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PANEL SESSION: EDUCATION FOR SIMULATION PRACTICE—FIVE PERSPECTIVES

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ABSTRACT

This panel session is based on the responses of simulationists representing various segments of simulation practice, to an article on the required skills of a simulation analyst. The perspectives represented are those of academia, government, industry, military, and research. First, the essence of the reference article is provided. Then, the five perspectives are presented. Finally, inferences are drawn from the five perspectives and the reference article.

1 INTRODUCTION

Five different positions are taken in reference to the article "Required Skills of a Simulation Analyst," by Matt Rohrer and Jerry Banks (1998). The article is referred to as R&B. In this section, R&B will be introduced. Then, the reaction of each respondent to R&B is provided. In the last section, inferences are drawn,

The most efficient way of presenting R&B is to show three tables, each with a set of tasks considered pertinent to the simulation analyst and the skills needed to accomplish those tasks. The tasks correspond roughly to the steps in the simulation process as discussed by Banks et al. (2000) and Law and Kelton (2000). R&B discussed the skills in three categories; those that are required, those that are desired, and those that are acquired.

Table 1: Required Skills of a Simulation Analyst

Task	**Required Skills**
Data collection	Detail-oriented, technical
Conceptual model development	Systems understanding
Specification development	Technical writing
Model construction	Logical thinking, creativity, good memory
Verification/validation	Detail-oriented, skeptical
Experimentation	Organized, analytical
Reporting	Technical writing
Presentation	Persuasive

Table 1 shows the required skills. Thus, a person needs to be detail oriented and analytical to perform the task of data collection. These are skills that are brought to the job. Table 2 shows the desired skills for a person to become a successful simulation analyst. For example, a person needs to be naturally skeptical in order to do a good job at data collection. In some cases, there are no skills that match a task and that row of the table has been deleted.

Table 2: Desired Skills of a Simulation Analyst

Task	**Desired Skills**
Data collection	Skeptical
Conceptual model development	Experience
Model construction	Simulation software experience, abstraction, debugging
Verification/validation	Pragmatic, real-world experience
Experimentation	Statistical competency
Reporting	Ability to make inferences
Presentation	"Quick on their feet"

Finally, Table 3 shows the acquired skills of a simulation analyst. These are skills learned on the job. R&B provides much more extensive discussion of these tables.

Table 3: Acquired Skills of a Simulation Analyst

Task	**Acquired Skills**
Data collection	Patient
Conceptual model development	Abstraction
Specification development	Simulation specification and structure
Model construction	Flexibility of approach
Verification/validation	Understanding of accepted methods
Presentation	Software for presentation

2 HEIMO H. ADELSBERGER AND MARKUS BICK (ACADEMIA)

The typical academic deals on the one hand with research activities and on the other hand with educational tasks. We want to start with a short statement of typical research areas within the field of simulation: modelling techniques, software and technological paradigms, process models, mathematical theories, and, occasionally, software applications. Accordingly, we can derive specific tasks performed by a simulation analyst.

With respect to traditional educational programs, we distinguish between different qualification levels:

- *theoretical*,
- *methodological*, and
- *application oriented*.

Theoretical qualification implies applying theories as well as developing theories on one's own. This knowledge lasts approximately ten to twenty years. In contrast, *methodological* qualification enables the application of theories and the development of new products and services, lasting approximately five to fifteen years. A*pplication oriented* qualification supports the use of software products. We can say that this qualification is valid for approximately two to five years.

According to this qualification system, academic education relates to theoretical and methodological knowledge. This classification underlines the results of R&B. All things considered, we agree with R&B with respect to the theoretical fundamentals and agree that the typical tasks performed by a simulation analyst are those shown in Tables 1, 2, and 3. Simulation analysts also need skills or traits such as ability to listen and negotiate, possession of a strong work ethic and the ability to build rapport with customers.

Based on the above tasks and traits, we derive curricula for educating simulation analysts. Teaching the highly complex domain of simulation requires well-elaborated strategies for efficient education.

So far, these strategies and the corresponding curricula have been provided by traditional academic education predominantly as a part of graduate programs in, industrial engineering, computer science, operations research, management science, and other related fields. Correspondingly, we can view this kind of traditional education as a 'preliminary action plan.'

Currently, the technological impact of information and communication technologies (ICT), especially the internet, enables students and teachers to participate in a global education community, independent from time and location. Recent educational concepts (e.g., the virtual or corporate university, and electronic educational markets) underline this development within the educational and training sector. As a consequence, traditional education in universities, continuing education programs and life-long-learning concepts become more important. This is caused by a permanent enrichment and enlargement of skill requirements, and the dissolution of fixed career profiles.

R&B emphasize the "people" side of simulation focusing on the enhancement of the next generation simulation analyst's capabilities. Since this represents the most obvious measure, this emphasis is obviously correct. Nevertheless, we would like to question this kind of strategy. We consider it to be appropriate not only to improve traditional education, but rather to revise the complete educational concept in the field of simulation. Naturally, we know of the peculiarities as well as the meaning of a good simulation education. Considering the different roles and fields of application of simulation, we can see different approaches in this context. On many occasions the terms simulation analyst, simulation practitioner, simulation professional, or simulation expert are used synonymously. In our opinion, the tasks and consequently the educational level of the participants mentioned before can vary with the size of individual simulation projects. Moreover, the domain experts, which are assigned to the project, should not be neglected.

For example, consider the director of a cultural center who wants to optimize the schedule of events, but the budget does not allow an exhaustive simulation study. Is the director excluded from applying simulation? Dividing the processes of a simulation study, the important steps might be performed solely by the director. Only guidance might be needed from a simulation expert. The occurrence of several problems in early projects can hardly be prevented. Furthermore, the director neither has the capabilities nor the experience in (simulation) model translation and the corresponding experimental design.

As a conclusion, a diversified education regarding the field of simulation should be envisaged. Providing problem solving and decision making skills to individuals from various backgrounds will improve their work performance significantly. Simulation can be used as a tool to utilize these skills efficiently.

Summarizing, the role of a simulation expert might shift significantly. The simulation expert should concentrate on facilitating simulation studies and act as a tutor for providing problem solving and decision making skills. The simulation expert will provide conceptual knowledge, by providing templates and customizable packages. This role of a tutor, facilitator, or advisor will help organizations to strengthen their confidence and improve the quality of simulation studies. The changing role of simulation experts might also lead to a paradigm change in the design of computer supported learning environments (CSLE) for simulation. The CSLE of the future must meet different requirements, e.g., *adaptivity and adaptability, reusability and recontextualization of the content*, and supportive of *multiple perspectives.*

Therefore, the changing job fields of simulation experts and domain experts will also impact educational processes. In order to meet these changing needs, new design strategies and practices will be necessary in the future.

A further discussion on design principles for teaching simulation can be found in (Adelsberger, Bick, and Pawlowski 2000).

3 CHARLES MCLEAN (GOVERNMENT)

At the National Institute of Standards and Technology, the goal of the program in Manufacturing Simulation and Visualization is to accelerate the development of standards that are needed by manufacturing users and simulation software vendors. As such, our government perspective with respect to simulation education is not necessarily different than the views of industrial users and simulation system developers. I believe that R&B presents a fairly comprehensive discussion of simulation education requirements. I think that there are some additional areas that might be added to enhance the skills of the simulation analyst.

At NIST, we have conducted a number of research projects in simulation over the years. We have worked with industry to solve real world problems. The models that we have built have used many of the major simulation software packages. Some of our recent models have been quite large. In fact, our recent focus on the development of standards for distributed simulation will help enable the construction of even larger models. See Kuhl (1999) for information on the Department of Defense's High Level Architecture (HLA), a standard for integrating distributed simulations. I believe that simulation students today should receive some introduction to HLA in their coursework. Other standards for distributed simulation may evolve in the future, but HLA is receiving a lot of attention worldwide today.

The teams that have worked on our models have included NIST staff, guest researchers, and contractors whose formal education has been as industrial engineers, manufacturing engineers, computer scientists, and electrical engineers. My graduate engineering education was in information engineering, otherwise known as computer science.

When simulation models were relatively small such that one engineer could understand and build the entire model, computer science skills were perhaps less important. As models have become larger, more complex, and possibly distributed, I believe that it is more important that the simulation analyst have stronger software engineering skills. Depending upon the simulation package that is used, considerable programming skills may be required to develop a model. Strong computer skills will help ensure that models are implemented correctly and efficiently, that they can be understood by team members, and that they can be re-used when appropriate. We have discovered this need first hand on our projects.

What software engineering skills are needed? Three major topic areas from the field of computer science come to mind: structured software development techniques, information modeling and data structures, and problem representation. These topics are presented below in what I consider a priority order.

3.1 Structured Software Development Techniques

Software Engineering by Ian Sommerville (2001) is a good introductory reference to many of the important topics in the field of computer science. In his text, Sommerville states that "Structured programming is a term which was coined in the late 1960s to mean programming without using goto statements, programming only using while loops and if statements as control constructs and designing using a top-down approach. The adoption of structured programming was an important milestone in the development of software engineering because it was the first step away from an undisciplined approach to software development."

My personal experience with many graduate level engineers over the years indicates that their programming skills are often severely lacking. Even some of the computer scientists could benefit from additional training in this area. I have often seen complex and convoluted code that is nearly impossible to decipher. If nothing else, all simulation analysts that are responsible for software development should obtain and read a copy of Kernighan and Plauger's *The Elements of Programming Style* (1974). This short book provides an excellent overview of programming style rules and examples in various programming languages.

3.2 Information Modeling and Data Structures

The objective of information modeling is to identify the conceptual objects or entities that comprise the system that is being modeled. Objects are depicted in an information model along with their characteristics or attributes. There are many different techniques and tools for performing information modeling. Many simulation systems support object-oriented programming, so object-oriented information-modeling techniques are probably an appropriate choice. Object-oriented modeling techniques offer perhaps a more disciplined and structured approach to capturing the behavior and data characteristics of a system to be simulated than that typically provided in current simulation courses. Shlaer and Mellor's text on *Object Lifecycles* (1992) provides a good introduction to those techniques.

3.3 Problem Representation

Since simulations typically seek to model the behavior of real systems, complex simulations may have a lot in common with intelligent systems. In the field of artificial intelligence (AI), one of the first things that students are taught is the role of representation in creating intelligent systems. Representation may often determine whether a problem can be solved with a computer in less than "geological time" or, for that matter whether it can be solved at all. Patrick Winston's book on *Artificial Intelligence* (1992) talks about a number of issues in problem representation. In his text Winston summarizes characteristics of good representation as:

- "Good representations make the important things explicit.
- They expose natural constraints, facilitating some class of computations.
- They are complete. We can say things efficiently.
- They are transparent to us. We can understand what has been said.
- They facilitate computation. We can store and retrieve information quickly.
- They suppress detail. We can keep rarely used information out of sight, but we can still get to it when necessary.
- They are computable by an existing procedure."

As simulations become more complex, modeling the behavior of humans and intelligent decision processes, we can expect the line between artificial intelligence and simulation to become blurred.

In conclusion, as R&B states, "simulation was actually born with and has grown up with the computer." There are certain fundamental skills that are expected of the software engineer and computer scientist. To the extent that the simulation analyst wears a software engineering hat among others, the analyst needs to develop stronger skills in that area. From my perspective, I feel that the three most important skills are in structure software development, information modeling, and problem representation.

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4 IAN MCGREGOR (INDUSTRY)

R&B describes the qualities necessary to be a simulation analyst and details the required approach to successfully complete simulation studies. While it is not my intention here to comment on R&B in any great detail, it nevertheless forms the background to the arguments that arise from it. R&B puts forward a conclusion that simulation should be a career rather than a step in a career path, and it is here that our opinions diverge. Despite the fact that a stable team of experienced analysts is undeniably the goal of all simulation group managers, there are many pragmatic reasons why this is a rare phenomenon. Within companies that include a simulation department it is also likely that this is not the best use of resources for the company as a whole, as the insight to be gained from working within the simulation department can be profitably applied throughout the business.

4.1 Simulation – Right up there with Statistics

A simulation model can be a blinding light – it can illuminate and it can confuse, it can make obvious the most detailed procedures and sequences and it can obscure that which is plain. Which of these it does is completely in the hands of the user – and the way the user exploits the tool is extremely communicative of the type of person he or she is, and of their approach to problems. Due to the technical nature of the simulation tool, the user is set apart from other members of a project team in that only the simulation analyst knows the internal workings of the model and the data that feeds it, and yet this separation can only be temporary. With the progression of the project it becomes known whether the simulation is a reliable and accurate representation of reality that helps understanding and leads to progress or whether it has been a dangerous distraction, wasting resources and holding up progress.

4.2 Simulation Bears the Torch

A simulation analyst is thrust into a privileged position, and also a vulnerable one. The analyst is required to expose the truth, to become the impartial judge of his or her more experienced and opinionated peers, to demonstrate that which is feasible and sure and discount that which is supposition and unsure. The qualities required to do this are those noted in R&B which relate to the reliable collection and usage of data, scrupulous and methodical model creation, verification and validation, but also, I would suggest, the ability then to convince and to evangelize to a degree that is not possible for the results to do alone. Why is this? Surely, cold hard fact should stand its ground on numerical merit alone. Experience demonstrates that solutions are rarely that straightforward – systems complex enough to require simulation studies are never measured by single metrics, and therefore explanation skills are necessary to transmit understanding from the privileged position of the analyst to the obscured view of the project manager.

4.3 Base Metal to Gold

A true simulation is a precise instrument – every part can be explained and justified, each data point verified and agreed upon, and yet due to the very nature of the technology, a simulation model is invariably a complex system requiring much analysis and understanding. The successful use of simulation can only result from the imagination and creativity of those who apply it and explain it to others – and this goes far beyond the checklist of attributes necessary to create and perform the simulation model itself. A good simulation analyst therefore does many things that culminate in the continued and expanded use of simulation – and this only begins with the definition of the analyst as set out in R&B. Armed with a credible and flexible model, the good analyst is now the center of attention – and this is where the concept of a career in simulation begins to look extremely unlikely.

4.4 Take Me to Your Leader

Provided that all the preliminary steps to this point have been carried out in a rigorous and methodological way, the analyst now finds himself or herself in a position of knowledge. The simulation model embodies all relevant project knowledge and the analyst is the person most likely to understand its dynamic properties and how to generate further knowledge from the model. This places the analyst fully in the spotlight – in a typical simulation study the model is frequently used as the test bed for developing ideas and solutions, and it is rare that the client does not get to see the model and participate in experimentation in some way. The analyst is then in a position to explain the approach, the company methodology, the alternatives, the choices that were made and which resulted in the solution being presented – in short, the analyst now presents the company back to the client.

4.5 Who is that Youngster?

Due to the central role it plays in any appropriate study, simulation has unavoidably provided a means by which a good analyst can display his or her qualities, or cannot fail to display them. The very same qualities that make the analyst good at simulation also make him or her invaluable in developing other parts of a company's business. So progression away from simulation analysis is often unavoidable. There remains an important question to be asked at this point, however. Even if this sequence of events is seen as unavoidable, is it necessarily a bad thing?

A case can be made for the fact that a good analyst who is 'moved up' in a company (and by implication, out of simulation analysis) will be able to continue to propagate the use of simulation within the company. The very fact that a company's best and brightest have been channeled through the simulation department should be seen positively – they will have been able to see the many facets of an automation project through the exacting methodology of simulation, and they will have worked within a multidisciplined team. It will remain in the company's interest to make sure that the technology gets the skilled resources necessary to make its implementation a success. The best simulation analysts are undoubtedly those with considerable experience in creating and running simulation models. Nevertheless, if the best way to expand the use of the technology is to accept that a certain number of proponents will always treat simulation as a step rather than a complete path, then we need to adapt to this.

5 RALPH ROGERS (MILITARY)

R&B provide an excellent list of the tasks and skills expected for a certain set of practitioners in the simulation community. They identify those practitioners as simulation analysts. The issue that their paper raises is perhaps not the skill set required of their *simulation analysts* who are, in fact, defined by R&B's skill set. The issue raised is a more semantic question of the term simulation analyst, how it is interpreted by different groups and people and what the phase "to practice simulation" means. These are of particular importance for consideration of simulation analysts and, for lack of a better word, for simulation professionals in the military community. When considering the question "Education for Simulation Practice" in particular with concern to the U.S. defense community, the skill set depends on what the simulation analyst is expected to do.

For a significant set of the defense community both uniform, civilian, and industrial, the simulation analyst leads a team where many of the simulation tasks required as well as the necessary domain expertise can be assigned to team members with expertise or strong skills in specific tasks. The analyst can concentrate on oversight, leadership, assessment and interpretation. The analyst in this situation is typically a highly trained and experienced individual certainly able to evaluate and direct individual team member's efforts. Such individuals probably have all of the attributes of the simulation analyst identified by R&B plus excellent interpersonal, leadership, and management skills. In short, they are highly valued, highly specialized professionals who are able to effect leverage and direct human and other resources to achieve a goal. The individuals in this set more likely represent the career path that R&B promotes. Clearly these are important and often key individuals. Their talents and expertise are relied on to support many key decisions and plans within the defense community. However, there are relatively few of these individuals in the defense community and very few within the uniform services.

More typically, I have found, an assignment falls to an officer, program manager, engineer, policy planner or other technical or administrative person in the organization to study a problem and pose solutions to the decision makers. The degree of dependency on, and efficacy of, simulation is strictly within the purview of the assigned analyst. Typically, the budget and staff are limited. It falls to the assigned analyst to do what can be done based on his or her skill and experience. From this standpoint, simulation is not the analyst's main area of expertise or responsibility nor may the assigned analyst have any simulation skills as defined by R&B. The analyst is typically a domain expert. Simulation is just another tool in his or her tool set or a tool to which he or she has access to address the domain that is of principal concern.

To a large extent, analysts are decision makers and managers who look to simulation to reduce the risks of their decisions through analysis or provide solutions to their training needs. This is where the task and skill set of R&B becomes important for consideration by the assigned analyst. The importance is not so much from the standpoint that the assigned analyst possesses the skill set but that they know that the skill set is required by someone and that they can obtain and use that expertise.

From this point of view of the use of simulation in decision processes and in the procurement of devices and services, the skill set for the practice of simulation becomes less about the task and methodologies identified by R&B and more about the understanding of the technology, its strengths, limitations, and appropriateness to the situation at hand. The skill set associated with these latter activities more accurately reflects what may be called the professionals who practice simulation. Indeed, the ability to effectively exploit and manage the technology of simulation in pursuit of specific strategic and tactical goals is one of the most sought after talents in the military community. Unfortunately, it is not clear exactly what is the skill set of this group of practicing simulation professional.

The typical academic approach is educate the individual to be a traditional simulation analyst as defined by R&B. The assumption is that too much detail is never a problem and that once the entire range of skills are mastered then one can be certain that no key skill is left out. However, the entire military community can not be expected to be educated as simulation analysts. A different skill set more attuned to a wider constituency needs to be identified and individuals educated in those area. Here is where R&B's plea for industry "…to recognize the benefits of successful simulation studies, and [should] provide continuing education, support for attending simulation related conferences, and compensate simulation practitioners accordingly" will best be addressed. It should be pointed out that the military community already substantially heeds R&B's plea. However, the simulation community, particularly the simulation education and training community has not been able to adequately address the military community's need associated with providing the educational experience necessary for a wide range of simulation practitioners.

In summary, the skill set identified by R&B is excellent for a particular set of simulation professionals. This set is important to a wide range of military concerns. However, there exists an extremely large demand for simulation practitioners who can use simulation technology in planning, decision making, procurement, training, and experimentation. Unfortunately, the skill set of this group of professionals has yet to be sufficiently identified and accepted to provide the necessary guidance required of the education community. Until the latter skill set is identified and reflected in a large cadre of simulation practitioners, the simulation analysts embodied by R&B's skill set will find themselves promoting methodologies and products to a user community that, in all likelihood, does not have the requisite knowledge to use the products the simulation community sells or effectively use the analysis performed.

6 JACK P.C. KLEIJNEN (RESEARCH)

This panel contribution is inspired by the review R&B of the qualifications required for simulation professionals. I offer the following comments from a *research perspective*.

Simulation did exist before computers became available; for example, Gosset performed his Monte Carlo experiments in the early 1900s (and published those results under the pseudonym of Student). But it is through computers - especially PCs - that simulation has become ubiquitous, as witnessed by the fifth survey on simulation software in Swain (2001).

Universities offer simulation classes, both at the undergraduate and the graduate level. And they do so, for a large variety of disciplines: Karplus (1977) surveys the spectrum of disciplines that use simulation. I would claim that any discipline that uses mathematical models applies simulation to estimate the dynamic behavior of those models.

My comments are biased by my experience as a teacher of simulation applied to management science, operations research, computer science, industrial engineering, and econometrics. As a researcher and consultant, I have worked on projects in these fields and in ecology, mechanical engineering, nuclear engineering, etc.

R&B lists *eight tasks* for simulation analysts (their list agrees with the list in the most popular simulation textbook, namely Law and Kelton (2000). I am focusing on the academic education needed to fulfill these tasks adequately.

6.1 Data Collection

R&B mentions time studies as one of the devices for collecting data. However, in Business Schools such studies are not taught, to the best of my knowledge. Anyhow, once input data are collected, they need to be analyzed and distributions may be fitted.

Obviously, this task requires *statistical education*: I define mathematical statistics as the science of collecting and analyzing sample data. And in simulation the input data are always only a sample, since the simulation model itself is supposed to reflect the behavior of the real system, in the future - either continuing or changing the environmental and controllable inputs.

More specifically, I focus here on the principles of garbage-in-garbage-out (GIGO) and sensitivity analysis. (I think that the term GIGO originated in computer science, not simulation.)

GIGO means that a computer program accepts nonsensical input data, processes those data with 100% accuracy, and presents the silly output to the users. In simulation the GIGO principle may be embellished by fancy animation: cars crash into each other, but continue without any damage! Hopefully, such nonsense will be detected in the verification phase; see Section 6.5 below.

Sensitivity analysis is always needed in simulation, because modeling is an art that involves assumptions on the input data. For example, several statistical distributions can be fitted to the same data. Fortunately, current software simplifies the fitting of such distributions, and provides measures of fit such as the chi-square and the Kolmogorov-Smirnov statistics as discussed in Law and Kelton (2000).

However, these measures of fit do not quantify the effects of changing the distribution on the final simulation output! By 'sensitivity analysis' I mean the systematic investigation of the reaction of the simulation responses to extreme values of the model's input or to drastic changes in the model's structure. For example, what happens to the customers' mean waiting time when the arrival rate doubles; what if the service distribution changes from exponential to lognormal; what if the priority rule is changed by introducing 'fast lanes'? Such an analysis helps identify the most important factors in a simulation study. To answer such questions, the simulation analysts need to perform experimentation (see Section 6.6 below). Also see Kleijnen (2000).

Once the analysts have identified the most important factors, they should try to collect more data on these factors. If such data cannot be collected (for example, because the data will become available only in the future), then *risk or uncertainty analysis* should be performed; see Kleijnen (1994).

Further, R&B emphasizes that analysts should be *skeptical*. I feel that such skepticism is at the heart of academic education: do not believe anything - even when it is printed! An example is this contribution.

R&B continues with 'a background in basic statistics is helpful in data analysis.' My experience is that *basic* statistics is hardly enough. Even students with good training in mathematical statistics find it hard to apply and interpret those mathematics in simulation practice. For example, I ask them: 'If you use common random numbers, what does that imply for the basic statistical assumption of identically and independently distributed variables?' Whereupon they fall silent ....

6.2 Conceptual Model Development

R&B claims that the capability to *abstract* is a key requirement of analysts. I feel indeed that one of the basic elements of academic education is such a capability. In practice, however, sometimes people object and say: 'This is too academic, too abstract'!

R&B continues with '[a] background in manufacturing will help the analysts understand the processes.' I would argue that more generally speaking, it is essential to know the real or 'object' system to be simulated (be it a manufacturing system or some other system). Otherwise, you simulate your own ignorance. Forming a team may help. But then students need to be trained in functioning as team members. I think that current academic education indeed pays attention to these *social skills*.

6.3 Specification Development

R&B points out that this task involves writing for a non-simulation audience, and that academic training does include technical writing. I would add that more training would not hurt. Writing is an art that needs practicing continuously. Personally, I find the *WSC guidelines for authors* required reading for my own students - and myself.

6.4 Model Construction

Obviously, this task involves computer programming. I would add that many analysts and users see simulation as a programming exercise: wrong, as the other tasks demonstrate! Moreover, I warn that simulation - unlike other operations research techniques - allows the inclusion of too many details. To avoid this trap, I advocate the *KISS* principle: keep it simple, stupid.

6.5 Verification & Validation (V&V)

Kleijnen (2000) emphasizes the role of mathematical statistics in V&V. In practice, simulations are often not validated through correct statistical techniques. For example, many a trace-driven simulation uses a scatter plot of simulated versus real outputs, and tests whether this scatter plot has unit slope and zero intercept. However, such a test rejects a true simulation model 'too often,' that is, more frequently than the pre-specified type I error rate (say) α.

Which statistical techniques can validate simulation models, depends on which *real-life data* are available, namely (i) no data, (ii) only output data, and (iii) both input and output data. Of course, as the data improve from (i) to (iii), the power of these techniques increases. Simulationists should be trained in these techniques, which include Student's t-statistic, linear regression analysis, and basic design of experiments (DOE).

6.6 Experimentation

DOE is needed for V&V, what-if analysis, and optimization. Kleijnen (1998) gives a survey of DOE techniques.

6.7 Reporting and Presenting Results

Please refer to Section 6.3, Specification Development.

6.8 Summary

In summary, simulation analysts have eight *tasks*, which correspond with the various *steps* in simulation projects. Many tasks require training in computer programming and mathematical statistics. Therefore simulation textbooks treat these two aspects in great detail. Moreover, it is important that the simulation team has knowledge of the real system to be simulated. This knowledge is taught in other academic courses, and improved through practice. Finally, social skills, and writing and presentation competence are valuable too.

7 CONCLUSION

In this section, differences, exceptions, and inference are drawn from the panelists in comparison to what appeared in R&B. Adelsberger and Bick add four skills or traits to the list given by R&B including the ability to listen and negotiate, possession of a strong work ethic and the ability to build rapport with customers. They also indicate that the role of a simulation expert might shift significantly dependent on the magnitude and scope of an investigation. The simulation expert should concentrate on facilitating simulation studies and act as a tutor for providing problem solving and decision making skills.

Charles McLean also sees additional areas that might be needed to enhance the skills of the simulation analyst. He indicates that that simulation students today should receive some introduction to HLA in their coursework. He says that other standards for distributed simulation may evolve in the future, but HLA is receiving a lot of attention worldwide today. McLean also states that the simulation analyst should have stronger software engineering skills including structured software development techniques, information modeling and data structures, and problem representation. McLean also predicts that the line between artificial intelligence and simulation will become blurred.

McGregor indicates a convergence from R&B in that simulation should not necessarily be considered a career path. Essentially, he says that the good simulation analyst will become noticed and 'moved up' in the organization. This is a positive indication as those that advance will have a better understanding of the system in which they are working and will have the experience of working in a multidisciplinary team.

Rogers indicates that the skill set identified by R&B is excellent for a particular set of simulation professionals. This set is important to a wide range of military concerns. However, there exists an extremely large demand for simulation practitioners who can use simulation technology in planning, decision making, procurement, training, and experimentation. Unfortunately, the skill set of this group of professional has yet to be sufficiently identified and accepted to provide the necessary guidance required of the education community. Until the latter skill set is identified and reflected in a large cadre of simulation practitioners, the simulation analysts embodied by R&B's skill set will find themselves promoting methodologies and products to a user community that, in all likelihood, does not have the requisite knowledge to use the products the simulation community sells or effectively use the analysis performed.

Kleijnen summarizes his remarks by saying that simulation analysts have eight *tasks*, which correspond with the various *steps* in simulation projects. Many tasks require training in computer programming and mathematical statistics. Therefore simulation textbooks treat these two aspects in great detail. Moreover, it is important that the simulation team has knowledge of the real system to be simulated. This knowledge is taught in other academic courses, and improved through practice. Finally, social skills, and writing and presentation competence are valuable too.

In summary, the skills in R&B form a basis for all of the five perspectives mentioned. However, each perspective has some additions to these skills or takes issue with the career path of the simulation analyst.

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