministry of Communication Affairs (MOCA), the Energy Committee of the Ministry of Economic Affairs (MOEA) and the Energy Research Group of the National Chiao Tung University (Tzeng et al.) in 1984.

In ton-kilometers, the modal share by vehicle type for different commodities shows little variation. Share for business heavy trucks is the highest, followed by private heavy trucks. Modal shares for private and business light trucks were small. The principal reason for the intensive use of business heavy trucks may be its long-distance delivery characteristics for intercity movement, fixed routes, and high percentage of utilization. Light trucks, on the other hand, are used for short-distance deliveries. In tons, the modal share by vehicle type is similar to that for ton-kilometers for most commodity types. Except for non-alcoholic beverages, miscellaneous foods, electrical machinery and equipment, and machinery products, other commodity types are heavily dependent on business heavy trucks for delivery.

Average delivery distances for canned food, plywood, rubber and rubber products, and industrial chemicals are longer than those of other commodities. The average delivery distances for cement, chemical fertilizers, and rice are found to be the shortest because those that are consigned for longer delivery distance are delivered by railway. High value-added products are generally transported to harbors by freeway for export. Therefore, they usually require long delivery distances. By vehicle type, the average delivery distance is greater for business heavy trucks; private heavy trucks come next, and private light trucks are the shortest. For canned foods, petroleum products, and machinery, the average delivery distance for light commercial

trucks is much longer than that for private trucks. This finding may be because it is most economical to use business light trucks to deliver small quantities of the aforementioned products over long distances.

In general, it is economical and efficient for a truck to be fully loaded to its maximum allowable size and weight limits. On the average, the loading factor for business light trucks is 58.27%, for private trucks 26.79%, for business heavy trucks 37.44%, and for private heavy trucks 28.68%. By commodity type, trucks which carry rice (41.91%), coal products (37.3%), cement (37.29%), petroleum products (36.73%), and industrial chemicals (36.68%) have high loading factors; those that carry electrical products (22.11%), and rubber products (23.26%), conversely, have low loading factors.

Generally speaking, private trucks have better fuel efficiency than business trucks in terms of kilometers per liter (km/liter). Average fuel efficiency for a private light truck is 13.58 km/liter; and for a business heavy truck it is 4.77 km/liter. By commodity type, trucks that carry crops (10.03 km/liter) or electrical machinery (9.33 km/liter) have better fuel efficiency. Those that carry cigarettes and wines (5.24 km/liter), coal and coal products (5.38 km/liter), petroleum products (5.69 km/liter), and forest products (5.72 km/liter), on the other hand, are less fuel efficient.

3.2. Model calibration

The process of model calibration are divided into three steps below:

(a) The regressions in the relationship between transaction coefficients and transportation cost (R^2=0.60 ~ 0.85), and between value-added and final demand (R^2=0.75 ~ 0.99) in each industry were built first.

(b) Combining the first step of the regression model, the dynamic interregional input-output model from four years data (1966, 1971, 1976, 1981) was calibrated for annual estimates (1971-1984). Then, the results of summation from the dynamic interregional input-output model can be checked with the figures in the national input-output tables (1971-1984). Errors are controlled to be less than 5% in each industry sector.

(c) The regression relationship was built (R^2=0.64 - 0.99) for commodity flow between product value and delivery weights (equation(7)) in each industry. Then the ton-kilometers (1971-1984) were estimated according to equation(8).

Finally, the energy consumption for motor freight transportation (1971-1984) was estimated by using equations (9) and (10) and the special survey data in 1984. The results were compared with transportation and energy statistics (1986). Errors were also controlled to be less than 5% in each year.

3.3. Forecast

Basic assumption: The following assumptions are necessary for forecasting the commodity flow, transportation flow and energy demand based on the above calibrated dynamic interregional input-output model.

A. Commodity flow model — input-output model

(a) input output coefficient $(a_{ij}^{rs}(k))$ and transaction coefficients $(t_j^{rs}(k))$ over periods are given from the calibrated model.

(b) Average operating costs are aggregated by vehicle type and, therefore are insensitive to the commodity types carried.

(c) Based on the goals and strategies of mid-long-range economic development [Prospects of socioeconomic changes to 2000 (1984) and Tzeng (1989)], the transportation sector will be improved by reducing transportation costs and adjusting the inter-industry interdependence structure between regions in each period[2].

B. Energy use

(a) Model share of ton-kilometers by vehicle type has the same ratios.

(b) Maximum allowable truck size and weight limits are unchanged.

(c) Loading factor by vehicle type is unchanged.

(d) Since it is difficult to predict fuel efficiency for each representative truck type, without changes, a five percent improvement in fuel efficiency and in the rate of empty trucks[3] is used for the scenarios.

Thus, in this paper, for mid-long-range economic development planning to 2000, as modified by transaction coefficients in 1996 and 2001, and using 1984 as a basic year for forecasting to 2001, the above assumptions were combined to conduct estimates for four scenario cases:

Case 1:   fuel efficiency and empty truck ratio are based on the year 1984.

Case 2:   fuel efficiency and an empty truck ratio of 5% to improve annually to the year (improvement plan 1).

Case 3:   infrastructure investment, i.e., building a second freeway and establishing a distribution center for commodity transshipment between intra-city and inter-city to reduce annual transportation costs (improvement plan 2).

Case 4:   carrying out cases 2 and 3 simultaneously (improvement plan 3).

3.4.   Results and discussions

After applying model results, fuel demands by vehicle types are summarized in Tables 1 to 4. Basically, motor freight transportation is a derived demand. Fuel consumption for freight transportation is influenced by economic development and growth in the GDP and in freight demand. Over the past decade, the total number of trucks on the road increased by 155% (9.80% annually); tonnage increased by 118%; ton-kilometers increased by 124% (8.38% annually); gasoline increased by 174% (10.85% annually); and diesel consumption increased by 180% (10.85% annually). These findings also show that :

(a) Both gasoline and diesel fuel consumption increased by 10% annually, especially after the opening of the Sun Yat-Sen Freeway.

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[2]For example, a second freeway will be finished from north to south, which will reduce annual transportation costs.

[3]In line with the goal of formulating the "Energy Consumption Standard Regulation" for trucks for about five percent improvement to the year 2001 by the Energy Committee, MOEA in 1986.

Table 1: Fuel Demands by Truck Type at Various Forecast Years—Case 1   units: kl

Modes	Fuel	Base year 1984	1991	1996	2001
private	gasoline	308,070	478,513	615,841	780,761
light truck	diesel	129,670	201,411	266,843	334,010
business	gasoline	9,082	14,833	19,176	24,537
light truck	diesel	9,269	15,138	19,665	25,082
private	gasoline	3,558	5,695	7,329	9,292
heavy truck	diesel	204,913	324,973	426,054	543,480
business	gasoline	16,003	23,507	30,253	38,355
heavy truck	diesel	957,943	1,407,172	1,827,988	2,331,806
total	gasoline	336,713	522,548	672,599	852,945
	diesel	1,301,795	1,951,694	2,535,550	3,234,381

Table 2: Fuel Demands by Truck Type at Various Forecast Years—Case 2   units: kl

Modes	Fuel	Base year 1984	1991	1996	2001
private	gasoline	308,070	437,761	554,727	694,937
light truck	diesel	129,670	184,258	230,389	284,642
business	gasoline	9,082	13,573	17,547	22,450
light truck	diesel	9,269	13,852	17,908	22,913
private	gasoline	3,558	5,205	6,596	8,263
heavy truck	diesel	204,913	299,774	374,826	463,092
business	gasoline	16,003	21,918	27,774	34,794
heavy truck	diesel	657,943	1,312,038	1,640,521	2,026,841
total	gasoline	336,713	478,457	606,644	760,444
	diesel	1,301,795	1,809,922	2,263,644	2,797,488

(b) Heavy trucks generally consume diesel fuel and light trucks consume gasoline. In Taiwan, both the number of heavy trucks in use and their ton-kilometer rates are larger than those for light trucks; therefore, diesel fuel was the major fuel consumed in motor freight transportation. Moreover, the government discoverages the use of gasoline by raising its prices, and limiting the availability of diesel fuel for passenger cars.

(c) Truck fuel consumption increases at a rate higher than that for the total number of registered trucks. This finding indicates that strategies introduced to improve the fuel consumption of trucks over the past decade were not very effective.

(d) The ton-kilometer rate for trucks increased at a rate lower than the total number of registered trucks, which indicates that the current utilization of trucks is also ineffective.

From these findings, the following conclusions may be drawn:

(a) For case 1, energy demands for freight transportation will increase because of the increased commodity flows resulting from economic growth and the changes in transaction coefficients, industrial structure, etc. within various regions.

(b) The beneficial effects of improvements in energy demand for motor freight transportation can be achieved if the government takes certain strategic steps:

Table 3: Fuel Demands by Truck Type at Various Forecast Years—Case 3   units: kl

Modes	Fuel	Base year 1984	1991	1996	2001
private light truck	gasoline	308,070	402,015	487,469	600,531
	diesel	129,670	169,212	204,392	255,442
business light truck	gasoline	9,082	12,466	15,116	18,622
	diesel	9,269	12,724	16,451	21,048
private heavy truck	gasoline	3,558	4,776	5,791	7,134
	diesel	204,913	275,065	332,252	415,236
business heavy truck	gasoline	16,003	20,492	24,875	30,644
	diesel	957,943	1,226,649	1,489,007	1,860,403
total	gasoline	336,713	439,749	533,251	656,931
	diesel	1,301,795	1,683,650	2,042,102	2,552,129

Table 4: Fuel Demands by Truck Type at Various Forecast Years—Case 4   units: kl

Modes	Fuel	Base year 1984	1991	1996	2001
private light truck	gasoline	308,070	379,403	437,488	501,043
	diesel	129,670	161,111	186,953	216,204
business light truck	gasoline	9,082	11,491	13,250	15,175
	diesel	9,269	11,727	13,608	15,175
private heavy truck	gasoline	3,558	4,395	5,071	5,808
	diesel	204,913	254,598	295,436	341,661
business heavy truck	gasoline	16,003	19,708	22,723	26,024
	diesel	957,943	1,190,212	1,381,122	1,597,217
total	gasoline	336,713	415,000	478,532	548,050
	diesel	1,301,795	1,617,648	1,877,119	2,170,819

Table 5: Annual Growth Rate of Energy Demand and Elasticity

Modes	Fuel	Annual growth rate (%)		Elasticity to GDP*	
		1984-1991	1991-2001	1984-1991	1991-2001
private light truck	gasoline	6.48	5.02	0.80	0.67
	diesel	5.96	5.18	0.73	0.69
business light truck	gasoline	5.15	4.74	0.63	0.63
	diesel	4.82	4.45	0.59	0.59
private heavy truck	gasoline	3.89	4.10	0.48	0.55
	diesel	3.74	4.20	0.46	0.56
business heavy truck	gasoline	3.02	2.82	0.37	0.38
	diesel	3.15	2.99	0.39	0.40

*Annual growth rates of GDP: 8.1% in 1984-1991 and 7.5% in 1991-2001.

    i. building new freeways to improve transportation systems for reducing transportation cost and energy (because of mitigating traffic congestion);

    ii. building intracity and intercity distribution centers to facilitate transshipments;

    iii. revising regulation to reduce the level of empty truck trips and to increase the efficiency; and

    iv. planning for mid-long-ranged economic development on the basis of changing the regional structure.

(c) The energy elasticities (to GDP) will be substantially below 1.0, because the freight transportation systems will improve to a high efficiency level and the industrial structure will also change continually to high value-added technology-intensive industries.

4.　Conclusions

A model was described of energy demand forecast for motor freight transportation in response to economic development and changes in the industrial structure. A dynamic inter-industry interdependent regional input-output model presented was used to estimate the total amount of freight transport for the various transportation modes.

The model is based on strategic plans, and it can be used to estimate energy demands and reductions in energy-use in motor freight transportation.

The purpose of this study was to illustrate that a regional input-output model can be extended to address problems in transportation, allowing for factors in regional structure and socioeconomic development to be taken into consideration for transportation policy.

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