Model verification & validation strategies and methods: an application case study

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2 authors:


Chenggang Yin
China Agricultural University


Alison Mckay
University of Leeds

Model Verification and Validation Strategies and Methods: An Application Case Study

Chenggang Yin*1 and Alison McKay2

*1 Department of Mechanical Design and Manufacture, College of Engineering, China Agricultural University, Beijing, China
E-mail: cgyin@cau.edu.cn
2 School of Mechanical Engineering, University of Leeds, Leeds, UK
E-mail: A.McKay@leeds.ac.uk

Abstract: Model verification and validation is an essential part of any modeling and simulation process. Many literatures report model verification and validation strategies and methods in a theoretical framework, but there is limited literature on the application of such strategies and methods to real-world simulation problems such as manufacturing operation system simulation. This research aimed to bridge the gap for a simulation case study from a large UK-based manufacturing company. This paper demonstrates model design and validation processes using a manufacturing case study, explains model verification and validation concepts, and demonstrates the application of a model verification and validation architecture. The emphasis of this paper is on model verification and validation strategies and methods. An example application of such strategies and methods to the verification and validation of a manufacturing operation system simulation case study is presented.

Keywords: Model Verification and Validation, Verification and Validation Strategies, Verification and Validation Methods, Manufacturing Operation Systems

1. INTRODUCTION

Model verification and validation is an essential part of simulation model development, and is normally carried out in parallel with the model design process. It is relatively straight forward to implement a simulation model, but more difficult to ensure that it is a useful model for real-world problem-solving. Model verification and validation ensures that a simulation model is useful for specified research problems in a real-world scenario.

Model verification and validation cannot guarantee that a model is 100% complete and correct for all possible applications [1, 2, 3, 4]. However, model verification and validation can provide evidence that a given model is accurate (within an accuracy range) to represent and understand specific research problems. Model verification and validation processes are complete when the required accuracy is achieved [2, 3, 5, 6].

There are many existing literatures reporting different aspects and views of model verification and validation processes, strategies and methods [2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13]. However, there is limited literature on the application of such strategies and methods for model verification and validation in real-world simulation problems. It is extremely important for modelers to incorporate appropriate model verification and validation strategies and methods in model development process in a systematic manner.

This paper presents an application of distinct strategies and methods to model verification and validation process, as part of simulation project based on a manufacturing operation system case study [21]. The case study came from a large UK-based manufacturing company. The research aim was to bridge the gap between model verification and validation theoretical research and simulation problem-solving practice.

The rest of the paper is structured in the following way. Section 2 introduces a simulation case study, Section 3 demonstrates model design and validation processes with respect to the case study, and Section 4 discusses model verification and validation concepts. On this basis, Section 5 introduces a model verification and validation architecture and Applications of different verification and validation strategies and methods to each stage of the simulation case study are shown in Sections 6 and 7 respectively and Section 8 concludes the paper.

2. MODEL VERIFICATION AND VALIDATION CASE STUDY

A manufacturing operation system case study from a large UK-based manufacturing company was used in the research. The aim of the simulation case study was to develop a computer-based simulation model representing the manufacturing operation system, and examine the system performance under a range of different operating conditions. The case study system involves a series of work teams that are allocated to different stages in a new product development process, e.g. preliminary design, detail design, manufacture and service. Fig. 1 gives the structure of the case study development process.

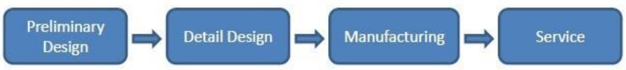

Fig. 1 Manufacturing operation system case study structure

The simulation case study arose from working with engineering teams in the company where researchers observed time resources consumed by additional rework in particular teams significantly influenced the operational

performance of the whole system. With a view to improving efficiency and product competitiveness, an opportunity was identified to apply modeling and simulation techniques to the manufacturing operation system. The ultimate goal of the research was to explore effective and efficient management strategies with aim to improve the manufacturing operation system performance.
Fig. 2 shows the three primary phases in the process used to carry out the simulation case study. Firstly, simulation problems were identified with a focus on research interests of owners of the manufacturing operation system case study; secondly, a conceptual model was built up to represent the simulation problem using data collected from the case study owners; and finally, a simulation model was developed as an implementation of the conceptual model.

Fig. 2 Simulation case study model verification and validation

As discussed in Section 1, all phases in the process of simulation model development need to be verified and validated. That is, the conceptual model needs to be validated with respect to the simulation problems, the simulation model needs to be validated with respect to both the conceptual model and the simulation problem. This was done by conducting a series of simulation experiments and comparing the simulation results from the model with real-world operational situations.

3. MODEL DESIGN AND VALIDATION PROCESSES

As introduced in Section 2, Fig. 3 shows a full cycle of the model design and validation processes for the simulation case study. It includes three research stages: simulation problems definition, concept model building, and simulation model development. It also includes two reverse research processes: model design process and model validation process.

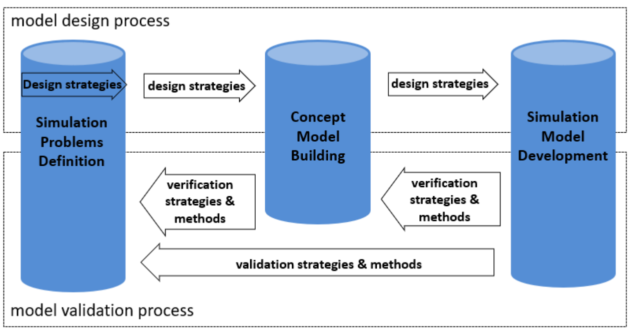

Fig. 3 Model design and validation processes

At the simulation problem definition stage, the case study manufacturing operation system was analyzed and formally defined with respect to a specified simulation purpose. By doing this, the simulation problems were identified and informed subsequent research activities.
At the concept model building stage, a concept model was built up to represent the simulation problems and demonstrate logical relationships in the case study system. At the same time, model verification strategies and methods were employed to ensure that the concept model represented the research problems with sufficient accuracy.
At the simulation model development stage, the concept model was implemented using a computer-based simulation model. A series of model verification strategies and methods were employed to ensure the simulation model represented the concept model with sufficient accuracy. In addition, the simulation model was validated with respect to the simulation problems by applying appropriate validation strategies and methods.
This paper focuses on the model validation process in Fig. 3, which includes three verification and validation phases: concept model verification with respect to the simulation problems, simulation model verification with respect to the concept model, and simulation model validation with respect to the simulation problems. Different verification and validation strategies and methods and their applications to the case study problem-solving are introduced in the following sections.

4. INTRODUCTION TO MODEL VERIFICATION AND VALIDATION

It is relatively straight forward to implement a simulation model but more challenging to ensure that the model is a meaningful representation of a real-world problem environment. Model verification and validation processes ensure that a simulation model makes sense for specific research purposes. Model verification and validation involves a series of strategies, methods and activities that, ideally, are an integral part of the simulation model design and development process.
Model verification deals with the identification and removal of errors in the model by comparing simulation model outcomes to practical solutions from the real-world situation [14]. For this reason, the purpose of model verification processes, which deal with logical relationships within and simulation specifications associated with the model [6, 7], can be seen as being to ensure the simulation model is complete and correct [8, 9]. On the other hand, model validation determines how accurate the simulation model is as a representation of a real-world system for the simulation purpose. [6, 7]. Model validation processes quantify the accuracy of the model by comparing simulation results to experimental or operational outcomes [6, 8, 9].
Contributions to model verification and validation knowledge domains include [2, 3, 5, 10, 11, 12, 13, 15].

5. MODEL VERIFICATION AND VALIDATION ARCHITECTURE

Fig. 4 shows a model verification and validation architecture [5] that was used to implement the model validation process in the simulation case study in Fig. 2.
Three model verification and validation phases are shown. Firstly, conceptual model verification ensures that the conceptual model is an accurate representation of the simulation problems identified in the real-world system. Secondly, simulation model verification ensures that the computer-based simulation model possesses sufficient accuracy to represent the conceptual model. And finally, simulation model validation entails a series of simulation experiments which focus on confirming the model's

accuracy, effectiveness and efficiency to understand the real-world problems. In addition, all data involved in model verification and validation processes itself needs to be validated.

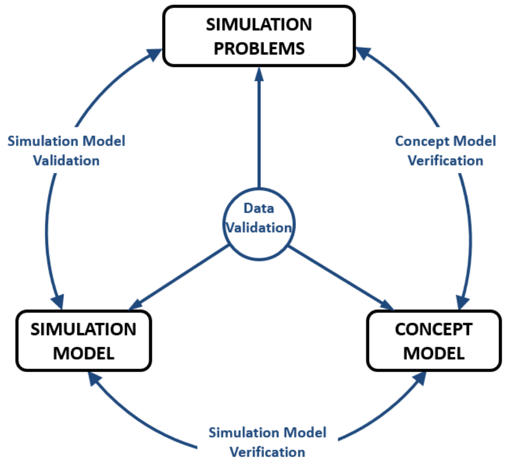

Fig. 4 Model verification and validation architecture

6. APPLICATION MODEL VERIFICATION AND VALIDATION STRATEGIES IN SIMULATION CASE STUDY

Researchers have developed distinct model verification and validation strategies with their experience in either academic research or industrial practice. Contributions to this knowledge domain include [2, 3, 5, 6, 16, 17]. There are four primary verification and validation strategies used in model validation processes [5].

- **Self-Validation:** The simulation model development team itself makes the decision as to whether a simulation model is valid or not.
- **Co-Validation:** The simulation team involves model users within the model development process; the model validation process is integrated with the model development process.
- **Independent Validation:** An independent third party decides whether a simulation model is valid or not.
- **Scoring Validation:** A scoring model is used to determine whether a simulation model is valid or not.

6.1. Model Verification and Validation Strategies Characteristics

Key characteristics of verification and validation strategies are summarized in Table 1 in terms of what the process involves and to roles of the people involved.

Table 1 Model verification and validation strategies

	self-validation	**co-validation**	**independent validation**	**scoring validation**
conductor	simulation model development team	both model development team and project owner(s)	an independent third party	simulation model development team
evaluator	model development team itself	model user or clients	the independent third party	model development team itself
description	the model development team itself makes the decision that whether the model is valid or not.	the model user is heavily incorporated within the model development and validation process.	a third party (independent from both model development team and model users) decides whether the model is valid.	scores are determined considering various aspects of the validation process.
comments	this is a subjective decision. It has its own advantages, since the model development team itself possesses best understanding of the model.	the validation activity is conducted by both model development team and the model users. this method shortens model development cycles.	independent assessment is conducted by an independent third party. model development time and budget significantly increase.	the validation result may be influenced by subjective nature of the method. over-confidence for a higher score may mislead the model users.

Each verification and validation strategy has distinct features which means that different strategies are suitable for different real-world model validation situations. The four strategies are further explained in the remainder of this section.

The Self-Validation strategy tend to be used in real-world modeling and simulation, where the modeler(s) decide whether the simulation model is valid or not, based on results from a series of simulation experiments under various operating scenarios. The advantage of applying this strategy is that the modeler possesses a better understanding of the model quality and limitations than others. On the other hand, the disadvantage is that the model validation result is vulnerable to modeler's subjective judgment. As a result, self-validation may produce a subjective decision [5]. However, it is still broadly applied in practice.

The Co-Validation strategy involves simulation model sponsor(s) within the model validation process. The sponsor(s) are members of the team carrying out model validation activities and making decisions. This strategy enables both model design and model validation to proceed in parallel, which produces potential advantages to reduce model development cycle. In addition, the responsibility of determining whether a simulation model is valid or not is moved to the model sponsor(s) party by using this strategy. Co-validation strategies shorten model development time, save costs, and increase model reliability as a result [5].

The Independent Validation strategy is conducted by an independent third party. Independent validation strategies ensures high credibility of model validation process and results. A prerequisite is that the third party has to understand the simulation purpose and the modeling process which can mean that independent validation cannot start until the model design process is completed. As a result, this validation strategy can consume a significant amount of additional time and budget. Independent validation strategies are best suited to large-scale, long-term, high-budget, and high-credibility model validation projects [18].

The Scoring Validation strategy considers different perspectives when users run the model [19]. The scoring model is designed, conducted, and analyzed by the modeler(s) themselves. Given that model users are typically not involved in the process, the scoring validation method is vulnerable to subjective validation judgment and, for this reason, is not often used in practice [5]. In addition, there is limited guidance in the literature on how to go about the design and development of suitable scoring models.

6.2. Application of Verification and Validation Strategies in Simulation Case Study

Based on the characteristics of each verification and validation strategy, Fig. 5 shows the different verification and validation strategies that we used in the simulation case study.

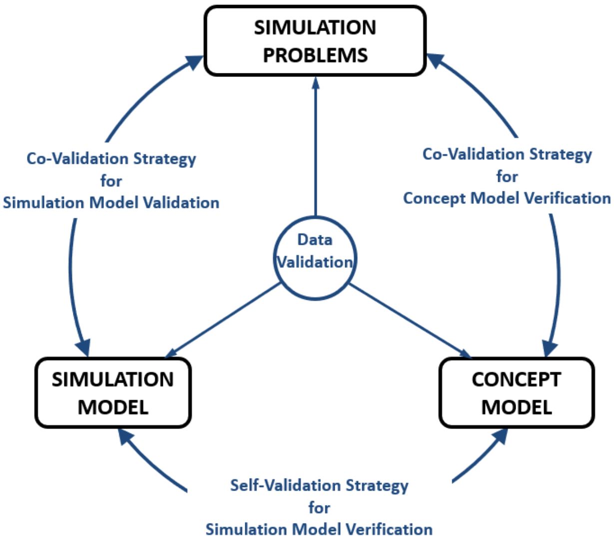

Fig. 5 Application model verification and validation strategies

As shown in Fig. 5, the Co-Validation strategy was applied to verify the conceptual model with respect to the simulation problems. This verification process involved both the modeler and case study owners. The main reason for using this strategy was that it capitalized on the wide experience and expertise of the case study owners. In doing so, the model development time was shortened, and future risks were significantly reduced.

The Self-Validation strategy was selected for the verification of the simulation model with respect to the concept model. The modeler himself was responsible for this verification process. Considerations for this selection were that the modeler possessed the best understanding of the simulation model design and programming code, so was able to use his judgement and reduce overall model development time and cost.

The Co-Validation strategy was used to validate the simulation model with respect to the case study problems. A series of simulation experiments were carried out and results were reviewed by the modeler and case study owners. The modeler continuously improved the model until the case study owners were satisfied with the simulation model performance and experimental results. In doing this, the simulation model was able to accurately represent the identified simulation problems and provide a reliable basis for problem solving in the real-world situation.

6.3. Summary

This section discussed four model verification and validation strategies: self-validation, co-validation, independent validation and scoring validation. The characteristics of each strategy were analyzed and discussed. The model verification and validation strategies applied to the simulation case study were then discussed. In summary, the co-validation strategy was used for concept model verification and validation of the simulation model with respect to the real-world problem, and self-validation was used to verify the simulation model with respect to the concept model.

7. APPLICATION OF MODEL VERIFICATION AND VALIDATION METHODS IN THE SIMULATION CASE STUDY

There are many model verification and validation methods developed for specific research interests. Contributions to model verification and validation methods development include [2, 3, 5, 10, 11, 12, 13, 15]. The following are different kinds of model verification and validation methods.

- Animation Validation
- Model to Model Validation
- Event Validation
- Extreme Condition Validation
- Face Validation
- Historical Data Validation
- Operational Graphics Validation
- Sensitivity Analysis Validation
- Predictive Validation
- Traces Validation
- Turing Test Validation

7.1. Model Verification and Validation Methods Characteristics

Each validation method has distinct characteristics which make them suitable for different real-world simulation purposes and validation criteria. Key characteristics of the model verification and validation methods are described in the remainder of this section.

Animation Validation: Simulation model operational behavior of each element is graphically displayed as the model runs over time.

Model to Model Validation: Outcomes of a simulation model being validated are compared with outcomes from another valid model, related to the same simulation problems.

Event Validation: Event occurrences in the simulation model are compared to those of the real-world system to determine how similar they are.

Extreme Condition Validation: The simulation model architecture and outputs are tested using extreme and unlikely combinations in the real-world.

Face Validation: Asking knowledgeable professionals about the system and whether the simulation model and its behaviors are reasonable.

Historical Data Validation: If historical data exists, some of the data is used to build the simulation model and the remaining data is used to determine whether the model performs as the system does.

Operational Graphics Validation: Observing entities' operational curves in simulation outputs, to determine whether the model performance is reasonable with respect to the real-world scenario.

Sensitivity Analysis Validation: This method consists of changing the values of the input data and parameters of a simulation model to determine the effect upon the performance of the model and its output. The same relationship should occur in the simulation model as in the real-world system.

Predictive Validation: The simulation model is used to predict the system performance, and comparisons are made between the performance produced from the system and the forecast from the model, in order to determine if they are the same or similar enough.

Traces Validation: The behaviors of different types of specific entities in the simulation model are traced through the simulation model operation to determine whether the model's logic is correct and the necessary accuracy is obtained.

Turing Test Validation: Individuals who are knowledgeable about the real-world operational system are asked whether they can discriminate between outputs from the real-world system and the simulation model.

7.2. Application Verification and Validation Methods in Simulation Case Study

Fig. 6 shows applications of model verification and validation methods in the simulation case study.

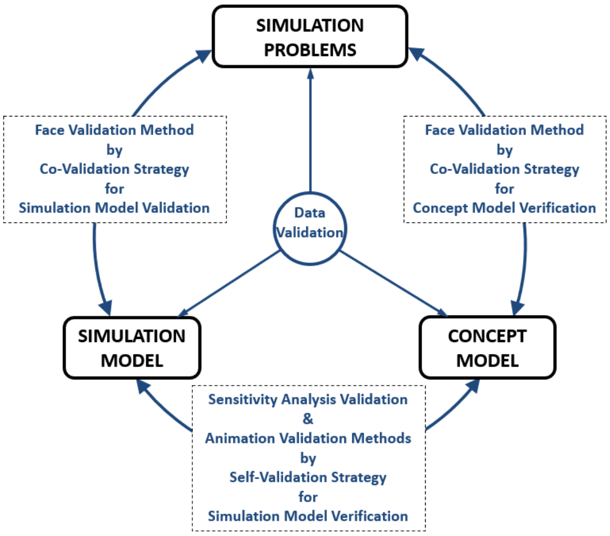

Fig. 6 Application model verification and validation methods

The Face-Validation method was selected for verification of the conceptual model with respect to the simulation problem. Both modeler and case study owners were involved in the concept model verification activities, which were integrated into concept model building process in a parallel pattern. The case study owners advised the modeler how and where to improve the concept model until the model performed accurately enough to represent the real-world system. The advantage of face-validation is that the modeler can use best practice and knowledge from the case study owners in the development and verification of the concept model, which reduces modeling time and increases model reliability.

Both Sensitivity Analysis and Animation methods were employed in the verification of the simulation model with respect to the concept model. Model verification activities were carried out by the modeler himself. To apply the sensitivity analysis validation method, the modeler designed and conducted a series of sensitivity experiments and analyzed model results. The simulation model was improved and modified until the simulation model accurately represented the concept model. The research used agent-based simulation (ABS) NetLogo as the simulation tool. NetLogo includes a simulation world where autonomous agents act and interact with each other. The feature of the NetLogo tool enabled application of animation validation method in the simulation model verification process [20].

Face-Validation method was employed for simulation model validation with respect to the real-world problem. The validation team involved both modeler and case study owners. Firstly, the case study owners designed a series of simulation questions that would be addressed by operating the simulation model. The modeler then designed a series of simulation experiments to provide answers to these questions. Both modeler and case study owners conducted simulation experiments and analyzed simulation results from the simulation model. Model improvements and modifications continued until the case study owners were satisfied with the simulation model results.

7.3. Summary

This section discussed a series of model verification and validation methods and their key characteristics that were applied to the simulation case study. In summary, the face validation method was used for concept model verification with respect to the simulation problem, both sensitivity analysis and animation methods were employed for simulation model verification with respect to the concept model, and the face validation method was applied for validation of the simulation model with respect to the case study problem.

8. CONCLUSIONS

Model verification and validation is an essential aspect of the model development process. Many literatures report model verification and validation concepts, policies, strategies and methods, but there is little on applications of such strategies and methods to real-world engineering simulations problems such as design and manufacturing.

This research bridged the gap between model verification and validation theory and practice in a real-world simulation case study. The research used a simulation case study from the manufacturing operation system of a large UK-based manufacturing company. The purpose of the simulation case study was to develop a simulation model that represented the real-world system, conduct experiments on the simulation model, and analyze simulation results with a view to improving operational management of the case study system.

The simulation case study included three primary phases: simulation problem definition, concept model building and simulation model development. The research framework also included two reverse processes: model design process and model validation process.

This paper emphasized the model validation process within the whole research framework. Four common model verification and validation strategies are: self-validation, co-validation, independent validation and scoring validation. This paper discussed characteristics of these strategies and described their application to the simulation case study along with the application of different verification and validation methods. In summary, a co-validation strategy was applied for concept model verification, self-validation was selected for simulation model verification, and co-validation was employed for simulation model validation. In terms of validation methods selection, face validation method was used for concept model verification with respect to the simulation problems, both sensitivity analysis and animation methods were employed for simulation model verification with respect to the concept model, and face validation was used for simulation model validation with respect to the simulation case study problems.

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AUTHOR BIOGRAPHIES

Chenggang Yin is a Lecturer in Department of Mechancial Design and Manufacture, China Agricultural University. He holes a PhD in Mechanical Engineering at University of Leeds, UK. He obtained M.Eng at Beijing Institute of Technology. He worked as a research fellow (internal team leader) for H2020 RiserSure project at London South Bank Innovation Centre (LSBIC) in TWI Ltd between 2016 and 2017. He worked as a project engineer at InnoTecUK Ltd from 2014 to 2016. He has been a visiting scholar at University of Alberta, Canada, between 2009 and 2010. His research interests include product design and development, modeling and simualtion, agent-based simulaiton, complex design system, decision-making mechanism, orgnizational behavior, and others.

Alison McKay is Professor of Design Systems at the University of Leeds and director of the Leeds Socio-Technical Centre. She holds a PhD in Mechanical Engineering. Her research centres on socio-technical aspects of engineering design systems and the networks of organisations that both develop and deliver products to market, and support them through life to disposal or reuse. The focus of her personal research lies in the establishment of systematic and, where possible, well-founded underpinnings for such systems, in particular, for the definition of product data.