System Dynamics in Urban Transportation Planning and Policy Analysis

Indra K. Khanna, N. Singh and Prem Vrat
Indian Institute of Technology, Delhi.

ABSTRACT

A simulation model of the passenger transportation system is presented. The model has been built in order to carry out a series of simulation experiments. The purpose of these experiments is to compare the effects of some transportation policies on road congestion, modal-split, air pollution and transportation fuel consumption. System dynamics principles have been used for simulating the model. The statistics of Delhi urban area have been used to calibrate the model.

INTRODUCTION

The population of Delhi urban area has been growing at a fast rate. In 1971, Delhi had an urban population of 36.47 lakhs and in 1981 it had grown to 57.68 lakhs, and is expected to reach a staggering figure of 122 lakhs by 2001. Expansion in Government employment and the industrial base of the Delhi area have been the major stimuli for rural to urban migration (Gupta 1982, pp.21-28). In addition, an estimated million people come to Delhi every day from the satellite towns. Out of this million strong floating population, about two lakh persons settle down every year, thereby adding to the already strained urban passenger transportation system of Delhi.

The mass transportation facilities in Delhi are provided by buses and to a lesser extent, by ring rail. The dependence on public transport in Delhi is much less as compared to Bombay, Calcutta, and Madras. Other modes of passenger transportation in Delhi, include motor-cars, taxis, scooters, autorickshaws and bicycle rickshaws, horse-driven tongas and bicycles. The heterogeneous nature of traffic accentuates the transportation problem by increasing road-congestion, which also increases transportation fuel consumption and air pollution.

PURPOSE

The purpose of this study is to construct a simulation model of the transportation system and use it as a policy analysis tool. The study has been carried out in close cooperation with the experts connected with transportation planning. The model has been so developed that policy alternatives as suggested by the planners, can be tested.

The initial data inputs to model are of two kinds. Firstly, largely qualitative information and comments obtained from experiencedtransport planners Secondly, quantitative published data obtained from various sources. Values of some parameters have been supplied exogeneously.

SELECTION OF THE MODELLING STRATEGY

Traffic and transportation planners must deal with a very complicated system with human, economic, physical and technical factors involved. It is possible to set up a wide range of different models depending upon which sub-systems are considered important to the problem in question(Holst 1977, p. 7). The models can be divided into two main groups, simulation models and optimization models. In each group several different modelling and solution techniques can be applied e.g. static or dynamic models, different algorithms, etc.

System dynamics offers us a methodology for understanding certain types of complex problems (Richardson 1981, p. 1) as are encountered in today's transportation systems. It focusses on the structure and behaviour of systems composed of interacting feedback loops. The structure defines how the variables interact (pidd 1984, p. 187). Casual diagrams allow the analyst to quickly communicate the structural assumptions underlying his model (Goodman 1974, p.5). They help to identify the feed back structure of systems as a prelude to analysing the behavioural characteristics of the feedback systems . In general a system dynamics study has a two-fold objective (Coyle 1977, p. 19).
1. Explaining the systems behaviour in terms of structures and policies.
2. Suggesting changes to structure, policies, or both, which will lead to an improvement in the behaviour.

It is because of the above mentioned characteristics that system dynamics methodology has been chosen to simulate and analyse the transportation system, in this study.

THE MODEL

For the purpose of analysis, the model is divided into four main sectors: Socio-economic , passenger transportation, environment and energy (Tran 1979) In the socio-economic sector the atributes of urban area, such as population, industries, houses, employment and land-use are modelled. In the transportation sector, buses, personalized modes of transport and rail transit are modelled. In the environment sector, air pollution, and in the energy sector , fuel consumption are modelled. These four sectors interact with each other and the sectoral interactions form the main feedback loops. The feedback loops of the transportation sub-system are shown by influence diagrams, in the next section.

TRANSPORTATION SUB-SYSTEM

The main attributes of the transport sub-system are the roads, buses, personalized modes, and ring rail. Figure 1 represents the bus transit activities of the transportation sub-system.

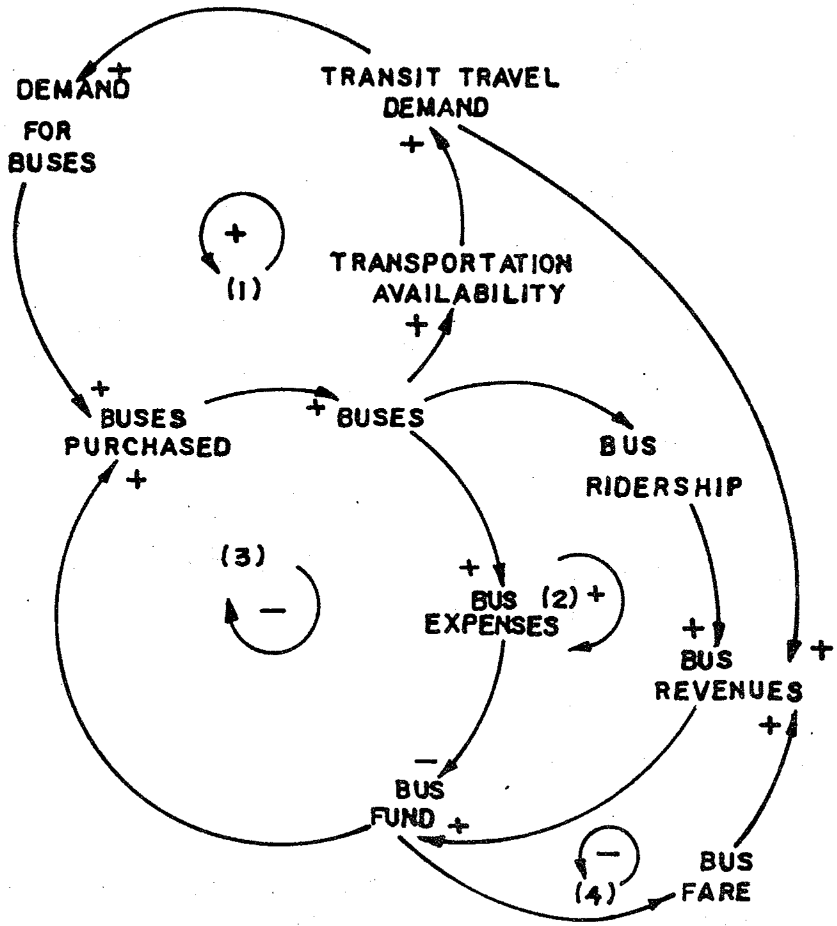

FIG. 1 BUS-TRANSIT FEEDBACK LOOPS

The positive loop 1 represents an explosive growth in the number of buses, with an increase in transit travel demand.
As number of buses increases, bus ridership will go up, generating more revenues. This will further increase the number of buses as shown by positive loop 2.
However, the positive loop 1 and 2 are counteracted by negative loop 3. With the increase in the number of buses, bus expenses will go up, thus reducing the bus fund.
Negative loop 4 shows the effect of bus fare on bus revenues and bus fund.

Figure 2 represents the feedback loops of the personalized mode usage in the transportation sub-system.
Negative loop 1 shows the effect of traffic density on the average vehicle speed.
Positive loop 2 shows the relationship between personalized vehicle trips and mass transit trips.

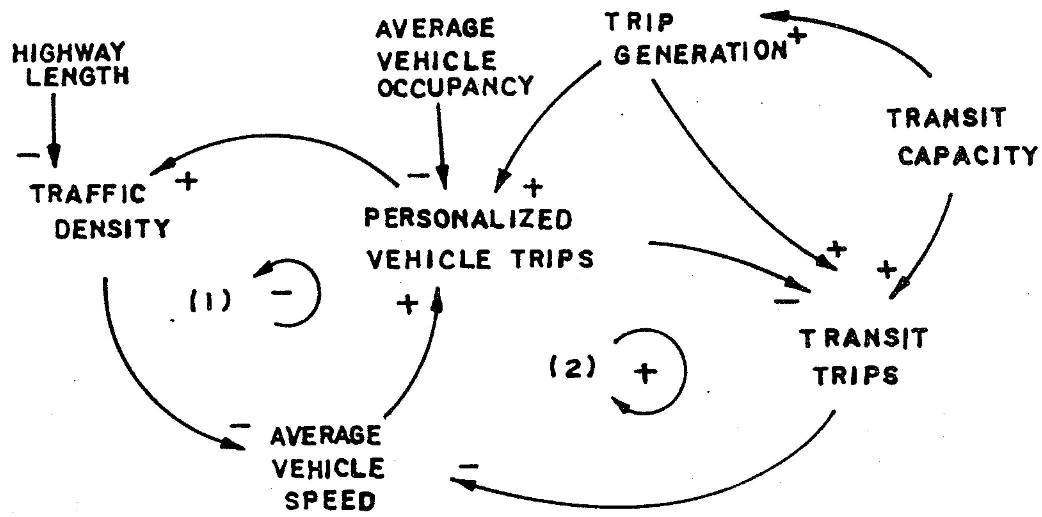

FIG. 2 FEEDBACK LOOPS FOR PERSONALIZED MODE OF TRANSPORT

Figure 3 represents the feedback loops of the ring rail transit.

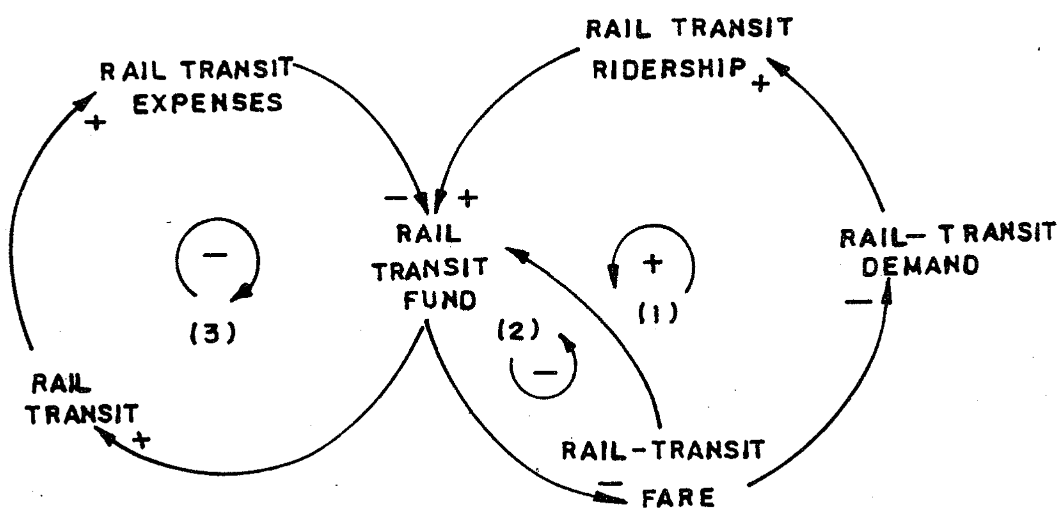

FIG. 3 RING-RAIL TRANSIT FEEDBACK LOOPS

The positive loop 1 represents the growth of rail ridership with decrease of rail fare.
The negative loop 2 represents the decline of rail transit fund with decrease in rail fare.
The negative loop 3 shows the effect of declining rail transit fund on the rail transit services available.

MODEL CALIBRATION

The base year chosen for initializing the simulation model is 1971. The date from 1971 to 1981 has been used to calibrate the model. Figure 4 shows the actual and simulated values of some of the parameters used for calibration.

	Actual value	Simulated value
Population	57.68 lakhs	56.48 lakhs
Buses	3488	3502
Bus ridership	30.96 lakhs/day	31.66 lakhs/day
Transit modal split	0.60	0.58

FIGURE 4

COMPARISON OF ACTUAL AND SIMULATED VALUES FOR 1981

The model, so calibrated, has been used to project the values upto year 2001.

POLICY ANALYSIS

An improvement of urban transportation system seems unlikely to occur unless new policies are implemented. In this study three different policies have been used to simulate the behaviour of the system, beyond 1985.

POLICY 1

Petrol price has been increased by 15% by Central Government in the year 1985. The first policy analysis relates to this price hike. Due to this price increase the generalized cost of travel by personal vehicle will increase. This will result in a decreasing auto modal split fraction as shown in figure 5. The mass transit systems will take the diverted trips, resulting in an increase of mass transport modal split. This shift from private vehicle trips to mass transit trips also results in a decrease in highway traffic density. The effects of this policy on fuel consumption are shown in figures 6 and 7. This policy is expected to bring about the following changes by 2001, .

Petrol consumption	8.74 % decrease
Diesel consumption	0.54 % increase
Pollution	2.26 % decrease

POLICY 2

In the second policy run the car parking fee has been raised to rupees 10/- from the present rupees 2/-, in addition to the increased fuel price. As shown in figure 5 this policy will result in a further decrease in private vehicle usage. The diverted trips will be taken up by the mass transit system.

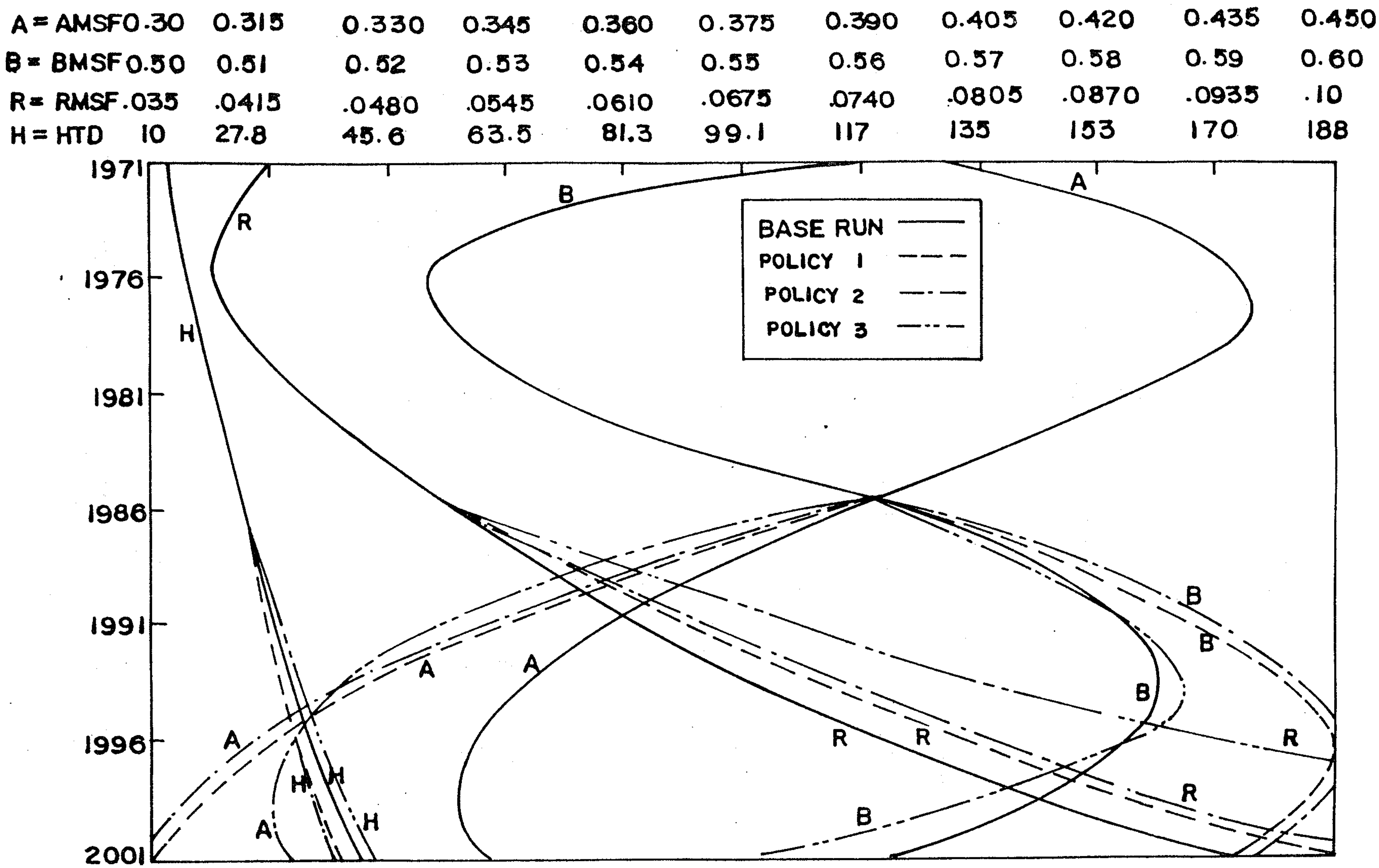

FIG. 5 MODAL SPLIT AND HIGHWAY TRAFFIC DENSITY

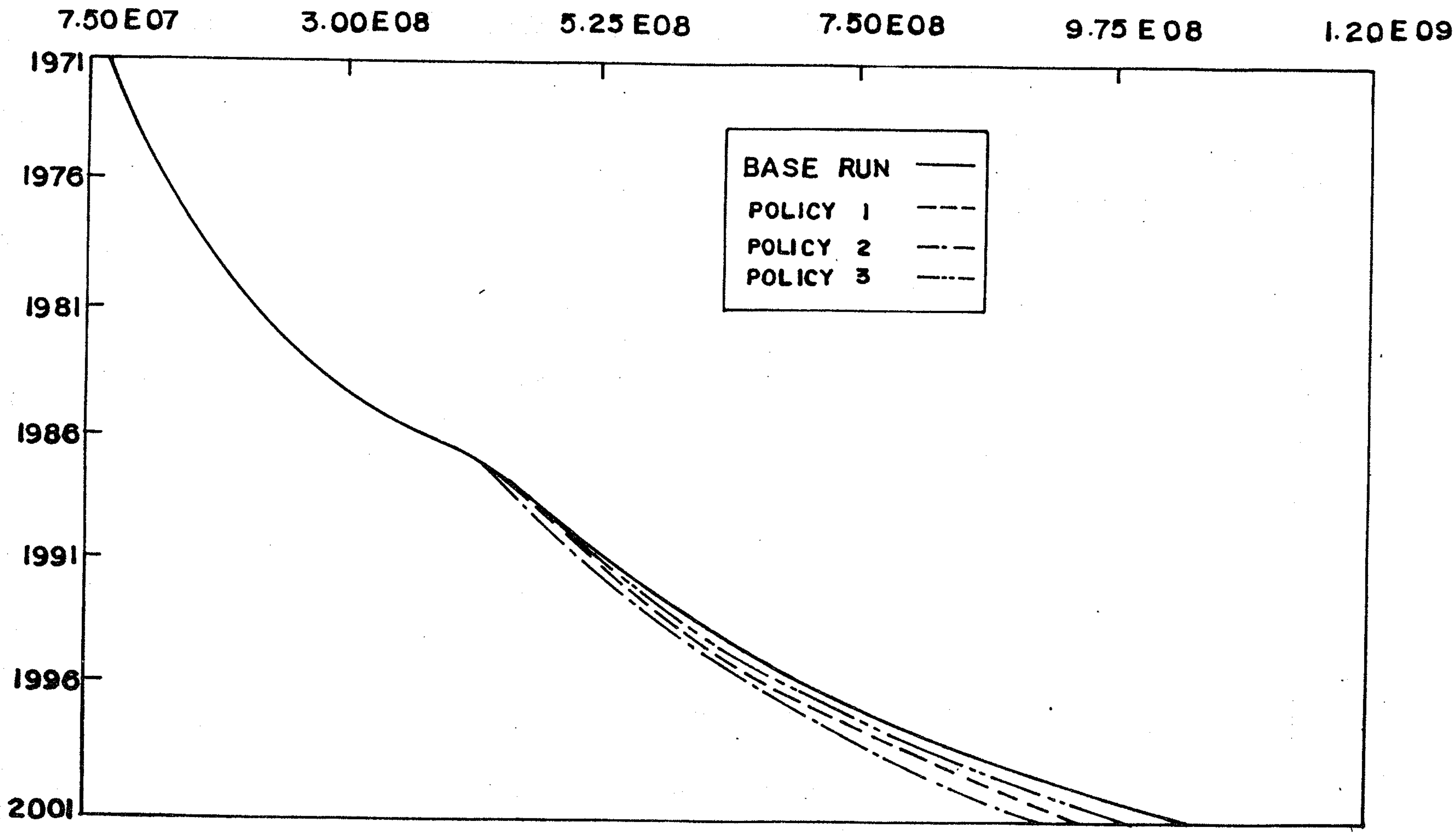

FIG. 6 PETROL CONSUMPTION (LITRES)

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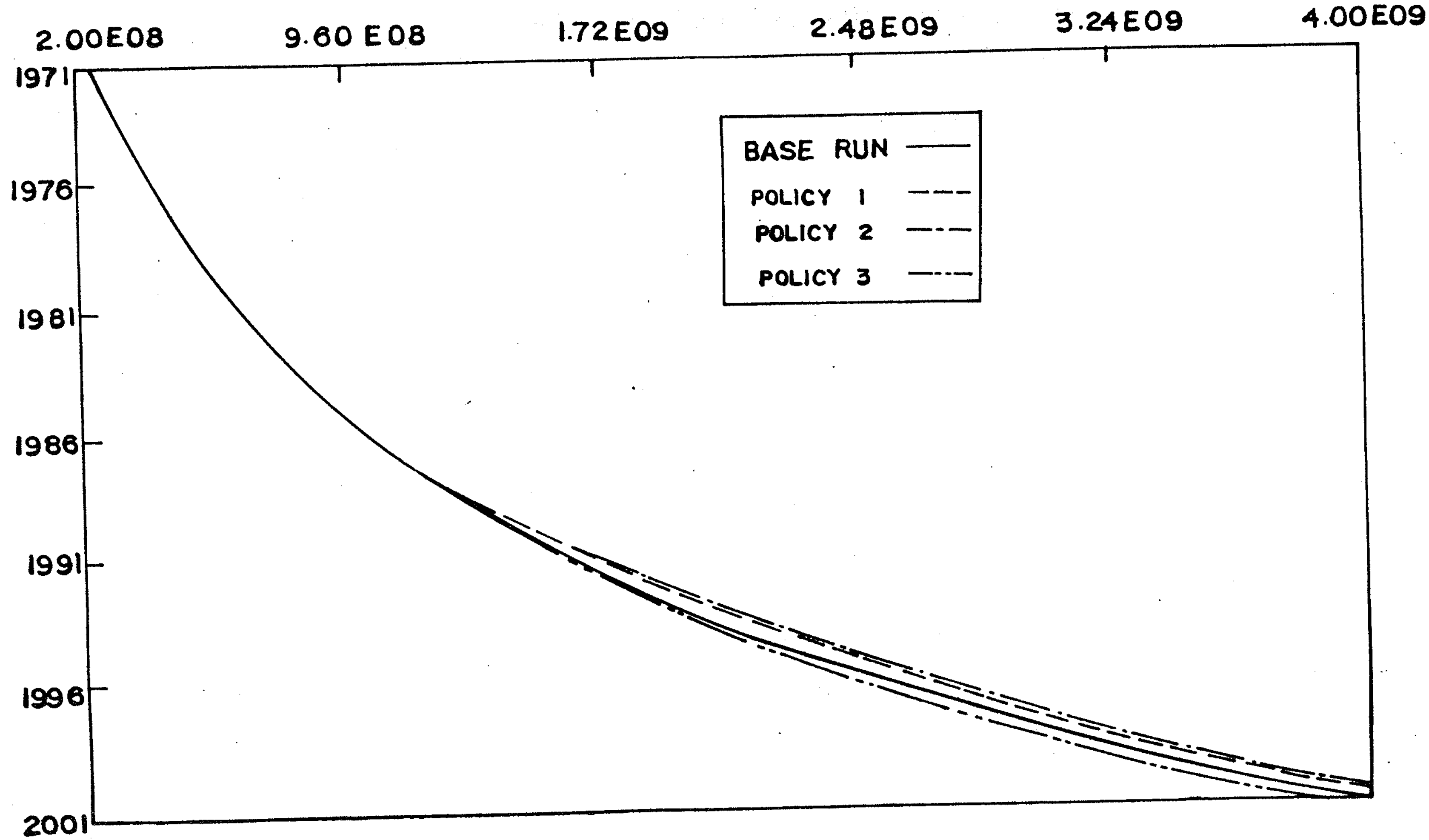

FIG. 7 DIESEL CONSUMPTION (LITRES)

However, the modal split changes are not very significant. The change in traffic density is also very small.
Figure 6 and 7 show the effects of this policy, on fuel consumption. With reference to the base run values, the following changes are expected by 2001.

Petrol consumption	9.71 % decrease
Diesel consumption	0.58 % increase
Pollution	2.88 % decrease

POLICY 3

In addition to changes in the first two policies, the bus fares have also been revised upwards, with effect from 1985, in this policy run. The present and proposed bus fare structures are as follows:

Distance	Present fare	Proposed fare
Upto 4 km	0.30 rupee	0.40 rupee
over 4 km, upto 12 km	0.40 rupee	0.50 rupee
Over 12km, upto 16 km	0.40 rupee	0.75 rupee
Over 16km, upto 20 km	0.50 rupee	1.00 rupee
Over 20mk	0.75 rupee	1.00 rupee

Due to the bus fare increase, the generalized cost of bus travel increases. As the rail fare is not increased, the mass transit trips are expected to shift towards ring rails, as seen in the figure 5. This will result in an increased rail modal split fraction, and a sight decrease in bus modal split fraction.

OTHER POLICIES

Some other policies should also be analysed. Ring rail, at present charges a flat fare of 1 rupee per trip. The effect of reduction in ring rail fare and relating it with trip length can also be studied. Another policy which can be analysed is to reduce the number of private vehicles on roads, say by half. This can be done by allowing only vehicles with even registration numbers, on roads, on even dates and with odd registration numbers on odd dates. This will result in reduction of peak hour traffic density. For such a policy to work an efficient public transport system is a must.

CONCLUSIONS

A continuous system simulation model has been used to investigate the effectiveness of a number of policy changes to reduce the traffic congestion, fuel consumption and air pollution generation.
The policy changes examined are by no means a complete set of changes which might have been studied. Although this has enabled to provide insight regarding the structure and operations of the urban transportation system . Worthy

suggestions for policy alternatives were difficult to obtain. Some more policies, in addition to those suggested above should also be analysed, before a specific recommendation can be made.

REFERENCES

Coyle, R.G. Management System Dynamics. New York: Wiley, 1977.

Goodman, M.R. Study Notes in System Dynamics. Cambridge: Mass. Wright-Allen Press, 1974.

Gupta, J.D. " Regional Land Use and Transportation Development Optimization Model for Delhi Region of India", Transportation Research Record, 848, pp. 21-28.

Holst, O. A Survey of Traffic and Transportation Models, Lingby, IMSOR, 1977.

Pidd, M. Computer Simulation in Management Science Chichester, Wiley, 1984.

Richardson, G.P., and A.L. Pugh III. Introduction to System Dynamic Modelling with Dynamo. Cambridge, Mass. MIT Press, 1981.

Tran, T.K. An Urban Transportation Policy Planning Methodology: System Dynamics Approach. Blacksubrg, Virginia, 1979.