A Review of Validation Methods in Construction Simulations Studies

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***Abstract*— Simulation models are widely used to reflect the behavior of a certain system and to study the effect of specific changes on the overall system. Simulation models are used in the construction industry for problem solving, optimization or testing new methods. Implementing a new simulation model may face some challenges unless verification and validation of a model are performed to show that the model has achieved its objectives. Some simulation studies do not apply a systematic validation process to validate their model because of many reasons such as time, cost and the availability of data. This research project focuses on studying the validation methods used in construction simulation studies and how they are frequently used. Sixty papers were collected from three different sources: Automation in construction, Journal of Construction Engineering and Management, and Winter Simulation Conference. The selected 60 papers were studied, and it was found that not all simulation studies apply systematic validation processes. It was also found that the comparison with real data is the most widely used validation method in simulation studies. Besides, on the other hand, the comparison with expert opinion shows a good practice since it involves experts from the construction industry in the model building stage or by using their experience to evaluate the model output in terms of reliability.**

***Index Terms*—validation, verification, simulation, construction, modeling**

I. INTRODUCTION

A model is a representation of a system used to predict the consequences if a specific action is taken into account. Also, it is used to determine the properties of the system by driving inputs and observing outputs. Simulation is carried out to study the properties of an object or a system in small scale and reflecting the results into reality to help solve problems and to support the decision-makers by providing informative data [1]. Implementing simulation models effectively is the primary concern in the simulation world; that's why model verification and validation should be considered in any simulation model. Model verification means that the simulation program is working correctly with no execution errors and is consistent with the model. On the other hand, model validation means that the simulation model gives a satisfactory result close to reality. Model validation is an integral part of any simulation project because implementing a model without being validated might show the opposite results from what is expected [2]. The main objective of verification and validation is to make sure that the model is sufficiently accurate. In the validation and verification processes, several problems may arise, and it is essential to be recognized [1]:

- Real-world data sometimes may be inaccurate: simulation models usually developed to simulate or integrate a real system and the accuracy of the model is measured by comparing the simulation model data with the actual system data. The collected real data are samples, and if it is collected using the wrong procedure, it will provide incorrect representation of the real system. Real data in some cases have a fluctuating nature; for example, if the data are collected from the production facility at different times or periods, the data distribution will not be the same.
- No real-world may exist to compare against: some of the simulation models are to simulate a new system like production facilities, and these models may have no real data since there is no real system that exists in reality, therefore it is difficult to test or guarantee the validity of the model.
- General validity does not exist: simulation models are made to specific objectives, and the validation is only made to make sure that a model meets its objectives. General validity does not exist because of the difference is simulation models objectives and validating a model against a particular purpose does not mean that it is valid for another.
- Time availability: simulation models go through a long and, sometimes, iterative process, starting from model building to validation. Time restriction controls the ability to validate every aspect of the model. Cost also controls the time available for the model builder because the cost increases with time spent on the model.

Validation is an essential step in simulation studies because of the necessity of providing a valid model to

Manuscript received March 11, 2020; revised July 1, 2020; accepted September 1, 2020.

doi: 10.18178/ijscer.10.1.43-47

offer accurate data. This research work investigates the validation methods used in simulation studies, mainly in construction industry-related research. Journal and conference papers from three different resources (Journal of Construction Engineering and Management, Automation in Construction and Winter Simulation Conference) were reviewed. The reviewed papers from the three resources were studied to see how often a validation process is adopted in the simulation studies and what validation methods were most commonly used.

II. VALIDATION METHODS

A. *Validation Methods*

Many papers and books describe different types of validation techniques; some of them described the validation techniques in details and some of them in an aggregated way. Table I shows the different types of validation techniques described by Sargent [2].

TABLE I. VALIDATION TECHNIQUES [2]

No.	Validation Technique	Description
1	Face Validity	Face validity is asking people knowledgeable about the system, whether the model is reasonable.
2	Traces	The behavior of different types of specific entities in the model are traced (followed) through the computerized model to determine if the model's logic and the computer program are correct and if the necessary accuracy is obtained.
3	Historical Methods	- Rationalism Method: assumes everyone knows whether the underlying assumptions of a model are true. - Empiricism method: requires every assumption and outcome to be empirically verified. - Positive Economics method: requires only that the model be able to predict the future and is not concerned with its assumptions or mechanisms.
4	Multistage Validation	It consists of three stages: 1. Developing the model's assumptions on theory, observations, general knowledge, and intuition. 2. Validating the model's assumptions where possible by empirically testing them. 3. Comparing (testing) the input-output relationships of the model to the real system.
5	Internal Validity	Several runs of a stochastic model are made to determine the amount of stochastic variability in the model.
6	Sensitivity Analysis	This validation technique consists of changing the input and internal parameters of a model to determine the effect upon the model and its output.
7	Comparison to Other Models	Comparison of the simulation model results with other validated simulation model.
8	Historical Data Validation	Using part of historical data (if it is available) to build the model and using the remaining parts to validate it.
9	Predictive Validation	The model is used to predict the system behavior and tests are made to determine if the system behavior and the model's forecast are the same.
10	Event Validity	The events of occurrences of the simulation model are compared to those of the real system to determine if they are the same.
11	Live Graphics	Computer output graphics of the model's operational behavior are evaluated.

In simulation study process, validation and verification are sometimes performed in parallel, and it is described as in different ways such as Conceptual Model Validation, Data Validation, White-Box Validation, Black-Box Validation and Experimental Validation [3].

The Conceptual Model Validation is determining that the content, theories and assumption are correct and the problem entity representation in the model logic, structure and mathematical relationships are reasonable. The theories and the assumption of the model are normally tested using statistical methods and numerical analysis [4].

Data Validation is usually time-consuming, difficult and costly. Data usually used for three purposes; developing the model, validating the model and to exercise the approved model. Sufficient data related to the problem is the main key point to establish the theories and assumption for the models as well as to develop the logical and mathematical relationships in the model. A large amount of data makes the validation easier, but with a small amount of data; it will be difficult to analyze it, and a certain statistical method should be used like Boot Strapping. Furthermore, this process is associated with problems such as redundant data, lost data, inconsistent data, mismatched data etc. [5].

White-Box Validation is determining that the model parts represent the real-world element with good accuracy, while Black-Box Validation is determining that the overall model represent the real world with good accuracy. Both White- and Black-box Validation comes under what is called “operational validity” which is determining that the output behavior of the simulation model has sufficient accuracy for the model to represent the real world. Operational Validity usually follows two steps validation process, which is exploring the model behavior and comparison of output behavior. The comparison of output behavior can be either with real data, other validated model or with expert opinions [3].

The other validation method is called Experimental Validation which means that the experimental procedure is providing accurate results for the purpose it was made for.

B. *Validation of Output Behavior in Simulation Studies*

Various validation methods are implemented in simulation studies. Comparison with an existing system is widely used in validating a simulation model. The output data of the model is compared with the output data from the existing system, and if the data show close values, then the model is considered valid. This way, validation uses numerical statistics like sample mean, sample variance and correlations functions. For example, Hong and Hastak [6] carried out a project, studying the simulation on the construction process of FRP bridge deck panels. Hong and Hastak [6] used a simulation study to determine the productivity and cost per hour of installing fibre-reinforced polymer (FRP) bridge deck panel and partial- depth precast concrete deck construction, and the simulated output results were compared with an existing system results for validation purposes. Two statistics were used in this project for comparison, which is operating count and means duration. The comparison showed that the two values from the simulation model and the existing system are almost the same and the model is valid for implementation. Chana and Lu [7] carried another simulation project on material handling system simulation in precast viaduct construction. The project objective was to improve the effectiveness of the material handling system on a precast viaduct construction project by using simplified discrete-event simulation approach. Monte Carlo technique was used in the project to validate the output data (average total cycle duration, and the probability of completing the operational cycle before a specified time) by comparing it with the existing system data.

Another approach of validating a simulation model is by comparing the output data of the model with expert opinion or decision-makers whether or not there is an existing system. This validation method was used by Baldwin, Austin, Hassan, and Thrope [8]. Baldwin, Austin, Hassan, and Thrope [8] carried a project in planning building design by simulating information flow. The author described the simulation model development, validation and the potential application during the planning and design phases of building projects. The model was based on discrete event simulation, and the discipline-based information flow models of building design processes were used to define the activities of the simulation model. The model was validated by extended demonstrations to professionals responsible for design management within three large construction organizations. The demonstrations were carried to get feedback on the operations and output by distributing a questionnaire to design managers. The model was validated, and the project showed the feasibility of modeling the building design process using a discrete event technique.

Model to model comparison validation method is also used to validate simulation models. In this method, numerical statistics or graphical plots of the model can be compared with the comparable numerical statistics or graphical plots from the other validation model.

C. *Statistical Methods for Validation*

Simulation models usually use statistical methods is their validation process. The statistical methods depend on the data availability so that the comparison of the simulated data with real data can be performed. Kleijnen [9] defined simulation as experimentation which requires statistical analysis, proceeded by statistical design and if mathematical statistics is used, then the correct statistics should be applied. The kind of data available controls the statistical procedure to be used and it is discussed in three cases by Kleijnen [9] as follow:

- Case 1: No data is available

In this case, the expert knowledge is used to obtain quantitative knowledge utilizing simulation and the model is developed based on expert knowledge which a qualitative knowledge. If the model input and output behavior are violating the qualitative knowledge, then the model is questioned to investigate the error. It is impossible to claim for validation if data is not available and sensitivity analysis should be at least perform to measure or to examine the response of the simulation model to certain factors and to show whether these factors have effects that agree with experts prior qualitative knowledge. This process shows which factor is essential and how to change these factors to optimize the real system.

- Case 2: Real data output (Classic tests)

In this case, two statistical methods can be used, which are t-statistic and distribution-free tests or bootstrapping. The t statistic is a measure of how extreme a statistical estimate is. This statistic can be computed by subtracting the hypothesized value from the statistical estimate and then dividing by the estimated standard error. Usually, the hypothesized value would be zero but not in all situation. Bootstrapping is used for estimating the sampling distribution of an estimator by sampling with replacement from the original sample with the purpose of estimating of standard errors and confidence intervals of a population parameter like a mean, median, proportion, odds ratio, correlation coefficient or regression coefficient.

- Case 3: Real data input and output (Trace driven)

A Particular kind of regression analysis can be used in the trace-driven simulation. Regression analysis is computing the differences and sums of real and simulated outputs, regress these differences on the sums and test for zero intercepts and zero slopes. In non-normality case, bootstrapping of the difference between the average simulated and real outputs gives the best results.

III. How Common is the Validation Process Applied and What Common Validation Methods Used ?

In this research, work 60 research work was studied. The research papers were collected from three different sources that are Automation in construction, Journal of Construction Engineering and Management, and Winter Simulation Conferences. Articles having a word "Validation" as a keyword or appear in its title were only selected. It was found that ten different validation methods were used. Table II shows the types of validation methods used and their frequencies.

TABLE II. VALIDATION METHODS USED IN 60 PAPERS AND THEIR FREQUENCIES

No.	Validation Method	No. of Papers	%
1	Comparison with real data	33	55
2	Comparison with other models	6	10
3	Comparison with expert opinion (Face validity)	6	10
4	Sensitivity analysis	4	6.67
5	Experimental validation	2	3.33
6	Verification instead of validation	3	5
7	Traces	2	3.33
8	Historical data validation	2	3.33
9	Internal Validity	1	1.67
10	Live Graphic	1	1.67

It can be seen from Table II that the comparison with real data is the most frequently used validation method. The comparison with real data has different naming, such as comparison with historical data or comparison with field data. The comparison in this method is typically carried in three different ways described as follow:

- A straight comparison of the model output with the real data.
- Comparing the model output with real data using a statistical approach.
- Comparison of the model output with real data using a graphical approach.

The second point is the most popular way of validating the output of the simulation model. The statistical approach is a very much dependent on the availability of the data, for example, if sample population distributions are measured and simulated, then overall populations tests are applicable like unpaired t-test or non-parametric distribution test [6]. In simulation studies, studies that use Comparison of the model output with the real data using a statistical approach, most of the simulation models are validated using the statistical technique by getting the mean, the root mean square, and confidence interval. For example, Huang, Chen and Sun [11] compared the average results of the model output with the real data. Lu and Lam [12] carried a research project on the simulation optimization integrated approach to planning ready mixed concrete production and delivery, and the average of the model output was compared with the average real data.

Comparison with other model is the easiest way to check the validity since all data is available to compare with. As an example of this method is presented by Marzouk and Moselhi [13] paper which was about object-oriented simulation model for earthmoving operations. The output of the model was compared to those generated using Caterpillar software.

Comparison with expert opinion provides good accuracy for the model since it depends on the participation of experts from the industry on evaluating and accrediting the simulation model. East, Martinez, and Kirby [14] used expert opinion validation method to provide credibility for their model. They included the direct participation of an expert in a continuous nature of participation which provides an ultimate proof that the model has been verified and validated.

Comparison with expert opinion is not widely implemented in simulation studies because of some reasons listed as follow:

- Very time consuming since the experts are busy in their business.
- It is expensive because the cost is directly related to time.

Sensitivity analysis, as discussed previously, is a validation technique that consists of changing the input and internal parameters of a model to determine the effect of parameters varies on the model and its output. Sensitivity analysis can be linked with graphical tests to compare and to check the trend of each variable when changed. Many papers used sensitivity analysis to check the effect of a different variable on the model. Still, an important question raises itself, which is" Is the model valid or not?" because maybe changing different variables may show the same trend but still doesn't mean that the model is valid. The question was answered by Ng, Khor, Tiong, and Lee [15]. Ng, Khor, Tiong, and Lee [15] used sensitivity analysis in his paper, which was about simulation modeling and management of large basement construction project. Different variables were tested to identify the relative impact and importance of each variable. The author carried a graphical comparison before the sensitivity analysis to make sure that the model itself is valid. This point shows that the sensitivity analysis is not enough to validate simulation models, and it should be combined somehow with another validation method.

Experimental validation, as discussed previously, means that the experimental procedure is providing accurate results for the purpose it was made for. This method is performed by applying an experimental procedure or sometimes by using different testing scenarios to the model to check the model output. Zhai, Tiong, Bjornsson, and Chua[16] carried the validation method in his paper on the simulation-based planning for precast production with two critical resources. An experiment test, using a realistic size planning problem, was used to validate the model. An experimental procedure was developed to test the model using three different production planning approaches. Actual planning method was first conducted to establish base production plan. Based on information collected from the precast plant and base plan with the other three plans were evaluated, and the validity of the model was checked by comparing the experimental output of different approaches applied in the model.

Verification, as discussed previously, means that the model is working correctly with no bugs, but in some papers, verification was used as a tool to validate the model. For example in Park, Kim, Lee, and Han [17] article, a supply chain management model for ready mixed concrete was discussed. Park, Kim, Lee, and Han [17] provided a separate section to discuss model verification and application instead of validation.

For testing, internal validity usually several runs of a stochastic model are made to determine the amount of stochastic variability in the model. An example of this method can be found in Unsal and Taylor [18] paper, which is about "Modeling Interfirm Dependency: Game-Theoretic Simulation to Examine the Holdup Problem in Project Networks". Unsal and Taylor [18] managed the internal validity of the model by keeping assumptions as simple as possible. In internal validity, true causes of model outputs are addressed, and strong internal validity is achieved by the strong justification that casually links the independent and dependent variables. Internal validity was used because part of the paper is trying to establish a causal relationship and to conclude that the model has made a difference by showing the existence of the potential for the holdup.

Live graphic validation is defined as the evaluation of model operational behavior by computer output graphics. It is much useful and easier to validate many aspects of normal operation models. For example, Rekapalli and Martinez [19] discussed a simulation model that runs simulations and animations concurrently. Live graphic validation method was found the best to validate the model since there is no actual statistical data to perform.

IV. Conclusion

Performing validation process in any simulation model is essential to show that the main objectives of the model are achieved. Applying a comprehensive validation process is challenging because of two main factors which are time and cost. Different researches use different validation approaches. In this research, 60 research works of construction-related studies from three different sources were collected and studied. Comparison with real data was found to be the most common simulation validation method used in simulation studies. Also, comparison with expert opinion is a common practice since it involves experts from the construction industry either in the model building stage or by using their opinion on evaluating the model output in terms of reliability. Data availability controls what validation method is more suitable than others; especially when using statistical approaches. Unfortunately, in construction related simulations, the availability of data in the right format and structure is not common. Such a challenge makes it difficult to formulate a general model validation method.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mubarak Al Alawi and Yasser Mohamed conducted the research and wrote the paper.

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