A SAMPLE VERIFICATION AND VALIDATION FRAMEWORK FOR OPEN SOURCE SIMULATION SOFTWARE

AÇIK KAYNAK BENZETİM YAZILIMLARI İÇİN ÖRNEK BİR DOĞRULAMA VE GEÇERLEME ÇATISI

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Submitted to

Graduate School of Science and Engineering of Hacettepe University

as a Partial Fulfillment to the Requirements

for the Award of the Degree of Master of Science

in Computer Engineering.

2022

“Or what if everything we know and love were just a computer simulation rendered for entertainment by a superintelligent alien species?”

— Neil deGrasse Tyson

ABSTRACT

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Aug 2022, 70 pages

Verification and Validation (V&V) activities performed in the life cycle of a software project are necessary to meet technical specifications and requirements. Likewise, V&V activities in a simulation project's life cycle have a critical role in ensuring the validity of the relevant model. Accordingly, these activities must be carried out successfully in order to determine the consistency of the simulation model that is being developed with its real or hypothetical system. To achieve this, it is expected that the most suitable V&V methods are to be evaluated, selected and then applied within the scope of the simulation project.

Until recently, various V&V methods have been produced and made available for using at certain stages of the software cycle. Unfortunately, it is not possible to apply so many methods at the same time, considering such project constraints as time and resources. Therefore, in the field of Modeling and Simulation, selection and application of V&V methods in a proper and efficient way for the project in question poses a big problem.

In the present study, upon reviewing the existing literature on the subject, the missing aspects crucial for the selection of the suitable V&V techniques were examined first. Afterwards, a sample framework that can guide the selection of the most appropriate methods for the V&V processes of simulations has been offered. The current study made use of score-based method selection processes rather than the traditional method selection techniques, by taking requirements and metrics of the relevant simulation project into account. The proposed framework was applied using open source simulation software project data. And the practical results show that the framework developed in this study significantly optimizes the V&V method selection process compared to general-purpose method selection techniques.

Keywords: Simulation, Modeling, Verification and Validation, Method Selection, Test, Metric

ÖZET

AÇIK KAYNAK BENZETİM YAZILIMLARI İÇİN ÖRNEK BİR DOĞRULAMA VE GEÇERLEME ÇATISI

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Tez Danışmanı: Doç. Dr. Harun ARTUNER

Ağustos 2022, 70 sayfa

Bir yazılım projesinin yaşam döngüsünde gerçekleştirilen Doğrulama ve Geçerleme (DG) faaliyetleri, teknik şartname ve gereksinimlerin karşılanması bakımından gereklidir. Aynı şekilde bir simülasyon projesinin yaşam döngüsündeki DG faaliyetleri ilgili modelin doğruluğunun ve geçerliliğinin sağlanmasında çok önemli bir yere sahiptir. Çünkü geliştirilmeye çalışılan simülasyon modelinin gerçek ya da varsayımsal sistemiyle olan tutarlılığını tespit etmede bu faaliyetlerin başarılı bir şekilde yürütülmesi gerekmektedir. Bunun sağlanabilmesi için de en uygun DG metotlarının simülasyon projesi kapsamında değerlendirilerek seçilmesi ve ardından uygulanması beklenmektedir.

Günümüze kadar yazılım döngüsünün belli aşamalarında kullanılmak üzere yığınlarca farklı türlerde DG metotları üretilerek kullanıma sunulmuştur. Ne yazık ki bu kadar metodun aynı anda uygulanmaya çalışılması zaman ve kaynak gibi proje kısıtları göz önüne alındığında pek mümkün olmamaktadır. Modelleme ve Simülasyon alanı için de DG metotlarının projeye uygun ve verimli bir şekilde seçilerek uygulanabilmesi, çözülmesi gereken bir problem haline gelmiştir.

Bu tez çalışmasında öncelikle konuyla ilgili mevcut literatür taranarak, simülasyonlara yönelik DG metotlarının seçiminde yetersiz kalan yönler irdelenmiştir. Ardından bu alana en uygun metotların seçimine kılavuz olabilecek örnek bir çatı önerilmiştir. Burada geleneksel metot seçim tekniklerinden farklı olarak, ilgili simülasyon projesinin gereksinimleri ve metrikleri hesaba katılarak skor-tabanlı bir metot seçim yaklaşımı geliştirilmiştir. Önerilen çatı, açık kaynak kodlu bir simülasyon yazılımının proje verileriyle denenmiş ve uygulamanın sonuçları bu çatının DG metot seçim sürecini önemli ölçüde optimize ettiğini göstermiştir.

Anahtar Kelimeler: Benzetim, Modelleme, Doğrulama ve Geçerleme, Metot Seçimi, Test, Metrik

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor, Assoc. Prof. Dr. Harun ARTUNER, for all his support, including advice, criticism and guidance during the whole process.

Also, I would like to thank the members of thesis comittee for their participation and valuable opinions.

I am also grateful to my manager, Aylin HATİP İPEK, for all her insightful suggestions, attempts to facilitate the administrative procedures and support.

I would like to thank my family for their moral support during this study.

Besides, I would like to thank my parents-in-law for their hospitality, delicious contributions and good wishes.

And I would like to express my deepest thanks to my beloved wife Fatma Büşra YILDIRIM ALTINOK who has stood by me all the time. Without her endless love, understanding and encouragement, I could not keep my spirits and motivation high.

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SYMBOLS AND ABBREVIATIONS

Symbols

#	Number
C	One Hundred
C_j	Method Selection Criterion
M_x	Method
P_i	Method Property
W_k	Metric Value

Abbreviations

Com. M. Ver.	Computerized Model Verification
Con. M. Val.	Conceptual Model Validation
D. Val.	Data Validation
FR	Functional Requirements
KLOC	Thousands of Lines of Code
M&S	Modeling and Simulation
NFR	Non-functional Requirements
Opt. Val.	Operational Validation
V&V	Verification and Validation
VV&T	Verification, Validation and Testing

1. INTRODUCTION

In the mid to late 1950s, as computer systems became more widely available, computer simulations of physical systems and processes became a critical component of scientific and engineering research. Later, as computers got smaller, cheaper and faster, the use of simulations for both fundamental research and practical engineering grew dramatically [1]. Simulation models are thus being used more frequently to address issues and make decisions. The issue of whether the model and its behavior are as expected is relevant not only to the creators and users of the model, but also to those who are informed by the results of the model and those who are affected by the decisions based on these models. To address this problem and show the degree of correctness supplied between the physical system and the computer model, verification and validation activities are performed.

On the other hand, a model should be developed for the purpose of a particular goal and the model's validity should also be assessed in light of this goal. If the model's goal is to answer a range of questions, the model's validity must be evaluated separately for each question. A model may be correct for one set of experimental conditions but not for another and the model is regarded valid for a set of experimental conditions if its accuracy is within its acceptable range, which is the amount of accuracy necessary for the model's desired accuracy. This generally entails describing the model's related output variables and determining the level of precision necessary. This generally entails describing the model's related output variables and determining the level of precision which should be determined previous to model development or very early in the model development process is necessary. If the variables involved are random variables, the properties and functions of random variables, such as means and variances are usually of primary interest and used to determine model validity. Before getting a sufficiently valid model, multiple variations of the model are generally produced and validation of this model is usually regarded as a procedure and is frequently included in the development process [2].

As for engineering problems, simulations are only useful if the simulation outputs can be relied on. The concept of V&V of simulation models has been established and codified utilizing theoretical frameworks and methodologies for V&V from the onset of M&S.

These approaches were originally designed for empirical process modeling, but as the usage of physics-based computer models expanded, a qualitative and experimental-based method for V&V became the standard. The simulation is regarded as reasonably verified and usable for more complicated test scenarios if the simulation results closely match the empirical results [1].

All of these above-mentioned aspects have led to the production of abundant methods for V&V processes after many years of research. The methods cover both software engineering methods and statistical techniques. However, due to time and budget constraints, it is not possible to apply all methodologies for any V&V cycle. At the same time, the methods to be used in V&V processes must be compatible with the simulation model specifications in order to provide applicability. All these challenges require designing a system that can accurately and effectively manage the validation process of simulation models. Otherwise, problems such as disruption of the development and validation processes of the simulation model, insufficient budget, inability to meet the requirements and wasted effort may occur. Therefore, this study aims to resolve problems related with these issues via designing and developing proper V&V method selection framework [3].

The outline of the following sections for this thesis study:

- Section 2: provides the general information for simulation models and V&V.
- Section 3: outlines related works on V&V method selection.
- Section 4: presents the methodology used for the V&V method selection framework proposed in this study.
- Section 5: gives the application and results of the framework methodology developed for an open source simulation software project in this study.
- Section 6: describes the general conclusion and future work.

2. BACKGROUND

In this section, some topics that can form the basis for the studies in the field of simulation V&V are given before the thesis study. These are:

- “Simulation Models”: An overview of simulation models,
- “Verification and Validation Concepts”: Various definitions of V&V,
- “Verification and Validation Process for Simulation Models”: General V&V procedures,
- “Verification and Validation Methods for Simulation Models”: Commonly used simulation V&V methods.

2.1. Simulation Models

Modeling and simulation (M&S) is the act of using models as the basis for simulations to provide data required for operational or technical decision making. M&S can be considered as physical or analytical representation of a process, system, entity or phenomenon [4, 5]. Although "modeling" and "simulation" are commonly used synonymously in disciplines where M&S is just employed as a technique, both are acknowledged as distinct and equally important concepts within the field of M&S. Modeling is described as the directed abstraction of realism that results in the formal definition of a conceptualization together with its underlying hypotheses and constraints. And M&S attaches particular emphasis to models that enable the development of an operable version on a computer. The operation of a model throughout time is referred to as simulation. Simulator issues are generally centered on implementation, whereas modeling focuses on conception; modeling is more concerned with abstraction than simulation is with implementation [6].

There are other definitions of M&S in the literature as well. For instance, Bratley et al. describe as observing the model outputs of a system after proving it the proper inputs [7]. Shannon describes as the process of developing a model of a theoretical system, using it to conduct experiments, and then using the findings to compare alternative management strategies and decision-making processes [8, 9].

A summary of the M&S derived from the definitions above can be shown in Figure 2.1 in terms of the relationships between the concepts.

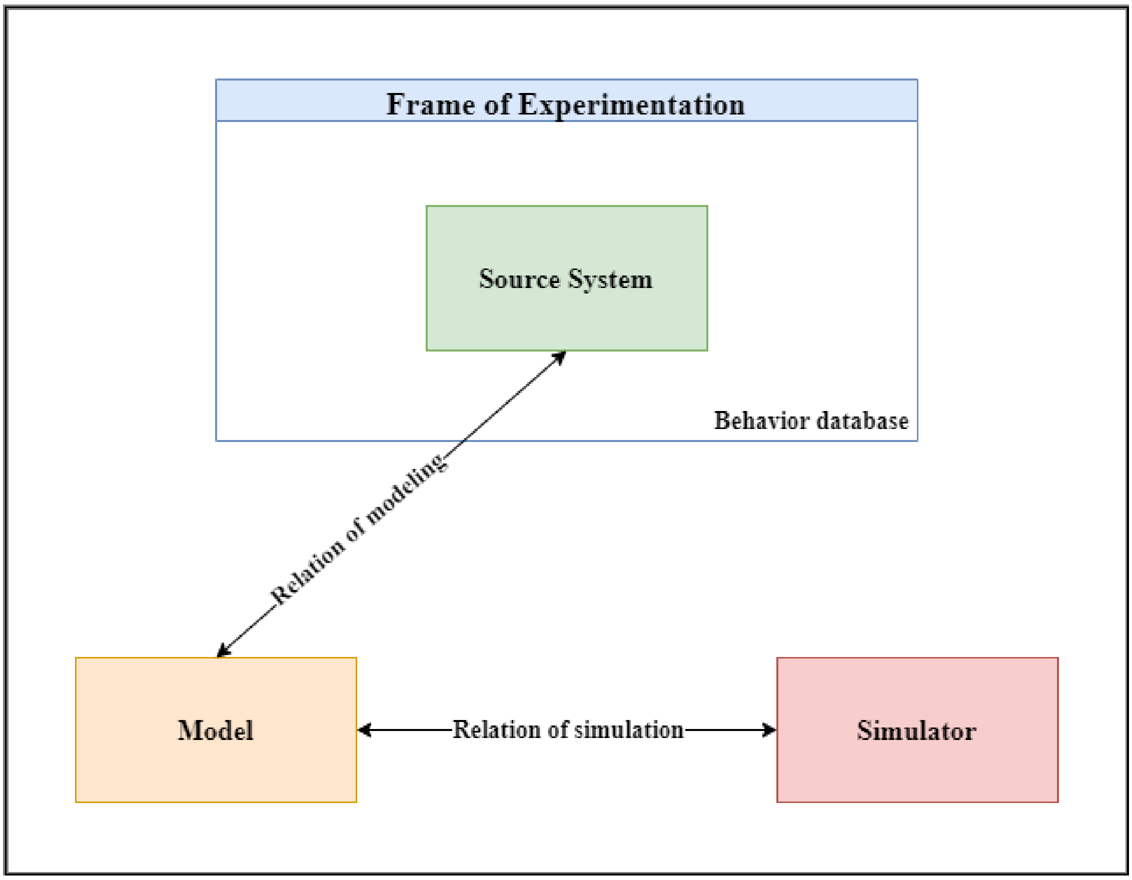


Figure 2.1 Framework for a Model Simulator Experiment [10]

It is commonly known that M&S is used in engineering. It is used by engineers across all application domains and it has been included into the core of engineering management knowledge. M&S supports cost-cutting, enhancing the quality of systems and products, as well as recording and preserving lessons gained. Analysts, operators and engineers must pay particular attention to its progress, because the results of the simulation depend entirely on the quality of the underlying model. To determine if the simulation's results apply to the actual world, the user must understand the hypotheses, conceptions and limitations of the simulation's implementation. Models can also be updated and improved utilizing data from real-world experiments. Because of its diverse application fields, M&S is frequently mistaken for a pure application, but M&S is a distinct discipline and engineering management must acknowledge this when applying M&S [6].

M&S are used for a variety of purposes, including performance evaluation, verification, prediction, research, training, entertainment, and education. Industrial processes, social systems, computer systems, corporate organizations, government systems, ecological and environmental systems and other complex processes and systems all use simulation techniques. Interdisciplinary study domains such as design system decision-making mechanisms, management of integrated product teams, new product development processes and organizational management have all benefited from modeling and simulation approaches. Terminologically, some simulation techniques can be classified as physical, interactive, continuous, discrete-event, stochastic, deterministic, hybrid, standalone, distributed, parallel, interoperable and agent-based simulations. Among them Agent-Based Simulation (ABS) and Discrete-Event Simulation (DES) are two widespread methods in operational management systems. ABS is a rapidly evolving modeling and simulation approach for modeling and simulating industrial processes and complicated scientific systems. DES is a mature methodology and creates models in a top-down architecture with monitor time-based behaviors inside a system. ABS is a newer approach compared to DES and uses a bottom-up design with randomly determined behavior [11].

Also specified by the U.S. Department of Defense in the Modeling and Simulation Dictionary, LVC Simulation (Live, Virtual, Constructive) categorization is a popular category for M&S:

- *Live:* Because they are not conducted against a live adversary, they are classified as simulations and involve actual individuals running real systems, as well as live simulations of military training situations utilizing real equipment.
- *Virtual:* Real people are utilized to operate virtual simulation systems that place a Human-in-the-Loop in the center, allowing them to control motor functions, make choices and interact.
- *Constructive:* It is a computer software in which actual individuals provide input to simulations but are not involved in the decision-making process [12].

2.2. Verification and Validation Concepts

Verification and validation concepts have various definitions in the literature according to their perspectives and usage patterns. For instance, while verification has two aspects as design and implementation, validation as conceptual and results. Some definitions are:

- Verification is the process of confirming that a model implementation and its associated data accurately match the conceptual description and requirements provided by the developer.

- Validation is the process of determining if a simulation model and the data it uses properly reflect the real world in light of the applications for which it is designed [13].

- The verification of a model is a software-level procedure that ensures that it operates as expected and does not call for any understanding of the model's outputs; rather, it is a check to make sure that the model's equations are correctly implemented in software.

- The validation involves comparing model’s outputs against experiments to determine its accuracy [1].

There are also some more concise definitions as well:

- Blotter claims that verification entails "solving the equations appropriately" whereas validation entails "solving the appropriate equations [14]."

- Likely, Boehm defines verification as “Are we constructing the product properly?” and validation as “Are we constructing the proper product [15]?”

According to the Capability Maturity Model (CMMI-SW v1.1):

- Software verification is “The process of reviewing software to see if the outputs of a particular development phase fulfill the requirements established at the beginning of that phase.” [IEEE-STD-610]

- Software validation is “The process of assessing software to see if it fulfills requirements either during or after development [16].” [IEEE-STD-610]

A key objective of V&V is to establish a model confidence so that it may be used to forecast problem entity activities in hypothetical circumstances. Furthermore, V&V ensures that a model works correctly, and produces accurate, relevant results when used together [1].

The next sections employ these definitions which apply to all upcoming model and simulation types.

2.3. Verification and Validation Process for Simulation Models

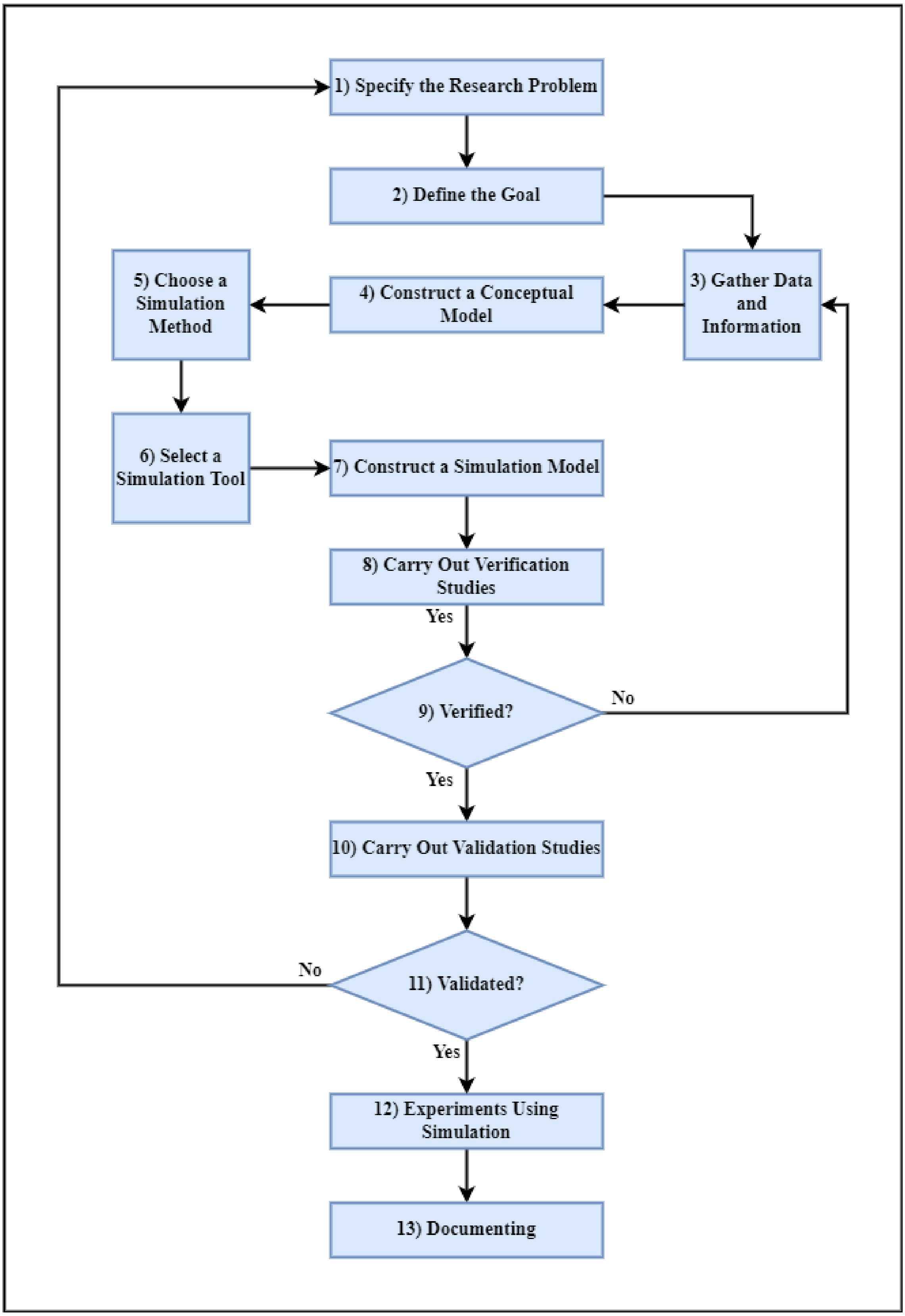


Figure 2.2 Modeling and Simulation Process with V&V [11]

The creation of a problem statement, conceptual model development, simulation model design and related V&V processes are all guided by modeling and simulation methods. Between them, model V&V aims to make the simulation model relevant in a real-world setting. Therefore, in addition to model creation and development, the M&S method involves model V&V as in Figure 2.2. Validation of the simulation model in relation to the real-world situation and the conceptual model are among the model V&V operations [11].

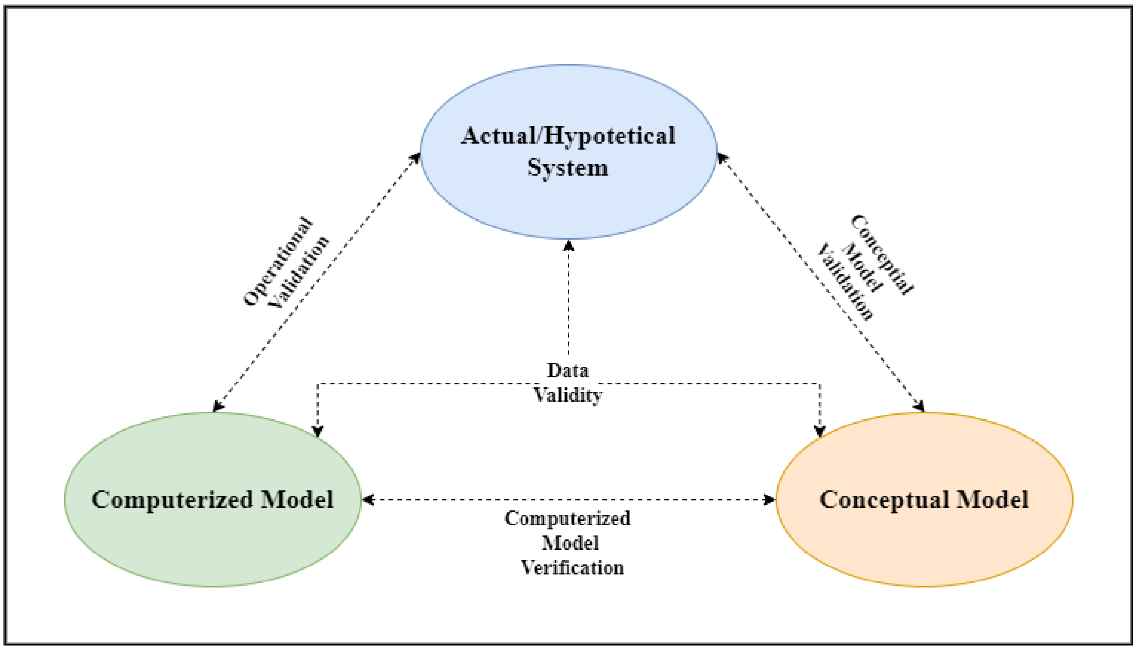


Figure 2.3 Simulation Model Development Process in a Simplified Form [17]

Simple version of the simulation model development process is represented in Figure 2.3. The model items explanations:

- **The problem entity (actual/hypothetical) system:** idea, scenario, policy or phenomenon to be modeled.
- **The conceptual model:** logical, mathematical or pictorial representation of the problem entity (system) created for a specific study. An analysis and modeling step is used to build this model.
- **The computerized model:** a digital version of the conceptual model. This model is developed during the implementation phase, and conclusions regarding the problem entity are drawn during the experimentation phase by running computer tests on this model [17].

Application of the V&V model for simplified model development process descriptions:

- **Conceptual model validation:** validating a conceptual model entails establishing if the theories and assumptions supporting it are accurate and whether the model's representation of the problem object (system) is "reasonable" in context of its intended use.
- **Computerized model verification:** verifying the conceptual model's computer programming and implementation via a computational process.
- **Operational validation:** determining if the output behavior of the model exhibits a sufficient range of accuracy for the purpose for which it was designed and throughout the domain in which it was meant to be used.
- **Data validity:** assurance that the information required for model development, model testing and model experimenting to solve the issue is complete and accurate [17].

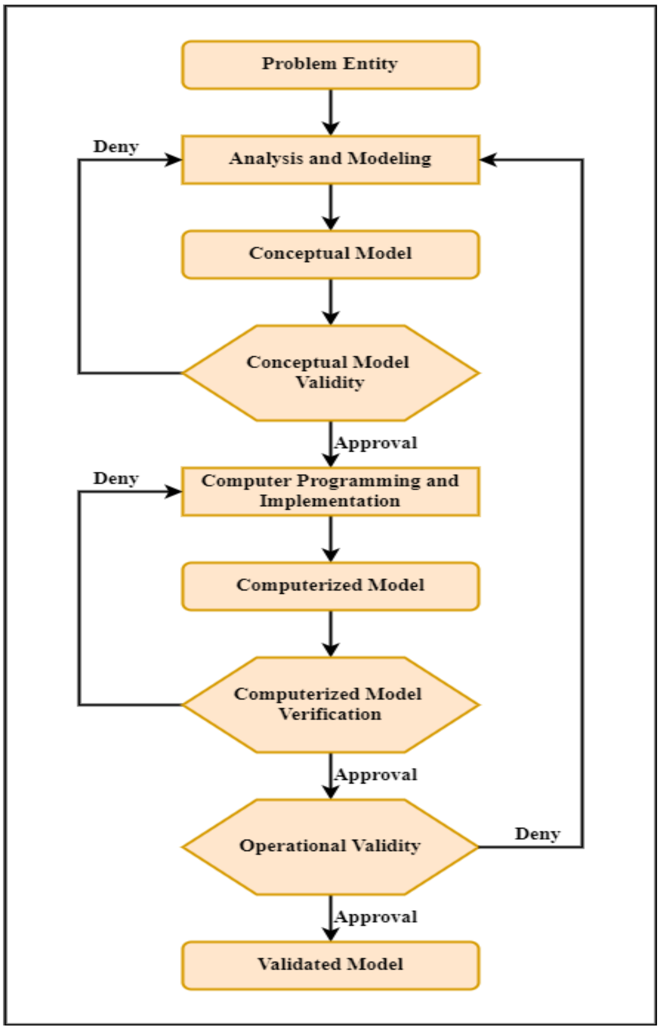


Figure 2.4 An Iterative Model Development Approach for V&V of Simulations [17]

Building up a correct simulation model is an iterative process in which numerous iterations of the model are created before a valid model is acquired as specified in Figure 2.4. The steps can be listed as follows:

1) The first step is to analyze and construct a theoretical model of the problem entity, after which a model of the problem entity is produced.
2) Following is the conceptual model's validation. This procedure is carried out repeatedly until the theoretical model is complete.
3) A computational model of the verified conceptual model is developed by simulating the theoretical model and putting it into practice on a computer.
4) Following that, the computational model verification is completed. The correctness of this model is ensured after repeating the relevant procedure until it succeeds.
5) Operational validation is carried out following the computational model's verification. This process might need model modifications in both the conceptual and computational models. When a model is changed, V&V must be done again. When a model is changed, V&V must be performed again. This procedure is iterated until the simulation model is valid.

Determining that a model is completely valid throughout the whole range of its intended applicability is frequently highly costly and time-consuming. Instead of this, tests and assessments are carried out until there is enough confidence in the model's validity for its intended use. Unfortunately, model validation is generally fairly expensive, especially when a high level of model confidence is required. Figure 2.5 shows the correlation between the cost of model validation and the model's usability to users as a function of model confidence.

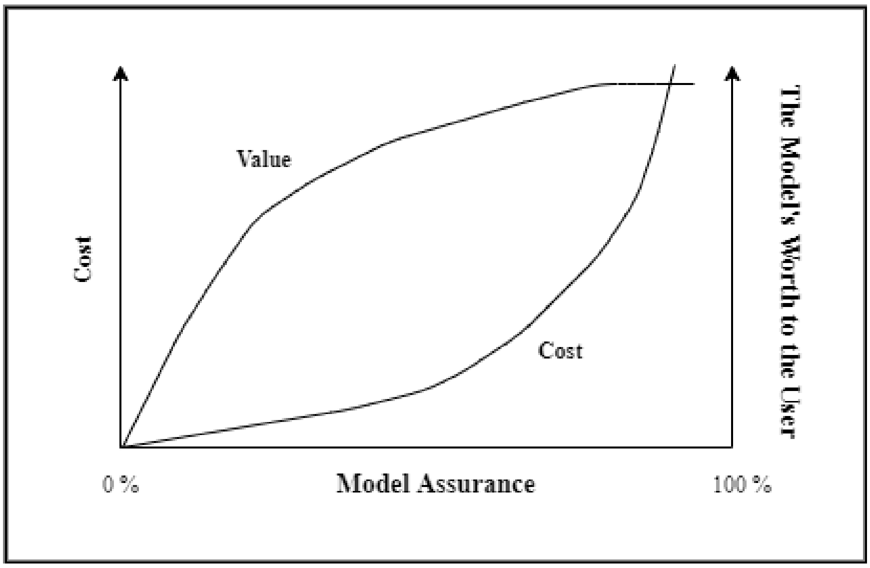


Figure 2.5 Cost and Model Assurance Diagram [17]

Simulation models used to predict system behavior, such as system outputs are the focus of the V&V process and two related concepts:

- **Model usability:** determined by how simple the model and operating instructions are.
- **Model credibility:** creating assurance that potential consumers should use a model and the information generated from [17].

Another related concept is Simulation Fidelity that describes how accurate a simulation is and how closely it mimics the real-world equivalent. It is categorized by three levels as low, medium and high:

- *Low*: The bare minimum of simulation necessary for a system to take inputs and respond with outputs.
- *Medium*: Reacts to stimuli automatically although with limited precision.
- *High*: Almost indistinguishable from the genuine system or as close as feasible [18].

2.4. Verification and Validation Methods for Simulation Models

With their expertise in either academic research or business, researchers have created several model V&V techniques and each of them has its own set of characteristics, which implies that various strategies are better suited to particular real-world and simulation scenarios. Therefore, before moving on to V&V techniques, four basic assessment approaches to these techniques are described:

- **Self-Validation:** The simulation model development team is the one who decides whether or not a simulation model is valid. The decision is based on the findings of many tests and assessments carried out during the model development process.
- **Co-Validation:** Model users are included in the model development process by the simulation team and the model validation process is integrated into the model creation process. This method is most commonly used while working with a small model development team.
- **Independent Verification and Validation (IV&V):** The credibility of the simulation model is assessed with the assistance of a third party that is independent of the simulation developers, users or supporters. The IV&V method is commonly performed when creating large-scale simulation models and it is usually done in one of two ways:
    1) The development of a simulation model is performed concurrently with IV&V, and the current stage of development should not move further until it has complied with the V&V standards.
    2) After the simulation model has been constructed, IV&V is performed. A comprehensive IV&V is often both costly and time-consuming.
- **Scoring Validation:** The validity of a simulation model is determined using a scoring methodology.

Co-Validation and IV&V techniques are advantageous over others because of satisfying simulation model credibility. When the IV&V method is used, there is a much higher likelihood that the model will be accepted as valid and the model's results will be true by others. This is especially true when the model's related issue is costly, involves a high-risk situation, or when it is planned that the model's results be approved by the general public [17, 19].

V&V of simulation models can be performed using a variety of techniques, and the way they categorize them may also vary.

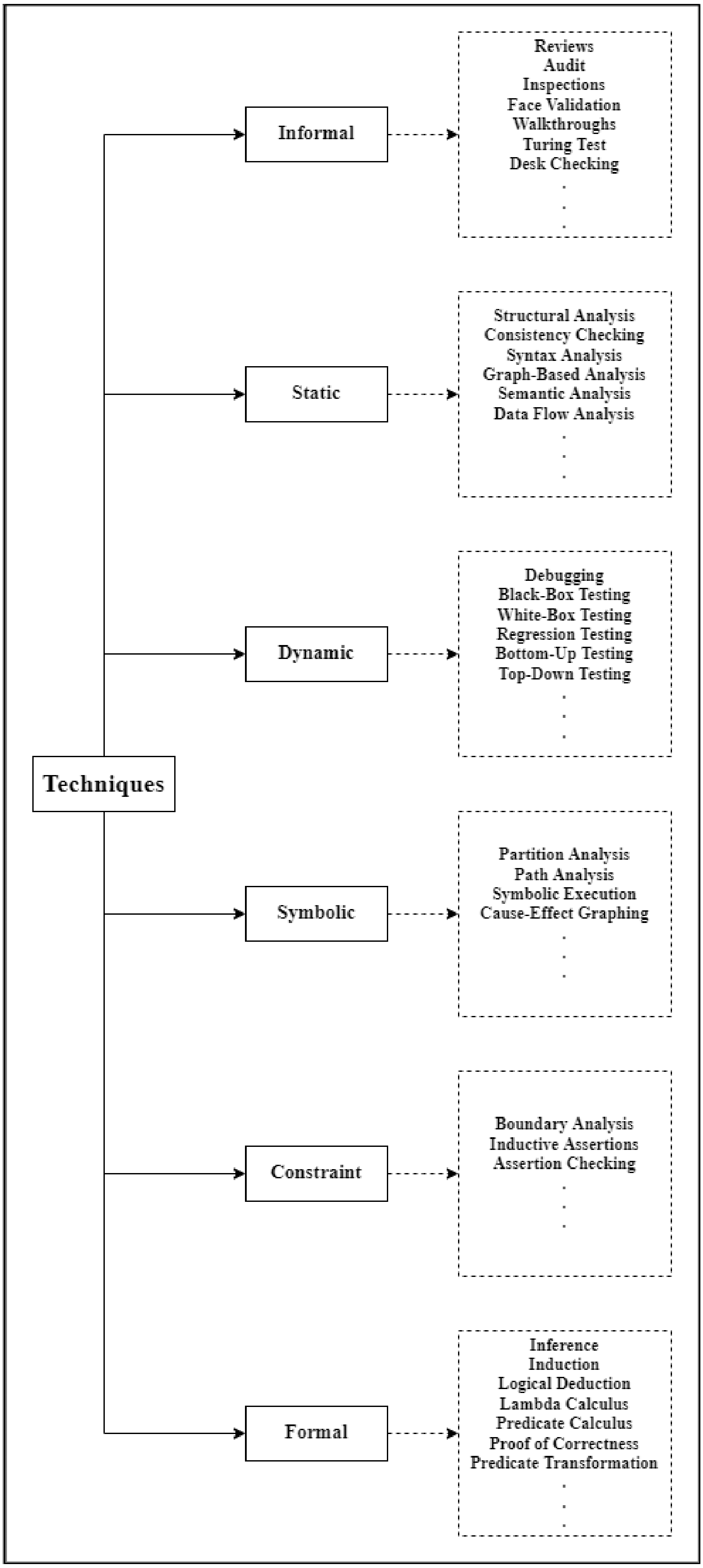


Figure 2.6 Verification, Validation and Testing Techniques Classification [19]

According to Balci, six unique credibility evaluation viewpoints are used to classify V&V and testing techniques (VV&T) as illustrated in Figure 2.6. Their mathematical formality levels increase from up to down. At the same time, their complexity levels increase and due to this applicability of them decreases as well. These techniques can be explained as below:

- *Informal:* These are the most often used methods, and since they lack proper mathematical formalization, they heavily rely on subjectivity and human reasoning.
- *Static:* These methods which assess a static model's source code's accuracy based on its characteristics are also widely employed. They can be performed mentally or with the help of several automated tools; computer execution of the model is not necessary.
- *Dynamic:* These methods are used to evaluate the performance of the model and require model execution. This requirement is linked to model instrumentation, which involves adding extra code to an executable model in order to gather data about the model's behavior while it runs.
- *Symbolic:* They are employed to evaluate the dynamic behavior of the model as it is being executed and resemble dynamic VV&T approaches. The conversion of the symbolic data along the model execution pathways is what drives the production of expressions as output from a simulation model which takes symbolic inputs as input.
- *Constraint:* Assertion checking, boundary analysis and inductive assertions are used in conjunction with these approaches to assess the accuracy of the model.
- *Formal:* These methods are the most effective model for formal verification of accuracy when they can be used, since they are based on mathematical correctness proofs [19].

Balci found over 70 techniques, which he divided into four groups then: informal, static, dynamic and formal. His list is the most accurate representation of the body of work on methods and it is still the most comprehensive. In addition to them, numerous techniques have been proposed over the years, a subset of which can be used in V&V research. Furthermore, based on the input they need or the purpose for which they are employed, methods can be classified in a variety of ways [20].

The most widely used methods for verifying and validating simulation submodels or general models:

- *Animation:* The model's operational behavior is visually shown as time passes by in the model.
- *Comparison to Other Models:* Results from other reliable simulation models are contrasted with those from the validated simulation model.
- *Degenerate Tests:* By choosing proper input and internal parameter values, one may predict how degenerate the behavior of the model will be.
- *Event Validity:* To determine whether the "events" of the simulation model and the actual system are comparable, they are contrasted.
- *Extreme Condition Test:* For any extreme and improbable combination of levels of components in the system, the model structure and outputs should be reasonable.
- *Face Validity:* Enquiring about the plausibility of the model and/or the behavior with persons who are familiar with the system.
- *Historical Data Validation:* When historical data is available, some of it is used to build the model, and the remainder is used to verify whether it behaves like the system.
- *Historical Methods:*
    - *Empiricism:* It necessitates empirical validation of all assumptions and outcomes.
    - *Positive economics:* It does not care about the model's assumptions or structure; it only cares about how well the model can predict the future.
    - *Rationalism:* It presupposes that everyone is aware of whether a model's underlying assumptions are accurate, and that logic deductions from these assumptions are utilized to build the right model.
- *Internal Validity:* Several runs are carried out to quantify the internal variability of a stochastic model. If the issue entity exhibits a lot of unpredictability, the policy or system under consideration may be problematic if the model's results are also problematic.
- *Multistage Validity:* Owing to this method:
    - The model's assumptions are established based on theory, observations, and general knowledge,
    - The model's underlying assumptions are experimentally evaluated,

    - The input and output connections of the model and the actual system are compared.
- *Operational Graphics:* The values of several performance measures are graphically exhibited as the simulation model iteratively runs through time; in other words, performance indicators' dynamical behaviors are visually represented as the simulation model iteratively runs through time to check their validity.
- *Parameter Variability - Sensitivity Analysis:* With this technique, input and internal model parameters are changed to examine how the changes impact the model's behavior or output. The model should be linked in the same ways as the actual system, and before it is used, the sensitive parameters those that might significantly alter the model's behavior or output should be sufficiently correct.
- *Predictive Validation:* The system's behavior is predicted by the model, and then contrasts are made between the system's actual behavior and the model's predicted behavior to determine if they match. The system's data may come from a working system or from testing it through experiments like field testing.
- *Traces:* To check if the logic is correct and the necessary accuracy is met, the behavior of different types of specific entities in the model is tracked through it.
- *Turing Tests:* The ability to distinguish between system and model outputs is tested on individuals who are familiar with the workings of the system being modelled [21].

In addition to qualitative methods mentioned so far, there are also available statistical (mathematical) methods to apply for simulation models VV&T:

Analysis of Variance (ANOVA), Anderson-Darling Test, Chi-square Test, Coefficient of Determination (R^2), Cramér-von Mises Criterion, Durbin-Watson Statistic, Factor Analysis, Hotelling’s T^2 Test, Kolmogorov-Smirnov Test, Kuiper’s Test, Mann-Whitney-Wilcoxon Test, Multivariate Analysis of Variance (MANOVA), Principal Component Analysis (PCA), Simultaneous Confidence Intervals, Spectral Analysis, Student’s t-test, White Test [22].

3. RELATED WORKS

Many studies have been conducted on simulation V&V activities in the literature, and as a result, different approaches have been produced. While some of these are not preferred in terms of applicability, some of them form the basis of the approaches still used today. In this section, the contributions of the prominent studies on V&V method selection procedures and the aspects that are open to development are discussed in chronological order.

Deslandres and Pierreval develop an expert system that integrates simulation validation techniques from various sources into a single level of knowledge that is then supported with specialized knowledge of statistics, simulation and validation techniques [23]. Prototype development is, however, subject to significant restrictions since it is difficult to create a validation expert system. An example of the method classification tree revealed in this study is shown in Figure 3.1.

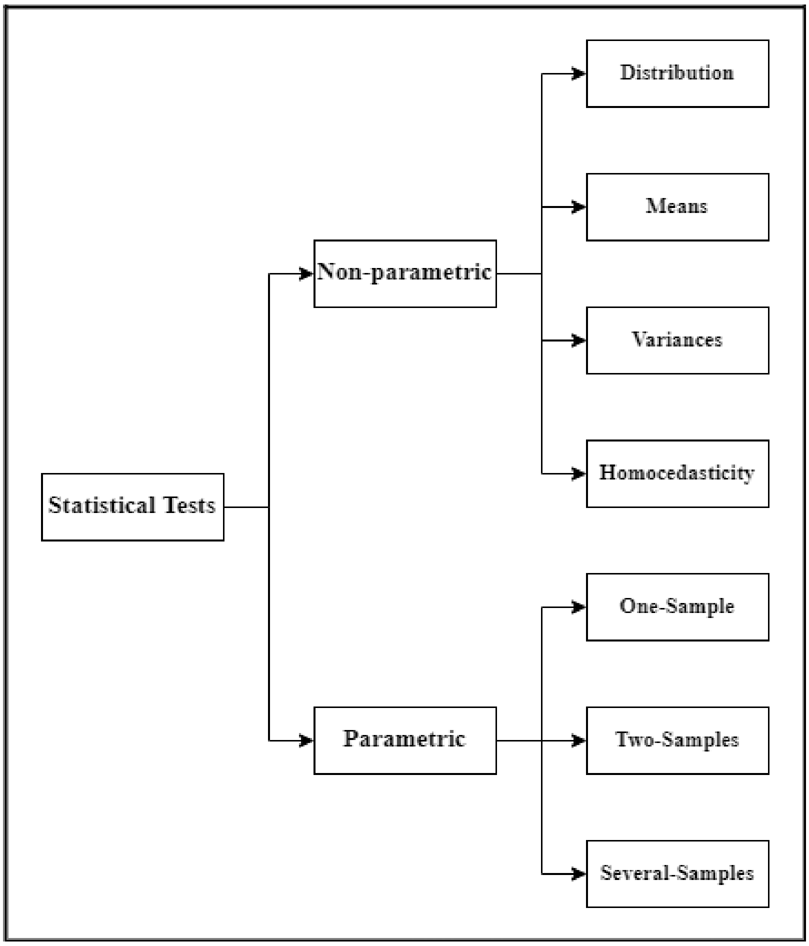


Figure 3.1 The Validation Methods Class Hierarchy [23]

Balci proposes the "A classification of V&V methods for traditional or object-oriented simulation models" methodology and the "Use of V&V methods across the M&S development cycle" approach (as in Figure 3.2) [24]. Although the simulation V&V method classification and accreditation principles provide a solid foundation for this study, it does not include any method selection procedure.

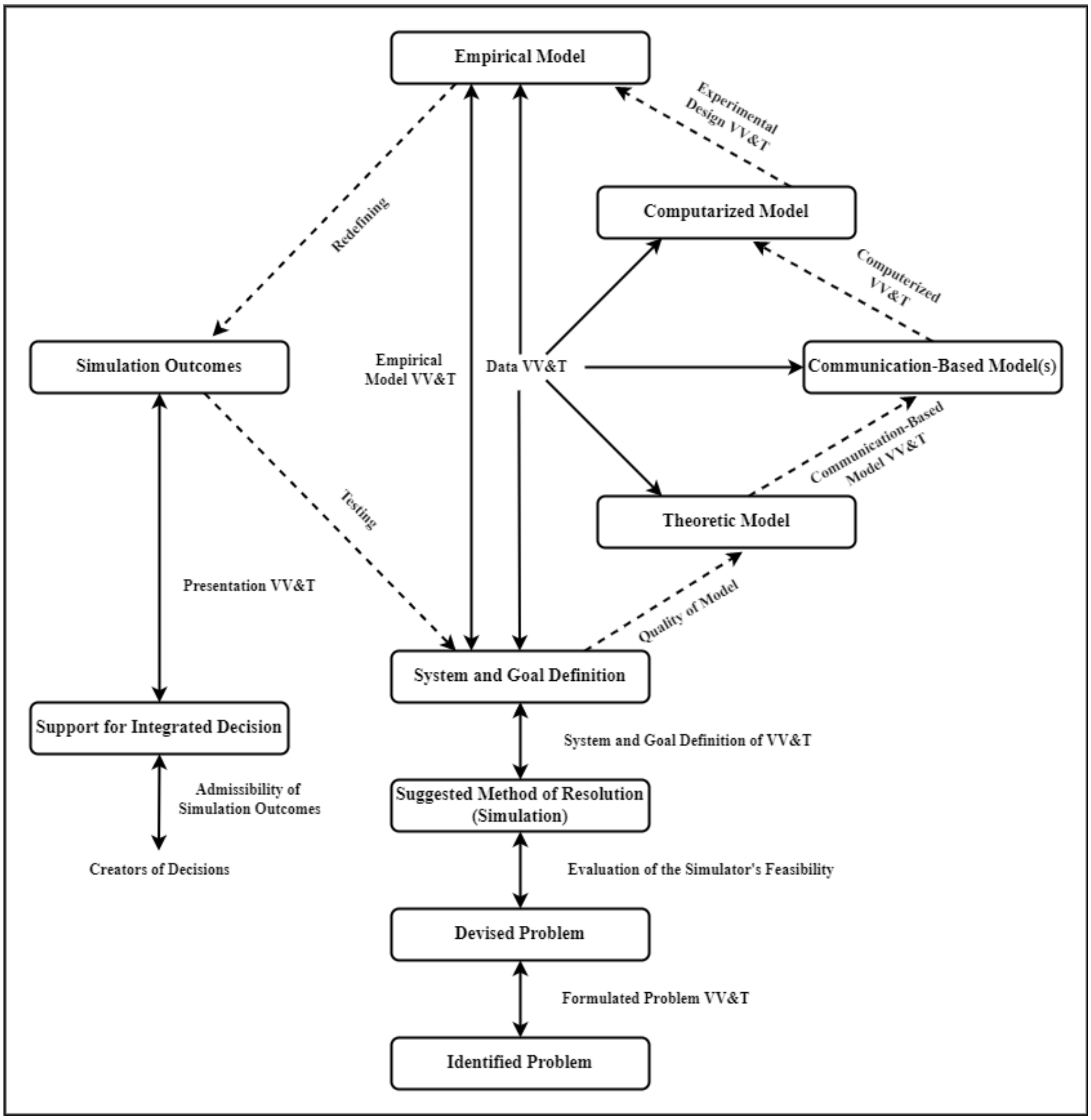


Figure 3.2 The Stages of a Simulation Study [24]

Wang explains how to characterize a catalog for selecting simulation V&V technique choices and then suggests coming up with a plan to use the catalog to choose the right methods for particular simulation projects [25]. Despite being more specialized, this strategy does not consider associated simulation metrics or calculations when choosing methods. The methodology developed in the study is presented in Figure 3.3.

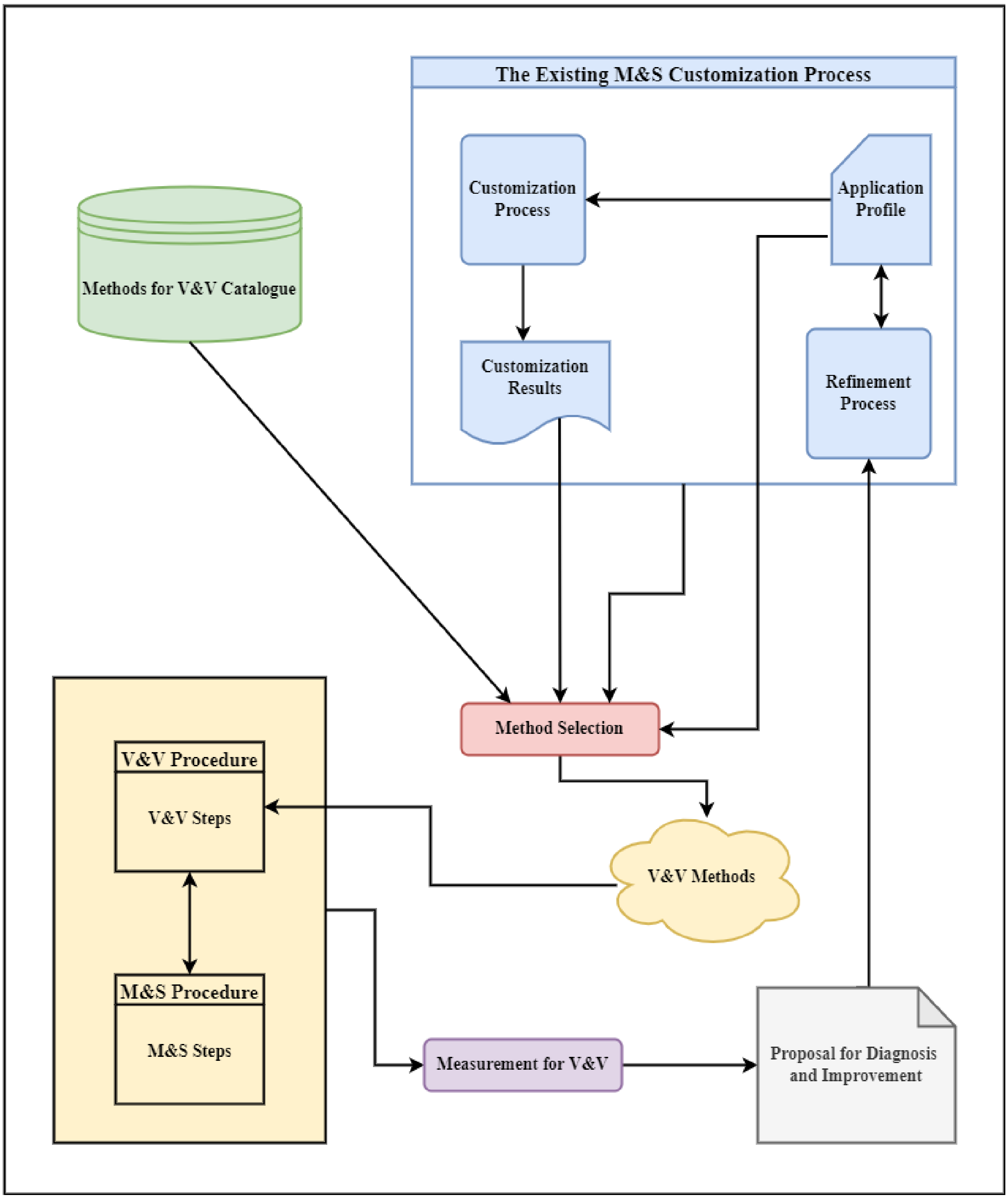


Figure 3.3 Method for Extensive Planning and Customization [25]

Roungas et al propose a framework for optimizing the V&V process for simulations. In this way, it is aimed to refine the complex and long list of V&V methods by making a series of queries (availability of source code, real data, game work and objectivity, etc.) [26]. An example of this refinement approach can be seen in Figure 3.4.

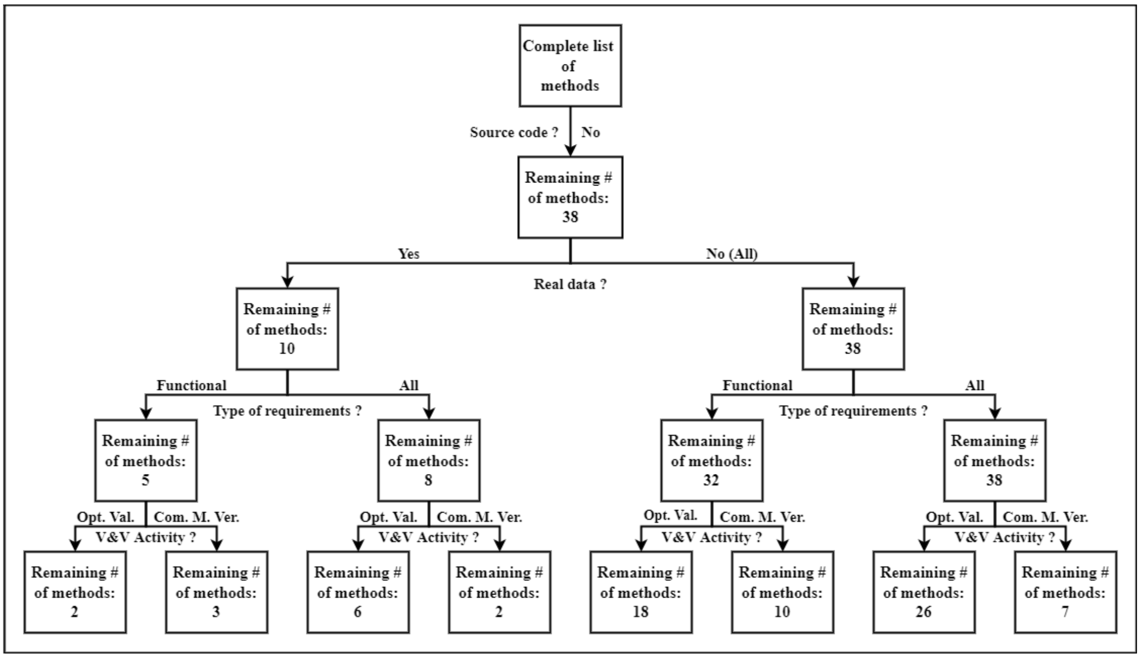


Figure 3.4 Refinement Process Tree Graph for Choosing a Technique [26]

One of the inadequacies of this study is that the simplification process is done with a limited number of queries, which may lead to the elimination of methods that may be useful in the V&V process. Another inadequacy is that it does not contain a specific method selection strategy for the simulation project.

Table 3.1 Classification of Operational Validity [27]

Decision Strategy	**Traceable System**	**Non-traceable System**
Subjective Strategy	• Utilizing visual displays to compare • Investigate model behavior	• Investigate model behavior • Contrasting with other models
Objective Strategy	• Comparing data using statistical techniques	• Utilizing statistical tests for compare to different models

Sargent's research is primarily concerned with the V&V of simulations to precisely forecast actual system behavior in an observable setting while considering the model's assurance ranges into account [27]. However, the techniques utilized are primarily restricted to formal (statistical) testing and few systems as stated in Table 3.1. In addition, there is insufficient information regarding the use and ongoing development of this strategy.

4. DEVELOPING A SAMPLE FRAMEWORK FOR V&V METHOD SELECTION

In this section, the V&V method selection framework developed within the scope of the thesis study is explained.

4.1. Introduction

After determining the inadequacies of the studies mentioned in the previous section in V&V method selection, the following problems are mostly emphasized during this study in order to design planned framework:

- Limited method selection techniques in the field of simulation V&V process,
- The distinctive properties of the methods are not sufficiently specified,
- There are very few approaches to the characteristics of the project, which will carry out V&V activity,
- The lack of prioritization among the methods to be selected and the need for optimization.

Considering the problems mentioned above in the developed framework, the following approaches are suggested:

- V&V methods are profiled and each method is expressed uniquely, making it easier to evaluate in the selection process,
- Ability to identify priority methods with a score-based selection technique where candidate methods will be scored according to certain criteria(s),
- To be able to carry out a more target-oriented V&V process by considering the method selections in the context of the relevant simulation project with the requirements and metric information,
- Ability to adapt to changes related to the project and revise the selection process accordingly,
- Applicable to other software projects besides simulations.

Thanks to these innovative approaches, it is aimed to further improve the V&V processes of simulations.

4.2. Overview of the Methodology

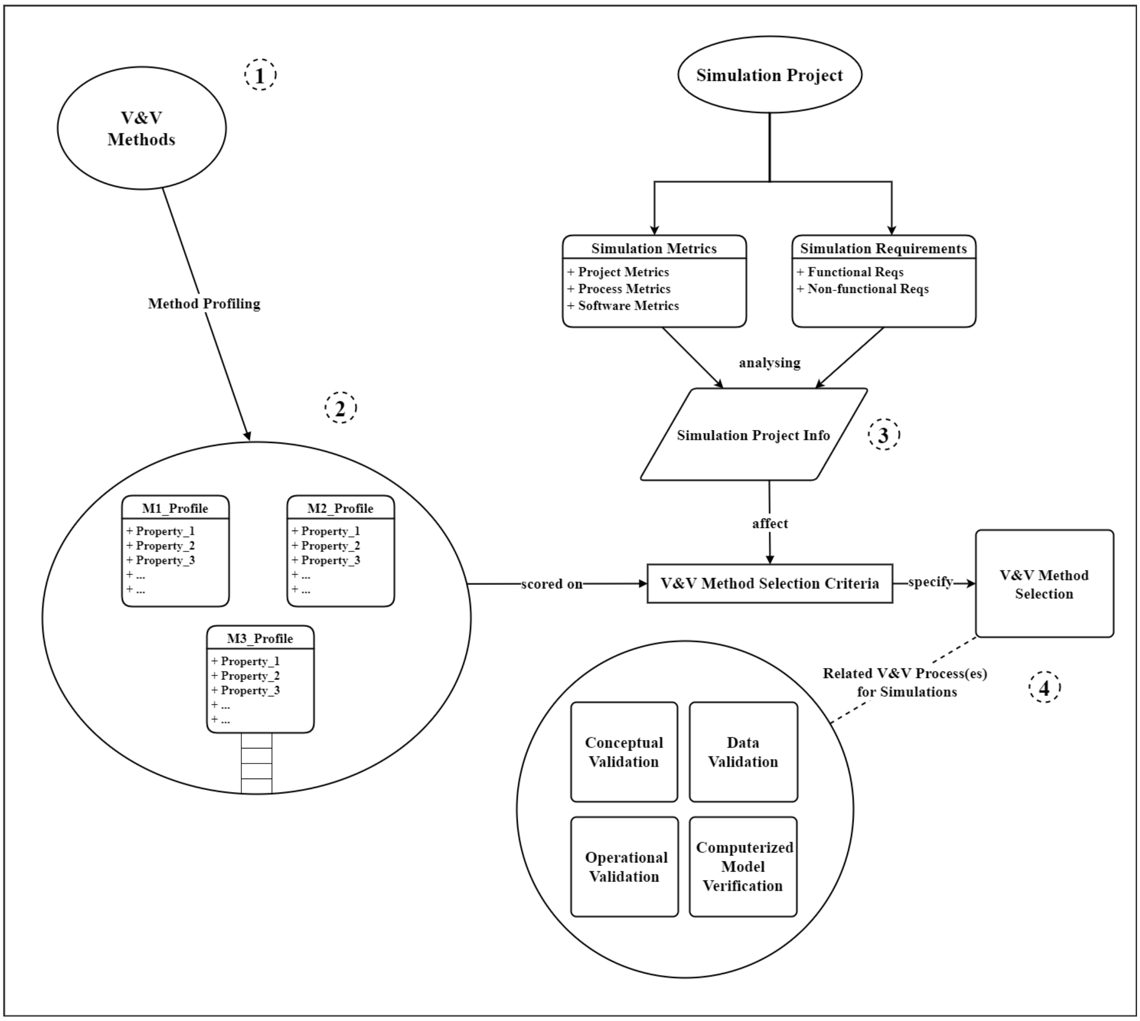


Figure 4.1 V&V Method Selection Methodology on the Proposed Framework

The overview of the framework developed for the V&V method selection is shown in Figure 4.1. The main steps of the methodology used are given below:

1. **V&V Method Set Initialization:** First of all, candidate methods whose names are known should be collected in an environment (e.g. database) and defined with an alphanumeric number (Ex: M1, M2, M3, …).
2. **V&V Method Profiling:** Methods created in the set should undergo a profiling process and have an identity consisting of distinctive properties.
3. **Simulation Project Info Analysis:** The requirement and metric information of the target project whose V&V method selection process will take place, should be analyzed.

4. **Score-Based V&V Method Selection Depending on Criteria:** The score of each of the previously profiled methods should be calculated based on certain selection criteria. First, a score calculation is made for all simulations, independent of the project information. If there is a simulation software project where V&V activity will be performed, the relevant method scores are recalculated. As a result, in both cases, the methods to be applied in the relevant simulation V&V processes are classified for selection.

In the following sections, the steps specific to this study outlined above will be examined in more detail.

4.3. Initializing the Candidate V&V Methods

Before starting V&V activities, all candidate methods which have the potential to be used in the initial selection process should be kept in a database. The methods mentioned here may be predefined and currently used methods, or they may be newly developed and ready-to-use methods. Each method should be defined as Mx (M: method, x: method number) respectively, and in the first stage, they will not have any other properties other than their names. Once all methods are defined in this way, they must go through the method profiling process in the next step in order to have an unique ID.

4.4. V&V Methods Profiling

As mentioned in the previous sections, it is assumed that there are plenty of methods in the literature for the V&V process of software. When these come together in the determination process of the project, it is inevitable that a very complex set will occur. This set can be reduced a little more when it is considered for specific software such as simulation, but still, choosing from such a set without any criteria, goals or strategies complicates the V&V process. As a first method, classification can be made according to certain criteria and similarity groups can be created. However, in order to express V&V methods, each must have characteristics that distinguish it from the others so that they can be uniquely identified.

In this study, it is tried to define the characteristics of V&V methods with predetermined queries as specified in Table 4.1. Thus, the first step in the selection process is completed by profiling the existing V&V methods. Especially when a new candidate V&V method is included in the system, it is aimed to standardize the method definition process thanks to this identification template.

Table 4.1 Method Profiling Template

Property #	**Definition**	**Possible Values**	**Related Criteria**
P1	Access to source code necessity	False, True	Practicality
P2	Data requirement from the actual system	False, True	Practicality
P3	Type of related requirements	FR, NFR, Both, None	Both
P4	Related V&V activities	Com. M. Ver., Con. M. Val., D. Val., Opt. Val., All, Combinations, None	Practicality
P5	Evaluation type	Objective, Subjective	Practicality
P6	Competence (knowledge + experience) level	Low, Mid, High	Cost
P7	Complexity level	Low, Mid, High	Cost
P8	Participants requirement	Low, Mid, High	Cost
P9	Formality level	Informal, Static, Dynamic, Formal	Cost

The explanations of the headings in the table (Table 4.1):

- **Property #:** In this column, the number of each property of the method is specified and this list expands when new properties are introduced.
- **Definition:** What each property means is written and it also serves as a query for possible answers.
- **Possible Values:** It covers the possible answers according to the definition of the method properties and includes logical, optional, multiple choice, etc.
- **Related Criteria:** It is used to specify the method selection rule. In other words, it indicates the corresponding numerical score of the possible value(s) of the method properties can take. It can be default criteria ("Practicality", "Cost") or defined later (Ex: "Reliability").

4.5. Simulation Project Data Analysis

In the V&V process, it is not enough for the method selection to depend only on the profile properties, because the method selection starts to be effective when the relationship is established with the project's features. For this reason, obtaining the project's information is essential for the V&V method selection strategy. In this study, project information is examined in two different categories, namely requirements and metrics (as in Figure 4.2).

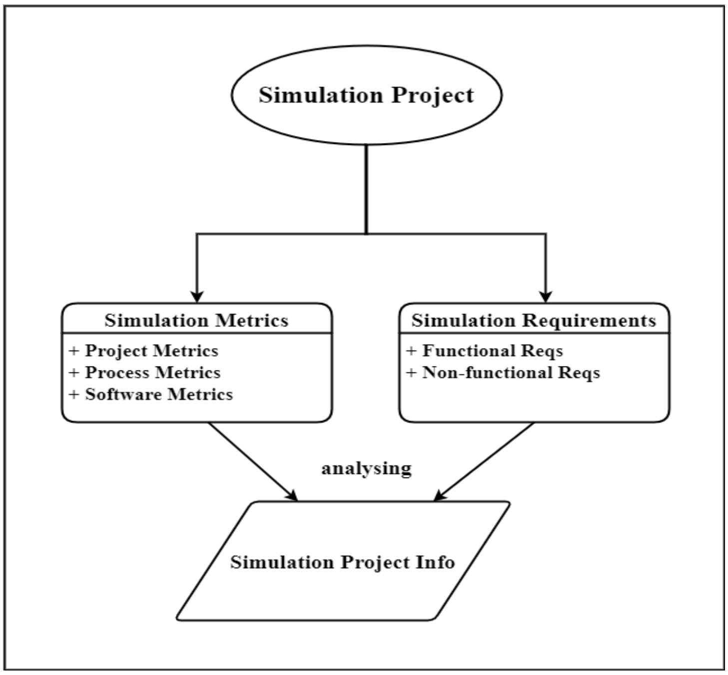


Figure 4.2 Simulation Project Data Analysis Scheme

4.5.1. Simulation Project Requirements Analysis

As in many software projects, there are functional and non-functional requirements for the simulation software project that are decisive for the product to appear as desired. While the functional requirements concern the technical capabilities expected from the product that will emerge, the non-functional requirements are related to the non-behavioral software quality features of the product. Both types of requirements are included in the evaluation in this study because they are related to the V&V process of the target simulation.

In this methodology, it is thought that after the requirements of the simulation project are obtained, they become an effective factor in the relevant V&V method selections. For example, in the method selection process, it is thought that functional requirements are effective on the "Practicality" criterion, and non-functional requirements are effective on the "Cost" criterion. Functional requirements are expressed as FRx, while non-functional requirements are expressed as NFRx (x: sequence number of requirements) for the target project. Moreover, non-functional project requirements can be used as an additional method selection criteria.

4.5.2. Simulation Metrics Analysis

The goal of tracking and evaluating software metrics may be summed up as figuring out how good a product or process is already, finding ways to make it better, and forecasting how good it will be once the software development project is through. Thus, benefits such as increasing the return on investment (ROI) within the scope of the project, pinpointing regions for development, coordinating tasks, minimizing overtime and costs can be achieved. For all these reasons, obtaining and analyzing the relevant metrics for the V&V processes, as in the simulation software development process, contributes to the method selection process. In this section, the metrics potentially to be used in the analysis are examined in 3 categories:

- Simulation project metrics (Table 4.2)
- Simulation process metrics (Table 4.3)
- Simulation software metrics (Table 4.4)

Table 4.2 Simulation Project Metrics [28]

METRIC	DEFINITION AND/OR FORMULA	RELATED METHOD PROPERTY (#)
Index of stability requirement	It allows to see the size and impact of requirement modifications. *1 - ((# of added + # of removed + # of modified) / initial requirements in total) x C*	P2
Simulation project productivity	It is a measurement of the output for a unit of input from a related process. *(Real Project Size) / (Real effort put into the project)*	P8
Productivity in the creation of test cases	*Real # of test cases / The time actually spent creating test cases*	P8
Productivity in the execution of test cases	*Real # of test cases / Actual amount of time spent testing*	P8
Productivity in the detection of defect	*(Real # of defect as testing and review) / (The time actually spent for testing and review))*	P8

Productivity in the fixation of defect	*(Real # of issues resolved) / (Time actually spent correcting errors)*	P8
Variation in effort	It is the difference between the effort that was anticipated and the actual effort needed to activity completion.	P8
	(Actual Effort - Intended Effort) / Intended Effort x C	
Variation in effort for a phase	It is the difference between the effort that was anticipated and what was actually expended during different project phases.	P8
	(Effort put in related phase - Related phase's projected effort) / (Related phase's projected effort) x C	
Variation in plan	It is any gap between the anticipated and actual times at which a task is completed.	P4
	(Begin variation + (Dates in the calendar - Scheduled days in the calendar)) / Scheduled days in the calendar x C	
Variation in planning for a phase	It represents the difference between a project's planned and real timelines for each phase.	P4
	(Dates in the calendar for a phase - Scheduled days in the calendar for a phase + Begin variation for a phase) / (Scheduled days in the calendar for a phase) x C	

Variation in size	It is the difference between the project's estimated and actual size (typically in FP (A Function Point) or KLOC).	P7
	(Real size - Approximated size) / Approximated size x C	

Table 4.3 Simulation Process Metrics [28]

METRIC	**DEFINITION AND/OR FORMULA**	**RELATED METHOD PROPERTY (#)**
Density of remaining defects	*(complete defects discovered by clients) / (overall defecs, comprising those discovered by clients) x C*	P6
Effectiveness of defect removal	It measures how well problems were found and kept from getting to the consumer.	P6
	(1 – (complete defects discovered by clients / overall defects)) x C	
Efectiveness of review	It is described as the effectiveness at utilizing or identifying review flaws during the verification step.	P6
	(# of defects found after review) / (# of defects found overall) x C	
Effectiveness of testing		P6

	1 - ((defects discovered after acceptance) / all defects found during testing) x C	
Frequency of defect	It is calculated by dividing the total number of software defects found during development by the software's overall size (normally in FP (A Function Point) or KLOC).	P7
	(overall defect count) / (size of the project in FP or KLOC)	
Poor quality's cost	It is the price of using faulty products and procedures.	P8
	(efforts to rework) / (overall effort) x C	
Quality's cost	It evaluates how well quality efforts function inside a company. And it has a financial expression.	P8
	(all quality attributes) / (overall effort) x C	

Table 4.4 Simulation Software Metrics [29]

METRIC	DEFINITION AND/OR FORMULA	RELATED METHOD PROPERTY (#)
Code and data quality	The quality of the source code and data used is scored. *Ex: A+, A, B, C, D, E*	P2
Code churn	It shows how many lines of code were added, changed, or removed during a predetermined amount of time. The need for attention in the software development project may be indicated by an increase in code churn.	P2
Code language	The development languages used are indicated. *Ex: C/C++, C#, Java, Python*	P7
Cycle time	It provides information on the time required to alter a software and use that modification.	P7
Impact	It assesses how each modification to the source code affects the software development project. A modification to the code that affects several files could	P7

	have a bigger effect than one that just affects one file.	
Time between failures and recovery on average	They measure the software's effectiveness in a real-world setting. These software metrics try to measure how effectively the software restores or maintains data because software failures are mostly inescapable.	P7
Simulation crash rate	It is determined by dividing a simulator's failure rate by the number of times it is utilized.	P7
Simulation type	The type of target simulation is defined. *Ex: Dynamic simulation, process simulation, discrete event simulation*	None
Size-specific metrics	They are often stated as KLOC and focus on the software's size. *Ex: Errors, defects or cost per KLOC*	P7

4.6. Method Selection Process

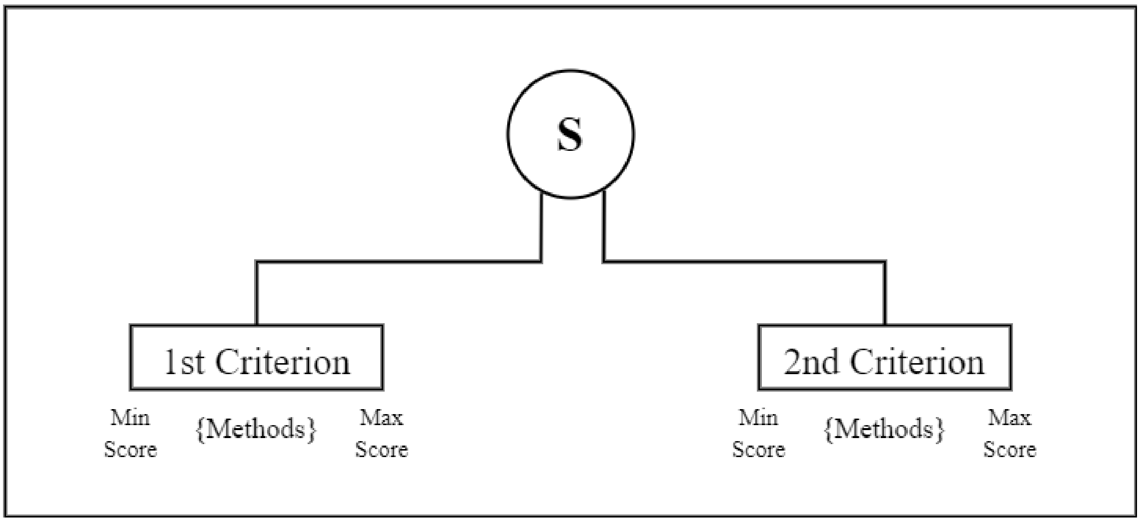


Figure 4.3 Method Selection Representation for Main Criteria

4.6.1. Method Selection Criteria

There is a need for one or more criteria about how the V&V methods selection process will be made. In this study, the main selection criteria is determined as "Practicality" and "Cost". As represented in Figure 4.3, when "Practicality" is chosen as 1st criterion, applicability level of the candidate method can be determined. On the other hand, when the "Cost" is chosen as the 2nd criterion, it can be determined how much this method is cost in terms of time, effort and resource needs. Each criterion type has a different effect on possible values of the method properties and selectability level of the candidate method.

The first goal in the method selection process is to balance practicality and cost criteria of V&V methods, because there is a trade-off between them. However, with the information of the project is obtained and clarified, this balance may change in different directions on the criterion ranges and the method selection process may begin to be more target-oriented. Apart from these criteria, additional criteria may also be defined depending on the project needs or progress.

4.6.2. The Scoring System

Related index definitions:

i = method property, j = method criterion, n = # number of terms, x = method, k = metric

Ex: **if** j=1 **then** criterion: “Practicality”, **else if** j=2 **then** criterion: “Cost” for P_1, M_1 (1st property of the 1st method)

The scoring algorithm steps for the framework is introduced below:

Algorithm 1: Identifying scoring values specific to criterion

Input: Two integers i, j and two numbers a and b, where $i \geq 1$, $j \geq 1$, $a < b$

Output: score, where $a \leq score \leq 10$

```
if i=3 and j=1 then
    S($P_i$, $C_j$) = possible_value_1: score_1 or possible_value_2: score_2
else if i=3 and j=2 then
    S($P_i$, $C_j$) = possible_value_1: score_2 or possible_value_2: score_1
return possible_value: score
end
```

Algorithm 2: Scoring each method properties with the selection (scoring) function

Input: Two integers j, n where $j \geq 1$

```
procedure ($P_i$, $C_j$)
i = 1,  j = 1
while $i \leq n$
    if possible_value(s) then
        $P_i$ = {possible_value: score}
    i = i+1
end while
end procedure
```

Algorithm 3: Calculating the method score

Input: Three integers i, j and x where i ≥1 and j ≥ 1 and x ≥1

Output: $M_x C_j$

```
i = 1,  x=1, $M_x C_j$ = 0
while i ≤ n
    if $P_i$ $C_j$ = 0 then
        $M_x C_j$ = 0
        return
    else
        $P_i$ $C_j$ = {possible_value: score}
        $M_x C_j$ = $M_x C_j$ + $P_i$ $C_j$
        i = i+1
end while
return ($M_x C_j$ / n)
end
```

After completing the scoring steps, the method selection process can be performed with decided selection rule (eg. method prioritization).

4.6.3. Generic Method Selection Based on Main Criteria

When the method selection process is made without target project each properties' scores for main criteria "Practicality" and "Cost" are calculated:

- S(P_1, C_1) = True: 1 **or** False: 10
- S(P_2, C_1) = True: 1 **or** False: 10
- S(P_3, C_1) = NFR: 2.5 **or** FR: 7.5 **or** Both: 10
- S(P_3, C_2) = FR: 2.5 **or** NFR: 7.5 **or** Both: 10
- S(P_4, C_1) = Com. M. Ver.: 2.5 **or** Con. M. Val.: 2.5 **or** D. Val.: 2.5 **or** Opt. Val.: 2.5 **or** All: 10 **or** Combinations: total scores of V&V activities selected
- S(P_5, C_1) = Subjective: 1 **or** Objective: 10
- S(P_6, C_2) = Low: 1 **or** Mid: 5 **or** High: 10
- S(P_7, C_2) = Low: 1 **or** Mid: 5 **or** High: 10
- S(P_8, C_2) = Low: 1 **or** Mid: 5 **or** High: 10

- S(P_9, C_2) = Informal: 2.5 **or** Static: 5 **or** Dynamic: 7.5 **or** Formal: 10

Score Range for C_1 and C_2: [1,10]

To ensure the principle of highest “Practicality” and lowest “Cost” values, method selection starts with the highest P/C score.

High priority method selection rule: $\frac{M_x C_1}{M_x C_2}$ = {max}

4.6.4. Specific Method Selection in the Presence of Project Information

After analyzing the data of the simulation project and obtaining the necessary information, the main criteria rules may be revised and new selection strategies can be created. Additionally, specific criteria other than the main criteria may be created associated with non-functional requirements and included for method selection process.
Score value exceptions of some properties for the main criteria:

- S(P_3, C_1) = {related possible value} + (total # of FR covered(%)), None: 0
- S(P_3, C_2) = {related possible value} + (total # of NFR covered)
- S(P_4, C_1) = None: 0

Algorithm 4: Calculating the final method score
Input: Three integers x, j and k, where x ≥1, j ≥1 and 1 ≤ k ≤ 1
Output: final_score

```
if metric has no relation with related method property then
    $W_k$ = low:1
else if metric has partial relation with related method property then
    $W_k$ = mid:3
else if metric has complete relation with related method property then
    $W_k$ = high:5
end
return ( $M_x C_j * W_k$)
end
```

5. PRACTICE OF THE FRAMEWORK AND RESULTS

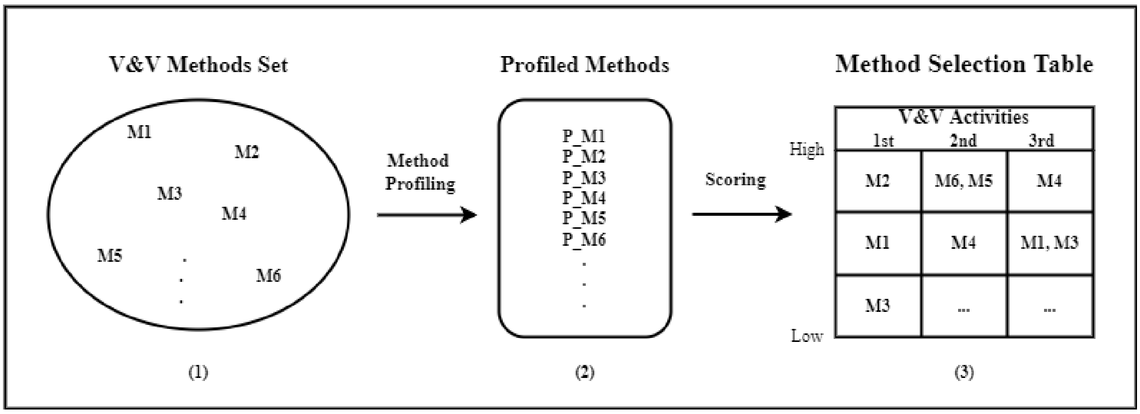
This section presents an experimental study for the implementation of the V&V method selection framework developed for this thesis and shares the results. It consists of two main parts:

1. **General-Purpose V&V Method Selection:** V&V method selection process for common simulation study.
2. **Specific-Purpose V&V Method Selection:** Studying the framework with the project data of an open source simulation software.

5.1. General-Purpose V&V Method Selection

This part is a preliminary preparation for the “Specific-Purpose V&V Method Selection” stage, since the approach here is intended directly for simulation concepts without any simulation project information. The selection priorities of the V&V methods here are determined only by their compatibility with the simulation concept. The main steps of this study (as exemplified in the Table 5.1) are listed below:

1. The candidate methods to be selected in V&V activities are identified in the initialization set.
2. The methods in the set undergo a profiling process and their scores are calculated considering the main criteria.
3. Method selection table is generated for generic use.



V&V Activities		
1st	2nd	3rd
M2	M6, M5	M4
M1	M4	M1, M3
M3	...	...

Figure 5.1 Basic V&V Method Selection Procedure

5.1.1. V&V Method Set Initialization

M1 = Acceptance Testing
M2 = Alpha Testing
M3 = Assertion Checking
M4 = Audit
M5 = Beta Testing
M6 = Black-Box Testing
M7 = Bottom-Up Testing
M8 = Boundary Value Testing
M9 = Branch Testing
M10 = Cause-Effect Graphing
M11 = Comparison Testing
M12 = Concurrent Process Analysis
M13 = Condition Testing
M14 = Data Dependency Analysis
M15 = Data Flow Analysis
M16 = Data Interface Testing
M17 = Debugging
M18 = Desk Checking
M19 = Equivalence Partitioning Testing
M20 = Extreme Input Testing
M21 = Face Validation
M22 = Field Testing
M23 = Graphical Comparisons
M24 = Inspections
M25 = Invalid Input Testing
M26 = Lambda Calculus
M27 = Logical Deduction
M28 = Loop Testing
M29 = Model Interface Analysis
M30 = Object Flow Testing
M31 = Path Testing
M32 = Performance Testing
M33 = Predicate Transformations
M34 = Product Testing
M35 = Proof of Correctness
M36 = Real-Time Input Testing
M37 = Regression Testing
M38 = Reviews
M39 = Security Testing
M40 = Self-Driven Input Testing
M41 = Sensitivity Analysis
M42 = Standards Testing
M43 = Statement Testing
M44 = State Transition Analysis
M45 = Stress Testing
M46 = Syntax Analysis
M47 = Trace-Driven Input Testing
M48 = User Interface Testing
M49 = Visualization or Animation
M50 = Walkthroughs

Figure 5.2 Initial Set of V&V Methods

First of all, the process starts with the initialization of the set of available methods that have the potential to be used in V&V activities. In this study, as shown in Figure 5.2 the selection process is started over 50 methods [26]. The selection order of the methods in the set is not important in the first place, but after scoring methods, processes such as elimination, grouping, categorization some changes are expected in terms of prioritization and the total number of methods to be used.

5.1.2. Method Score Results After Profiling

After the previous step, the methods in the set undergo a profiling process and their values are assigned. Then the final scores of each method are calculated according to the main criteria:

- $\frac{M_1C_1}{M_1C_2} = 1{,}13$
- $\frac{M_2C_1}{M_2C_2} = 1{,}13$
- $\frac{M_3C_1}{M_3C_2} = 0{,}83$
- …
- $\frac{M_{50}C_1}{M_{50}C_2} = 2{,}68$

According to the score calculations here in Appendix-2, the methods to be chosen as a result of the ordering of the ratios from high to low can be listed. After calculating the average scores of the methods in the previous stage, method selection processes can be made under the relevant V&V activities.

5.1.3. Generated Method Selection Table for General-Purpose Usage

Table 5.1 Method Selection Table 1

Method Selection Level	**V&V Activities**			
	Com. M. Ver.	**Con. M. Val.**	**D. Val.**	**Opt. Val.**
1	M14, M15, M44	M50	M41	M25, M30, M40, M45
2	M46	M11, M29	M14, M15, M44	M19, M20

3	M3, M10, M12	M9, M13, M28, M31, M43	M16	M48
4	M32	M27	M27	M21
5	M5	M24, M38	M47	M49
6	M26	M35		M23
7	M8, M9, M13, M28, M31, M43	M47		M6
8	M42	M4		M2, M5
9	M27			M22
10	M7, M17			M27
11	M35			M1, M34
12	M18			M36
13	M33, M37, M39			

Table 5.1 shows the V&V method selection order (from higher method score to low) due to their scores without target simulation project. As can be seen from the method selection level (1st column), there can be more than one method at the same level which complicates the methods selection process. Because the target simulation information for which the V&V operation will be performed is not provided. This problem highlights the need to improve the method selection process. However, these results are useful in terms of prioritizing methods with higher practicality and lower cost when V&V activity of any simulation is required.

5.2. Specific-Purpose V&V Method Selection

Assuming that “General-Purpose V&V Method Selection” steps are completed, the following steps are ready to be applied:

1. Simulation project information including project requirements and metrics are retrieved from the target simulation project.
2. New method scores are calculated according to the project information.
3. Method selection table is revised for project-specific use.
4. Priorities of simulation V&V method selection processes are specified.

5.2.1. Simulation Project Overview

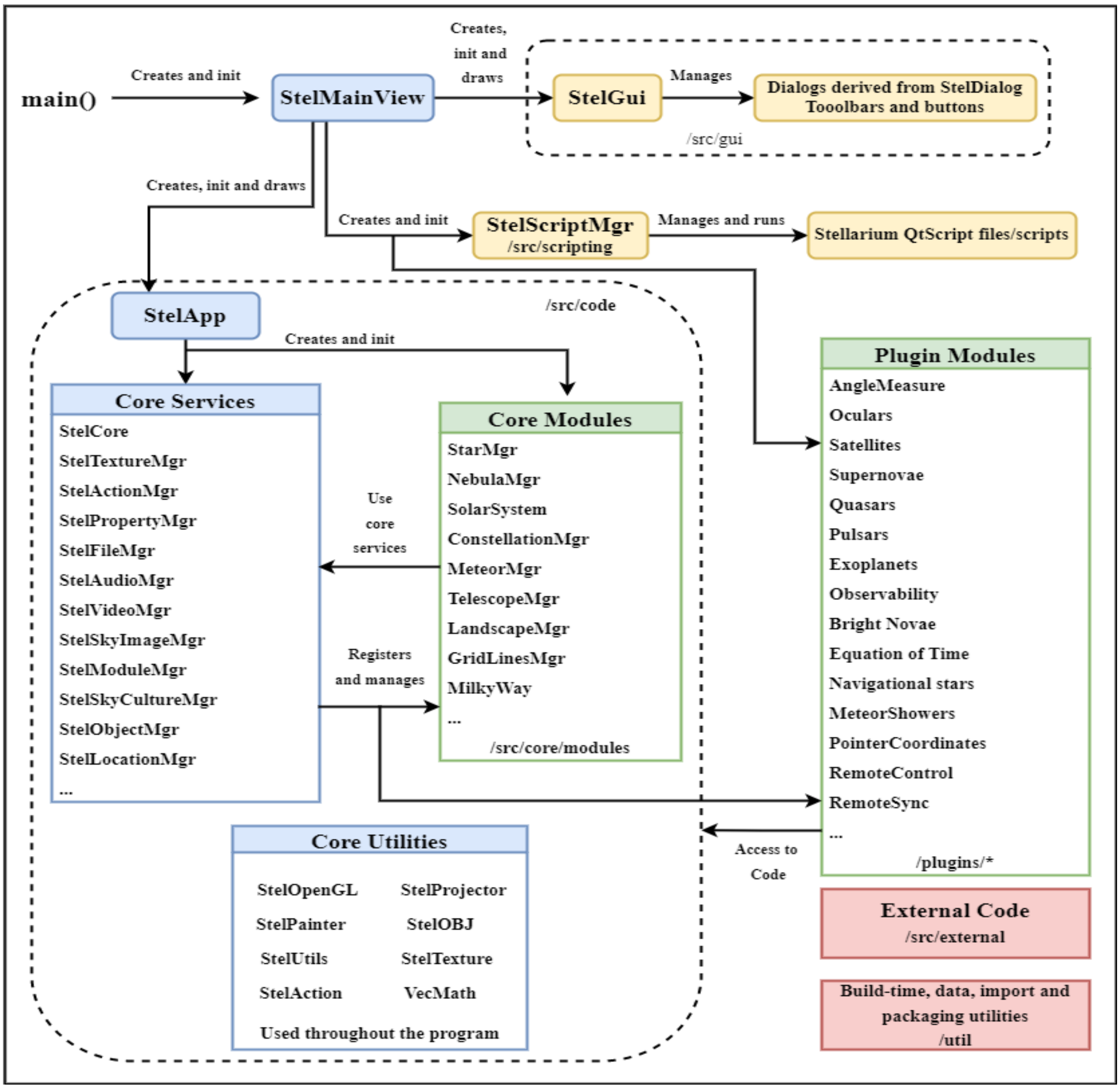


Figure 5.3 Stellarium Program Architecture [32]

The open source simulation project is chosen to practice the developed framework, because there are many V&V methods that have source code access, which makes it easier to work on the related project.

Brief description of target simulation project:

Stellarium [30] is the free open source planetarium simulation software. The purpose of the Astronomy software Stellarium is to generate 3D photo-realistic sky in real time using OpenGL. It shows planets, nebulas, stars, constellations and other objects like ground, landscape, atmosphere, etc. as if seen from eyes, binoculars or an amateur telescope. Stellarium has a GitHub repository containing source code files and other comprehensive project data, and is also the primary resource to be used in this work [31]. The program architecture in Figure 5.3 belongs to the Stellarium (v0.22.2) simulation software whose metrics will be analyzed through open source code access.

Parameters to be evaluated for this project analysis:

1. Effort
2. Code distribution
3. Code and data quality
4. Cost breakdown
5. Code complexity
6. Code release version changes
7. Code findings severity
8. Total lines of code or project size
9. Total number of requirements covered
10. V&V activities

5.2.2. Simulation Project Information Retrieval and Data Analysis

All data or information in Table 5.2 was obtained from the GitHub [31] data provisioning tools of the Stellarium Project.

Table 5.2 Stellarium Project Information

PROJECT REQUIREMENTS	Retrieved Information	Affected Method Property (#)
Functional Requirements	● FR1 = Ability to show objects in the sky at the correct location, time and date. ● FR2 = Accuracy of satellite transit path. ● FR3 = Historical data validity of objects with periodic orbits. ● …. ● FR30 = Being able to synchronize correctly with the telescope connected to the software. (Total: 30)	P3
Non-functional Requirements	● NFR1 = Maintainability ● NFR2 = Documentation ● NFR3 = Readability	P3

	● NFR4 = Correctness ● NFR5 = Security (Total: 5)	
SIMULATION METRICS	**Retrieved Information**	**Affected Method Property (#)**
1. Project Metrics		
1.1. Total # of contributions	148 peers	P8
1.2. Cost of technical debt removal	$60,610	P6
1.3. Equivalent engineering effort	865.85 hrs	P8
1.4. Estimated annual budget	$8.232,57	P8
2. Process Metrics		
2.1. Ongoing V&V Activities	● Com. M. Ver. ● D. Val. ● Opt. Val.	P4
3. Software Metrics		
3.1. Code distribution per language	● C++ (50.0%) ● C (35.0%) ● TeX (8.3%) ● CMake (1.9%)	P7

	● Javascript (1.3%) ● HTML (0.7%)	
3.2. Code quality	A++ (score ~ 98)	P1
3.3. Data quality	A+ (score ~ 90)	P2
3.4. Lines of code	468.2k	P6
3.5. Comparing version changes	● v0.22.2 vs v0.22.1 Commits: 311, FilesChanged: 1,283 ● v0.22.2 vs v0.22.0 Commits: 384, FilesChanged: 1,414	P5
3.6. Cost Breakdown		
3.6.1. Cost of remove defect	$4,015	P6
3.6.2. Cost of refactor duplicate code	$735	P6
3.6.3. Cost of reduce code complexity	$5,740	P6
3.6.4. Cost of improve code reliability	$50,120	P9
3.7. Long Functions	f13% (1438 long functions out of 11872 functions)	P6

3.8. Complex Functions	f2% (168 complex functions out of 11872 functions)	P7
3.9. Duplicated Lines	1% (1732 duplicated slocs out of 594644 slocs)	P6
3.10. Distribution of violations per severity	● Critical: 8 ● Error: 12 ● Warning: 12 ● Recommendations: 70	P9

The project data was analyzed according to Table 5.2 considering the evaluation parameters intended to V&V method selection:

1. The overall engineering cost for code development or V&V activities for this project is calculated as 148 x 865.85 man hours, resulting in an average effort requirement Therefore, moderate level effort requiring methods (number of participants required) are better suited for the project budget.
2. Development code languages are mostly low-level languages. Therefore, the requirement for knowledge and experience required for the methods to be selected should be at a high level.
3. Code and data quality is higher when compared to other similar projects in GitHub, so this feature should be a lower priority for the relevant V&V activity.
4. More formal and complicated methods that require a medium or higher level of competency can be selected to ensure coding cost optimization.
5. Code complexity levels were observed to be low to medium for this project. Therefore, the methods to be applied for verification should also be at these levels.
6. Software release versions and operations related to changes between them affect code size or structure in the repository. Therefore, the selection of methods to be

used for open source code may also be affected. Minor changes have been observed between successive versions of Stellarium.

7. Violations detected in the source code are provided using static analysis tools. Therefore, objective evaluation methods with static type formality will take precedence.
8. Stellarium is a medium size project with approximately 500 KLOC. It will therefore require at least intermediate competence in the application of the methods.
9. Project requirements have been gathered in 2 different categories (FR and NFR) and candidate methods will be evaluated in scoring according to their coverage of these requirements.
10. V&V activities can be performed as 3 different simulation cycles (Table item 2.1).

5.2.3. Revision of the Method Selection Scores

The method selection for the main criteria is revised according to the project characteristics and the score ranges of the values are updated accordingly as follows:

- S(P_1, C_1) = True: [5,10] **or** False: [1,5]
- S(P_2, C_1) = True: [1,5] **or** False: [5,10]
- S(P_3, C_1) = {related possible value} + (total # of FR covered(%)) **or** None: 0
- S(P_3, C_2) = {related possible value} + (total # of NFR covered(%)),
- S(P_4, C_1) = Com. M. Ver.: 2.5 **or** Con. M. Val.: 2.5 **or** D. Val.: 2.5 **or** Opt. Val.: 2.5 **or** All: 10 **or** Combinations: total scores of V&V activities selected **or** None: 0
- S(P_5, C_1) = Subjective: [1,5] **or** Objective: [5,10]
- S(P_6, C_2) = Low: [0,3] **or** Mid: [3,6] **or** High: [7,10]
- S(P_7, C_2) = Low: [0,3] **or** Mid: [3,6] **or** High: [7,10]
- S(P_8, C_2) = Low: [0,3] **or** Mid: [3,6] **or** High: [7,10]
- S(P_9, C_2) = Informal: 2.5 **or** Static: 5 **or** Dynamic: 7.5 **or** Formal: 10

The Conceptual Validation phase, one of the main simulation V&V processes in the framework, is ignored as it is assumed that the related process has already been completed for this project. Therefore, only other V&V processes (Com. M. Ver., D. Val., Opt. Val.) are considered. After the previous step, the methods in the set undergo scoring process and then the final scores of each method are calculated according to the main criteria:

- $\frac{M_1 C_1}{M_1 C_2}$ = 36,81
- $\frac{M_2 C_1}{M_2 C_2}$ = 26,90
- $\frac{M_3 C_1}{M_3 C_2}$ = 21,48
- …
- $\frac{M_{50} C_1}{M_{50} C_2}$ = 0

Score details are given in Appendix-2.

5.2.4. Generated Method Selection Table for Specific Usage

Table 5.3 Method Selection Table 2

Method Selection Level	**V&V Activities**		
	Com. M. Ver.	**D. Val.**	**Opt. Val.**
1	M15	M15	M49
2	M10	M47	M6
3	M46	M44	M1
4	M7	M27	M5
5	M43	M16	M25

6	M9		M30
7	M8		M20
8	M44		M2
9	M34		M40
10	M13		M19
11	M31		M35
12	M3		M23
13	M17		M45
14	M28		M41
15	M37		M21
16	M27		M48
17	M32		M27
18	M42		M36
19	M18		
20	M39		

Table 5.3 shows the V&V method selection order (from higher method score to low) due to their scores intended for Stellarium Project.

5.3. Practising Results

- Firstly, when comparing Table 5.1 with Table 5.3, it is clearly seen that the number of selection levels in Table 5.3 is much longer. The reason for this is that the score values that the method properties can take in Table 5.3 are more diverse and in a wide range because of metrics scores. As a result, a distinctive scoring for each method is calculated as in Table 5.3. This result indicates that the applicability of the methods are increased.
- Secondly, the number of methods per selection level has been reduced as seen in Table 5.3, so the cost of V&V activity in terms of method selection is decreased.
- Thirdly, one of the V&V activities (Con. M. Val.) for the method selection table was removed, because it was already completed in the project. Thus, V&V methods M4, M11, M24, M29, M38, M50 related to the relevant activity were eliminated from the selection table (Table 5.3). Likewise, other V&V methods M12, M14, M22, M26, M33 were also removed from the table, because they do not cover functional requirements of the project. As a result, the method selection set was reduced from 50 to 39. Accordingly, it is expected to save time during the application of the methods.
- Finally, Table 5.3 results shows that an optimized and project-specific method selection strategy, especially in terms of practicality and cost criteria is provided by this study.

The methodology suggested in this study has been shown to be superior to conventional method selection strategies in light of these results.

6. CONCLUSION AND FUTURE WORK

This section presents the conclusion of this study and future work on new features that can be added to the V&V framework.

6.1. Conclusion

The goal of this study was to present a methodology that enables the selection of several V&V techniques that may be used in accordance with the requirements and metrics of the corresponding simulation project. To achieve this, a more comprehensive and target-oriented framework has been developed by making use of the relevant preliminary studies. In section 4, the details of the V&V method selection framework developed specifically for this study are explained. This section also covers methods profiling, criteria-dependent scoring techniques, score-based V&V method selection and incorporating simulation project information analysis into method selection, unlike related studies. In the 5th part of the study, a sample method selection scenario is carried out with an applied study on the data of the open source simulation project to test the developed framework. Considering the results of this practice, the more project information is obtained from the target simulation project, the more specific method selection process and accordingly an optimized V&V process is possible thanks to the score-based method selection technique proposed for this study.

During this study, a conference paper regarding with V&V method selection approach for simulations has been published (the publication link can be found in Appendix-1).

As a result, it is expected that this study will guide and contribute to simulations V&V activities for both academic and industrial fields in the scope of software engineering.

6.2. Future Work

Future work that can be built is presented in this section. Features and explanations that can be added to the current framework:

- *Historical data mining for enhanced project analysis:*

  A more advanced analysis process is aimed by evaluating the historical simulation project data cumulatively.

- *Dynamic method selection:*

  When any M&S application is being developed, new project features may be continually discovered and the established needs and restrictions may change. As a result, the application profile must be developed and modified accordingly. Therefore, based on the status of the application profile, a new selection of the identified project tasks should be produced. Dynamic method selection can be used for this type of adaptation.

- *Statistical methods selection process:*

  Statistical technique selection methodologies can be included into simulation projects that require particularly high precision results.

- *Gartner Report adaptation:*

  After collecting and evaluating sufficient data of the simulation project, it will be possible to make predictions and draw a road map towards the future of the project in the context of verification and validation activities.

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APPENDICES

APPENDIX 1 - Proceeding that has been accepted for the publication

Y. K. Altinok, H. Artuner and A. H. İpek, "Verification and Validation Methods Selection Based on Goal-Oriented Categorization for Simulations," 2021 2nd International Informatics and Software Engineering Conference (IISEC), 2021, pp. 1-5, doi: 10.1109/IISEC54230.2021.9672448.

APPENDIX 2 - Score Tables

Method Profiling Values for Practicality Criteria

Methods	P1	P2	P3	P4	P5
M1	False	False	Both	Opt. Val.	Objective
M2	False	False	Both	Opt. Val.	Objective
M3	True	False	FR	Com. M. Ver.	Objective
M4	True	False	NFR	Con. M. Val.	Subjective
M5	False	False	Both	Opt. Val.	Objective
M6	False	True	FR	Opt. Val.	Objective
M7	True	False	Both	Com. M. Ver.	Objective
M8	True	False	Both	Com. M. Ver.	Objective
M9	True	False	Both	Con. M. Val. & Com. M. Ver.	Objective
M10	True	False	FR	Com. M. Ver.	Objective
M11	False	False	Both	Con. M. Val.	Objective
M12	True	False	FR	Com. M. Ver.	Objective
M13	True	False	Both	Con. M. Val. & Com. M. Ver.	Objective
M14	True	False	FR	D. Val & Com. M. Ver.	Objective
M15	True	False	FR	D. Val & Com. M. Ver.	Objective
M16	False	False	NFR	D. Val	Objective
M17	True	False	Both	Com. M. Ver.	Objective
M18	True	False	Both	Com. M. Ver.	Subjective
M19	False	False	FR	Opt. Val.	Objective
M20	False	False	FR	Opt. Val.	Objective
M21	False	True	Both	Opt. Val.	Subjective
M22	False	True	Both	Opt. Val.	Objective
M23	False	False	Both	Opt. Val.	Objective
M24	False	False	Both	Con. M. Val.	Subjective
M25	False	False	FR	Opt. Val.	Objective
M26	True	False	FR	Com. M. Ver.	Objective
M27	False	False	Both	All	Objective
M28	True	False	Both	Con. M. Val. & Com. M. Ver.	Objective
M29	False	False	Both	Con. M. Val.	Objective
M30	False	False	FR	Opt. Val.	Objective

M31	True	False	Both	Con. M. Val. & Com. M. Ver.	Objective
M32	False	False	NFR	Com. M. Ver.	Objective
M33	False	True	FR	Com. M. Ver.	Objective
M34	True	False	FR	Con. M. Val. & Com. M. Ver.	Objective
M35	False	False	Both	Opt. Val.	Objective
M36	False	True	FR	Opt. Val.	Objective
M37	True	False	FR	Com. M. Ver.	Objective
M38	False	False	Both	Con. M. Val.	Subjective
M39	False	False	NFR	Com. M. Ver.	Objective
M40	False	False	FR	Opt. Val.	Objective
M41	False	False	FR	Opt. Val.	Objective
M42	False	False	NFR	Com. M. Ver.	Objective
M43	True	False	Both	Con. M. Val. & Com. M. Ver.	Objective
M44	True	False	FR	D. Val. & Com. M. Ver.	Objective
M45	False	False	FR	Opt. Val.	Objective
M46	True	False	FR	Com. M. Ver.	Objective
M47	True	True	Both	D. Val & Con. M. Val.	Objective
M48	False	False	NFR	Opt. Val.	Objective
M49	False	True	Both	Opt. Val.	Objective
M50	False	False	Both	Con. M. Val.	Subjective

Method Profiling Values for Cost Criteria

Methods	P3	P6	P7	P8	P9
M1	Both	Mid	Mid	High	Dynamic
M2	Both	Mid	Mid	Mid	Dynamic
M3	FR	Mid	Mid	Low	Dynamic
M4	NFR	Low	Low	Mid	Informal
M5	Both	Mid	Mid	Mid	Dynamic
M6	FR	Mid	Mid	Low	Dynamic
M7	Both	High	Mid	Low	Dynamic
M8	Both	Mid	Mid	Low	Dynamic
M9	Both	Mid	Mid	Low	Dynamic
M10	FR	Mid	Mid	Low	Dynamic
M11	Both	Mid	Mid	Low	Static
M12	FR	Mid	Mid	Low	Dynamic
M13	Both	Mid	Mid	Low	Dynamic
M14	FR	Mid	Mid	Low	Static
M15	FR	Mid	Mid	Low	Static
M16	NFR	Mid	Mid	Low	Dynamic
M17	Both	Mid	Mid	Low	Dynamic
M18	Both	Mid	Low	Mid	Informal
M19	FR	Mid	Mid	Low	Dynamic
M20	FR	Mid	Mid	Low	Dynamic
M21	Both	Mid	Low	Mid	Informal
M22	Both	Mid	Mid	Low	Static
M23	Both	Mid	Mid	Low	Dynamic
M24	Both	Low	Mid	High	Informal
M25	FR	Mid	Mid	Low	Dynamic
M26	FR	High	High	Low	Formal
M27	Both	High	High	Low	Formal
M28	Both	Mid	Mid	Low	Dynamic
M29	Both	Mid	Mid	Low	Static
M30	FR	Mid	Mid	Low	Dynamic
M31	Both	Mid	Mid	Low	Dynamic
M32	NFR	Mid	Mid	Low	Dynamic
M33	FR	High	High	Low	Formal
M34	FR	High	High	Low	Formal
M35	Both	Mid	Mid	High	Dynamic
M36	FR	Mid	Mid	Low	Dynamic
M37	FR	Mid	Mid	Low	Dynamic
M38	Both	Mid	Low	High	Informal
M39	NFR	Mid	Mid	Low	Dynamic
M40	FR	Mid	Mid	Low	Dynamic
M41	FR	Mid	Mid	Low	Static
M42	Both	Mid	Mid	Low	Dynamic
M43	Both	Mid	Mid	Low	Dynamic
M44	FR	Mid	Mid	Low	Static
M45	FR	Mid	Mid	Low	Dynamic
M46	FR	Mid	Mid	Low	Static
M47	Both	Mid	Mid	Low	Dynamic
M48	NFR	Mid	Mid	Low	Dynamic
M49	Both	Mid	Low	Low	Static
M50	Both	Low	Low	Mid	Informal

Method Scores for Practicality Criteria (General-Purpose V&V Method Selection)

Methods	P3	P6	P7	P8	P9	Avg Score
M1	10	5	5	10	7,5	7,5
M2	10	5	5	5	7,5	6,5
M3	2,5	5	5	1	7,5	4,2
M4	7,5	1	1	5	2,5	3,4
M5	10	5	5	5	7,5	6,5
M6	2,5	5	5	1	7,5	4,2
M7	10	5	5	1	7,5	5,7
M8	10	5	5	1	7,5	5,7
M9	10	5	5	1	7,5	5,7
M10	2,5	5	5	1	7,5	4,2
M11	10	5	5	1	5	5,2
M12	2,5	5	5	1	7,5	4,2
M13	10	5	5	1	7,5	5,7
M14	2,5	5	5	1	5	3,7
M15	2,5	5	5	1	5	3,7
M16	7,5	5	5	1	7,5	5,2
M17	10	5	5	1	7,5	5,7
M18	10	5	1	5	2,5	4,7
M19	2,5	5	5	1	7,5	4,2
M20	2,5	5	5	1	7,5	4,2
M21	2,5	5	1	5	2,5	3,2
M22	10	5	5	1	5	5,2
M23	10	5	5	1	7,5	5,7
M24	10	1	5	10	2,5	5,7
M25	2,5	5	5	1	7,5	4,2
M26	2,5	5	5	1	10	4,7
M27	10	10	10	1	10	8,2
M28	10	5	5	1	7,5	5,7
M29	10	5	5	1	5	5,2
M30	2,5	5	5	1	7,5	4,2
M31	10	5	5	1	7,5	5,7
M32	7,5	5	5	1	7,5	5,2
M33	2,5	10	10	1	10	6,7
M34	10	5	5	10	7,5	6,7
M35	2,5	10	10	1	10	7,5
M36	10	5	5	1	7,5	5,7
M37	10	5	5	1	7,5	5,7
M38	10	5	1	10	2,5	5,7
M39	7,5	5	5	1	7,5	5,2
M40	2,5	5	5	1	7,5	4,2
M41	2,5	5	5	1	5	3,7
M42	10	5	5	1	7,5	5,7
M43	10	5	5	1	7,5	5,7
M44	2,5	5	5	1	5	3,7
M45	2,5	5	5	1	7,5	4,2
M46	2,5	5	5	1	5	3,7
M47	10	5	5	1	5	5,2
M48	2,5	5	5	1	7,5	4,2
M49	10	5	1	1	5	4,4
M50	10	1	1	5	2,5	3,9

Method Scores for Cost Criteria (General-Purpose V&V Method Selection)

Methods	**P3**	**P6**	**P7**	**P8**	**P9**	**Avg Score**
M1	10	5	5	10	7,5	7,5
M2	10	5	5	5	7,5	6,5
M3	2,5	5	5	1	7,5	4,2
M4	7,5	1	1	5	2,5	3,4
M5	10	5	5	5	7,5	6,5
M6	2,5	5	5	1	7,5	4,2
M7	10	5	5	1	7,5	5,7
M8	10	5	5	1	7,5	5,7
M9	10	5	5	1	7,5	5,7
M10	2,5	5	5	1	7,5	4,2
M11	10	5	5	1	5	5,2
M12	2,5	5	5	1	7,5	4,2
M13	10	5	5	1	7,5	5,7
M14	2,5	5	5	1	5	3,7
M15	2,5	5	5	1	5	3,7
M16	7,5	5	5	1	7,5	5,2
M17	10	5	5	1	7,5	5,7
M18	10	5	1	5	2,5	4,7
M19	2,5	5	5	1	7,5	4,2
M20	2,5	5	5	1	7,5	4,2
M21	2,5	5	1	5	2,5	3,2
M22	10	5	5	1	5	5,2
M23	10	5	5	1	7,5	5,7
M24	10	1	5	10	2,5	5,7
M25	2,5	5	5	1	7,5	4,2
M26	2,5	5	5	1	10	4,7
M27	10	10	10	1	10	8,2
M28	10	5	5	1	7,5	5,7
M29	10	5	5	1	5	5,2
M30	2,5	5	5	1	7,5	4,2
M31	10	5	5	1	7,5	5,7
M32	7,5	5	5	1	7,5	5,2
M33	2,5	10	10	1	10	6,7
M34	10	5	5	10	7,5	6,7
M35	2,5	10	10	1	10	7,5
M36	10	5	5	1	7,5	5,7
M37	10	5	5	1	7,5	5,7
M38	10	5	1	10	2,5	5,7
M39	7,5	5	5	1	7,5	5,2
M40	2,5	5	5	1	7,5	4,2
M41	2,5	5	5	1	5	3,7
M42	10	5	5	1	7,5	5,7
M43	10	5	5	1	7,5	5,7
M44	2,5	5	5	1	5	3,7
M45	2,5	5	5	1	7,5	4,2
M46	2,5	5	5	1	5	3,7
M47	10	5	5	1	5	5,2
M48	2,5	5	5	1	7,5	4,2
M49	10	5	1	1	5	4,4
M50	10	1	1	5	2,5	3,9

Final Method Scores (General-Purpose V&V Method Selection)

Methods	P	C	P/C
M1	8,5	7,5	1,13
M2	8,5	7,5	1,13
M3	6,2	7,5	0,83
M4	3,4	2,5	1,36
M5	8,5	7,5	1,13
M6	6,2	7,5	0,83
M7	6,7	7,5	0,89
M8	7,2	7,5	0,96
M9	7,2	7,5	0,96
M10	6,2	7,5	0,83
M11	8,5	5	1,70
M12	6,2	7,5	0,83
M13	7,2	7,5	0,96
M14	6,7	5	1,34
M15	6,7	5	1,34
M16	7	7,5	0,93
M17	6,7	7,5	0,89
M18	4,9	2,5	1,96
M19	8	7,5	1,07
M20	8	7,5	1,07
M21	4,9	2,5	1,96
M22	6,7	5	1,34
M23	8,5	7,5	1,13
M24	6,7	2,5	2,68
M25	8	7,5	1,07
M26	6,2	10	0,62
M27	10	10	1,00
M28	7,2	7,5	0,96
M29	8,5	5	1,70
M30	8	7,5	1,07
M31	7,2	7,5	0,96
M32	7	7,5	0,93
M33	6,7	10	0,67
M34	7,2	7,5	0,85
M35	8,5	10	0,96
M36	6,2	7,5	0,83
M37	6,2	7,5	0,83
M38	6,7	2,5	2,68
M39	5,2	7,5	0,69
M40	8	7,5	1,07
M41	8	5	1,60
M42	7	7,5	0,93
M43	7,2	7,5	0,96
M44	6,7	5	1,34
M45	8	7,5	1,07
M46	6,2	5	1,24
M47	5,4	5	1,08
M48	7	7,5	0,93
M49	6,7	5	1,34
M50	6,7	2,5	2,68

Method Scores for Practicality Criteria (Specific-Purpose V&V Method Selection)

Methods	P1	P2	P3	P3'	P4	P5	Avg Score	W_k	Coverage (%)	Final Score
M1	1	10	10	110	2,5	10	33,13	3	100	99,38
M2	1	10	10	60	2,5	10	20,63	3	50	61,88
M3	10	10	7,5	19,5	2,5	10	10,50	3	12	31,50
M4				0			0,00	1		
M5	1	10	10	85	2,5	10	26,88	3	75	80,63
M6	1	1	7,5	97,5	2,5	10	27,75	3	90	83,25
M7	10	10	10	72	2,5	10	23,63	3	62	70,88
M8	10	10	10	44	5	10	17,25	3	34	51,75
M9	10	10	10	46	5	10	17,75	3	36	53,25
M10	10	10	7,5	62,5	2,5	10	21,25	3	55	63,75
M11				0	0			1		
M12				0				1		
M13	10	10	10	41	5	10	16,50	3	31	49,50
M14				0				3		
M15	10	10	7,5	21,5	5	10	11,63	3	14	34,88
M16	1	10	2,5	2,5	2,5	10	6,25	3		18,75
M17	10	10	10	31	2,5	10	13,38	3	21	40,13
M18	10	10	10	34	2,5	1	11,88	1	24	11,88
M19	1	10	7,5	23,5	2,5	10	11,50	3	16	34,50
M20	1	10	7,5	32,5	2,5	10	13,75	3	25	41,25
M21	10	10	10	90	2,5	1	25,88	1	80	25,88
M22				0				1		
M23	1	10	10	36	2,5	10	14,63	3	26	43,88
M24				0	0		0,00	1		0,00
M25	1	10	7,5	42,5	2,5	10	16,25	3	35	48,75
M26				0				3		
M27	1	10	10	15	10	10	11,25	3	5	33,75
M28	10	10	10	25	5	10	12,50	3	15	37,50
M29				0	0		0,00	1		0,00
M30	1	10	7,5	35,5	2,5	10	14,50	3	28	43,50
M31	10	10	10	36	5	10	15,25	3	26	45,75

M32	1	10	2,5	2,5	2,5	10	6,25	3		18,75
M33				0				3		
M34	1	10	10	66	2,5	10	17,50	3	56	52,50
M35	10	10	10	45	5	10	22,13	3	35	66,38
M36	1	1	7,5	12,5	2,5	10	6,50	3	5	19,50
M37	10	10	7,5	14,5	2,5	10	9,25	3	7	27,75
M38				0	0			1		
M39	1	10	2,5	2,5	2,5	1	4,00	1		4,00
M40	1	10	7,5	25,5	2,5	10	12,00	3	18	36,00
M41	1	10	7,5	10,5	2,5	10	8,25	3	3	24,75
M42	1	10	2,5	2,5	2,5	10	6,25	3		18,75
M43	10	10	10	55	5	10	20,00	3	45	60,00
M44	10	10	7,5	20,5	5	10	11,38	3	13	34,13
M45	1	10	7,5	17,5	2,5	10	10,00	3	10	30,00
M46	10	10	7,5	14,5	2,5	10	9,25	3	7	27,75
M47	10	1	10	24	5	10	10,00	3	14	30,00
M48	1	10	2,5	2,5	2,5	10	6,25	3		18,75
M49	1	1	10	58	2,5	10	17,88	3	48	53,63
M50				0	0			1		

Method Scores for Cost Criteria (Specific-Purpose V&V Method Selection)

Methods	P3	P3'	P6	P7	P8	P9	Avg Score	W_k	Coverage (%)	Final Score
M1	10	13	5	5	10	7,5	8,1	3	3	2,70
M2	10	12	5	5	5	7,5	6,9	3	2	2,30
M3	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M4	7,5	7,5	1	1	5	2,5	3,4	1		3,40
M5	10	13	5	5	5	7,5	7,1	3	3	2,37
M6	2,5	6,5	5	5	1	7,5	5	3	4	1,67
M7	10	12	5	5	1	7,5	6,1	3	2	2,03
M8	10	11	5	5	1	7,5	5,9	3	1	1,97
M9	10	11	5	5	1	7,5	5,9	3	1	1,97
M10	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M11	10	11	5	5	1	5	5,4	5	1	1,08
M12	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M13	10	11	5	5	1	7,5	5,9	3	1	1,97
M14	2,5	3,5	5	5	1	5	3,9	5	1	0,78
M15	2,5	3,5	5	5	1	5	3,9	5	1	0,78
M16	7,5	7,5	5	5	1	7,5	5,2	3		1,73
M17	10	12	5	5	1	7,5	6,1	3	2	2,03
M18	10	11	5	1	5	2,5	4,9	3	1	1,63
M19	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M20	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M21	2,5	7,5	5	1	5	2,5	4,2	3	5	1,40
M22	10	12	5	5	1	5	5,6	5	2	1,12
M23	10	11	5	5	1	7,5	5,9	3	1	1,97
M24	10	15	1	5	10	2,5	6,7	1	5	6,70
M25	2,5	4,5	5	5	1	7,5	4,6	3	2	1,53
M26	2,5	3,5	5	5	1	10	4,9	3	1	1,63
M27	10	11	10	10	1	10	8,4	3	1	2,80
M28	10	11	5	5	1	7,5	5,9	3	1	1,97
M29	10	11	5	5	1	5	5,4	3	1	1,80
M30	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47

M31	10	11	5	5	1	7,5	5,9	3	1	1,97
M32	7,5	7,5	5	5	1	7,5	5,2	3		1,73
M33	2,5	3,5	10	10	1	10	6,9	3	1	2,30
M34	10	11	5	5	10	7,5	6,9	3	1	2,30
M35	2,5	3,5	10	10	1	10	7,7	3	1	2,57
M36	10	11	5	5	1	7,5	5,9	3	1	1,97
M37	10	11	5	5	1	7,5	5,9	3	1	1,97
M38	10	15	5	1	10	2,5	6,7	3	5	2,23
M39	7,5	7,5	5	5	1	7,5	5,2	3		1,73
M40	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M41	2,5	3,5	5	5	1	5	3,9	3	1	1,30
M42	10	15	5	5	1	7,5	6,7	3	5	2,23
M43	10	11	5	5	1	7,5	5,9	3	1	1,97
M44	2,5	3,5	5	5	1	5	3,9	3	1	1,30
M45	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M46	2,5	3,5	5	5	1	5	3,9	5	1	0,78
M47	10	11	5	5	1	5	5,4	5	1	1,08
M48	2,5	3,5	5	5	1	7,5	4,4	3	1	1,47
M49	10	11	5	1	1	5	4,6	5	1	0,92
M50	10	14	1	1	5	2,5	4,7	1	4	4,70

Final Method Scores (Specific-Purpose V&V Method Selection)

Methods	P	C	P/C
M1	99,38	2,70	36,81
M2	61,88	2,30	26,90
M3	31,50	1,47	21,48
M4			0
M5	80,63	2,37	34,07
M6	83,25	1,67	49,95
M7	70,88	2,03	34,86
M8	51,75	1,97	26,31
M9	53,25	1,97	27,08
M10	63,75	1,47	43,47
M11			0
M12			0
M13	49,50	1,97	25,17
M14			0
M15	34,88	0,78	44,71
M16	18,75	1,73	10,82
M17	40,13	2,03	19,73
M18	11,88	1,63	7,27
M19	34,50	1,47	23,52
M20	41,25	1,47	28,13
M21	25,88	1,40	18,48
M22			0
M23	43,88	1,97	22,31
M24			0
M25	48,75	1,53	31,79
M26			0
M27	33,75	2,80	12,05
M28	37,50	1,97	19,07
M29			0
M30	43,50	1,47	29,66
M31	45,75	1,97	23,26
M32	18,75	1,73	10,82
M33			0
M34	52,50	2,30	25,86
M35	66,38	2,57	22,83
M36	19,50	1,97	9,92
M37	27,75	1,97	14,11
M38			0
M39	4,00	1,73	2,31
M40	36,00	1,47	24,55
M41	24,75	1,30	19,04
M42	18,75	2,23	8,40
M43	60,00	1,97	30,51
M44	34,13	1,30	26,25
M45	30,00	1,47	20,45
M46	27,75	0,78	35,58
M47	30,00	1,08	27,78
M48	18,75	1,47	12,78
M49	53,63	0,92	58,29
M50			0