A SYSTEMS APPROACH TO ESTIMATE THE OPTIMAL MODAL MIX OF PASSENGER TRANSPORT

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JANUARY 2014

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Submitted

In fulfilment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JANUARY 2014

Certificate

This is to certify that the thesis titled **"A Systems Approach to Estimate the Optimal Modal Mix of Passenger Transport"** being submitted by Pradeep Singh Kharola to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy is a record of the bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy. The results contained in this thesis have not been submitted in part or in full, to any other university or institute for the award of any degree or diploma.

Dated :**January 2014**

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Acknowledgments

I would like to, first and foremost, thank **Prof. Geetam Tiwari** who supervised my work on this thesis and provided valuable guidance. I would also like to express my profound gratitude to Late **Prof. Arun Kanda** who inspired and motivated me apart from giving me an indepth exposure to various concepts of Industrial Engineering which have been used in this research.,

I am also grateful to **Prof. Dinesh Mohan**, TRIPP (Transportation Research and Injury Prevention Program, IIT Delhi -a WHO collaborating centre), who often showed me the direction I should take in completing this research.

I am thankful to the Bangalore Metropolitan Transport Corporation (BMTC) who gave me access to all their data and more importantly provided me with human resources to collect the voluminous data required for this research.

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Abstract

Passenger transport systems are complex and comprise several inter-acting subsystems. Besides, these systems are influenced by the external environment also. The external environment is a very wide term and encompasses factors such as social and cultural values, geography, demography, state of economy, tax regime and most importantly laws and rules made by public authorities. Some of the parameters of the external environment like social values, geography, climatic conditions etc. cannot be varied in the short to medium term but some, like the laws, rules, taxes, number of buses, parking policies, fares of public transport system, priorities etc. can be altered by the government. The latter category of parameters- which are amenable to change by the government - constitutes the 'policy regime'. Any alteration in the policy regime impacts the transport scenario – modal mix, journey speed, congestion in public transport as well as roads etc. Currently the decision about the policy regime are taken in a rather adhoc and fragmented manner – the taxes are decided by the need to generate more revenues, the bus fares are decided keeping in mind the profitability of the bus companies, the parking fees are decided by the city governments totally oblivious of its impact on passenger scenario and so on. The policy makers can be enabled to adopt a systems approach instead of a fragmented one if they could be provided with a model of the passenger transport system which helps them to assess the impact of any change in the policy regime on the transport scenario. This research seeks to evolve a mathematical model which would be able to estimate the impact of changes in the policy parameters on the traffic scenario such as congestion on roads, modal mix, air pollution caused by vehicles, traffic crash rate etc.

The research started with an extensive literature survey. Urban transportation is an interdisciplinary subject of study and draws from different streams of science and arts namely economic theory, mathematics and as well as operations research, human behaviour,

environment science, transportation engineering, financial management etc. Concepts of estimation of mode choice, value of travel time, quantification of externalities, organisational structures, system dynamics and optimisation techniques formed the base for the current study. The intricacies of the interactions between various subsystems in a transportation network have been appreciated by the urban planners. The integrated land use transport models were developed in the 1960s. These models evolved further subsequently. However, the systems approach has not been widely used. Similarly researches into the impact of the policy parameters on the transport scenario have been few.

Bangalore city, where bus is the dominant mode of public transport, was chosen for development and testing of the model. The first step in development of the model was the identification of the independent and the dependent variables. The independent variables are the short term decision levers, namely - fares of the public transport system, the parking charges, the price of fuel (determined by the tax on fuel) and the number of public buses on road. The variables which describe the traffic scenario - the journey speed or the journey speed, the modal mix and the congestion on road and in buses are taken as the dependent variables. The travelling population was categorised into - persons not owning any motorised means of transport, persons owning motorised 2 wheelers (2W) and persons owning motorised 4 wheelers (4W). A survey was conducted and all travellers were grouped into an income-trip length matrix, for each category.

The next step was to link the independent and the dependent variables through a causal loop diagram. This involved use of several intermediate variables. The development of the causal loop diagram led to two important discoveries. The journey speed in conventional mode choice models is taken as given and constant. But through the causal loop diagram it was revealed that the journey speed which is used in estimating the modal split cannot be taken as ‘given’ but it is rather a function of the modal mix(number and type of vehicles present on the road) also. Similarly the cost of travel by bus is not constant. As the load factor in the bus increases so does the cost of discomfort.

Once the causal loop diagram was complete representing all inter-relationships, the next step was to derive a mathematical formulation for each link. For some of these relations mathematical functions were available but for quite a few, empirical relations were required to be estimated by carrying out actual observations/surveys. With all links getting defined through mathematical equations the consequential task was to find a solution that would satisfy all these equations. The large number of equations, their non linear nature and voluminous data made recourse to computer inevitable. A heuristic solution methodology was evolved and a computer programme was written accordingly. The computer programme gave the journey speed, the number of 2W on road, the number of 4W on road, the number of 2W and 4W owners travelling in buses and the load factor in the buses for any combination of the independent variables. From the values of the traffic scenario the external cost of pollution could be worked out easily as secondary data was available from research which converted the vehicle-kms into quantum of emissions and then to monetary value of health impacts. Similarly with secondary data and research it was possible to estimate the cost of crashes for any traffic scenario.

The mathematical model developed enabled one to study the impact of the different decision levers, viz. i) Parking Charges, ii) Bus fare iii) Tax on Fuel and iv) No. of buses on the roads. The impact on each one of these parameters was varied individually and jointly and the traffic scenario on the road was obtained. The impact of variation in each one of these decision variables on the journey speed and the load factor in buses was studied.

The model revealed that as the bus fare increases, the journey speed declines almost linearly and so does the dynamic load factor of buses. Increase in fare pushes passengers from buses to 2W and 4W thereby reducing the journey speeds. The dynamic load factor in the buses is a function of both journey speed as well as the number of passengers in the bus. When a passenger in bus leaves and goes to 2W or 4W it reduces the number of passengers in the buses and increases the congestion on road thereby reducing the journey speed and this in turn increases the load factor in the bus. At lower speeds the effect of further reduction in speed balances (or sometimes outweighs) the factor of vacancy created in the bus.

Increase in taxes on fuel increases the cost of travel by 2W and 4W leading to increase in load factor in the bus as well as the journey speed. However, it needs to be understood that there is a limit to load factor in buses as a bus has a limit on its capacity. Once this limit of bus capacity is about to be breached, it is time to immediately increase the number of buses on the road.

Using the model, the journey speed and the dynamic load factor in the buses were worked out for different values of parking charges for 2 Wheelers (2W) and 4 Wheelers (4W). As expected, an increase in the parking charges results in an increase in journey speed and at the same time increase in the load factor in buses.

Varying the number of buses was tried through the model and the model gave results on expected lines. More importantly it revealed that an initial increase in the number of buses gives substantial increase in journey speed. It also indicated that there is an optimum number of buses for a city.

Finally the traffic scenario was also obtained by changing all the decision variables together. Thus the model was able to achieve the objective of making available a tool in the hands of decision makers through which they would be able to evaluates the impact of their decision and thus would be able to take better if not optimal decisions.This thesis has made significant contribution to the available research literature on city passenger transport. In precise terms following are the contributions:

- Using the model, the decision makers can easily evaluate the impact of variation in policy parameters. This model, with few adjustments can be used for any city.
- The present research would help all the organisations and the policy planners to understand the complexities of urban transport systems. The entire city transport system has been viewed with an integrated systems approach. An understanding of the holistic approach adopted in the present research would force the governments to rethink and evolve new structures to handle the passenger transport in cities.
- This research has questioned the basic assumption in the traditional approach that the journey speed is a given parameter in any mode choice analysis. The thrust of this research is that the journey speed itself depends on the modal mix on the roads and cannot be an independent variable. In the present research this interdependence of the modal split and the journey speed has been duly factored in.

This research has opened up a new frontier for further research. While developing the model a number of assumptions were made to simplify the model. These assumptions may be relaxed and more rigorous models can be developed. Secondly, for finding a solution a heuristic approach was adopted. It should be possible to mathematically get the values of journey speeds and load factors directly rather than deducing them through the heuristic approach. This was necessitated because the systems model gave a set of large number of equations which could not be solved simultaneously. Further research could be done to arrive at a solution mathematically rather than relying on a heuristic approach which in fact was an exhaustive enumeration approach which is not very efficient.

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