A SYSTEM DYNAMICS MODEL OF TRANSPORTATION ENERGY DEMAND

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ABSTRACT

This paper presents a system dynamics model of the transportation energy demand in Singapore. The transportation sector in Singapore is heavily dependent on oil and is one of the major consumers of energy. Thus, it is essential to model the transportation energy demand to be able to see the implications of changes in economic situation and oil prices.

The transportation sector is divided into passenger transport and freight transport. Five modes of passenger transport are considered. The Mass Rapid Transit is included in this model as it will be the major mode of public transport in 1990's. The ratio of per capita energy consumption to per capita income is used to indicate the change in energy consumption as income changes. With this as a basis policy changes such as price of fuel and regulation of ownership of private motor vehicles are made.

The model can be used to test various scenarios, e.g., changes in economic conditions and in fuel prices. The simulation results can then be used to examine the various policies that could be implemented to alter the transportation energy demand situation. The model has been calibrated using available information and some policy analyses have been performed with the model.

INTRODUCTION

Singapore is an island state without any indigenous energy resources. It is entirely dependent on petroleum imports for its energy needs. Most of the secondary energy it uses (like gas, electricity and gasoline) are produced from crude oil. There are ways to reduce the dependency on crude oil through using more of other energy sources, namely natural gas or coal. This is feasible in most of the major energy demand sectors but not transportation. Oil will continue to be the major energy source for the transportation sector, at least before the end of this century.

Although Singapore is the third largest refining centre in the world, very little has been done on energy policy modelling. One of the possible ways to study energy policies is by system modelling or simulation. The purpose of this paper is to present a system dynamics model for the transportation energy demand in Singapore. This model serves as a submodel for the model currently being developed for the entire energy system of Singapore.

THE BASIC TRANSPORTATION ENERGY MODEL STRUCTURE

In the transportation energy demand model, transportation is divided into two sectors; the passenger transport sector and the freight transport sector. These two sectors are further divided into different modes. The passenger transport sector consists of five modes which include cars, taxis, motorcycles, buses and the MRT (Mass Rapid Transit). The freight transport sector has two modes, i.e. the light goods vehicles and the heavy goods vehicles. This basic structure of the sectorial breakdown is illustrated in Figure 1.

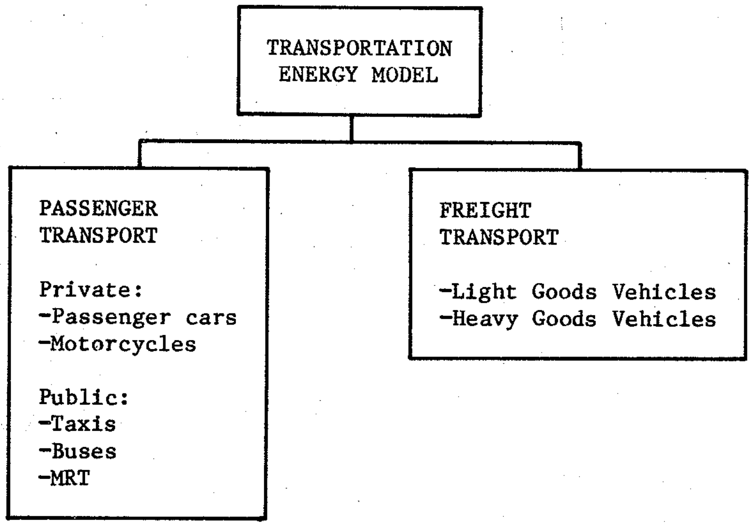

Figure 1 Basic Transportation Energy Model Structure

The Passenger Transport Sector

Passenger transport is defined as any trips undertaken by an individual by means of a vehicle that involves energy consumption. On a national level, the energy demand for passenger transport is determined by the number of individuals travelling (the population), the needs and length of their journeys, the transportation cost and the technical characteristics of the vehicles.

In Singapore, most of the motorized vehicles can be categorized into four types: cars, taxis, motorcycles and buses. Another public transport mode, which is expected to start operation in 1988, is the Mass Rapid Transit (MRT). Figure 2 shows a causal diagram illustrating the interaction between those factors that influence the passenger transport energy demand. In this figure, the passenger car mode is used for illustration.

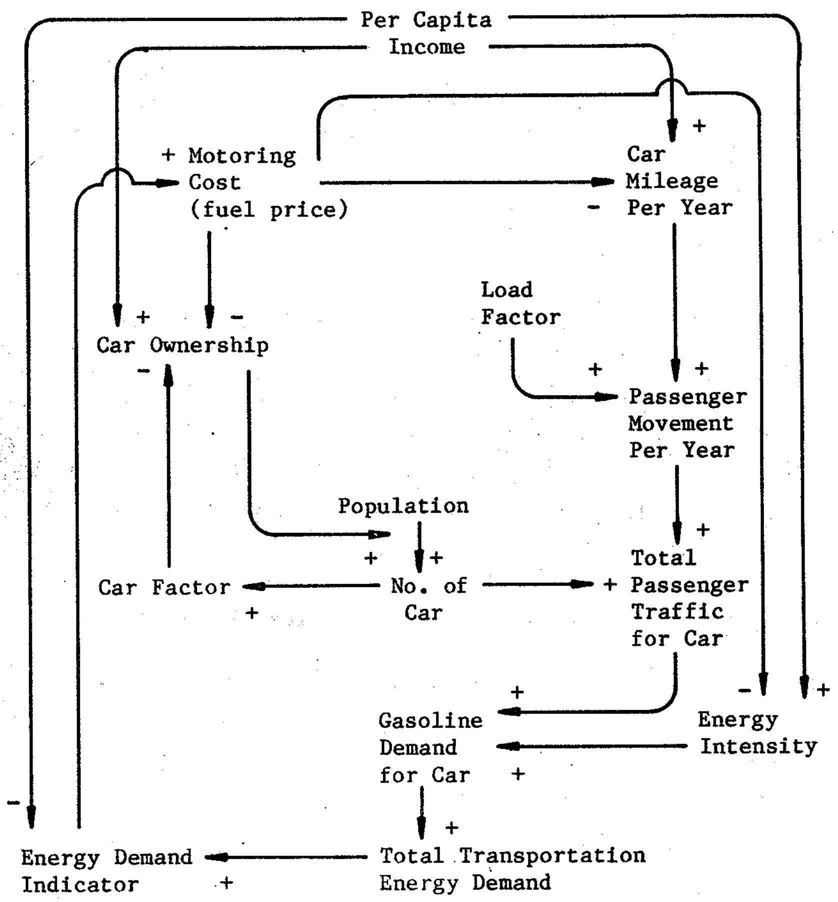

Figure 2 Factors Influencing Passenger Transport

The definition of each factor is discussed as follows:

a. Per Capita Income

The initial value of the per capita income at the year 1972 is set at $3200 with an annual growth rate of 11.67% for the base run. The growth rate the per capita income for the scenarios will be discussed later.

b. Transportation cost

The transportation cost should include fuel costs (cost of gasoline and diesel), vehicle cost, cost of maintenance, taxi or bus fare, etc. But, due to insufficient information available, only the fuel costs are considered in this model.

c. Population

The population of Singapore in 1972 was about 2.15 million. In this model, a mean yearly increase of 1.5% is assumed. With this growth rate, the population in 1992 is expected to reach 2.9 million. The increase in population will cause an increase in the number of vehicles due to increased travel needs.

d. Car Mileage Per Year
(Kilometer travelled per car per year)

Some studies [Ang 1983, Wadhwa 1979, Chateau and Lapillonne 1978] have found that the distance travelled per car per year is a function of income and transportation cost (fuel price). The relationship is such that as income increases, people will tend to travel more and vice versa. In contrast to income, the fuel price has a negative effect on travel; i.e. as fuel price increases, people will tend to travel less and vice versa.

The income and price elasticities, and the saturation levels of vehicle mileage for different modes of transport assumed are tabulated in Table 1.

Table 1 Vehicle Mileage: Income and Price Elasticities, and Saturation Levels

Transportation Mode	Income Elasticity	Price Elasticity	Saturation Level
Passenger Car	1.5	-0.2	13500 (km/vehicle per year)
Taxi	1.7	-0.3	60000
Motorcycle	1.9	-0.1	12000
Bus	-0.3	1.2	70000

e. Vehicle Ownership
(Car per capita)

Vehicle ownership is defined as the total number of vehicles divided by the total population. In some studies [Ang 1983, Wadhwa 1979], the vehicle ownership level is assumed to follow a logistic curve with an eventual saturation level. In this model, the income and price effects on vehicle ownership are also included.

The vehicle ownership will increase as the household income increases. As people become richer, they will buy a passenger car or a motorcycle; or they will travel by taxi instead of travelling by bus. Therefore, the vehicle ownership levels for cars, motorcycles and taxis will increase simultaneously. The vehicle ownership for buses will increase, remain at a constant level or even decline, depending on the travel needs. In contrast, the increase in transportation cost (fuel price) will retard the growth of vehicle ownership.

Table 2 shows the income and price elasticities and the saturation levels of vehicle ownership for various modes of transport. The saturation level for passenger cars is set at 0.25 car/capita, i.e. at maximum, we assume an average of a car per household (4 persons).

Table 2 Income and Price Elasticities and the Saturation Levels for Vehicle Ownership

Transportation Mode	Income Elasticity	Price Elasticity	Saturation Level
Passenger Car	1.2	-0.6	0.25 (car/capita)
Taxi	1.1	-0.9	0.02
Motorcycle	1.5	-0.8	0.10
Bus	-0.5	1.1	0.008

f. Load Factor

The load factor is defined as the average number of passengers per vehicle. The load factor is constant for each mode, as illustrated in Table 3. The passenger-kilometer carried per year per vehicle is obtained by multiplying the load factor with the vehicle-kilometer per year per vehicle. The load factors used in this paper were estimated from data and procedures described in [Graham 1980].

g. Energy Intensity

Energy intensity is the term used for describing how much energy is consumed for transporting one passenger-kilometer. The assumptions for energy intensity are:

(i) as income increases, people tend to buy more luxurious cars or motorcycles with bigger engine capacity. Therefore, there is a tendency for the modal energy intensities to rise.

(ii) as transportation cost (fuel price) increases, people tend to buy more economic cars or motorcycles and hence, a decrease in the modal energy intensities.

Table 3 shows the income and price elasticities for the modal energy intensity assumed in the model.

Table 3 Load Factor; Income and Price Elasticities for modal energy intensity

Transportation Mode	Load Factor	Income Elasticity	Price Elasticity
Passenger Car	2.0	1.0	-0.8
Taxi	2.0	0	-0.4
Motorcycle	1.2	1.0	-0.8
Bus	40.0	0	0.4

There are many other factors influencing the energy intensity of a vehicle. These factors are fuel efficiency, weight of vehicle, travelling speed, road conditions, etc. For simplification, these factors have not been taken into account in the model at this stage.

h. Energy Demand for Passenger Transport

The modal energy demand is obtained by multiplying the modal passenger-kilometer by its energy intensity.

i. Car Factor

The car factor is defined as the ratio of the actual number of cars to the desired number of cars (at the saturation level).

$$\text{Car Factor} = \frac{\text{Actual Number of Cars}}{\text{Desired Number of Cars}}$$

This factor has a negative effect on car ownership and it will retard its growth as the number of cars increases too rapidly.

j. Energy Demand Indicator

The energy demand (consumption) indicator is the ratio of per capita energy consumption to per capita income.

$$\text{Energy Demand Indicator} = \frac{\text{Per Capita Energy Consumption}}{\text{Per Capita Income}}$$

This indicator is a measure of how fast the growth of energy consumption as compared to the growth of income. It is not desirable to have a ratio which increases over time. It is best to keep this indicator to a constant level or decreases over time.

The Freight Transport Sector

Any trips that transporting goods or materials from one place to another for the purpose of processing, manufacturing and consumption are classified under the freight transport. The methodology for determining energy demand for freight transport is similar to that for passenger transport.

Energy demand is determined by the total freight movement in ton-kilometers and the specific modal energy consumption in energy use per ton-kilometer. In this model, only freight by road is considered as inland traffic. International traffics by sea and air are excluded from the model. The freight transportation in Singapore can be broadly grouped into two modes, viz, the Light Goods Vehicles (LGVs) and the Heavy Goods Vehicles (HGVs). The majority of the LGVs use gasoline as fuel while the HGVs use diesel fuel. Each mode is assumed to share half of the total inland traffic in ton-kilometer per year. This assumption can be changed or modified if there is better information. The basic structure of the freight transport is shown in Figure 3.

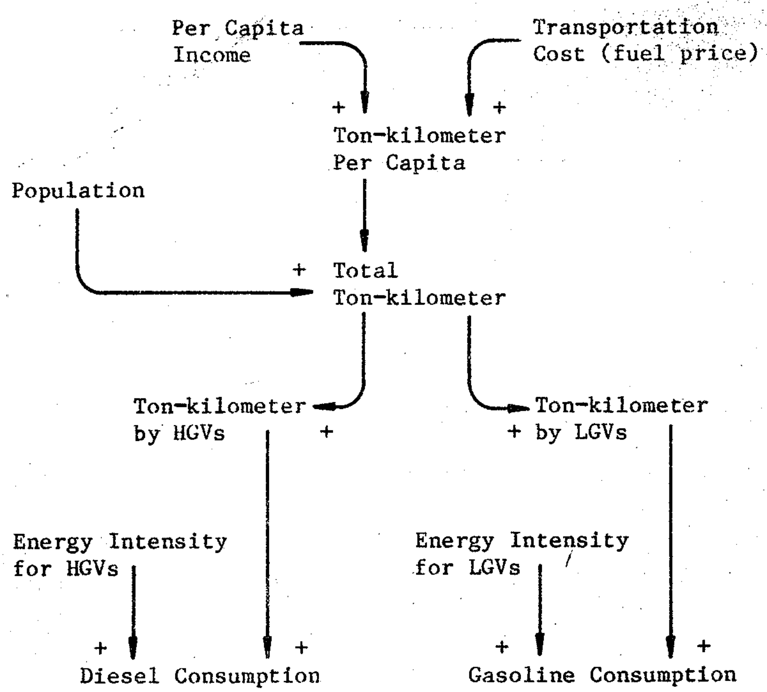

Figure 3 Basic Structure of Freight Transportation

It may be noticed that there is no feedback loop in the basic structure of the freight transport sector. It is because regardless of income, fuel price or energy consumption, a trip for transporting goods will be made if there is such a necessity.

Referring to Figure 3, an increase in income will cause an increase in ton-kilometer per capita due to a high level of economic activities. The price effect on ton-kilometer per capita is not as significant as the income effect.

SIMULATION RESULTS OF BASE RUN

The results presented in this section are for the following assumptions:

a. 11.67% growth per annum in per capita income;
b. 3% growth per annum in fuel prices after 1980; and
c. 1.5% growth per annum in population.

The assumptions are summarized in Table 4.

Table 4 Summary of Model Input Assumptions

Year	Per Capita Income ($)	Price of Gasoline ($/kwh)	Price of Diesel ($/kwh)	Population (million)
1972	3200	0.0120	0.0104	2.15
1977	5720	0.0407	0.0346	2.31
1982	10220	0.1076	0.0953	2.50
1988	18270	0.1261	0.1056	2.70
1992	32630	0.1446	0.1159	2.90

It must be kept in mind that the base run is not a forecast, as the fuel prices and income are not expected to grow steadily in the future. The base run is taken as a basic projection to which projections based on other scenarios can be compared.

Taking passenger car projections as an example. In the base run, the average distance travelled by a car is expected to rise from 10000 km/yr in 1972 to 13270 km/yr in 1992. The car ownership was 0.06 cars per capita in 1972 and it will increase to 0.1304 cars per capita in 1992. With these levels of car ownership, the total number of cars is found to increase from 122600 in 1972 to 359900 in 1992. The product of passenger-kilometer per car and the total number of cars gives the total passenger-kilometer travelled by cars.

The average energy intensity is expected to drop from 43 grammes of oil equivalent (GOE)/pkm in 1972 to 26.81 GOE/pkm in 1992 [Ang 1983]. With these energy intensities, the gasoline demand of passenger cars are found to be 105.5 thousand tons of oil equivalent (TTOE) and 256.1 TTOE in 1972 and 1992, respectively. The results are summarized in Table 5.

Table 5 Summary of Simulation Results

Year	Vehicle kilometer per Car	Car Ownership (car/capita)	No. of Cars	Total Passenger-kilometers by Car x 1E6	Energy Intensity (GOE/pkm)	Gasoline Demand (TTOE)
1972	10,000	0.0600	122,660	2453	43.00	105.5
1977	11,550	0.0696	153,500	3546	39.49	140.0
1982	12,450	0.0827	196,600	4898	35.43	173.5
1987	12,980	0.1001	256,300	6658	30.56	203.5
1992	13,270	0.1304	359,900	9554	26.81	256.1

The detailed results for all modes of passenger transport can also be obtained from the simulation run.

The electric-powered MRT is expected to take up a 20% share of the total passenger-kilometers when it starts operating in 1988. It is assumed that the pkm share for buses will drop as part of the bus users will switch to MRT. The pkm percentage share for MRT will increase as more people switch from other to this mode.

The shares of passenger-kilometer by modes are summarized in Table 6.

Table 6 Modal Shares of Passenger Traffic in pkm (percentage)

Year	Passenger Car	Taxi	Motorcycle	Bus	MRT
1972	21.84	3.45	5.72	68.99	-
1977	22.92	5.78	6.88	64.42	-
1982	22.84	7.73	7.01	62.42	-
1987	22.08	8.57	6.45	62.90	20.00 (1988)
1992	22.96	9.53	5.96	37.55	24.00

ALTERNATIVE SCENARIOS

The model can be used to conduct controlled scenario experiments on the system represented. The effects of different economic situations and fuel prices can be tested.

In this paper, three growth rates for per capita income are considered. These are an economic depression, an economic boom and a normal growth (as shown in Figure 4(a)):

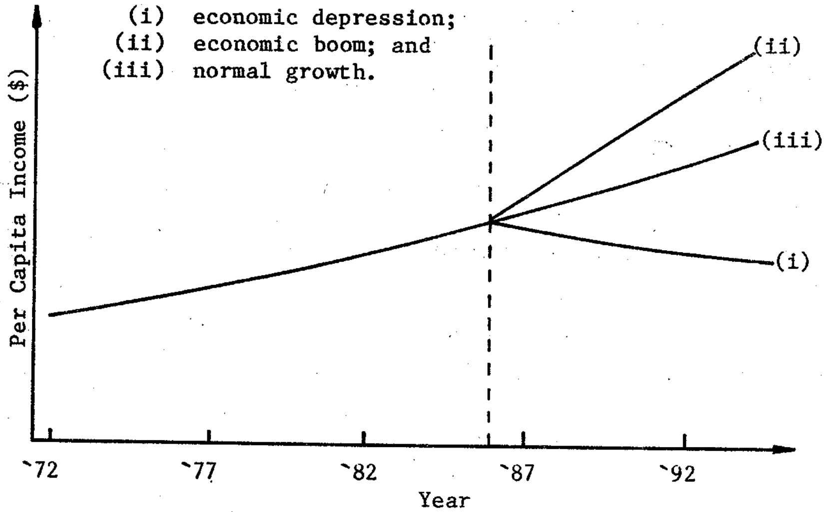

Figure 4(a) Scenario Assumptions

For fuel prices, three situations were assumed for the year after 1985 (Figure 4(b)). These situations are:

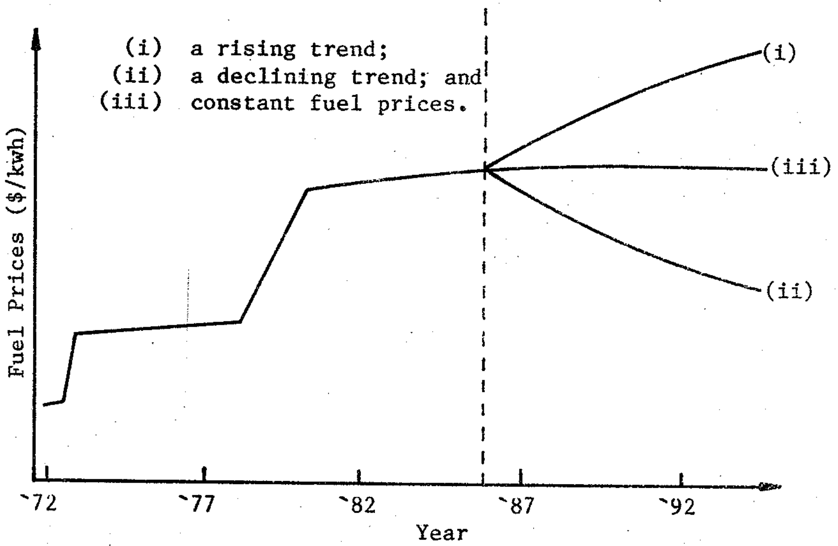

Figure 4(b) Scenario Assumptions

The results of the scenario experiments are summarized in Tables 7(a)-(e). Passenger car mode is used for illustration.

Table 7(a) Vehicle-kilometer Per Car Per Year

Income / Fuel Price	Economic Depression	Normal Growth	Economic Boom
Declining	12800 (1985) 12650 (1988) 12440 (1992)	12800 13060 13280	12800 13120 13340
Constant	12800 12640 12390	12800 13060 13270	12800 13120 13330
Rising	12800 12630 12340	12800 13050 13260	12800 13110 13320

Table 7(b) Car Ownership (cars/capita)

Income / Fuel Price	Economic Depression	Normal Growth	Economic Boom
Declining	0.0922 (1985) 0.1018 (1988) 0.1125 (1992)	0.0922 0.1048 0.1323	0.0922 0.1056 0.1392
Constant	0.0922 0.1017 0.1116	0.0922 0.1047 0.1304	0.0922 0.1055 0.1370
Rising	0.0922 0.1016 0.1107	0.0922 0.1046 0.1283	0.0922 0.1054 0.1346

Table 7(c) Total Passenger-kilometers (x 10^7)

Fuel Price \ Income	Economic Depression	Normal Growth	Economic Boom
Declining	586 (1985) 669 (1988) 773 (1992)	586 712 969	586 721 1025
Constant	586 669 764	586 711 955	586 720 1008
Rising	586 668 754	586 710 939	586 719 991

Table 7(d) Energy Intensity (GOE/pkm)

Fuel Price \ Income	Economic Depression	Normal Growth	Economic Boom
Declining	32.46 (1985) 29.02 (1988) 23.47 (1992)	32.46 29.72 27.09	32.46 29.84 27.58
Constant	32.46 28.98 22.69	32.46 29.69 26.81	32.46 29.82 27.36
Rising	32.46 28.92 21.66	32.46 29.66 26.44	32.46 29.78 27.06

Table 7(e) Gasoline Demand for Car (TTOE)

Fuel Price \ Income	Economic Depression	Normal Growth	Economic Boom
Declining	190.5 (1985) 194.3 (1988) 181.4 (1992)	190.5 211.7 262.7	190.5 215.1 282.9
Constant	190.5 193.8 173.3	190.5 211.2 256.1	190.5 214.7 276.0
Rising	190.5 193.1 163.4	190.5 210.7 248.5	190.5 214.1 268.0

Based on the results in Tables 7(a)-(e), several comments can be made.

For a particular trend of the fuel prices, an increase in per capita income caused:

a. an increase in vehicle-kilometers per car per year. Also, an economic depression caused the vehicle-kilometers per car to decrease over time.

b. an increase in car ownership. The increase in car ownership over time during an economic boom is faster than that during an economic depression.

c. an increase in total passenger-kilometers. It is found that during an economic boom, a declining fuel price resulted in a high total passenger-kilometers. It is due to a high car ownership and mileage in this combination.

d. an increase in modal energy intensities. During an economic depression, the energy intensity for cars declined very fast over time because people switched to more economic cars.

e. an increase in gasoline demand. A high gasoline demand is expected during an economic boom with a declining fuel price. In fact, the gasoline demand increases by about 10% in this combination as compared to the base run.

For a particular growth of per capita income, an increase in fuel prices caused:

a. a slight decrease in vehicle-kilometer per car per year. The price effect on car mileage is not as significant as income effect.

b. a decrease in car ownership. It is because as fuel prices (transportation cost) increase, people find it difficult to maintain a passenger car and switch to other modes of transport.

c. a decrease in total passenger-kilometer due to a decrease in car ownership.

d. a decrease in modal energy intensities. It is because as fuel prices increase, people tend to buy more economic cars.

e. a decrease in gasoline demand. The gasoline demand decreased by about 30% for a rising fuel price during an economic depression, as compared to the base run.

By conducting these scenario experiments, policy makers can actually observe how the system responses after the implementation of a policy. This serves as an aid to reduce error and to increase confidence in the policy making process.

CONCLUSIONS

The basic structure of the Singapore Transportation Energy Model was established. The base model was calibrated to fit the historical trend. The supply of energy was not considered in this model because there is an over-capacity in the refinery sector; and the supply of fuel was assumed to be able to meet the requirement of the transportation sector.

The model can be used for policy and scenario experiments by changing the appropriate parameter. By using this model, the ratio of per capita transport energy consumption to per capita income was found to be having a decreasing trend. This shows that the growth rate of energy consumption is lower than that of income. In fact, the declining trend of this ratio is due to the structure of the model. The behaviour of this model is governed more by its internal structure than by the correctness of parameters.

Several conclusions could be drawn based on the simulation results including the base run:

a. The energy demand for transportation is related to the income and the fuel prices. An increase in income causes an increase in energy demand, while an increase in fuel price causes a decrease in energy demand.

b. The base run shows that the energy demand for transportation increases from 592.8 TTOE in 1972 to 954.4 TTOE in 1992.

c. The scenario of an economic depression with a declining fuel price can be used to describe the present situation of Singapore. The results show that the transportation energy demand increases from 890.3 TTOE in 1985 to 950.0 TTOE (954.4 TTOE for the base run) in 1992. The reduction of energy demand (as compared to base run) may not be a good sign as it could be an indication that the economic activities and hence travel needs are reducing due to the prolonged depression.

It should be mentioned that this model is very flexible as additional parameters and sectors can be easily incorporated to improve its structure. It is also necessary to update the model continually with respect to changing conditions, better data availability and increased knowledge.

FUTURE RESEARCH WORK

The transportation energy model has been able to fit the historical data satisfactorily. It was also used for scenario experiments in this paper. Although the basic model structure has been established, it is by no means a complete model; the model can be further improved in several ways.

The various modes of transport in this model were built in different modules for flexibility. The only link that was built in this model was the substitution of bus passenger-kilometers by the MRT passenger-kilometers. This modular structure can be improved by introducing more links among other transport modes to obtain a better substitution effect among them.

The model assumptions can be re-evaluated to include more factors and data to improve its structure. The data for the average vehicle mileage in passenger transport sector and the average tonnage carried per vehicle in freight transport sector were not available. A survey for these data can be conducted so that the model's reliability can be enhanced.

The costs of transport controls the future energy demand. In this model, only the fuel prices were included as the cost of transport. It is suggested that other costs such as vehicle cost, cost of maintenance, taxi or bus fare should be included in the model if the information for these costs are available.

It is possible to establish links between the freight transport sector and the industrial activity. As the industry produces more goods (finished or unfinished products), more tonnage has to be transported from place to place and hence more freight transport energy demand.

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