PHYSICAL SYSTEM THEORY RESEARCH INVESTIGATIONS OF LARGE SCALE TRANSPORTATION SYSTEM PROBLEMS

by

M. C. MATHUR

Electrical Engineering Department

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Dedicated to the memory of my

parents
and
father-in-law

CERTIFICATE

Certified that the thesis entitled, 'Physical System Theory Research Investigations of Large Scale Transportation System Problems', which is being submitted by Mr. M.C. Mathur for the award of degree of Doctor of Philosophy in Electrical Engineering of the Indian Institute of Technology, Delhi, is a record of the student's own work carried out by him under my supervision and guidance at the Indian Institute of Technology, Delhi.

To the best of my knowledge, the matter embodied in this thesis has not been submitted elsewhere for the award of any other degree.

P. S. Satsangi

(P.S. Satsangi)
Professor
Electrical Engineering Department
Indian Institute of Technology, Delhi
New Delhi - 110016

New Delhi

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ABSTRACT

From among several possible perspectives the one adopted in this thesis is that a transportation system of an urban area can be regarded as an embedding within the comprehensive urban activity system. This hierarchical construct helps in studying the nature of interaction between the activity system and the transportation system which takes the form of supply demand equilibrium. Transport models of gravity type developed using Wilson's [84] entropy maximising approach do not appear to reflect the supply-demand framework explicity and are not capable of accounting for behavioural characteristics of transport service users besides suffering from several other drawbacks.

In part I of the thesis Wilson's method of entropy maximisation is examined from the physical system theory point of view. Whereas Wilson's entropy maximising approach considers the transportation system in aggregate as a single entity to develop an expression for the 'system entropy', the physical system theoretic modelling framework as well as the systemic entropy maximising methods presented in this thesis take recourse to a component-to-system construct to formulate the requisite expression for the 'system entropy' if so desired. It is shown that the physical system theory method and systemic entropy

maximising method yield not only the same results in the cases studied as produced by Wilson's entropy maximising method but they are also endowed with certain intuitively appealing and operationally viable property. This property has the desirable effect of enabling any of the various relevant forms of system-level model to be developed by hypothesizing suitable relationships among the flow-volume and level-of-service variables of the transport links in a manner which is both consistent in the network theoretic sense as well as commensurate with the desired system model in the behavioural form, unlike the situation that obtained in the case of Wilson's approach.

It is also shown that the maximisation of entropy implies that the generalized 'KCL' is satisfied by the volume of flow variables and the most probable flow distribution rule is obtained for the links if the levels of service on all links between an origin-destination pair are identical. It is observed that, for 'arbitrary' demand functions, the physical system theoretic solutions for flow on a transport network need not be the most probable i.e. the entropy might not attain its maximum value. However, if we made a choice of demand functions such that the flows were the most probable ones thereby achieving a maximum value for entropy, then the levels-of-service on all links would be equal.

In part II we have considered an emerging concept of recomposability based on the realisation that the selection of a set of arbitrary subsystems interconnected in any way may not constitute a desired overall system. It is through a proper design of the structural features and characteristics of subsystems and through a manipulation of the structural model of interconnection among subsystems that the systemic outputs may be made to achieve the overall objectives within permissible tolerance under specified operation. Recomposability is viewed as a problem of determining which subsystems of an overall system are adequate in the sense that specific properties of the overall system can be recomposed from a knowledge of the corresponding properties of the constituent subsystems. In the context of this problem a potentially important idea of recomposability analysis has been defined which is a process of investigating the possibilities of recomposing desirable properties of overall systems from a basis of the corresponding desirable properties of their various subsystems. We have hypothesized a basic operational procedure of (i) comprehending a whole, (ii) decomposing the whole, and (iii) methodizing recomposition.

The idea of recomposability is viewed as a 'systemic design-by analysis' procedure. This procedure if followed is expected eventually to provide us a system which is going to closely satisfy design aims and objectives. This is important because a once-through design process by synthesis proceeding directly from the specification to realization of design in a single pass is difficult to obtain except in a few simple and straight forward cases. The only alternative left is to go through an iterative process as outlined in the recomposability analysis procedure. The added advantage in following this procedure is that it is revealed whether the whole is recomposable (in terms of desired properties or attributes such as overall systemic solution, overall system stability, optimisation, reliability, sensitivity etc.) from a knowledge of the corresponding subsystems.

The thesis includes an application of the recomposability analysis to a transportation system of an urban area, with special emphasis on a physical system theory based methodology of recomposition using a certain 'connection' equation. This methodology has been used to determine overall transport network systemic solutions from a basis of subnetwork solutions. The methodology is general and is applicable to all physical systems. It is also computer implementable. An algorithm developed here suggests that one need not know subnetwork solutions per se to recompose overall systemic solutions. Instead, operationally, one would need to go through certain general steps. This methodology, it is believed, has a tremendous scope of application in areas of large scale control systems and related issues.

Part III of the thesis included investigations carried out in the specific context of a transportation system to establish the fact that grouping technique and equivalencing technique may be gainfully employed to reduce the computation costs while analysing appropriate features of socioeconomic systems which are representable as a physical system network. This is done by evolving computationally efficient and practical procedures for handling large networks by dividing or grouping a large network into a relatively small study subnetwork and a relatively large external subnetwork using strong connectivity criterion.

Two methods based on the branch-formulation-technique are developed to obtain mtrs (multiterminal representations) by means of 'growing' repeatedly contigous subnetwork on a 'nucleus' nodepair and a 'nucleus' node which includes equivalent terminal representation of the previous stages. The last stage of this process yields the desired mtr with respect to boundary nodes. The matrix inversion is totally avoided in this process. The mtrs of the study and external subnetworks are then combined to establish the overall representation with respect to boundary nodes. The network formed at the boundary nodes is solved to obtain desired flows on the transport links.

Successful importation of dynamic equivalencing technique and associated concept of Ward type distribution factors which have been widely used in power system analysis, into a socio-economic context such as a transportation system of an urban area, is also demonstrated. The methodology is very useful as all the chief advantages of determining equivalent network representation on the basis of distribution factors seem to apply to transportation system networks also just as much as in the case of large and complex power systems. Effects of traffic generations in the external subsystem represented in the form of flow drivers are readily transferred so that the study subsystem flow drivers are duly modified in the form of equivalent flow drivers incorporating the influence of the external subsystem. Study subsystem solutions under such conditions capture the influence of the eliminated external subsystem. The methodology is highly efficient computationally and requires much less number of steps to achieve the desired solutions.

Finally the concluding chapter highlights the contributions of research investigations reported in this thesis and suggests future avenues of research which remain open for further investigations.

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