A System Analysis of Effectiveness of Energy Saving Measures in Transport

by

HIDEO NAKAMURA
University of Tokyo

TAKEO UEMURA
Ministry of Transport, Japan

TATEO NISHII
Japan Transport Economics Research Center

NORIHIRO SHIOMI
Mitsui Jyoho Kaihatsu, Japan

ENERGY SAVING MEASURES IN PASSENGER TRANSPORT

Studies on the energy saving measures in Japan have been motivated by the so called "oil crisis" which occured in the end of 1973, under the grave realization that there was a limit in the energy resources. In particular, the transportation field in general have to rely on the petroleum energy as much as 90% or more, and therefore, the transport is one of the most important sectors where the energy saving is inevitable.

This paper is a brief report of an analysis on effectiveness of some energy saving measures in passenger transport. The analysis is done by two different approaches, the first is to estimate amount of energy saving by some measures which could be practicable in near future and the second is to evaluate dynamic impact by several measures which could be applied in an emergency of energy shortage, such as last "energy crisis".

1. Energy Saving Measures in the Passenger Transport Sector

Discussion was made among some twenty experts from various fields by means of so called brain storming, to derive some one hundred measures for the energy saving. These measures were sorted out under the criteria of (a) purpose and method (b) field of application and (c) mode of transport, and the following 15 measures were selected for detailed analysis of the effectiveness, from the viewpoints of the practicability and the expected effectiveness:

1) Lightening of railway vehicles
2) Utilization of electric regenerative braking system with thyristor chopper
3) Lightening of automobiles
4) Recommendation for radial tires
5) Speed limit on expressway
6) Speed limit for express railway (Shinkansen)
7) Increase of exclusive lane for commuter buses
8) Limitation of entry of private cars into center of cities
9) Increase of gasoline tax
10) Increase of tax rate for automobile registration and weight
11) Increase of air fares
12) Expansion of the express railway (Shinkansen) network
13) Cutting down some air routes replaceable by rail
14) Introduction of the zone control system of traffic signals
15) Replacement by wide-bodied aircraft

2. Effect of Energy Saving Measures

Energy consumption in passenger transport is represented as,

$$E = \frac{Q_c}{p_c} l_c + \frac{Q_b}{p_b} l_b + \frac{Q_r}{p_r} l_r + \frac{Q_a}{p_a} l_a + ---$$

E: whole energy consumption in passenger transport
Q: traffic volume (Kcal)
l: average energy consumption (Person. Km)
p: load factor (Kcal/Km. Vehicle)
c: automobile (Person/Vehicle)
b: bus
r: rail
a: aircraft

Therefore, energy saving can be achieved by the following three processes:

1) Improvement in the energy consumption of vehicles or carriers
2) Increase of load factors of the vehicles or carriers
3) Shifting of passenger to the energy saving-type modes.

The amount of the energy saving caused by these measures is estimated according to the flow-diagram as shown hereunder:
For the estimation, three major types of model are applied, namely

(1) Estimation model of split by modes and types of vehicles
(2) model of traffic conditions

(3) model of energy consumption of vehicles.

(1) model of split by modes and types of vehicles. This model is comprised of three submodels of (a) modal split model for short distance trips (b) modal split model for long distance trips (c) model for share of types of private cars. The changes of shares in the modes and types of vehicles which are resulted from change in cost and time for travelling caused by application of the energy saving measures are estimated by this model.

(2) traffic conditions model. This model describes traffic conditions such as congestion of highways, cruising speed, load factors, etc. These traffic conditions are derived from the transport demand, modal split and existing traffic facilities and equipment.

(3) energy consumption model. This model describes the energy consumption of various types of vehicles of each mode in reference to weight of vehicles, passenger capacity, engine power, etc, under various conditions of running, such as cruising speed, frequency of stopping.

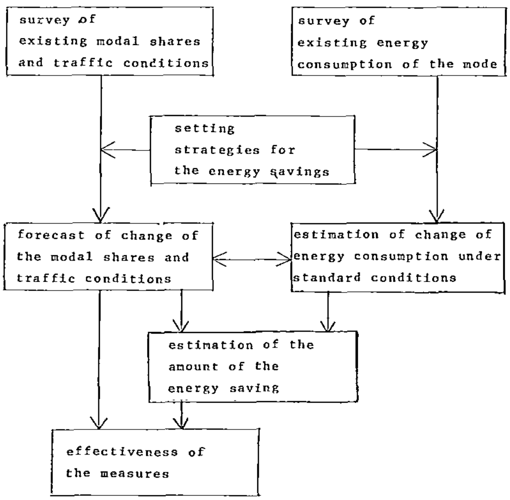


Table 1 shows amount of saved energy estimated by applying the above mentioned models.

3. Practicability of each saving measure

Each of the afore-mentioned energy saving measures is not free from causing some impacts in the society and its economy and is sometimes causing some difficulties of institutional, technical nature and financial burden involved for the actual application. These varying factors cannot be discussed in minute detail in each of energy saving measure, practicability of each measure was assessed from comments and opinions expressed by experts engaged in the field of transportation by means of enquete.

The enquete contained the items of (a) Impacts on the traffic users, environment, economy and others to be caused by measures for energy saving, (b) Costs and time to be involved, and (c) Other problems and their solutions, and asked for evaluation as well as the free expression of comments.

The Table 1 also shows the results of assesment thus obtained.

Table 1: Results of the estimation and points to be raised

Measure	Assumptions and conditions	Results			Background and problematic points
		Energy to be saved 10^9 kcal	Ratio of savings within specific mode of transport (%)	Ratio of savings within the whole transport (%)	
1) **Lighlening of railway vehicles** weight saving 22.1% by aluminum body Energy for production of vehicles + operation	Ratio of lightening is the actual one obtained by "Rapid Transit Corp." life of wagon is set in accordance with pertinent law * Electric cars 13yrs * Diesel cars 11yrs * Passenger cars 20yrs	1,245	8.6	0.70	* Availability of aluminum & electricity * Lessening of profitability due to higher cost * Safety problems
2) **Utilization of electric regenerative braking system with thyristor chopper** Electric cars and locomotives	* Ratio of regeneration is set at 27.8% which was obtained by "Rapid Transit Corp." by experimental running	1,998	12.6	1.11	* Problems of induction wave disturbance * Lessening of profitability by higher cost * Applicability or selection of routes * Adopted by several lines
3) **Lightening of automobiles** Reduction of 10% of the weight of whole automobiles	* Energy for production of aluminum is counted for the energy for production of bodies * Life is set at 6 years	6,729	6.2	3.74	* Technically, it is difficult to put off more of weight * Some problems in safety and endurability * Contradictory to air pollution control * Availability of aluminum & electricity is questionable
4) **Application of radial tyres** Lessening of rolling friction (all vehicles) at 20%		2,258	1.5	1.25	* Lessening of riding comfort and increase of noise
30%		3,349	2.2	1.86	

5) **Speed limit on expressways**	* Assumed 20 km/h speed down * Average speed is obtained by experimental running * Checked at Tomei (Tokyo-Nagoya), Meishin (Nagoya-Kobe) and Chuo (Tokyo-Nagoya via Matsumoto) express-ways	3,568	21.4	0.43	* Practicable execution of speed control will be difficult * May cause a traffic congestion * Effects on over-all traffic will be rather small because the high speed transit volume is not so great
6) **Speed limit for Shinkansen** * 20 km/h slow down * Shifting to air is counted	* Apply to Tokyo-Osaka-Okayama section * Increase of energy efficiency is estimated from energy consumption model for railway * Shifting to air is estimated by modal split model for air/railways	1,448	38.3	0.80	
7) **Increase of exclusive lanes for commuter buses**	* Peripheral effects on traffic in surrounding areas are placed out of investigation * Effects on the traffic of private cars are counted as increase of waiting time due to traffic congestion and the modal shifting rate is derived from the modal split model * Lessening of energy efficiency of private cars is counted as the increase of idle time	−412	−9.0	−0.2	Effects on the general traffic in particular cargo traffic should be further studied
8) **Limitation of entry of private cars into the city centre** * Surcharge ¥ 500 per entry ¥1,000 per entry	* Change of modal split is counted by means of modal split model of private car vs. public transport	853 1.456	4.5 7.6	0.47 0.81	* Practicable execution is rather questionable ° Collection of surcharge ° Selection of objective cars (chargeable or nonchargeable) * Increase of congestion in public transport medias
9) **Increase of Gasoline Tax** increase by 50% increase by 100%	Basic price is set at the price of March 1973 (¥ 65) per lit.) Share of private cars is estimated by the modal split model of private cars vs. public transport	6,512 11,118	5.7 9.7	3.62 6.18	* Non-selective increase of tax will be questionable * Some consideration onto freight transport & public transport should be made * Objectives of investment from the increased tax revenue shall have to be carefully selected
10) **Increase of Automobile Tax for registration an weight** Registration Tax by two times	Same as above	719	0.6	0.40	Effective to encourage the trend of compact cars
Increase of Weight Tax 4 times greater than the tax rate of 1972 (¥ 10,000 per 0.5 tons)	Total volume of traffic by private cars is assumed at constant	397	0.3	0.22	Effect will not be so great
11) **Increase of air fares** * 10% increase * 50% increase	* Shifting to rail is estimated by the modal split model for rail vs. air * Deduction of number of flight frequency is estimated to be proportionale to the decrease of traffic	392 322	3.8 12.9	0.22 0.73	* Consideration on the route where there is no alternative * May generate decrease of noise problems in the areas adjacent to airports
12) **Expansion of the express railway network** * 2,800 km. lines in Kyushu, Jyoetsu and Hokkaido areas	* Shifting from air due to shortening of travelling time is estimated from the model * Consumption of energy for construction of basic facility and equipment is estimated from actual case of the existing lines	2,476 −57,428	13.3	1.38	* Problems of noise and vibration * Energy consumed for newly generated traffic demand will be enormous * When energy consumption for the construction of the facilities is taken into account, it will hardly be a saving measure
13) **Abolishment of some air routes which are replaceable by alternatives** * Where the difference of travelling time is within 1 hour		1,023	10.0	0.57	* Selection or justification of such routes is difficult * Decrease of noise problems in airport areas
14) **Introduction of the zone control system of traffic signals** Applied in 50% of whole urban area	Cruising speed and frequency of stopping are estimated refering the existing systems in the CBD of Tokyo	7,064	10.7	3.91	Good effect on environment No negative effect
15) **Replacement by wide-bodied aircraft sized aircraft** Introduction of jumbo aircraft to 10 trunk routes (Load-factor is estimated at 65%)	B-747 and L-1011	754	13.1	0.42	Decrease in the Load-factor must carefully be avoided Deduction of flight frequency and selections of routes should be carefully agreed upon

4. Emergency measures for energy saving against "oil crisis" and analysis of the effects

1) Outline of model structure

In order to assess the energy saving measures against a short range oil crisis, the system dynamics model (referring to the transport and the petroleum supply) is developed. And it is used to evaluate the efficiency of each countermeasure.

The model is comprised of two sectors, namely, "Economic" and "Transport" and is to be sub-divided as shown in the following figure (Figure 2).

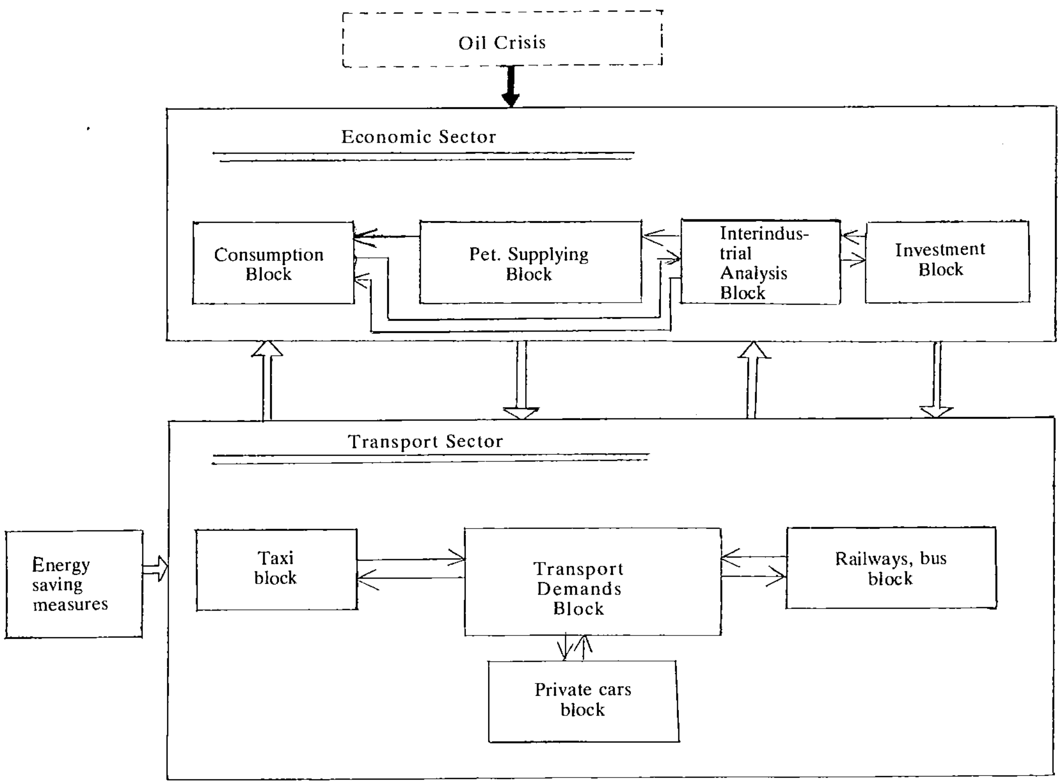


Figure 2

Petroleum supplying block describes relationship between amount of oil import, stock, and supply in every month. The price of petroleum is resulted from these conditions. In the *consumption block,* final demand of domestic consumption which are caused by consumer price, is estimated. On the other hand, the *investment block* shows relationship between economic growth rate and demand for private investment. The final demand which is owing to final consumption and the investment is input to the *interindustrial block* and gross national product is estimated by input-output model. The total amounts of petroleum which are needed in every industry to maintain this economic equilibrium are estimated from this model. Thus the change of petroleum demand caused by the restriction of oil supply is estimated by these models.

Three blocks in the *Transport Sector* are in a position to reflect how the fuel price (Gasoline, LPG, light oil and electricity) and some energy saving measures affect the transport demand in each of transport mode, and shows how the reduction in the demands eases off the supply and results new equilibrium stage of demand and supply.

Applying this system model, the traffic demands of each mode which are affected by economic activities under the restriction of petroleum supply and also energy saving measures in transport are macroscopically forecast, and a procedure of approaching to a new balanced state in transport modal shares and economic activities will be shown, so that it could be applicable to find out some suitable measures in oil crisis which will not cause much disturbance of the socio-economic activities of the country.

2) Results of simulation

Simulation was conducted under the assumption that the oil crisis occurred in the end of 1973 had lasted until June of 1974 and that the oil supply capacity was surpressed down to 75% of the total demand, and the following five countermeasures were studied of their effects.

(1) Control or regulation over the fuel supply at service stations
(2) Limitation of speed on expressways
(3) Increase of petroleum tax
(4) Adjustment of train and bus fares
(5) Petroleum supply control policy over transport modes

As the result, the following points were observed:

(1) Economic Activities (Fig. 3)

(a) Decrease of oil consumption is delayed in rate and time than that of oil supply. Therefore, the amount of oil stock is going to decline very quickly.

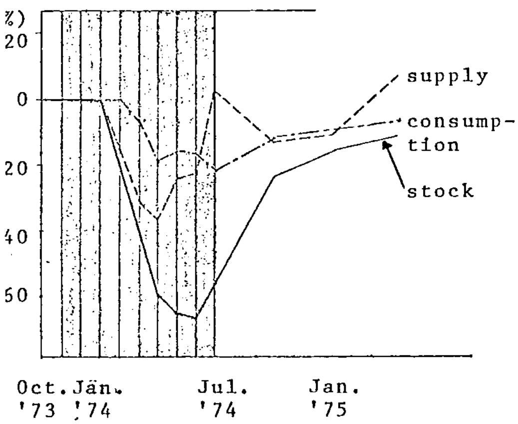
(b) The final demand follows to the decrease of oil supply, but in a smaller rate.

(c) The consumer price is rising up inversely proportionally to the oil stock and levels off in the highest level.

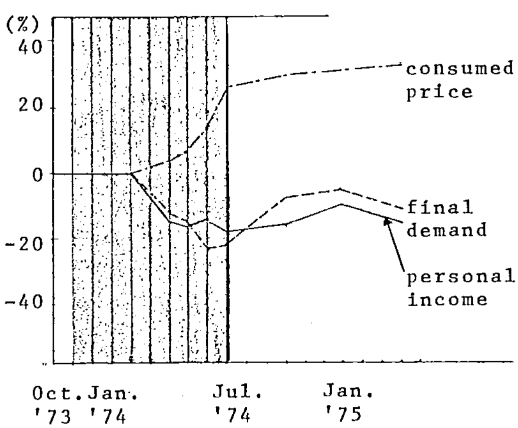
(d) Traffic volume of taxis and private cars decreases violently, so that the demand of gasoline is balanced with the supply.

(e) The traffic volume of mass transportation does not decline and light oil will be in short supply.

Supply and demand of oil



Economic index



Traffic volume

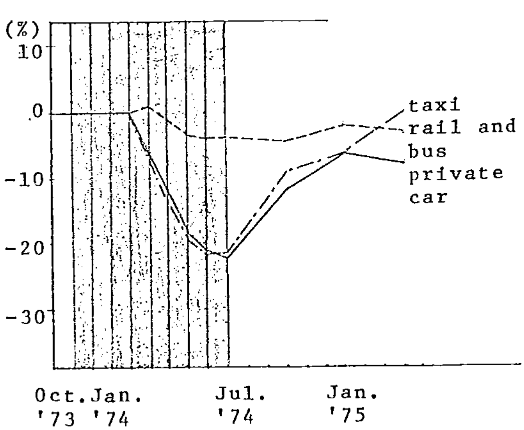


Figure 3

(2) The effects of the energy saving measures in transport (Fig. 4)

(a) Restriction of fuel supply at service station has the most effect on the energy saving in passenger transport.

(b) When the restriction of supply at service station, limitation speed in expressways, adjustment of mass transport fares and increase of petroleum tax are applied, consumption of gasoline will be reduced in 10%, though light oil will be consumed slightly more.

(c) One year after the end of the shortage of oil supply, fluctuation of modal share will be stabilized and the share of private cars will be reduced at 3%, though that of mass transit will increase at 2%.

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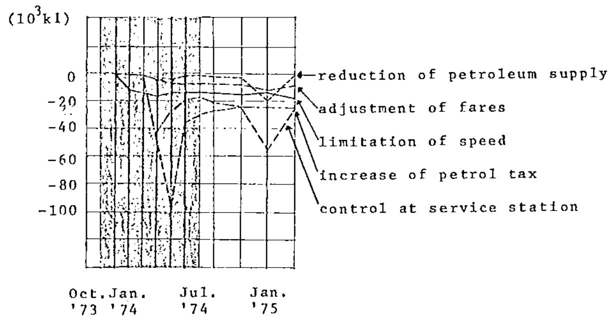
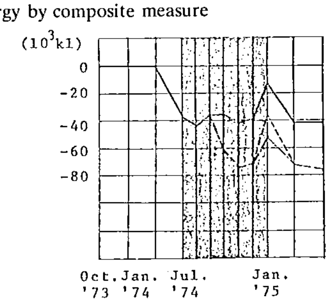
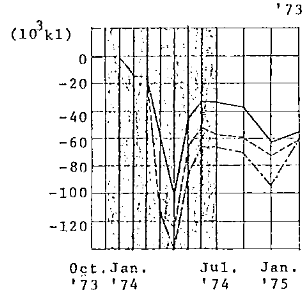
Amount of saved energy by each measure



Amount of saved energy by composite measure





———— control at service station + limitation of speed

– – – – control at service station + limitation of speed + adjustment of fares

—·—·— control at service station + limitation of speed + adjustment of fares + reduction of petroleum supply

Figure 4