Some remarks about chosen structural aspect of System Dynamics method

Elżbieta Kasperska

Institute of Mathematics
Silesian University of Technology
Kaszubska 23, 44-100 Gliwice, Poland
e-mail: e.kasperska@polsl.pl

Abstract : The paper contains some remarks about chosen structural aspect of System Dynamics method. One of them relates to classical assumption about rate characteristic of flows in SD model. The problem of possibility of extension of this description was already undertaken in some papers of author. The main idea consists in "embedding" the matrix equations in classical structure of SD. By applying the Gauss or Legras method we can solve algebraic system of equations (for example: mass balance, cost balance, labour balance), by inverting the matrix of such system, during the simulation of SD model.

The second remarks concerns the problem of normative character of approaches type "optimization", link with simulation on SD models. Such efforts were undertaken by many authors, last years mainly by prof. Coyle and Kasperska with colleagues.

In this paper the problem of embedding the optimization in simulation and vice versa, will be undertaken in the context of evolution of structure of SD models, specially theirs simplification. At the end some conclusions about the subject of consideration will be formulated.

Résumé : Nous présentons quelques remarques concernant un certain aspect structurel de la démarche Dynamique des Systèmes. Une d'entre elles est liée à l'hypothèse classique quant aux taux qui caractérisent les variables de flux dans les modèles de Dynamique des Systèmes. La possibilité d'étendre cette description a déjà été présentée par l'auteur dans diverses publications. L'idée principale consiste à « incorporer » les équations matricielles au sein d'un structure de Dynamique des Systèmes classique. En appliquant la méthode de Gauss ou de Legras, on résout un système d'équations algébriques (par exemple : balance des masses ou des coûts, ou de travail) en inversant la matrice d'un tel système, pendant le processus de simulation du modèle dynamique.

La deuxième remarque a trait au problème du caractère normatif des approches de type « optimisation », liées au processus de simulation de modèles dynamiques. Des travaux en ce sens ont été entrepris par divers auteurs, en particulier par les professeurs Coyle et Kasperska et leurs collègues.

Le problème d'incorporation de l'optimisation au sein de la simulation, et vice versa, sera étudié ici dans le contexte de l'évolution de structure de modèles de Dynamique des Systèmes, et en particulier leur simplification. On proposera en conclusion quelques idées concernant l'approche décrite.

1 Introduction

The structural problems, within System Dynamics method, seems to be still of the first importance. The world famous theory of Forrester[1 2 3 4], Coyle[5 6 7 8], and many others, are based on some assumptions generally know on the field. Last couple of years some ideas of extending the description of the structure of: rates, levels and auxiliaries, has occurred. The Kasperska's idea of "embedding" the matrix equations in classical structure of SD was already described in some papers[9 10 11 12].

---

[1] FORRESTER J. W. (1961), *Industrial Dynamics*, MIT Press.
[2] FORRESTER J. W. (1969), *Urban Dynamics*, MIT Press.
[3] FORRESTER J. W. (1971), *World Dynamics*, Wright-Allen Press, (Massachusetts).
[4] FORRESTER J. W. (1972), *Principles of Systems*, Cambridge Press, (Massachusetts).
[5] COYLE R. G. (1978), *System Dynamics – the state of the art,* p. 3-23, Dynamica 5.
[6] COYLE R. G. (1994), *Cosmic and Cosmos. User manual,* The Cosmic Holding Co.
[7] COYLE R. G. (1996), *System Dynamics Modelling. A Practical Approach.* Chapman & Hall.
[8] COYLE R. G. (1998), *The practice of System Dynamics: milestones, lessons and ideas from 30 years experience,* p. 343-365, System Dynamics Rev. 14.
[9] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2000), *Some extension of System Dynamics method – theoretical aspects,* Proc. 16th IMACS World Congress, M. Deville, R. Owens, ed., IMACS, 718-10, 1-6.

The next remark in paper will be concerned of the problem of normative character of approaches type "optimization", link with simulation on SD models. Such efforts were undertaken by few authors, last years mainly by prof. Coyle[13]. Kasperska with her colleagues has applied the idea of embedding optimization in simulation and vice versa in papers[14 15 16 17 18].

Specially the problem of evolution of structure of SD models (for example: simplification) was the point of interest for author.

2 Some remarks about chosen structural aspect of System Dynamics method

The classical assumption of the system Dynamics method mentions only one property of flow, which is analysed and modeled , the so called "rate of flow". The requirements of practical application compel the addition of some more characteristic of flows. The problem of possibility of extension of this description was already undertaken by Kasperska.

The main idea consists in „embedding" the matrix equations is classical structure of SD. One of the author's first attempt of such "embedding" was described in papers[19 20]. In figure 1 on example of the production system, in view of Łukaszewicz[21 22] symbols, is presented.

---

[10] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2000), *Some extension of System Dynamics method – practical aspects*, Proc. 16th IMACS World Congress, M. Deville, R. Owens, ed., IMACS, 718-11, 1-6.
[11] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2001), *Some dynamics balance of production via optimization and simulation within System Dynamics method.* 19th International Conference of the System Dynamics Society, J. H. Hines, V. G. Diker, R. S. Langer, J. I. Rowe, ed., SDS, 1-18.
[12] KASPERSKA E. (2002), *Cybernetic formulation of some functions of management – types of simulation and optimisation approaches within the System Dynamics method.* 20th International Conference of the System Dynamics Society, P. I. Davidsen, E. Mollona, V. G. Diker, R. S. Langer, J. I. Rowe, ed., SDS, 1-11.
[13] COYLE R. G. (1999), *Simulation by repeated optimization*, p. 429-438, J. Opt. R. S. 50.
[14] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2002), *Optimal dynamical balance of raw materials – some concept of embedding optimisation in simulation on system dynamics models and vice versa.* 20th International Conference of the System, P. I. Davidsen, E. Mollona, V. G. Diker, R. S. Langer, J. I. Rowe, ed., SDS, 1-23.
[15] KASPERSKA E., SŁOTA D. (2003), *Two different methods of embedding the optimisation in simulation on model DYNBALANCE(2-2)*, 21st International Conference of the System, Dynamics Society , P. I. Davidsen, E. Mollona, V. G. Diker, R. S. Langer, J. I. Rowe, ed., SDS, 1-23.
[16] KASPERSKA E. (2005), *Dynamika Systemowa – symulacja i optymalizacja (in Polish)*, Silesian University of Technology Eds. Gliwice.
[17] KASPERSKA E., MATEJA-LOSA E. (2005), *Simulation embedded in optimization – a key for the effective learning process in (about) complex, dynamical systems*, ICCS 2005, LNCS 3516, 1040-1043. Springer Verlag Berlin Heidelberg.
[18] KASPERSKA E., SŁOTA D. (2005), *Optimization embedded in simulation on models type System Dynamics - some case study*, ICCS 2005, LNCS 3514. 837-842, Springer Verlag Berlin Heidelberg.
[19] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2000), *Some extension of System Dynamics method – theoretical aspects*, Proc. 16th IMACS World Congress, M. Deville, R. Owens, ed., IMACS, 718-10, 1-6.
[20] KASPERSKA E., MATEJA-LOSA E., SŁOTA D. (2000), *Some extension of System Dynamics method – practical aspects*, Proc. 16th IMACS World Congress, M. Deville, R. Owens, ed., IMACS, 718-11, 1-6.
[21] ŁUKASZEWICZ R. (1975), *Management Systems Dynamics (in Polish)*, PWN, (Warsaw).
[22] ŁUKASZEWICZ R. (1976), *The direct form of structure models within System Dynamics.* p. 36-43, Dynamica 2.

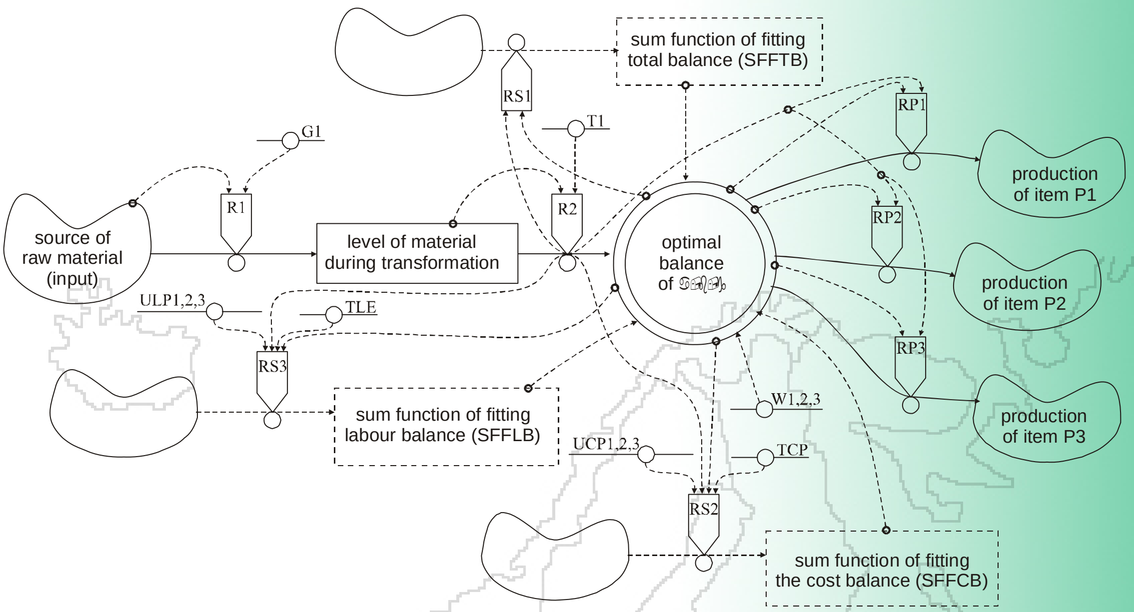

Figure 1. Dynamic balance of production

The dynamic balance of flows during simulation requires the Gauss method of solving the algebraic system of equations, by inverting the matrix of the system in the course of simulation. This method takes advantage of the some version of *DYNAMO for Windows*[23] operating on a category not common to the SD method – the so called: "array" (an array is not an ordinary matrix, its element can be: levels, rates, auxiliaries).

The matrices of system $Mx = b$ are:

$$M = \begin{pmatrix} 1 & 1 & 1 \\ UCP1 & UCP2 & UCP3 \\ ULP1 & ULP2 & ULP3 \end{pmatrix}, \qquad b = \begin{pmatrix} R2(t) \\ TCP \\ TLE \end{pmatrix},$$

where:

$UCPi$ - unit cost of the production of product $Pi, \quad i = 1, 2, 3$;
$ULPi$ - unit labour of the production of product $Pi, \quad i = 1, 2, 3$;
$R2$ - output rate of raw material (production);
TCP - total cost expenditure of production;
TLE - total labour expenditure of production.

In paper[24] Kasperska with her colleagues have applied the idea of constrained optimization to the idea presented above. It was interesting to investigate the so called "pseudosolution" of differences: $Mx - b$ (see Legras[25]) at the condition $x_i \geq 0, \quad i = 1, 2, 3$.

In such a case of balance of production, we have to solve the system of equations, which is created from the balance of the value of three properties of flow: mass balance ("rate of flow" in Forrester sense), cost balance and personal balance. The idea of such balances required the extension of matrix M to the form of:

[23] *Professional DYNAMO 4.0 for Windows. Reference manual* (1994), Pugh – Roberts Associates (Cambridge).
[24] KASPERSKA E., MATEJA-LOSA E., SŁOTA D., (2001), *Some dynamics balance of production via optimization and simulation within System Dynamics Method*, Proc. 19th International Conference of the System Dynamics Society, J. H. Hines, V. G. Diker, R. S. Langer, J. I. Rowe, ed., SDS, 1-18.
[25] LEGRAS J. (1974), *Methodes et Technique De L'Analyse Numerique*, Dunod (Paris).

$$M = \begin{pmatrix} 1 & 1 & 1 \\ ucp1 & ucp2 & ucp3 \\ ulp1 & ulp2 & ulp3 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where:
ucpi - unit cost of the production of product $pi, \quad i = 1, 2, 3$;
ulpi - unit labour of the production of product $pi, \quad i = 1, 2, 3$.
The matrix b should be extended to the form:

$$b = (r2, \quad tcp, \quad tle, \quad b4 \quad b5 \quad b6)^T,$$

where:
r2 - output rate of raw material (production),
tcp - total cost expenditure of production,
tle - total labour expenditure of production,
bi, i=4, 5, 6 - the number of large value.
The solution of equation:

$$Mx = b$$

has taken the form:

$$x = (M^T M)^{-1} M^T b.$$

It was not so complicated to programme such operation in *DYNAMO for Windows*. As the results of such "embedding", we achieved, in each step of simulation, the optimal balance of system $Mx = b$ (the "pseudosolution" minimizes the norm $\|Mx - b\|$).

Now, let's concentrate our attention on normative and evolutionary aspects of SD method. The problem of achieving the desired behavior of model (system) lies in choosing the objective criteria, which mappings the authors of model preferences in real economic situations. In the process of optimization the values of so called ordinary and structural parameters are chosen, what modifies the structure of system. Lets, for example, consider the problem of minimizing the cost of production from three raw materials, by the specific objective function, that takes in consideration the "penalty": from losse of profit from sale, and from cost of inventorying. Such model was already described in paper[26].
On this model Kasperska has made the simplification experiments[27]. The achieving structure was simpler then that in the beginning of the process of optimization. The evolution of the structures in automatic process programmed in *COSMOS*[28], we may compare with evolutionary process of learning during modeling the experiments on model (or rather – with model). Time for the conclusions.

---

[26] KASPERSKA E., MATEJA-LOSA E. (2005), *Simulation Embedded in Optimization – a key for the effective learning process in (about) complex, dynamical systems*, V. S. Sunderam, G. D. Albada (Eds): ICCS 2005, LNCS 3516, pp 1040-1043, Springer – Verlag Berlin Heidelberg.
[27] KASPERSKA E. (2005), *Symulacja na modelach o zmiennej strukturze a proces uczenia się (w) organizacji (in Polish)*, Proc. 23rd School of Systems Simulation, Duszniki Zdrój (Poland), In print.
[28] COYLE R. G. (1994) *COSMIC and COSMOS. User Manual*, The Cosmic Holding Co.

3 Final remarks and conclusions

The purpose of the paper was to present some remarks about chosen structural aspect of System Dynamics method. The structural aspects of SD seems to be of great importance since the pioneering works on the field. Last couple of years some ideas of extending the description of the structure and normative study type “optimization” have occurred. Final conclusions of the paper are as follows:

- The idea of “embedding” the matrix equations in classical structure of SD, allows to mapping many characteristics of flows, which represents its different properties.
- As a result of “embedding” matrix equations in SD structure, we achieve (in each step of simulation) the optimal balance of system: $Mx = b$ (the “pseudosolution” minimizes the norm $\|Mx - b\|$.
- The problem of achieving the desired behavior of system, lies in choosing the objective criteria, which mappings the decision – makers preferences in real economic situation.
- The evolution of the structure of the system can be in some way automated, supporting the learning process in (about) system (for example: process of simplification of the structure).