SYSTEM DYNAMICS APPROACH TO VALIDATION

Branko Grčić
University of Split, Faculty of Economics,
Radovanova 13, Split, CROATIA
e-mail: grcic@oliver.efst.hr

Ante Munitić
University of Split, Maritime Faculty Dubrovnik
Zrinjsko-Frankopanska 38, Split, CROATIA
e-mail: munitic@mvsrce.srce.hr

Abstract: Model validation is a problem that both social and natural sciences have been facing with for many years. During the last decades it became particularly pressing in social sciences due to the development of contemporary complex tools for the modelling of real social systems. The system dynamics methodology is one of these new tools. Although it has been developed through relatively long period of time, it was rather "closed" for critical opinions especially those referring to the validation of system dynamics simulation models. This paper presents an insight in the system dynamics approach to model validation. It takes into consideration all relevant discussions about this matter, as well as some of the procedures and criteria used so far in the system dynamics models validation. Moreover, based on the evaluation of their advantages and disadvantages, certain formal criteria are provided aiming to strengthen the credibility of these models.

1. Bases for sistem dynamics approach to validation of models

Validation of simulation models is one of the most important phases in the process of modelling real systems. A series of methods and procedures has been developed so far for the purpose of building confidence in the real system models. Conversely, however, there is no universal concept or original procedure that could be applied to all cases when we want to represent the real system with a model. This is particularly true of the system dynamics. The bases of the approach to building confidence in the system dynamics simulation models (SDSM) can be expressed under the following tenets:

- The confidence in the SDSM is being acquired through confirmation of validity of each individual structural or control element in the global model architecture, which elements represent the analogue parts of the real system. In this case we deal with the *conceptual or structural validation* based on the successive, semi-formal, that is, mostly qualitative and also the interdisciplinary process of building confidence in the conceptual structure of a model.

- The confidence in the SDSM is also developed by confirmation of the sufficient degree of correspondence of the dynamic model-generated behavior of the modelled system with the observed or expected behavior (depending on whether the system has or has not its past) of the same system. Here, we speak about the *behavior validity tests* relying mostly upon formal, that is, quantitative methods and criteria.

Further in the paper we shall concentrate on these behavior validity tests and, besides mentioning the so-far utilized formal testing criteria and procedures, we shall propose another possible concept for shesking the replicative validity of the SDSM.

2. Formal tests of validity of the SDSM

In numerous papers dealing with the problem of validation of the SDSM's a criticism has been noted stating that the system dynamics insufficiently utilize formal and impartial quantitative procedures for testing the quality of models. The application of formal, quantitative validity tests in the system dynmics has been limited indeed. The reasons are manifold. One of them is the preference for conditional, "inaccurate" projection of the general dynamics of the modelled system (so-called *behavior pattern prediction*), as opposed to other methods of the simular purpose aiming at more precise estimate or prediction of the numerical value of a particular variable (so-called *point prediction*). Of no less importance is the dominating deterministic character of the SDSM's which affects the domain by unabling the application of the standard statistical representative tests. The application of the statistical tests in the system dynamics has also been limited by unfulfillment of the basic assumptions for their utilization (Barlas, 1989). One of the features of the system dynamics approach, among others, is in its aiming to include in a model as much as possible of those information that are estimated to contribute to the more complete description of global dynamic features of the modelled system. This often results in an inclusion of the deficiently accurate or even unmeasurable variables of the subjective character, thus elimanting in advance the posibility to apply any type of formal, quantitative validity test (Forrester and Senge, 1986). Another reason is related to the information system support: due to the most frequently long-term character of the SDSM's it is usually difficult to provide for the sufficiently longlasting and reliable series of historical empirical data, which also reduces the posibility of applying the formal validity criteria.

Regardless the aforementioned significant limitations to the application of formal validity tests of the SDSM's, the development of the system dynamics methodology has been accompanied with the constant striving after objectivity and strengthening of the integral process of building confidence in models by introducing certain formal criteria or procedures. One of the most remarkable contributions is that of *Y. Barlas* (Barlas, 1989) who concentrated on the very general behavior pattern validation of the behavior generated by the SDSM, which explains our giving him a prominence here. The starting - point of the Barlas's approach is the comparison of the model generated behavior pattern with the actual, that is, the observed behavior of the key variables of the modelled system. Here, a fact is taken into consideration, that the SDSM-simulation outputs are indeed the time series of data, the break down of wich creates a basis for comparison of the main dynamic features of these series and for conclusion making on the degree of their correspondencem, i.e. on the validity of the behavior pattern generated by the simulation model. Dynamic features, i.e. the time series components that are being obtained through the mentioned break down, are the following: *trend, oscillation period, oscillation phase, average value* and *the cycle variation amplitude.*

Of interest for this paper are the application limitations of the Barlas's multiple validity test, which the author himself emphasizes (Barlas, 1989). With respect to the steps of this procedure and to their interdependence it can be concluded that the procedure presumes the existence of a stationary, of the long-lasting stability and of the cyclic behavior pattern of the modelled system. On the other hand, this means that the procedure is inappropriate to validation of behavior during a relatively short period of time, particularly to the explicitly unstable and nonstationary behavior patterns. In such cases it is recommended to utilize the comparison of the original with the simulated behavior based on the graphic representation, that is on the approximate visual estimate.

However, the mentioned limitations otherwise permit and even stimulate the application of the so-called point-oriented approach whenever possible. Therefore, further in the paper, a particularly prepared "*statistical-validation block*" - the subroutine adjusted to the aforementioned point-oriented approach or the replicative validation of the SDSM is offered.

187

3. "Statistical-validation block - STV" of the SDSM

The selected simulation model formal validity criteria constituting the "STV" are of the known statistical-econometric character: *RMS-simulation error, RMS-percent error* and *Theil's inequality coefficient* (Koutsoyiannis, 1981), all assigned to estimation of the representativeness of each particular endogenous variable in the simulation model on the basis of the previously mentioned point oriented approach. The fundamental supposition for utilization of these criteria is that there exists a series of the observed data on the corresponding endogenous variable trend. The additional requirement at structuring of the subroutine "STV" is the possibility of its direct incorporation into the structure of any SDSM. This is provided by programming the subroutine in one of the known system dynamics programming languages, thus enabling the "STV" to serve not only for validation but also as a criterion for optimization of parameters within the model structure.

Further on, a general structural model "STV" of the universal subroutine for formal testing of the so-called replicative validity of the SDSM has been presented (*Figure 1*):

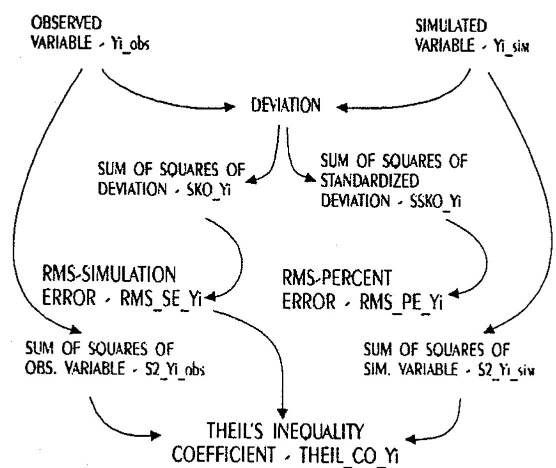

Figure 1. **Illustration of the general structural model "STV"**

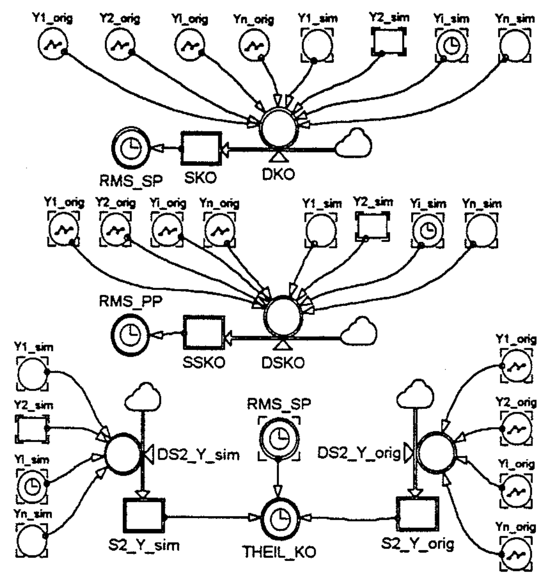

Figure 2. **Flow-diagram of the "STV"**

The "STV"-flow diagram in the POWERSIM notation, as illustrated in Figure 2, inevitably makes the integral part of the flowchart of every SDSM that utilize such approach to model validation.

In the DYNAMO notation, *the "STV" computer form* on the example of only one selected endogenous variable "Y" looks as follows:

```
L    SKO_Y.K = SKO_Y.J + DT*DKO_Y.JK      - state of summation of squares of the
                                            deviation of the Yi_obs from Yi_sim
N    SKO_Y = 0                            - initial state of summation of squares of the deviation
R    DKO_Y.KL = (Y_obs.K - Y_sim.K)**2    - increment of squares of the deviation
A    RMS_SP_Y.K = SQRT(SKO_Y.K / TIME)    - RMS-simulation error for variable Y
L    SSKO_Y.K = SSKO_Y.J + DT*DSKO_Y.JK   - state of summation of squares of the
                                            standardized deviation of the Yi_obs from Yi_sim
N    SSKO_Y = 0                           - initial state SSKO_Y
```

```
R    DSKO_Y.KL = ((Y_obs.K - Y_sim.K)/Y_obs.K)**2        - increment of squares of the
                                   standardized deviation
A    RMS_PP_Y.K = SQRT(SSKO_Y.K / TIME)    - RMS-percent error for variable Y
L    S2_Y_sim.K = S2_Y_sim.J + DT*D2_Y_sim.JK            - state of summation of squares
                                   of the simulated variable of the variable Y
N    S2_Y_sim = 0                 - initial state of the squares summation
R    DS2_Y_sim.KL = Y_sim.K**2    - increment of squares of the simulated variable Y
L    S2_Y_obs.K = S2_Y_obs.J + DT*D2_Y_obs.JK            - state of summation of squares
                                   of the observed value of the variable Y
N    S2_Y_orig = 0                - initial state of squares summation
R    DS2_Y_orig.KL = Y_orig.K**2  - increment of squares of the observed value of variable Y
A    THEIL_KO_Y.K = RMS_SP_Y.K / (SQRT(S2_Y_sim.K / TIME) +
                     + SQRT(S2_Y_orig.K/TIME))          - Theil's inequality coefficient
```

4. Conclusion

Emphasizing the informal, mostly qualitative character of the system dynamics approach to validation of simulation models on one side, that is, giving minor prominence to the formal, quantitative tests and procedures, on the other side, have very often been the subject matter of discussions and even of criticisms in the scientific circles dealing with the real systems modelling in general. The reactions of the system dynamics experts to such discussions and criticisms are variant: from those which emphasize the objective limitations to application of the traditional formal criteria and validity tests in the system dynamics, to those which, taking into consideration the aforementioned limitations, tend to the development of certain formal, quantitative procedures applicable to the validation of the SDSM's. The Barlas's multiple test procedure represents one of the attempts to establish the logical sequence of a certain number of the formal validation criteria and is adjusted primarily to testing the degree of correspondence of the geberal model-generated behavior pattern to the original or observed behavior of the real system (the behavior pattern validation). However, this procedure is suitable for the validation of models of a limited number of the real systems that have a longterm history of the stationary and, most often, of the cyclic behavior. Among others, this is the reason why another formal validation concept has been offered in this paper through the so-called "STV" validation concept consisting of the three point-oriented criteria-indicators. By incorporating the special subroutine "STV" directly into the structure of any SDSM it is not only possible to test efficiently the degree of correspondence of the simulated to the observed values of the main variables in the model, but also perform the additional, heuristic optimization of the model parameters utilizing the mentioned indicators as the optimization criteria.

References:

1. Barlas, *Multiple tests for validation of system dynamics type of simulation models,* European Journal of Operational Research, 42(1989), str. 59-87.
2. Y. Barlas and S. Carpenter, *Philosophical roots of model validation - two paradigms,* u: System Dynamics Review, No 2/1990, SD-Society, MIT, Massachusetts, str. 148-166.
3. G.E.P. Box and G.M. Jenkins, *Time Series Analysis,* Forecasting and Control, Holden-Day, San Francisco, CA, 1970.
4. J. Forrester and P.M. Senge, *Tests for building confidence in SD models*, u: A.A. Legasto Jr., J. Forrester and J.M. Lyneis, Eds., System Dynamics, TIMS Studies in the Management Sciences 14, North Holland, Amsterdam.
5. A. Koutsoyiannis, *Theory of Econometrics,* Second Edition, The MacMillan Press Ltd, London, 1981.
6. *POWERSIM - The Complete Software Tool for Dynamic Simulation,* User's Guide and Reference, ModellData AS, Norway, 1993.