The Direct Form of Structural Models within System Dynamics

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Abstract

A basis for co-operation in System Dynamics research is a common language for system managers and investigators. The System Dynamics model may be this language.

A form of structural model is proposed, taking as its base Forrester's flow diagram notation. Some features of structural models are:

They present the whole of the structure in a compact clear way.

Business interpretation of the model is easy, owing to its verbal components.

Use of the formally defined elements enables direct transformation of the structural form of the model into a mathematical form.

Introduction

For studying dynamic problems of social systems, SD proposes the use of different kinds of models, each of them suitable for specific applications. These are:

verbal models - create the information base,

causal models - explain the feedback loops or causality,

flow diagrams - show the topography of the system,

mathematical models - allow computer simulation

It is proposed to include in this series the form of structural model which shows clearly, directly and compactly the full structure of the described system. The following paragraphs describe the base, aims and content of the proposition.

S.D. Notation - the common Language for Managers and Scientists

The most important step in an S.D. exercise is the construction of the model of decision policy, information services and interaction of the system components. The model facilitates laboratory examination of the system's behaviour in reaction to a particular kind of external disturbance.

It is exceedingly difficult to fit an SD model to available numerical data gathered from the investigated system. There are many reasons for this difficulty, and they are discussed in the literature of SD(1,2). For now, it is best to acknowledge that the most useful models will be drawn from non-numerical sources, that is on the basis of individua knowledge of the system. Ideally, the model should be constructed by those who know the actual system, who understand its problems and who at the same time have a background in dynamic system analysis. The possibility of finding people with all these characteristic is very rate. The most hopeful solution of this question lies in the co-operation of managers of the investigated business organisation with scientists who are interested in the formal description of the managers problems and in solving them by means of scientifi methods. But first we must equip this interdisciplinary group with a common language which will help them to understand each other in the area of the examined object. The language may be SD model notation of the system structure as well as plots of the behaviour of this system obtained as the result of simulation. The notation would be clear enough for managers to be able to understand the description of their system prepar by scientists and rigorous enough for scientists to describe their conclusions about the system grounded on information received from managers.

Model Building and Verification

The model is an aid in evaluating management policies as it is possible to use it for laboratory research of policy consequences on system behaviour. However if the conclusion drawn from such research is to be useful, we should first verify the model.

The behaviour of a closed, self contained, industrial dynamics model is dependent on the structure of the model. By verification of the model we ensure its structural and behavioural conformity with the actual system. Thus the verifying process is connected with two complementary objectives:

1) Components and structure of the model should match elements and structure of the actual system.
2) The pattern of the behaviour of the model, obtained as a result of simulation, should not differ in any significant way from that of the actual system.

According to these two objectives it is easy to imagine that we should have two disti forms of models:

1) Structural model - the aim of which is to describe formally the structure of the actual system. Keeping in mind that the content of an SD model is drawn mostly on the basis of individual knowledge, and consequently the verification of the model is based on the same kind of knowledge, the structural model should be credible to managers of the investigated system.

2) Mathematical model - the aim of which is to simulate the behaviour of the actual system. Results of simulation from the computer are obtained directly in the shape of plots which are easily understood by managers.

The author proposes to include in the field of SD some form of structural model - under the name 'structural chart' which adds to model credibility.

Structural Charts

One of the aims of an SD model is to show formally, and in a readily understood form, the structure of an investigated business system, that is the main relations among the components. We understand that normally the essence of these components has been captured in the process of investigation of the dynamic behaviour of the business system. To read model structure from a set of many equations is a difficult task, especially for people unfamiliar with this type of mathematics. Some help comes from SD flow diagrams. Their standard symbols are clear, but they show only interconnections between parts of the system - not the structure which creates its dynamics. They only represent an intermediate transition between a verbal description and a set of equations. Thus managers as well as SD investigators who most often are engineers, econometricians, management staff, and more rarely mathematicians - may find difficulty in perceiving or transmitting the notion of structure.

The author proved that some extention of the SD flow diagram notation provides a suitable tool for construction of a structural chart which produces formal, compact, and clear patterns of the full system structure.

The proposition of the key elements of SD structure chart (3) developed on the base of Forrester's flow diagram notation (2), are displayed in Fig. 1. The following description comprises an explanation of the content of elements showen in Fig. 1.

a) Level - without changes

b) Flows - without changes

c) Decision point - introduction of decision function symbol F.

F may represent any mathematical relation - in the place of F we put then a symbol representing the considered relation. In addition the fragment of graphical symbol of the decision function may be completed with double frame (see h) which points that the function F is accurately and more clearly described on an annex sheet (the number of the description on the annex sheet corresponds with the number of the decision function).

d) Information throttle - represents flows of information I between two points denoted P_1 and P_2, according to the relation $I = \frac{P_2 - P_2}{D}$ where D is the value of the informati delay, P_1 and P_2 are instaneous values of levels or flows to points denoted P_1 and P_2 respectively.

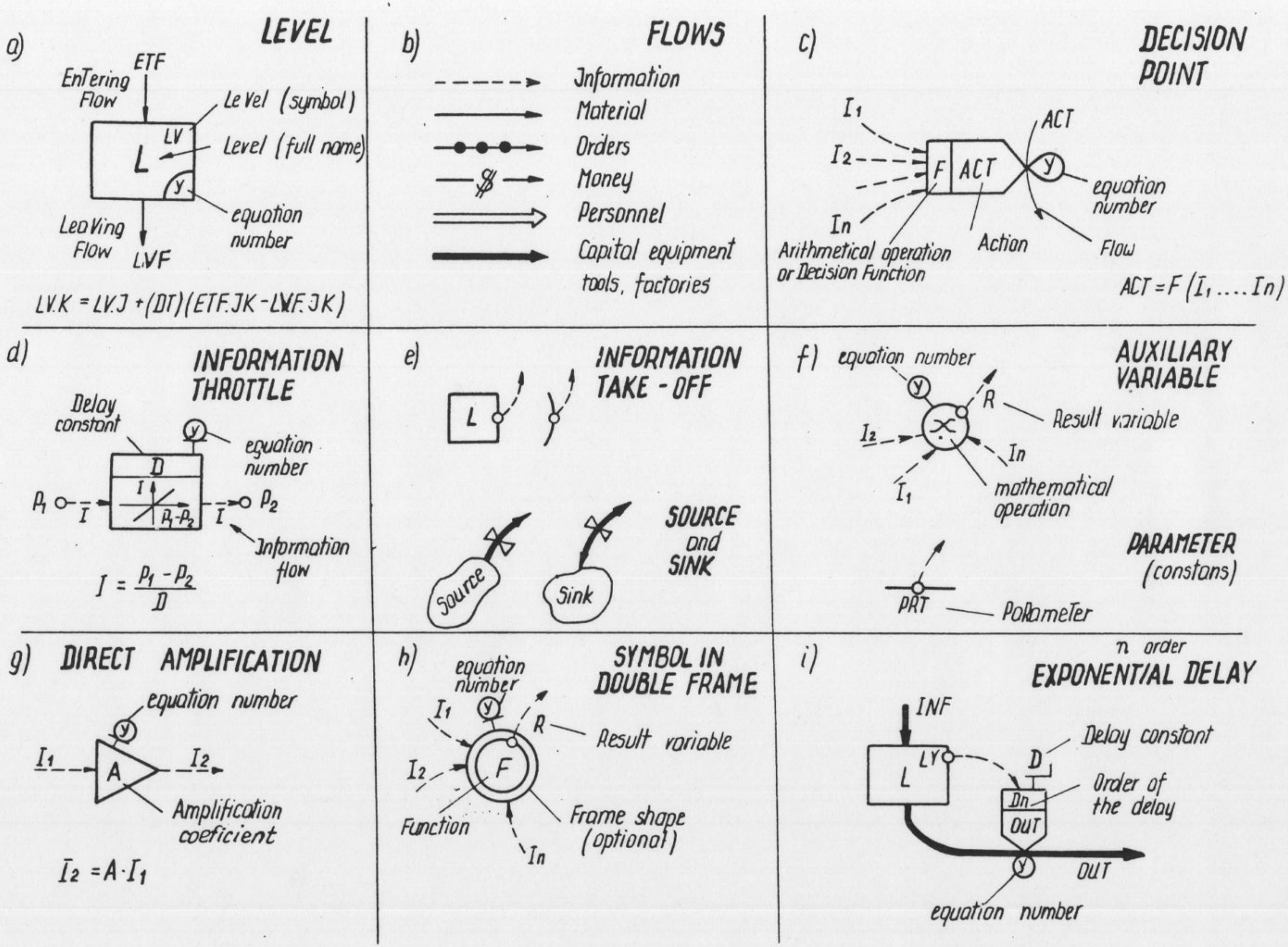

Fig.1 Elements of the structure models in Industrial Dynamics

The delay coefficient may have a constant value D, or its value may be a function D $(I_1 \ldots\ldots I_n)$ of the other actual system values. If the point denoted P_2 is a decision point, with information flow I as an input, the value of variable P_2 is null, and the relation takes the form $I = \frac{P_1}{D}$.

e) Information take off, source and sink - without changes.

f) Auxiliary variables - they are joined with additional graphical notation F, see c) points 1 and 2.

g) Direct amplification - represents direct amplification in the sense that the value I_2 may be larger or smaller than the value of I_1 according to the relation $I_2 = A.I_1$ where the amplification coefficient A may or may not be dimensionless. For example: it has dimensions when I_2 represents desired inventory measured in units and I_1 represen average order inflow measured in units/month. Amplification coefficient may have a constant value A, or its value may be a function A $(I_1, I_2 \ldots\ldots I_n)$ of the other actual system values.

h) Symbol in double frame - replaces notation of any function which is difficult to represent in simple, compact form, or replaces a component of the model when it is more convenient to describe separately the disaggregated details of this part. The frame announces that the function is described on the model's annex sheet. The form of notation on the annex sheet may be a simple mathematical relation, diagram, fragment of structural model and so on. The form is chosen individually for each case to secure clearness of the described function.

i) n order exponential delay - its graphical symbol is created by unification of level, flow and decision point symbols. The graphical symbol is joined to the top of decision point symbol and it embraces the letter symbol of delay constant (here the letter D). In the upper rectangle of decision point graphical symbol ⊥ the symbol D_n is placed, where n indicatesthe order of the delay - D_1 first order and so on.

Examples of Structural Charts

To illustrate the SD structural charts we show such charts for the well known exampl of Meadows (4) dynamic commodity cycle model in Fig.2. Coefficients with constant val of 100% are omitted. To facilitate perception of simplified diagrams of non-linear functions, their detail may be shown more exactly on annex sheet (units of variables an steady state values appear in Fig. 2 as supplements). We emphasise that_ the proposed structural chart presents the whole structure of the investigated system; business interpretation of the chart is comparatively easy owing to the verbal explanation; the use of formally defined elements, as in Fig. 1, enables direct transformation of this form of model into mathematical form - that is, the set of equations.

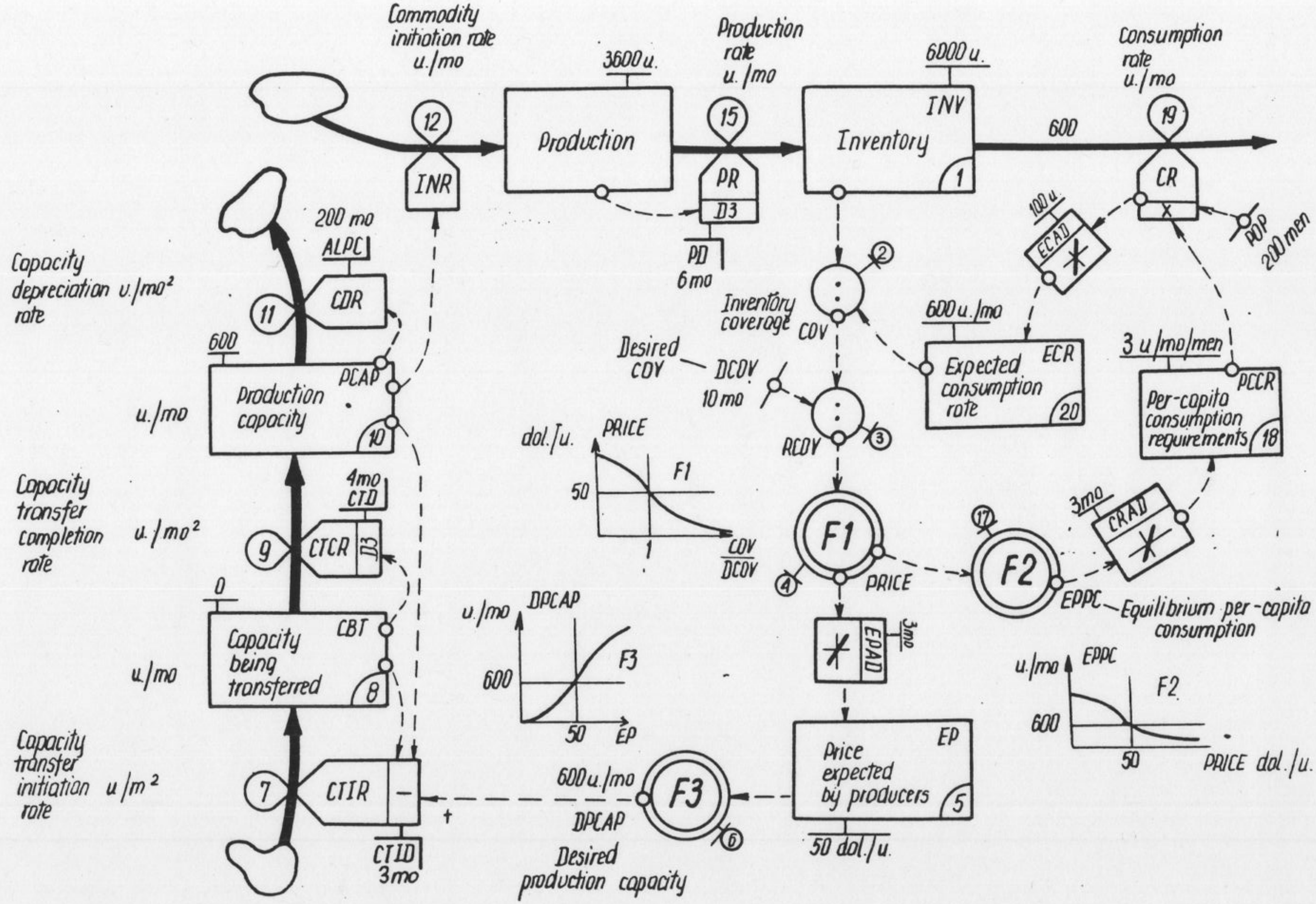

Fig. 2 Flow diagram of the Dynamic Commodity Cycle Model

(A structural chart representation of Forrester's Customer-Producer Employment System has also been produced and an English version is available from the author).

Features of Structural Charts

Structural charts represent in graphical form the full structure of the system, that is the pattern of interrelation and inter-connection between variables of interest. The structure is described clearly as each variable appears only once. Moreover, the graphical forms and connection of levels, flows and decision point symbols are represente in standard fashion. Information flow symbols, together with designation of the operations which are performed on data transmitted by the flows. The processed informati supplies decision points which control flow values. The whole pattern makes a picture of an information - decision system. The ease in interpreting model elements using verbal notes to describe their counterparts in the actual system makes for additional convenience.

For simulation, we need a mathematical model that is a set of equations describing system behaviour. The equations are directly obtained from the structural chart, the formal content of which contains all data needed. So we observe the correspondence of the mathematical model with the structural charts simplifies the building process for mathematical models.

Need for the Structural Chart

Looking for success in application of System Dynamics analysis, we should keep in mind all the time that the progress and results of our structure study must be clear to managers. The structural chart serves this aim.

We want to show that the manager can learn relatively easily to understand and use structural charts. The author points out some analogies between business and technical charts. We can distinguish only several kinds of basic elements in the charts which are common to them. This feature makes understanding of structural charts quite easy. For example, the chart of a television set (television electronic circuit diagram) can be read off and used as a work tool by personnel educated only to the level of a secondary technical school. Business SD charts are more complicated than the technical ones as they have several kinds of flows and levels rather than only one. However, the business manager is accustomed to these in his day-to-day control of the organisation. Thus he should be able to associate flows and levels with his ideas and make appropriate changes when desired.

We can add that structural charts may be useful for an SD analyst as well. As he can find all the information about the structure of the system and the main points of its interpretation on one sheet of paper it may be easier for him to grasp this structure in his mind. Thus it should be easier for him to analyse the influence of structure on behaviour.

The author has effectively used these charts while explaining the SD structure to business managers and students.

References

1. COYLE R.G. On the Scope and Purpose of Industrial Dynamics. International Journal of Systems Science, Vol. 4, No. 3, 1973

2. FORRESTER J.W. Industrial Dynamics, Cambridge, Mass. The M.I.T. Press, 1961

3. LUKASZEWICZ R Dynamika systemow zarzadzania/Management System Dynamics, Polish Scientific Publisher, Warsaw, 1975.

4. MEADOWS D.L. Dynamics of Commodity Production Cycles, Cambridge, Mass., Wright Allen Press, Inc., 1970.

5. ROBERTS E.B. The Dynamics of Research and Development, New York, Harper & Row, 1964.