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Małgorzata Łatuszyńska*

Szczecin University

PROBLEMS OF VERIFICATION AND VALIDATION OF COMPUTER SIMULATION MODELS

Summary

One of the most difficult issues, which a creator of a computer simulation model has to face, is to check, whether the constructed model adequately describes the modeled reality – that is to say, whether it is credible. In theory of computer simulation, the process of determining the model credibility is related to the concepts of verification and validation (W & W). This article aims to discuss the importance of validation and verification of simulation models, conceptual scope of these two terms, the relationship between the process of W & W and the various stages of modeling and simulation, and methods that can be used to determine the degree of reliability of a computer simulation model.

Keywords: computer simulation, model validation and verification

Introduction

One of the difficult problems that any author of a computer simulation model[1] has to face is how to confirm that the constructed model is a reasonable imitation of the real world, i.e. if it is credible. The final proof of the model credibility is its acceptation by the users. In the theory of computer simulation the process of confirming the model credibility is associated with the terms of *verification* and *validation* (Fishman, Kiviat 1968).

* mlat@wneiz.pl

[1] A computer simulation model is a logical and mathematical presentation of a term, a system or activities programmed in order to be solved by means of a computer (see Martin 1976, p. 13). Such a model is applied in recording the performance of a modeled system.

It is widely assumed in the reference literature (see the definitions in Table 1) that the *verification* is the process which confirms that the model has been correctly constructed. In other words – that the conceptual model has been transformed into a computer model with due diligence (Davis 1992). The *validation* is the process of building confidence in the model reasonability and applicability, that is of affirming that the model possesses a satisfactory range of accuracy consistent with the object and the purpose of the study (Carson 1986; Forrester, Senge 1980; Coyle 1977). To put it differently, it is a process of substantiating the range of the real system representation in the context of the specific model purpose, since it is the model applicability that determines both the aspects to be validated and the level of the validation detail (Mielczarek 2009).

Table 1

Definitions of validation and verification of the simulation model according to selected authors

Source	Validation	Verification
Schlesinger et al. 1979	Confirming that the model possesses a satisfactory range of accuracy consistent with its specific purpose	Confirming that the computer model is a sufficient representation of the conceptual model
Balci 1997	Substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the model and simulation objectives	Substantiating that the model is transformed from one form into another with sufficient accuracy
Robinson 2004, p. 209	Validation is a process of ensuring that the model is sufficiently accurate in relation to the examined system and the purpose at hand	Verification is the process of ensuring that the model design (conceptual model) has been transformed into a computer model with sufficient accuracy.
Pietroń 2006	Validation of the model is based on confirming that the computer model in the experimental environment possesses a satisfactory degree of accuracy which is consistent with its intended application	Verification means confirming the correctness of the model transformation from a formal model to a computer program
Mielczarek 2009	Model validation is a process of ensuring that in the range of its intended application the model demonstrates satisfying accuracy which is consistent with the adopted research purpose	Model verification is a process of ensuring that the model transformation from one form to another has been satisfactorily accurate

Source: own study based on Balcerak (2003, p. 28) and the above mentioned literature.

To sum up, in the process of the model validation the modelers check if the model accurately imitates the reality, whereas the purpose of verification is to confirm that the conceptual model has been correctly translated into a computer program. So, verification deals with the internal coherence of the model, while validation refers to the relationships between the model and the real world.

It should be noted that the meaning of the terms of *verification* and *validation* often varies. Some authors claim that distinguishing these two notions is a thing of the past and they regard them as synonymous (e.g. Pidd 1998, p. 33), while others consider verification as close in meaning to validation (e.g. Feinstein, Cannon 2003). The majority, however, agree that verification is a necessary, although insufficient, stage of validation (Balcerak 2003, pp. 27–44). Verification has a more narrow connotation and can be treated as an element of a broader process of validation (Robinson 2004, p. 209). In this article both notions are considered as two separate, equally important and overlapping stages of the modeling procedure that make up the process of testing the model applicability.

In the last few years many papers have been published concerning the verification and validation (V & V) of simulation models. In all of them the authors have underlined that until now no consistent V & V theories have been developed, nor methodological standards have been proposed. The purpose of this article is to point out the relations between the V & V process and the individual stages of simulation modeling as well as to present the techniques to be used for the V & V of simulation models.[2]

1. Validation and verification in the simulation modeling process

Simulation modeling is a system of activities selected specifically for the purpose of the research objective. Generally speaking, the process consists of three main phases:

- analysis and modeling,
- programming and implementation,
- experimenting.

More precise description of the simulation modeling process can be found in many publications, e.g. Naylor (1975, p. 33) and Gordon (1974, p. 37).

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In the analysis and the modeling phase a problem is defined in reference to the examined real system. Then a research objective is determined on the basis of which a conceptual model, i.e. a mathematical/logical/verbal representation of the examined system is created. In the programming and implementation phase modelers build a computer (or operational) model which is designed to be solved by means of a computer. Finally, in the experimenting phase, modelers carry out simulation experiments on the computer model, on the results of which the conclusions concerning the examined system are drawn (Sargent 1999).

The V & V are performed during each of the above modeling phases, i.e. on three fundamental levels of the simulation: the system related problem, the conceptual model and the operational (computer) model. The validation refers to the data, the conceptual and the operational model, whereas the verification concerns the computer model (the computer program), as shown in Figure 1 (Pietroń 2006).

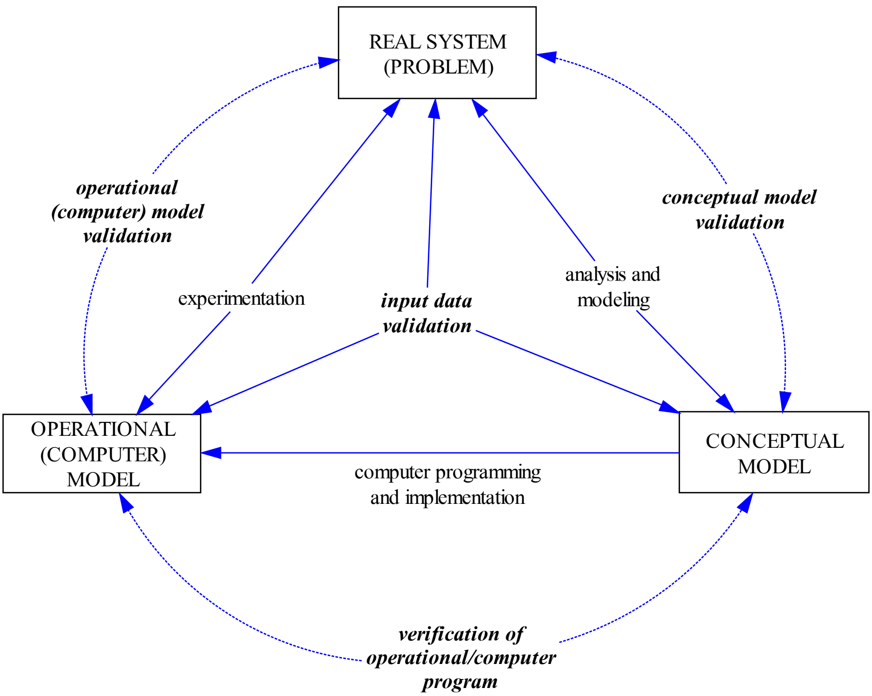

Figure 1. Validation and verification in the simulation modeling process

Source: own study based on: Sargent 2010 and Pietroń 2006.

The validation of the input data, the conceptual and operational models as well as the verification of the computer models are parts of the so called multi-level verification and validation of the simulation model (Mielczarek 2009, p. 107). There are also other approaches, e.g. Tyszer (1990, p. 163) uses the terms of retrospective (historical) and prospective (forecast) validations, while Zeigler (1984, pp. 25–26) distinguished three validation types: replicative, predictive and structural.

The input data validation can be defined as the process of ensuring the accuracy of the information about the real system that is needed in order to construct and to evaluate the model as well as to test it and carry out simulation experiments in order to solve the problem. Data credibility refers to their adequacy, preciseness, consistency and completeness (Pietroń 2006). Unfortunately, there are no ideal ways to confirm that the data are correct. All that we can do is develop good procedures of: (1) data collecting and updating; (2) testing the collected data through controlling their internal consistency; (3) data screening for outliers and determining if they are correct. When we deal with numerous data, the best option is to create a data base and keep it updated (Sargent 2010, p. 172).

The validation of the conceptual model (called the conceptual validation) aims at proving that the hypotheses and assumptions on which the conceptual model has been built are right and that the model representation of the real system, its structure, causal, logical and mathematical relations are rational within the intended range of the model application (Sargent 1999). So, the conceptual validation means the evaluation of the model assumptions and the qualitative assessment of the model structure and logics. The model assumptions (concerning e.g. linearity, independence of data or the stationarity of probability distributions) are tested by means of specific statistical methods, while the structure and logic are examined through *face validity*[3] and/or by event tracking technique where chosen dynamic objects are being tracked down when they are travelling within the model in order to analyze how logically and precisely the events are depicted (Mielczarek 2009, p. 108).

Verification of the computer model (program) aims to confirm that the code of the program describing the model has been developed correctly and that the

[3] The technique is based on confirming the model applicability by people who are knowledgeable of the real world system (expert or users). Special attention is paid to the reasonableness of the model or of its behavior, e.g. by confirming that the structure logic (the block diagram of the model) is proper and of the input-output relation is right (Pietroń 2006).

conceptual model has been accurately translated to the programming language (Sargent 1999). High quality of the computer program is ensured by software engineering which can apply numerous methods, techniques and tools to build satisfactory customer confidence in an IT product (Mielczarek 2009, p. 108). The programs (written in a general purpose language or in specialist languages) can be tested by means of a static method (e.g. by sequential testing of the algorithm or program instructions) or a dynamic method (e.g. by tracking the program behavior, top-down or bottom-up testing). See more on the methods of program testing in e.g. Jaszkiewicz (1997, pp. 189–204).

Table 2

Types of operational validation methods

	Observable system	Unobservable system
Subjective approach	Comparison of the data generated by the model and observed in the real system by means of the graphic output presentation Analysis of the model behavior	Examination of the model behavior by means of sensitivity analysis Comparison with the output generated by other models
Objective approach	Comparative analysis by means of the statistical procedures and tests	Comparison with the results generated by other models by means of statistical tests

Source: Sargent (2010, p. 174).

Operational validation checks if the output generated by the model in the context of the specific objective and the problem of the study is accurate enough for the model to be used in practice. Many methods and testing techniques of subjective-objective character are applied in the operational validation. Sargent organizes them depending if the system is observable or unobservable (i.e. it is possible to collect data concerning the operational behavior of the model) as presented in Table 2.

2. Techniques of V & V of simulation models

As mentioned before, at all stages of validation and verification modelers make use of various methods, techniques or validation and verification tests. In the reference literature we can find over 77 techniques of verification and validation of the simulation models which can be divided into four groups: formal, informal, static and dynamic ones (Balci 1997).

Informal techniques are mainly based on evaluating the model behavior according to the experts' subjective opinions. They are used with a view to decide if logical dependencies in the conceptual model as well as the model input-output relations are correct. The opinion is founded only on the observation of the model performance and no additional tests are conducted. Most common tests in this group (Balci 1997) are: the Turing test,[4] audits,[5] inspections[6] and the face validation.[7]

By means of static techniques we estimate the accuracy on the basis of the characteristics of the static source code. They primarily concern the process of the computer model verification and do not require starting the model. The correctness of the computer program code is assessed; the semantic and syntactic analysis is made; the structure and interface are examined, both in terms of the possible user's errors and the connection with the simulation model. The compiler for the simulation language is itself a tool for static validation. The most popular methods in this group are (Balci 1997) the consistency check, the data flow analysis, the structural analysis and the syntactic analysis.

The dynamic techniques require starting the model and are based on the examining the model behavior by observing its performance. The performance assessment can be made by comparing several different models simulating the same real system with the same input data. This group of techniques includes (Balci 1997): statistical techniques (the variance analysis, the regression analysis, statistical checks, consistency checks – the Chi-square test, Kolmogorov-Smirnov test, the confidence interval estimation), the sensitivity analysis, the visualization and animation of model behavior, the black box testing, the top-down or bottom-up testing, the visualization and the transparent box testing.

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[4] In the Turing test an expert (a person knowledgeable on the examined system) tells if the presented results come from a real system or from a model.

[5] Audits are the reviews of the work results and processes, usually conducted by external experts.

[6] Inspections are the techniques of visual analysis of the output of individual stages of the model creation applied in order to identify problems and to solve them.

[7] Face validation is conducted by specialists knowledgeable of the real system (experts, users) comparing the model behavior to the real system under identical input settings in order to confirm the model validity – in particular the reasonability of the model or its behavior, which is done by testing if the structure logic (a block diagram of the model) is appropriate and if the input-output relation is correct.

The formal techniques base on mathematical proofs of the model correctness. Although our today's scientific knowledge does not allow us to use them in the complex systems, they are a basis for other methods of the model validation and verification, such as the logical induction, conclusion and deduction or the predicate calculus. More on the techniques and methods of the simulation model V & V see e.g.: Martis 2006; North, Macal 2007, pp. 221–234; Ijeoma et al. 2001.

3. Approaches to the V & V of simulation models

There are four principal approaches to the validation and verification of simulation models. Each of them requires the V & V to be a part of the model construction procedures (Mielczarek 2009, p. 111; Balci 1998).

One of the most popular ones is conducted by a modeling team themselves. In this case the decision if the model is credible or not is made subjectively throughout the process on the basis of the results of the applied V & V techniques. However, the designers' decision can be too subjective, so it has been recommended in the reference literature to apply any of the other approaches, depending on a case (Sargent 2010).

If a team developing the model is small, they would rather ask the prospective model users to test the model validity. In this approach the responsibility for the model validation decision is transferred from the model designers to the model users (Sargent 2010).

Another approach, called the Independent Validation and Verification (IV & V), means that a third party is included in the decision-making process concerning the model credibility. That party must be independent from both the modeling team and the prospective model users. This approach is particularly recommended in case of big models, in the development of which several teams and high costs are involved. It is crucial for the third party to understand correctly the purpose of the model. Independent Validation and Verification can be conducted in two ways: (a) as parallel to the model construction and (b) after the simulation model has been built. In the former case the IV & V entity informs the modeling team about their opinion concerning the work done. The modelers cannot continue until the IV & V is not satisfactory. In the second version the evaluation can take various forms – from a simple acceptation of the V & V results presented by the modeling team to a sophisticated and also very cost and time-consuming procedure. Many authors claim that performing IV & V after the model has been completed is not efficient enough and, once chosen, it should be limited to the evaluation of the effects of V & V that has been done by the designers themselves (Sargent 2010; Wood 1986).

The last but not least approach to V & V is the scoring model. The examples of such models are given by e.g. Balci (1989), Gass (1993), Gass and Joel (1987). Various V & V aspects are attributed a certain number of points that are then summed up at individual V & V stages or make up a final score for the completed model in general. The simulation model is regarded as credible when the general score and the score of individual categories is larger than a certain defined value. Such an approach is rarely used in practice because it has its defects: (1) the model can receive a satisfactory number of points and still have errors that need to be corrected, (2) its ostensible objectivity is in fact subjective since the decision about the acceptable number of points is (usually) biased, (3) it can result in too much confidence in the model and (4) the scoring can be used as an argument to prove that one model is better than another (Sargent 2010).

Conclusions

The validation and verification procedures are a particularly important element of the simulation modeling process. Without conviction that the model is credible and that its output is correct it is not possible to use it as a decision-making tool. The V & V of simulation models is a difficult and time consuming process that requires extensive testing and assessment. Therefore it is crucial to perform it with certain rules in mind. Balci (1998) mentions several of them (see Table 3).

Table 3

Rules of the V & V of simulation models

No.	Rule
1	2
1	Validation and verification must be performed continually throughout the whole cycle of the simulation modeling
2	The V & V results cannot be interpreted on a true-false basis, i.e. assume that the model is absolutely correct or completely incorrect. The model is just a representation of the real world and as such cannot be fully correct

1	2
3	The simulation model is built with specific purpose in view and the assessment of its credibility must be performed within the range of this purpose
4	The V & V should be done by an independent entity. The model author usually (and often subconsciously) tends to confirm the validity of their work
5	The V & V process is difficult, it requires creativity and the ability to make an in-depth analysis. It is necessary to be knowledgeable of the system the model imitates, have experience in the V & V and expertise in simulation modeling
6	The model credibility can be confirmed only in the conditions in which tests have been performed
7	It is not possible to perform comprehensive testing of the model. The combination of all possible values input variables can lead to millions of sets of input parameters
8	The V & V process must be designed and documented
9	The model should be protected against type I, II and III errors (type I error happens when we reject the correct simulation effects; type II – when we accept the false simulation effects; type III – when we are working on a wrong problem or when the description of the problem does not contain a fully defined purpose of our study)
10	Model errors should be detected as soon as possible
11	We should recognize the possibility of the so called multiple model response. In case of several input variables we are not able to subsequently compare simulation effects with the values produced by the real system. For this reason a multivariate statistical analysis should be performed
12	Successful testing of sub-models do not confirm the correctness of the model in general. The errors that are acceptable in the sub-models can cumulate and, consequently, the whole model will be encumbered with a significant error
13	The problem of double validation should be spotted and solved. If it is possible to obtain for the system both input and output data, the V & V can be done by the comparison of the output of the model and the real system obtained in the same input situation. The problem lies in defining the correctness of input data – thus the term of double validation
14	The simulation model correctness is not a guarantee that the simulation effects will be correct as well
15	The accuracy of the purpose largely affects the acceptability and correctness of the model output. The purpose of simulation is not to find any solution, but a solution that will be accepted and applied by decision-makers

Source: own study based on: Balci 1998 p. 42 and Mielczarek 2009, pp. 111–113.

To sum up the issue of the validation and verification of simulation models it should be underlined that it is not possible to prove that a model is absolutely correct. Therefore the primary purpose of the V & V should be to create such confidence in the model that its output can be accepted by its users.

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PROBLEMY WERYFIKACJI I WALIDACJI KOMPUTEROWYCH MODELI SYMULACYJNYCH

Streszczenie

Jednym z trudniejszych problemów, z którymi musi się zmierzyć twórca komputerowego modelu symulacyjnego jest sprawdzenie czy zbudowany model w sposób właściwy opisuje modelowaną rzeczywistość. Celem artykułu jest zaproponowanie dyskusji na temat znaczenia walidacji i weryfikacji modeli symulacyjnych, zakresu pojęciowego obu terminów oraz metod, jakie mogą być używane do określenia stopnia wiarygodności komputerowego modelu symulacyjnego.

Słowa kluczowe: symulacja komputerowa, walidacja i weryfikacja modelu