VV&A SOLUTION FOR COMPLEX SIMULATION SYSTEMS

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Abstract: This paper presents a VV&A solution to effectively address VV&A problems arising during the development of complex simulation systems. First, a VV&A process is presented along with the development of a computer support tool, HITVICE, which helps to organize and manage the different VV&A activities. Second, the optimal design method for VV&A schemes is presented to produce an optimal scheme, according to which the valuable VV&A activities are selected and the VV&A cost is reasonably assigned. Besides, a tool based on Matlab fuzzy toolbox and Microsoft excel is developed to support this optimal design method. Thirdly, the suitable VV&A metrics for complex simulation systems are presented and a tool is developed to support the definition, decomposition, data collection and analysis of VV&A metrics. Finally, the validation support tool is developed to support the validation of complex simulation systems. The object oriented knowledge representation technique is employed to represent the knowledge and data concerning the validation, and expert system reasoning is used to realize the validation of complex simulation systems. This VV&A solution has been applied to the simulation systems under development and solved most VV&A difficulties.

Keywords: VV&A solution; VV&A process; optimal design method; VV&A metrics; validation support tool

1. INTRODUCTION

A significant element of any simulation study should involve the verification, validation and accreditation (VV&A) of the simulation system. Without thorough VV&A, there are no grounds on which to place confidence in the simulation results (Robinson, 1999).

Nowadays, simulations are increasingly used to support a wide range of development, analysis, acquisition and training functions, which usually have such features as the size and complexity continually growing, the expected lifetime continually increasing and the reusability and interoperability increasingly being emphasized. All these changes have tremendous impact on VV&A of such simulations, which results in a problem to be solved urgently: how to accomplish VV&A for complex simulation systems.

Aiming at the problems stated above, some suggestions or views have been presented (Dale, 2003; James and Robert, 1999; Patrick et al., 2000; Robert and Prscilla, 2000). For instance, the credibility, mainly focused on correctness in the past, should be expanded to include other quality characteristics like maintainability, reusability, and reliability (James and Robert, 1999). The VV&A activities should be carefully planned and tailored commensurate with the size of the project (James and Robert, 1999; Robert and Prscilla, 2000). Objective validation, mainly through statistical methods, should be increasingly employed to improve the confidence levels of models (Dale, 2003; James and Robert, 1999; Robert and Prscilla, 2000). Computer support tools should be developed and employed to solve the increasing difficulties of VV&A (Dale, 2003; Patrick et al., 2000). Although many such suggestions have been presented, they are no more than suggestions and there is still much work to be done.

To accomplish effective VV&A during the development of complex simulation systems, in this paper, we present a VV&A solution, which includes four parts: the VV&A process and support tool, the optimal design method and support tool for VV&A schemes, the VV&A metrics and support tool and the validation support tool. At present, the VV&A solution has been applied to the complex simulation systems under development and solved most VV&A difficulties.

The remaining of this paper is organized as follows. Section 2 presents the VV&A solution for complex simulation systems. Section 3 discusses the VV&A process and support tool. Section 4 discusses the optimal design method and support tool for VV&A schemes. Section 5 discusses the VV&A metrics and support tool. Section 6 discusses the validation support tool. Finally, Section 7 gives the conclusion and future work perspectives.

2. VV&A SOLUTION

To accomplish effective VV&A during the development of complex simulation systems, this paper presents a VV&A solution, which is shown in figure 1, and each part of the VV&A solution is explained as follows.

- **VV&A process and support tool**. The VV&A process provides a VV&A work flow to execute the VV&A of simulation systems. For complex simulation systems, we present a VV&A process and corresponding VV&A activities and develop HITVICE, a computer support tool, to help to organize and manage the VV&A process. HITVICE tailors VV&A activities commensurate with the size of the specific simulation system according to the optimal solution from the optimal design of the VV&A schemes.

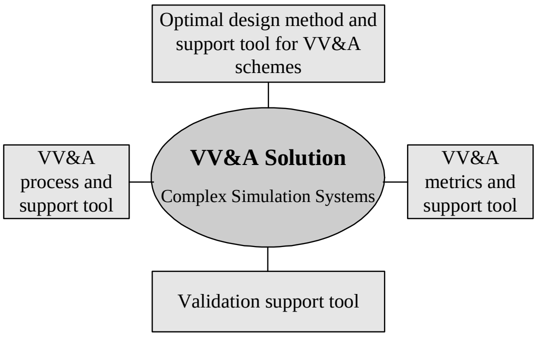

Figure 1: VV&A solution for complex simulation systems

- **Optimal design method and support tool for VV&A schemes**. The optimal design method for VV&A schemes is used to produce an optimal solution, according to which we select the valuable VV&A activities and effectively assign the VV&A cost. The produced VV&A schemes are used by the HITVICE to tailor the VV&A activities.
- **VV&A metrics and support tool**. The VV&A metrics are used to represent and quantify simulation credibility and present a quantitative perception for the users that employ simulation systems. Aiming at the complex simulation systems, we develop the suitable VV&A metrics and develop a tool to support the definition, decomposition, data collection and analysis of VV&A metrics. This tool helps to collect the data about the VV&A activities from HITVICE and use it to measure VV&A metrics.
- **Validation support tool**. The validation support tool is used to support the validation of complex simulation systems. Based on the analysis of validation difficulties, we employ the object oriented knowledge representation technique to represent the knowledge and data concerning the validation and use of expert system reasoning to realize the validation of complex simulation systems.

At present, this VV&A solution has been applied to some simulation systems under development and solved most VV&A difficulties. In the next sections, we will in depth discuss each part of the VV&A solution.

3. VV&A PROCESS AND SUPPORT TOOL

As most of us know, VV&A is an on-going process and integral part of the life cycle of modeling and simulation and therefore the definition of a complete and good VV&A process is essential before VV&A starts. To date, some VV&A processes have been developed to meet different simulation applications (DMSO, 1996; Jennifer and Cindy, 2000), such as the VV&A process for DIS and HLA, these processes, however, are only suitable for specific situations. Considering the factual situation of complex simulation systems development in China, we develop a more general VV&A process, shown in figure 2, which gives more reasonable and detailed VV&A procedures and activities.
Despite there being a reasonable VV&A process the practical VV&A of complex simulation systems is still full of difficulties. The VV&A of a complex simulation system often lasts a long time, involves a multiplicity of VV&A activities, people and resources, and deals with large numbers of VV&A documents. Therefore, the organization and management of such a process is extremely difficult. To facilitate this process and make it cost effective, we develop HITVICE, a computer support tool, to help organize and manage the VV&A process.

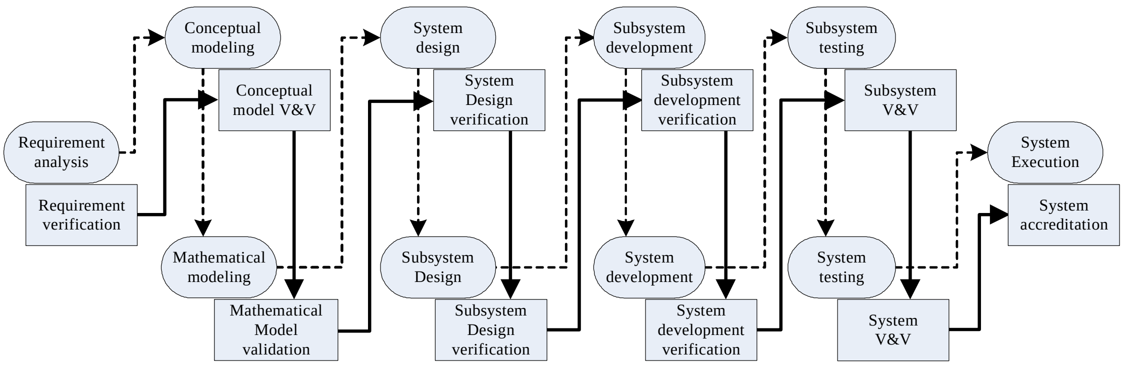

Figure 2: VV&A process for complex simulation systems

HITVICE is developed via Lotus Domino Designer and run in Lotus Notes environment, realizes workflow automation, hierarchical evaluation, CSCW, lifecycle data management, flexible authority control etc., and thus facilitates the VV&A of complex simulation systems. The main window of this tool is shown in figure 3, and the main functions are listed as follows (Fang et al., 2005).

Figure 3: Main window of HITVICE

- *VV&A workflow management*, which employs the workflow technique to realize flexible VV&A activities tailoring and process automation. HITVICE stores as many VV&A activities as possible and tailors these VV&A activities commensurate with the size of the specific simulation system according to the optimal solution from the optimal design of the VV&A scheme.
- *Instant message, Email, and discussion forum*, which allow the VV&A analysts to communicate instantly or indirectly.
- *Project, organization, data, document, and resource management*, which are responsible for managing different VV&A projects and organizations, data, documents and resources in each VV&A project, using the Lotus database.

4. OPTIMAL DESIGN METHOD AND SUPPORT TOOL FOR VV&A SCHEMES

With the size and complexity of simulation systems growing, how to design good VV&A schemes for complex simulation systems has become a more important problem than before. In an ideal world, the design of VV&A schemes would be based primarily on technical rationale and VV&A requirements, however, this is not so in reality (Mussing and Lacck, 1997). In fact, the design of VV&A schemes is mainly affected by cost constraints and therefore the designed VV&A schemes often cannot actually reflect the VV&A requirements of simulation systems.

Although there have been some researches on how to design VV&A schemes, they either only analyze the factors that probably affect the VV&A schemes (Mussing, 1995; Kilikauskas et al., 2002), or only give a quite informal and simple risk assessment process to roughly select the needed VV&A activities (Mussing and Lacck, 1997). In a word, the existing studies cannot provide an effective guide for designing VV&A schemes and therefore a good and applicable method is strongly needed to obtain reasonable VV&A schemes in order to effectively accomplish VV&A of simulation systems under given cost constraints.

To meet the VV&A needs during the development of complex simulation systems, we present an optimal method for designing VV&A schemes, this shown in figure 4. We employ fuzzy logic and fuzzy inference to assess the risk of each factor of each component in complex simulation systems, and the procedure is shown in figure 5. According to the risk of each factor, we determine the corresponding VV&A activities and cost and then establish a fuzzy linear relationship between the risk and cost for each factor, the process of which is shown in figure 6. Based on these relationships, we employ fuzzy linear programming to establish the optimal model of the VV&A scheme for the simulation system. According to the optimal solution from the optimal model, we select the most valuable VV&A activities, effectively assign the VV&A cost and draw up the optimal VV&A scheme (Liu et al., 2007).

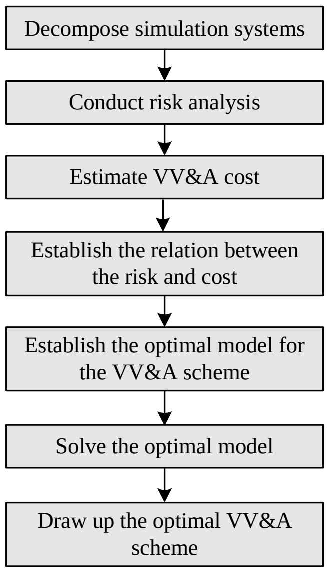

Figure 4: Optimal design process of VV&A schemes

The method above provides a rather objective way of designing VV&A schemes and has been applied to some complex simulation systems and proved to be effective. Also, the process of designing VV&A schemes is complex and it will cost more time and resources without a support tool. At present, a computer support tool for this method is being developed. The fuzzy reference of risks is realized using the Matlab fuzzy toolbox, the data collection and analysis are realized through Microsoft excel, and others, such as the solution of the optimal models, are realized using Microsoft Visual C++. In brief, the computer support tool provides the following functions:

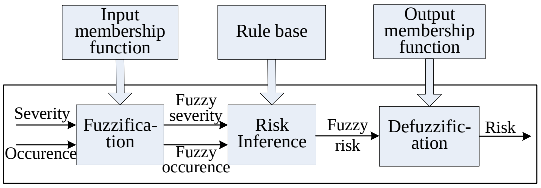

Figure5: Risk assessment process based on the fuzzy inference

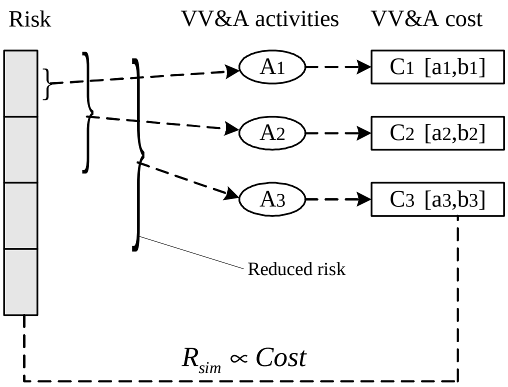

Figure 6: Process for establishing the relation between risk and cost

- *Risk failure modes selection*. For each component we determine the main factors that possibly cause failures. For example, for the conceptual model of a simulation system, we decompose it into an array of models and for each model we consider seven main factors that may cause failures, which include theories, assumptions, equations, logic, input/output variables, parameters, and random variables. This tool can help to select these failure modes.

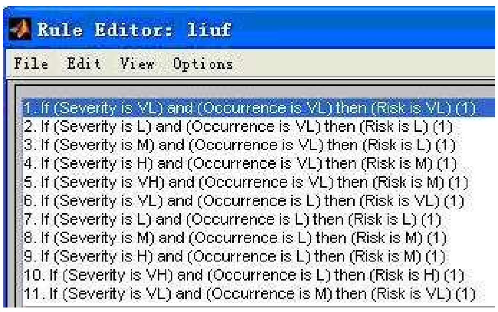

Figure 7: Interface for rule base editing

- *Risk quantification and inference*. We use the Matlab fuzzy toolbox to realize this function and figure 7 gives the interface for rule base editing and some rules.
- *Risk and cost data collection and analysis*. This function is realized with Microsoft excel. For example, figure 8 gives an interface for risk data collection and analysis.

Risk Data Collection and Analysis

Component	Factor	Experts	Expert Assessments		Collective Assessments		Risk of the factor Rsim
			Severity	Occurrence	Severity	Occurrence	
RM	Theories	E1	3	2	4	3.5	4
		E2	4	2			
		E3	5	3			
	Assumptions	E1	4	4	4.7	4	4.3
		E2	5	5			
		E3	5	3			
	Equations	E1	5	3	4.7	3	4
		E2	4	3			
		E3	5	3			

Figure 8: Interface for risk data collection and analysis

- *Optimal model establishing and solving*. Herein, the solution of the optimal models is realized using Microsoft Visual C++ and the optimal results are shown in Microsoft excel. For example, figure 9 gives partial optimal results of a project.

Component	Factor	VV&A activities	Expert number	Time (Minute)	VV&A cost (¥)
RM	Theories	Inspection	3	23	70
	Assumptions	Inspection	3	22	65
	Equations	Inspection	3	27	80
	Logic	Walkthrough	2	17	34
	Input/output variables	Walkthrough	2	10	20
	Parameters	Walkthrough	2	18	36
	Random variables	Inspection	3	10	30

Figure 9: partial optimal results

5. VV&A METRICS AND SUPPORT TOOL

As stated above, the credibility, most focusing on correctness in the past, should be expanded to include other quality characteristics like maintainability, reusability and reliability. Following this direction and considering the requirements of current complex simulation systems, we think that at least five metrics greatly contribute to the evaluation of simulation credibility, which are validity, correctness, interoperability, reliability and usability. Figure 10 gives the dependencies between these metrics and VV&A and figure 11 further gives the dependencies between these metrics and the VV&A process defined above. In the followings, we simply give the meanings of these metrics (Liu et al., 2005).

- *Validity* is defined as the quality of being inferred, deduced or calculated correctly enough to suit a specific application (Goss, 1999). The validation process establishes the validity of the model or simulation and provides a crucial piece of evidence to support model or simulation credibility for a particular application.

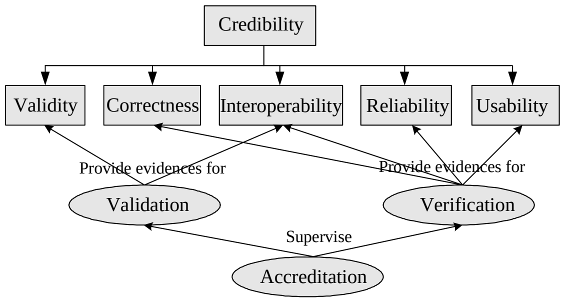

Figure 10: Dependencies between VV&A metrics and VV&A

- *Correctness* is dealt with by verification. When using a model or simulation, one expects it to be internally consistent and correctly described in all its different representation forms and components. Correctness is concerned with all these problems.
- *Interoperability* is the ability of a model or simulation to provide services to and accept services from other models and simulations, and to use the services so exchanged to enable them to operate effectively together (DMSO, 1997). With the expanding application ranges and purposes of simulation, interoperability has become an important factor that affects credibility.
- *Reliability* is defined as the ability of a product to perform a required function under stated conditions for a stated period of time. A complex simulation environment includes network, simulation host platforms, operating system, run-time support software, simulation application and etc. On the one hand, this complexity causes such effects as communication delays, noise or sudden cut-offs; on the other hand, such a complex system may hide errors and faults. All these problems relate to reliability.
- *Usability* is the reduced probability of simulation misuse. Simulations are credible only within a well-defined usage context, and only when they are properly used within that context. Any simulation attribute that reduces the probability of simulation misuse enhances its credibility within a given context (Mussing et al., 2000). Thus we also consider usability as an important metric to represent and quantify credibility.

Similarly, to support the definition, decomposition, data collection and analysis of VV&A metrics, we develop the VV&A Metrics Tool, which is based on Microsoft Visual C++ and Access database. This tool has the following main functions and figure 12 gives a representative interface of this tool.

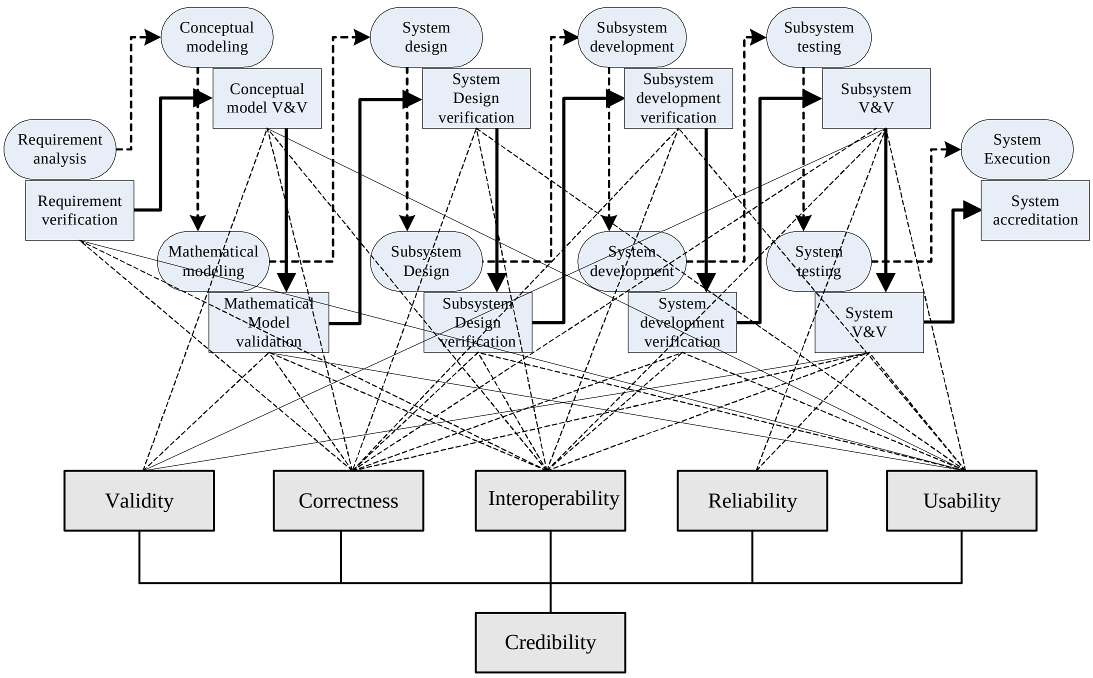

Figure 11: Dependencies between VV&A metrics and the VV&A process

- *Definition and decomposition of VV&A metrics*. According to the specific simulation system, users can use this tool to define suitable VV&A metrics, that is, users can add or tailor the VV&A metrics shown in the left column of figure 12 to make them suitable for the specific simulation system.
- *Data collection concerning VV&A metrics*. This tool can help to collect data about the VV&A activities from HITVICE and use it to measure VV&A metrics. This is realized by filling the data into the property pages, such as model validation page, metrics description page, expert qualification page and weight calculation page in figure 12.
- *Calculation and analysis of VV&A metrics*. This tool realizes automatic calculation and analysis of VV&A metrics and obtains the results corresponding to different levels of VV&A metrics, which are used to evaluate the credibility of a simulation system. This is realized in the weight calculation page and metrics calculation and analysis page in figure 12.

Figure 12: Representative interface of the VV&A Metrics Tool

6. VALIDATION SUPPORT TOOL

Compared to the validation of simple models, the manual validation of complex models becomes increasingly difficult. 1) A complex simulation system often consists of large numbers of simulation models. For validation purposes, validation of each model does not imply overall simulation credibility and vice versa, so we need to validate not only each model but also each of the composed models at different levels. Therefore, tremendous validation work is needed. 2) The limitations of statistical methods also result in difficulties of the validation of complex simulation systems. The use of statistical methods needs expert knowledge, of which the validation analysts often lack, and therefore the selection and use of statistical methods is also an important problem in validation (Deslandres and Pierreval, 1991). Such difficulties generate a stringent demand for automatic support tools.

The validation support tool should effectively support the validation of complex simulation systems and solve the problems stated above. It is based on these considerations that we chose to employ the object oriented knowledge representation technique to represent the knowledge and data concerning the validation, and use expert system reasoning to realize the validation of complex simulation systems. The general structure of the validation tool is shown in figure 13 and the functions of the key component are listed as follows (Liu et al., 2006).

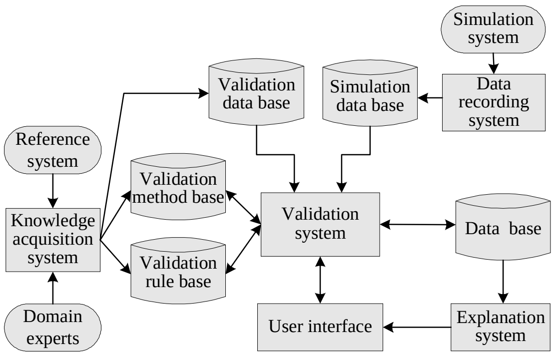

Figure13: General structure of the validation tool

- *Knowledge acquisition system*, which helps to acquire the knowledge and data concerning validation, translate them into the necessary forms and save them to the database.
- *Data recording system*, which is responsible for data recording of simulation systems, the data from which will be used to validate the simulation systems.
- *Validation system*. Using the predefined validation rules, the validation system calls the validation methods to compare the output data from the reference system and simulation system to realize the validation of the simulation system. In the validation system, the forward reasoning is used to select the suitable validation methods by searching the tree that represents different levels of validation methods, and the fuzzy reasoning is employed to obtain the certainties of rules for selecting validation methods. To better support validation, we develop different validation processes for static and dynamic performance parameters and events, and as an example, the validation process of static performance parameters is shown in figure 14. It is noted here that the validation tool supports not only the statistical validation but also the Turing test and face validation.
- *Validation data base*, which is responsible for storing the validation data, which is either the experimental data from the real system or the empirical data from experts.

- *Validation method base*, which is responsible for storing validation methods and helps the validation analysts to select suitable validation methods. There are a large number of methods for model validation, which can be simply classified into statistical methods, time sequence methods, data preprocessing methods among others. In the validation method base, these methods are organized as a tree. Besides, the attribute part of C++ classes is employed to store the facts of each validation method and the method part of C++ classes to store the rules of each validation method.
- *Validation rule base*, which is responsible for storing the global rules used in validation. These global rules include data searching rules, method selection rules, and etc. For example, when the validation system finds that multiple statistical methods are available, then the method selection rules can be used to select the most suitable statistical methods. These rules also are stored as C++ classes.

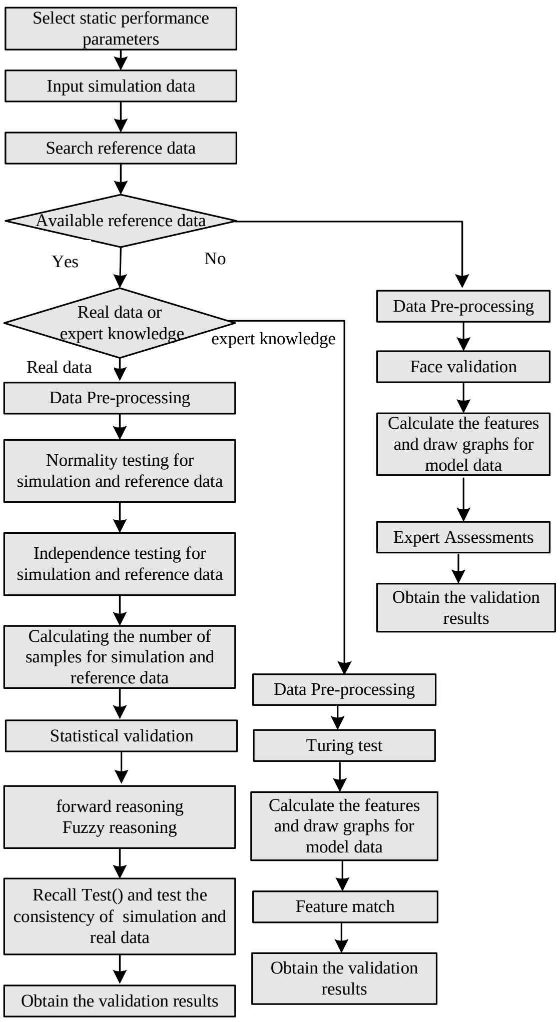

Figure14: Validation process for static performance parameters

The simulation validation tool is developed using the Visual C++ 6.0 and Microsoft Access 2000. Figure 15 gives the main interface of the tool and figure 16 gives one validation result interface for static performance parameters. The work process of this tool is briefly described as follows.

Figure 15: Main interface of simulation validation tool

Figure 16: Validation result interface of static performance parameters

1. The users read simulation data from the simulation data base and search the reference data from the validation data base through the user interface. According to the availability of the reference data, the users can select different validation approaches: statistical validation, Turing test or face validation.
2. The users preprocess the simulation data or reference data, such as normality testing and independence testing, by recalling the preprocessing methods stored in the validation method base to judge such features as the normality, independence and sample numbers,

which will be the inputs of the validation system.

3. The users use the validation system to accomplish model validation. For example, when the statistical validation approach is selected, the validation system should perform reasoning with the validation rule base and validation method base to select the suitable validation method to accomplish model validation.

The validation support tool provides guidance to effectively and efficiently validate simulation models and has been applied to some complex simulation systems. These applications show that this tool has the following advantages:

- The tool supports the whole validation process from determining validation objects to obtaining validation results, which greatly improves efficiency.
- The tool provides multiple methods for validating a model, which reduces the deficiency of using one method and improves the objectivity of model validation.
- The tool reduces the dependency on the experts by providing expert knowledge base. If simply trained, the validation analysts can do the validation work like the experts.

7. CONCLUSION

Based on nearly ten years experiences (Wang et al., 1999), the Control and Simulation Center has developed a complete VV&A solution for complex simulation systems, the main parts of which have been illustrated in this paper except the testing, recording, and analysis tools (Zheng et al., 2002; Song et al., 2005). At present, this VV&A solution has been applied to some simulation systems and solved most VV&A difficulties.

The support tools appearing in this paper have been developed separately and support different parts of VV&A, but each of them has to be improved with the simulation applications due to their continuous development and expansion. Future research will focus on the adaptation of these tools to specific simulation applications, and on their improvement. Meanwhile, the focus is on possibly ways of ensuring the interoperability among these tools and of establishing an integrated VV&A support environment.

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