A System View of Transportation System

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ABSTRACT

The Le Moigne's theory of General System is presented and applied to the transportation system. A model of this system, using accessibility and generalized cost as the variables to be controlled is also sketched.

INTRODUCTION

"The substantive challenge of a transportation system analysis is to intervene, delicately and deliberately, in the complex fabric of a society to use transport effectively, in coordination with other public and private actions, to achieve the goals of that society" (Manheim, 1979): a challenge on measure to be dealt with by a systemic approach. SYSTEM: few words have had so many definitions and interpretations; in this paper, we agree with Le Moigne(1977), in his defining a system as a structured entity, acting in an environment, with respect to a finality, and which may evolve, while keeping its identity. The choosen modus operandi is to step outside the system, or rather *systems*, defining thus an abstract entity, the General System, provided with a priori properties, and to build later, one, or more, models homomorphic to the system which interests us and isomorphic to the General System already defined. Acting this way, we have to put on stage another system: people, who analyse the 'real' system, and have to synthesize a model. Let us call this system the Modeller (Système de Représéntation, in the Le Moigne's book). It may be obvious, but not trifling to point out that the same system can be modelled in very different ways according to the aims of the model builders, and that to define the system's goals (the Modeller's, in this case) is the prime activity of the system itself. Furthermore, if the Modeller is a system , *he* too has to be isomorphic to the General System. (Fig. 1).
The General System, seen as an archetype, can as any other entity be considered from the point of view of an external observer: what is he doing? - functional or analytical definition; from that of an internal one: how is he made? - ontological definition; and through the eyes of an historian: how did the system become this particular system, and towards what is is its evolution directed? - morphogenetic definition (Fig. 2).
We have, thus, a grid of nine definitions, which will be compared, at least partially, with a transportation system, and so a method of furnishing its own 'systemography'.

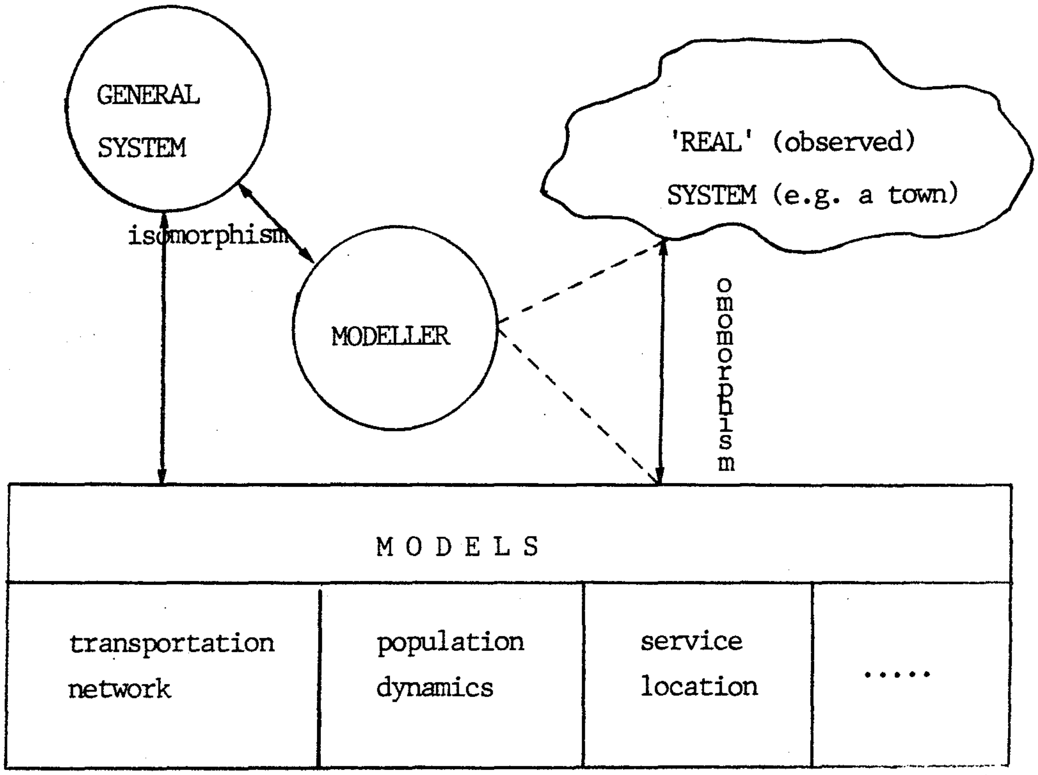

GENERAL SYSTEM
'REAL' (observed) SYSTEM (e.g. a town)
isomorphism
MODELLER
omomorphism
MODELS
transportation network
population dynamics
service location
.....

Fig. 1

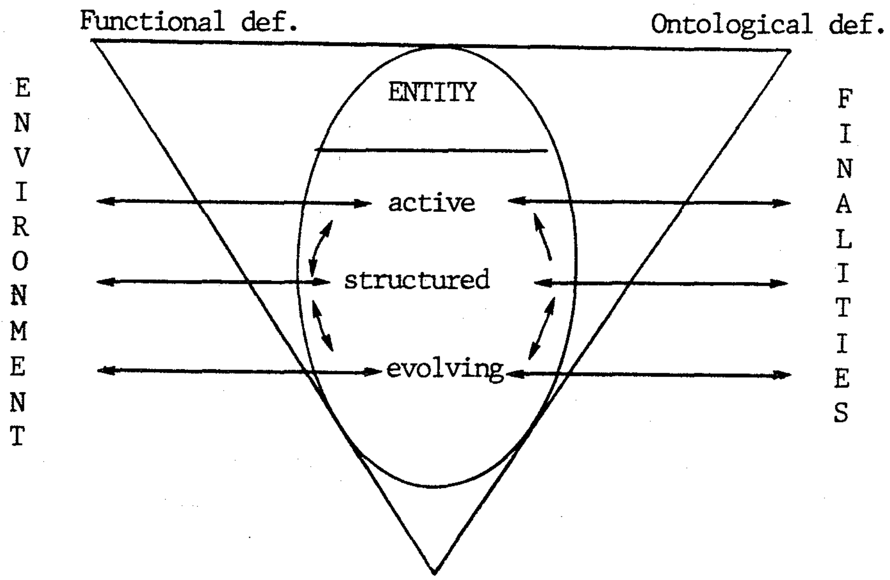
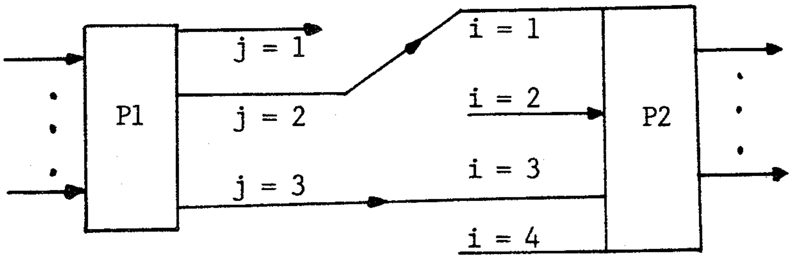

Functional def.
Ontological def.
ENVIRONMENT
FINALITIES
ENTITY
active
structured
evolving
Morphogenetic def.

Fig. 2

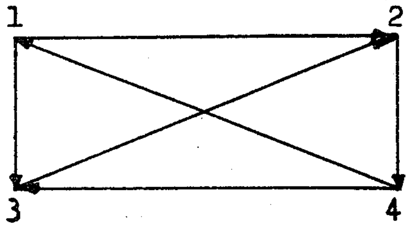
SYSTEM AS AN ACTIVE ENTITY

A system operates on flows of matter, energy and information which cross it, shifting them in space and time and modifying their shape or composition (stored goods, or recorded information can be thought as moving only in time). Moreover, these activities, will change the reciprocal relationships of the objects which make up the flows on which the system will have acted. Let us imagine a reference system, with four coordinates: one referring to space (S), one to time (T), one, broadly speaking, to shape (F) and one to the reciprocal relationships between points of this 'space'. The system, as an active entity, is functionally defined as an operator in the space STFR: a black engine, rather than a black box, acting on these flows. The flows themselves can be divided into two classes: those whose treatment is the sistem's objective), and those which are necessary for the system's operation. If in the abstract the flows on which a system operates consist of matter, energy and information, in practice, a transportation system accepts input and output flows of passengers and/or goods, which are moved in space and time (remembering the convention that people waiting and goods stored in transit are displaced in time only), as well as in the reciprocal relationships. Furthermore, in order to operate, a transportation system needs flows of energy and matter (vehicles and spare parts), in addition to those of personnel. Besides, there will be the unavoidable information flows, which will be divided into two categories: structured and unstructured. The first consists of data which have a standard form, sometimes imposed by law; the second are perhaps less remarkable, but they are fundamental: for instance the measure of transportation demand and supply, regional development opportunities,...,the reputation of a travel agent, those myriad data, sometimes fuzzy,on which are often based the decisions of both the firms and also of their customers. Last, but not least, there are financial flows. Up till now, we have illustrated the functional definition, namely, the point of view of an external observer. Now we must examine that of an internal observer - ontological definition. From this point of view, a system is a bounded network of active elements, processors, that is, elements dealing prevalently, or exclusively, with a particular flow in a particular manner: with respect to space, time and shape. To describe this network we can use two matrices: one of connection, the other of structure. The first is referred to each couple of processors, it is a (m x n) matrix with n equal to the number of outputs of the upstream processor, and m to the number of inputs of the downstream one: their elements, c_{ij}, are equal to 1 if i-th input of the downstream processor is connected to j-th output of the upstream processor, and equal to 0 to the contrary (Fig. 3-a). The structure matrix is a square one, and the number of its lines is equal to that of the system's processors: their elements, s_{ij}, are equal to 1, if at least one output of the i-th processor is connected to an input of the j-th processor, and equal to 0 to the contrary. So, if $s_{ij} = 1$ j-th processor follows the i-th and this upstream downstream partition can be of use when constructing a model. In this matrix we can also see feedback loops, shown by the presence of elements different from zero under the principal diagonal (Fig. 3-b).



$$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

a) Connection matrix for processors P1 and P2.



$$\begin{bmatrix} 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \end{bmatrix}$$

b) Structure matrix for the system of four processors 1, 2, 3, 4.

Fig. 3

In describing the physiology of the transportation system as with any other, we can stop at different aggregation levels: in this way a processor could be a lorry, a warehouse, or the whole transport company. In its turn, this last could be seen as a system, and hence we should have to repeat what we are saying about activity, structure and evolution. To sum up, a system, e.g. the transportation system, can be composed by sub-systems, often into competition to secure resources. These particular sub-systems must not be confused with those operation, information and piloting systems about which we will speak in the following definition.

Morphogenetically, the system as an active entity is presented, in the Le Moigne's theory, as a multilayer construction, formed by an operation, an information and a piloting system, the last of which is in turn parcelled out in decision, assessment and self-organisation, and finalisation subsystems (Fig. 4, with few variants with respect to the original Le Moigne's scheme). The operation system is the one which exchanges flows of matter, energy and information with the environment - we are at hardware level. As regards a transportation system, it is composed, depending on the aggregation level, by firms, or by means of transport, and by the infrastructures, whether private (buildings, depository, ...) or public (roads, bridges, ...). A problem arises from the fact that what we call here an operation system is what is generally intended when speaking of a whole transportation system, where exept for the odd comment *en passant* the other two components tend to be neglected.

It's not as if it were easy to identify the information and piloting systems. Information systems can exist, either formalised at single company level, or, for specific functions, at an inter-company level, as with the system of booking by airlines. Therefore among the first problems a system analyst has to trace are the channel or channels in which information is passed, often outside

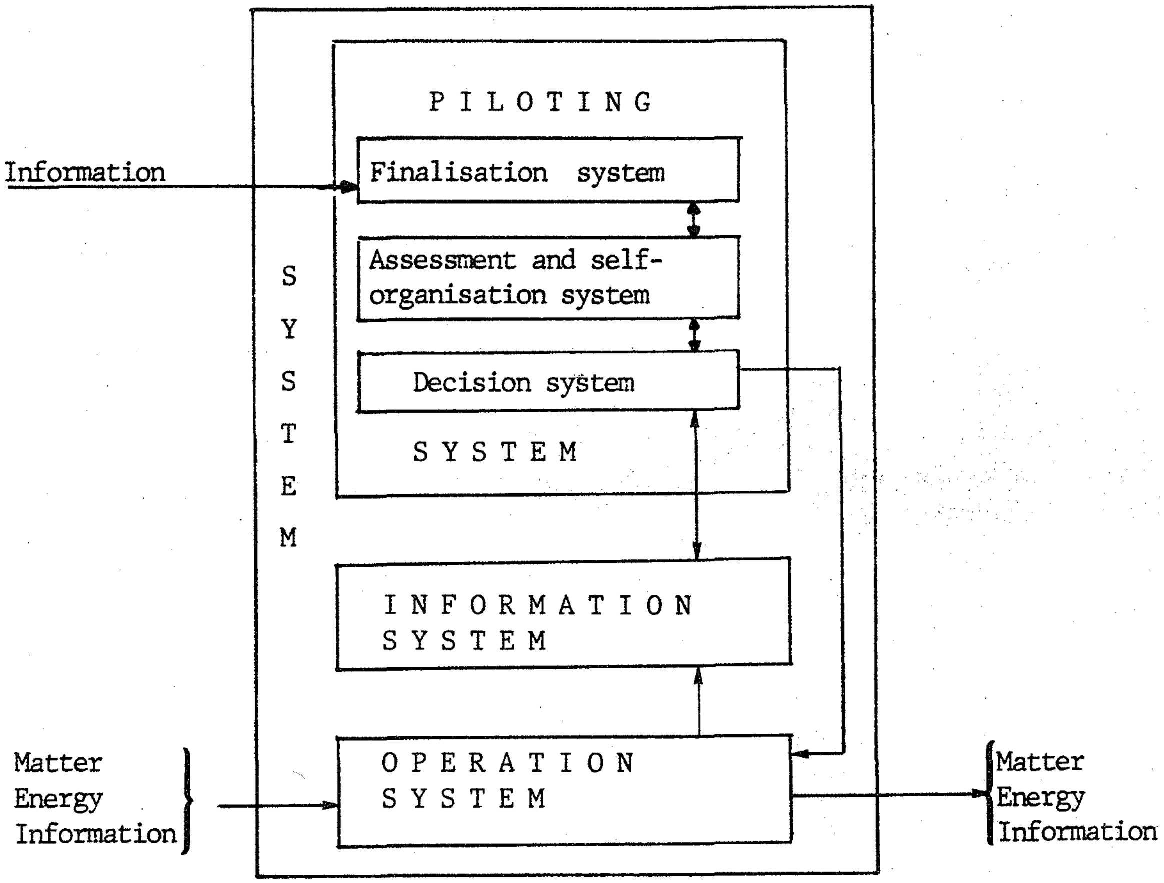


Fig. 4

well defined structures. As for the piloting system the situation is, if possible, worse; in particular, the finalisation subsystem is shared, at aggregate level, by the whole of society. In fact, given that a truly global modelisation is in practice impossible, the informational input to the finalisation system is nothing but the sharing of objectives chosen by society for that particular subsystem.
These objectives will be assessed on the basis of knowledge the piloting system has of the whole system; which will be reorganized, within the limits of possibility, to accomodate them; decision and operation phases follow.

TRANSPORTATION SYSTEM GOALS. A MODEL.

What are the finalities, the goals, of a transportation system? They are, or should be, those to improve accessibility of different zones, allowing the displacement of people and or goods from one place to another, in better conditions and with minimal waste of time and money. Quantitatively, the accessibility can be estimated in different ways (De Luca, 1985); the first is derived directly from the theory of rational choice behaviour: we have to maximize an utility function $U = U(\underline{x}, \underline{s})$, where $\underline{x}$ is the vector of distinctive features of each transportation option, and $\underline{s}$ the socio-economic vector of those who choose. Taking as understood De Luca's hypotheses, we can arrive at the formulation of the following index, A_i, also called 'location surplus', i.e.:

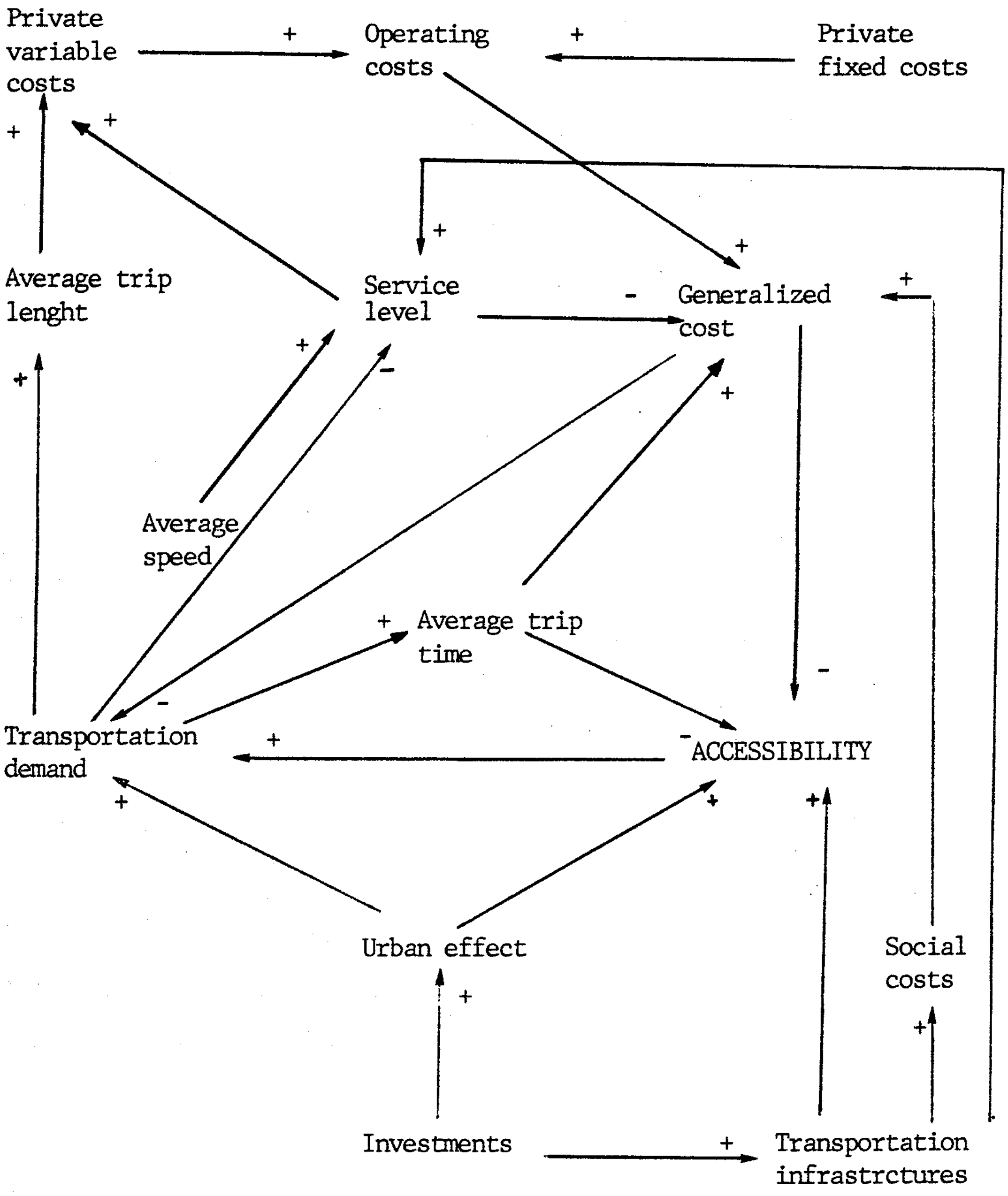


Fig. 5

$$A_i = \ln \sum_{mj} X_k \beta^{\circ} \exp(\beta_1 c^m_{ij} + \beta_2 t^m_{ij}) \tag{1}$$

where X_j is the attraction of j-th zone, and c_{ij}^m and t_{ij}^m are respectively the cost and the time for going from i-th to j-th zone, by transport mode m, and β_k are constant. The availability of services in the j-th zone, its urban effect, and the generalized transportation cost are the key variables of a model, see Fig. 5 for influence diagram, at present under analysis at the University of Cagliari, for the Sardinian interior (Agelli et al., 1985), but easily *portable* to other similar countries.

THE SYSTEM AS A STRUCTURED AND EVOLVING ENTITY

We have already seen a functional definition of the system as an active entity: the same definition as a structured entity is characterized in Le Moigne's theory by the state equation, which describes the system's trajectory in a state space, its kinematic behaviour. The system state is, defined we must not forget, from the point of view of an external observer, as the set of Input/ Output couples at a certain moment. But as the system is evolving, so there is the necessity to forecast its evolution by projecting oneself into the future, made possible by a state function.

Le Moigne connects this function to two types of, dual, measurement: entropy and variety. With regard to the kinematic and dynamic aspects, state equation, and function, Thom (1975) writes: "All models divide naturally ... into two a priori distinct parts: one *kinematic*, whose aim is to parametrize the forms or the states of the process under consideration, and the other *dynamic*, describing the evolution in time of these forms... We cannot hope for a global formalisation, but local formalisations are possible and permit us to talk cause and effect". To describe the system's state only in terms of I/O couples seems to us restricting: indeed at this point we no longer share Le Moigne's point of view: to use the set of levels as the set of state variables is the classical assumption of System Dynamics. In this way the model sketched in the preceding paragraph is nothing but Thom's "local formalisation".

The successive ontological and morphogenetic definitions of the system as a structured but evolving object, certainly provide us with interesting starting-points for research; research thought which assumes so highly generalized a character, that almost one arrives at the cognition theory. Some of these implications will be examined in a later study in an epistemological key.

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