Lancaster University Management School
Working Paper
2005/036

Practitioners' perception of the impacts of virtual reality on discrete-event simulation

Justice Ikpe Akpan and Roger Brooks

The Department of Management Science
Lancaster University Management School
Lancaster LA1 4YX
UK

Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

PRACTITIONERS' PERCEPTION OF THE IMPACTS OF VIRTUAL REALITY ON DISCRETE-EVENT SIMULATION

Justice Ikpe Akpan
Roger Brooks

Department of Management Science
Lancaster University Management School
Lancaster, LA1 4YX, UK

ABSTRACT

This paper presents the results from surveying simulation practitioners from industry and academics who have used 2D or 3D software applications for Discrete-Event Simulation (DES) projects. The survey focused on the impacts of Virtual Reality (VR) on DES activities. The findings indicate the software used, the applications areas, the stages in the simulation modeling process where Visual Display is commonly used, and a comparative evaluation of the benefits and costs associated with modeling in 3D over 2D. Other results indicate possible influence of each of the two displays on simulation results, effects on users' understanding of the modeled system and any corresponding influence on decision-making. The findings also incorporate the pitfalls to avoid when modeling in 3D, and speculations about the future of VR-based DES practice.

1 INTRODUCTION

The simulation community is currently witnessing a proliferation of 3D/VR modelling software and tools. But, despite an increase in VRSIM practice, there is a lack of empirical evidence establishing any clear benefits over conventional 2D modelling.

The current literature seems to dominated by fairly superficial assessment of the novelty of 3D/VR software, speculative claims about VRSIM and 'propaganda of success stories' in an attempt to sell simulation solutions. Most users who have adopted the VR technology in DES are left to rely on recommendations and subjective evaluations from partners and 'near-peers' (Smith, 2000) rather than empirical studies. Consequently, some simulation practitioners remain sceptical about VRSIM due to the lack of empirical evidence of any substantial benefits (Zutphen et al., 1996; Asthmeimer, 1999). It has now become necessary to address the important questions about the added value of VRSIM.

The rest of the paper discusses the claims about VRSIM as indicated in the literature, the aims and objectives of the survey and the survey design. Finally, the results of the survey are discussed.

2 CLAIMS ABOUT VRSIM

The current literature speculates a number of benefits of VRSIM. This section states the claimed benefits.

2.1 Problem Definition

3D display can result in a better problem definition that is easily agreeable by all stakeholders of the simulation project than 2D display (Wainer, 1997; Munro, Hook & Benyon, 1999).

2.2 Model Validation

It is easier to identify errors in 3D than 2D, which can result in a more accurate model. This is made possible by the excellent visualization capability of VRSIM. 3D display also enhances easy understanding of model behaviour during simulation runtime (Kamat & Martinez, 2000; McKay et al. 2002; Mesquita, Cunha, Henriques, Grave, Silva, 2000).

2.3 Generation of Ideas about the Modeled System

VR provides true to scale 3D graphics and animation, making simulation models easy to understand and invaluable for communicating new ideas and alternatives (Sheridan, 1992; Bennaton and Sivayoganathan, 1995).

2.4 Communicating with Clients and Presentation

3D graphics can be employed to simplify the presentation and interpretation of simulation results to the users, especially where the stakeholders from various disciplines/non-

technical personnel are involved (Barnes, 1997; Smith and Duke, 1999).

2.5 Model Credibility, Acceptance and Usability.

3D models easily convey results and make any recommendations arising from the simulation more convincing and credible, and also lead to increased confidence in the model (Jones, 1992; Tanriverdi & Jacob, 2001; Jacob et al., 1999; Kessler, 1999).

2.6 Improving the Quality of Managerial Decisions.

The details gleaned from the 3D models helps the decision-maker to base decisions on accurate and plausible simulation feedback instead of resorting to experience and personal judgement and helps the management to make more prudent decisions. Bridging the communication gap between model developer and management/non-technical personnel, VRSIM can become a catalyst for resolving complexities in the simulation models, and improves the quality of decision-making (Shannon, 1975).

3 SURVEY DESIGN

3.1 Objectives of the Survey

The main objectives of the survey were to identify the views of simulation practitioner about the hypothesised benefits of VRSIM, and to establish whether simulation practitioners and users in the industry also echo the enthusiasm about 3D/VR simulation of the software vendors.

3.2 The Sample

The target respondents for the survey were simulation consultants, model builders and users or decision-makers from the industry and academics. The selection of the survey sample was not based on any formal statistical method. Also, the population was not limited to any geographical boundary. Rather, effort was made to reach any respondents irrespective of country of residence or country of practice.

3.3 Questionnaire Administration

Two different sets of questionnaires were administered separately namely, questionnaire to model builders and users of 3D/VR Simulation software, and to the 2D modelers and users respectively. The survey was conducted between the months of March – May 2004. Three different approaches were employed to reach the respondents as explained in the section below.

3.3.1 Personal Contacts

In this approach, respondents were contacted individually during a two-day workshop of the Operational Research (OR) Society Simulation Study Group at Birmingham, UK in March 2004. After a brief discussion with each respondent, the appropriate version of the questionnaire was issued, which was later completed and returned (before the end of the workshop). A response rate of 100% for the 3D/VR and over 91% for the 2D was achieved using this approach (see Table1).

3.3.2 Online Survey

Here, the subjects completed and submitted the questionnaires online, with responses automatically collected into an Access Database. Over 63% of the 3D/VR responses and 71% of 2D were obtained through this approach.

The online respondents were first contacted by email with a link to the online version of the questionnaires. In addition to the subjects that we contacted directly, a major simulation software vendor in the United Kingdom also offered some assistance by emailing its customers/clients with the link to the survey web site, asking them to complete the questionnaires online. However, it was not possible to determine the response rate. This is because we did not know the number of potential respondents who actually received the covering email from the third party, or those who visited the site without completing the questionnaire.

3.3.3 Postal Survey

The postal survey was a last resort to get some known respondents to complete the questionnaire, after an initial contact by email was unsuccessful. The postal survey attained a 100% response rate as shown in Table 1.

Table 1: Survey Methods and Response Rate

	Survey Methods					
Outcome	**Personal Contacts**		**Online**		**Postal**	
	3D/VR	2D	3D/VR	2D	3D/VR	2D
Contacts	4	11	-	-	4	-
Response	4	10	14	25	4	-
Rate (%)	100	91	-	-	100	-
Received	3D/VR users = [22]		2D users = {35}			

After two months of effort in administering the questionnaire, 57 usable responses (22 responses from the 3D/VR modelers/users and 35 responses from the 2D subjects) were received. The fewer responses from the 3D/VR survey compared to the 2D sample appear to indicate the smaller number of 3D/VR modelers/users in the simulation industry at present.

4 RESULTS OF THE SURVEY AND DISCUSSION

This section presents and analyzes the results of the survey. For ease of comparison of responses from the two different categories of respondents (users of both 3D/VR and 2D applications, and users of only 2D applications), both results are summarized in the same Tables. In such cases, the results from 2D respondents are shown in the *curly* brackets.

4.1 Results of the Survey

Table 2: Business Sector of Respondents' Organizations

Organizations	3D Respondents		2D Respondents	
	Count*	%	Count*	%
Aerospace	9	11	4	9
Automotive	-	-	3	7
Consulting	15	17	6	13
Defence	16	19	-	-
Education	12	14	8	17
Electronics	5	6	1	2
Energy, Oil and Gas	10	12	4	9
Financial Services	-	-	1	2
Manufacturing	15	17	14	30
Healthcare	-	-	2	5
Media	1	1	1	2
Mining	-	-	1	2
Nuclear	2	2	1	2
Telecommunications	1	1	-	-

* Respondents selected more than one sector

Table 3: Job Titles of Respondents

Job Title	3D Respondents	2D Respondents
Consultant	2 [9%]	2 [6%]
Co-ordinator	-	1 [3%]
Engineer	5 [23%]	9 [26%]
Instructor	1 [4%]	5 [14%]
Manager / Decision-maker	5 [23%]	13 [37%]
Operational Researcher	6 [27%]	5 [14%]
System Modeller	3 [14%]	-
	n = 22	**n = 35**

Table 4: Number of DES Model Developed or Used

Number of Models	3D Models	2D Models
1 – 5	11 [50%]	3 [13%] {9, 26%}
6 – 10	6 [27%]	4 [18%] {7, 20%}
11 – 15	-	1 [5%] {5, 14%}
16 – 20	-	1 [5%] {4, 11%}
21 - 25	-	3 [13%] {5, 14%}
26 - 30	1 [5%]	1 [5%] { - }
31 - 35	-	-
36 - 40	-	1 [5%]
Over 40	-	4 [18%] {3, 9%}
No Response	4 [18%]	4 [18%] {2, 6%}

{}: Results from 2D Respondents

Table 5: Simulation Packages Used

3D Software	%	2D Software	%
ANSYS FLUENT	4	ARENA	9 {6}
AUTOMOD	4	AUTOMOD	3 {4}
BASESIM	4	ClinSim	- {2}
COSMO World	7	eM-PLANT	6 {2}
eM-PLANT	7	FORESS	- {2}
FLEXSIM	4	MathCad	- {2}
INNOVATE	4	Matlab	3 {2}
MAYA	7	POWERSIM	- {2}
QUEST3D	12	ProModel	3 {7}
REALIMATION	4	QUEST	3 {2}
SIMUL8	4	SIMAN	- {4}
Superscape VRT	7	Simple++	6 {2}
WINGS3D	4	SIMUL8	6 {11}
WITNESSVR	32	VenSim	- {2}
		WITNESS	61 {52}

{} = Values from 2D respondents

Table 6: Types of Problems Tackled

Problems Tackled	Using 3D Application		Using 2D Application	
	Count *	%	Count *	%
Facility Layout	14	29	9 {15}	12 {15}
Facility Planning	9	19	17 {18}	23 {19}
Long term Planning	2	4	6 {11}	8 {11}
Operational Control	5	10	12 {20}	16 {21}
Resource Allocation	6	12	10 {7}	14 {7}
Capital Investment Decision	7	14	12 {19}	16 {20}
Business Process Simulation	2	4	3 {3}	4 {3}
Budgeting	-	-	5 {3}	7 {3}
Invalid Choices	4	8	- {1}	- {1}

{} = values from 2D respondents.
* Respondents listed more than one type of problem

Table 7: The Use of Visual Display

Modelling Activities	Using 3D Display		Using 2D Display	
	Count*	%	Count*	%
Model Building	14	19	16 {29}	21 {26}
Model Testing & Validation	16	22	18 {31}	23 {28}
Model Run	15	21	16 {16}	21 {14}
Model Experimentation	11	15	17 {22}	22 {20}
Demo to Clients	17	23	10 {14}	13 {12}

{} = Values from 2D respondents.
* Respondents selected more than one option

Table 8: Reasons for Using 3D/VR

Reasons	Counts*	%
Helps in Model Development		
• VR modelling is more engaging for students	1	3
Model Testing and Validation		
• 3D display makes it easier to spot errors in the model	6	16
Ease of Model Understanding		
• Non-technical or non-experts can easily understand 3D model	5	14
• 3D Display is intuitive	2	5
• Customer can relate to a 3D model better	3	8
Visualization and communication		
• Excellent Communication with stakeholders	4	11
• Excellent quality of visualization and presentation	9	24
• Enhances model credibility as model is easily acceptable by clients	5	14
• 3D Conveys extra spatial information	2	5

* Some respondents provided more than one reason

Table 9: Evaluation of 3D/VR and 2D Modeling

Modelling Activities	3D Better	No Difference	2D Better	Don't Know
	[%]	[%]	[%]	[%]
Model Building	2 [13]	2 [13]	11[68]	1 [6]
Testing and Validation	9 [57]	5 [31]	1 [6]	1 [6]
Model Run	4 [27]	5 [33]	5 [33]	1 [7]
Model Experimentation	4 [29]	5 [35]	4 [29]	1 [7]
Demo to Clients	13[93]	0	0	1 [7]

Table 10a: VRSIM Users' Opinion on Time Taken to Perform Modeling Tasks

Modelling Activities	Shorter Time with 3D		Same Time with 2D		Shorter Time with 2D	
		[%]		[%]		[%]
Problem Definition	1	[6]	15	[94]	0	
Model Development	1	[7]		0	14	[93]
Testing and Validation	11	[73]	3	[20]	1	[7]
Model Analyses	3	[20]	6	[40]	6	[40]
Model Implementation	5	[38]	4	[31]	4	[31]
Decision-making process	1	[8]	2	[15]	10	[77]

Note: The values excludes the respondents who did not answer the question.

Table 10b: 2D Users' Opinion on Time Taken to Perform Modeling Tasks

Modelling Activities	Shorter Time with 3D		Same Time with 2D		Shorter Time with 2D	
		[%]		[%]		[%]
Problem Definition	11	[58]	7	[37]	1	[5]
Model Development	6	[32]	7	[37]	6	[32]
Testing and Validation	16	[84]	2	[11]	1	[5]
Model Analyses	3	[16]	9	[47]	7	[37]
Model Implementation	6	[33]	8	[44]	4	[22]
Decision-making process	10	[59]	2	[12]	5	[29]

Note: The values excludes respondents who did not answer the question

Table 11a: VRSIM Users' Opinion about an Effectiveness of 3D/VR v 2D Display

Criteria	3D Better	No Difference	2D Better	Don't Know
	[%]	[%]	[%]	[%]
Communication with Clients	16 [84]	1 [5]	2 [11]	0
Model Understanding	13 [68]	4 [21]	2 [11]	0

Note: The values excludes 3 respondents who did not answer the question.

Table 11b: VRSIM Users' Opinion about an Effectiveness of 3D/VR v 2D Display

Criteria	3D Better	No Difference	2D Better	Don't Know
	[%]	[%]	[%]	[%]
Communication with Clients	13 [45]	6 [21]	3 [10]	7 [24]
Model Understanding	12 [41]	8 [28]	0	9 [31]

Note: The values excludes 6 respondents who did not answer the question

Table 12a: VRSIM Users' Opinion on the Impact of 3D/VR and 2D displays on Simulation Results

Criteria	Better Solution	Same Solution	2D Better	Don't Know
	[%]	[%]	[%]	[%]
Does 3D enhance better Solution?	11 [69]	7 [31]	0	0

Note: The values excludes 4 respondents who did not answer the question

Table 12b: 2D Users' Opinion on the Impact of 3D/VR and 2D displays on Simulation Results

Criteria	Better Solution	Same Solution	2D Better	Don't Know
	[%]	[%]	[%]	[%]
Does 3D enhance better Solution?	2 [7]	16 [57]	1 [4]	9 [32]

Note: The values excludes 7 respondents who did not answer the question

Table 12c: Summary of Users' Comments on the Effect of Display Type on Simulation Solutions

Does 3D Enhance Better Solution?
Comments from 3D/VR Respondents - Answer is in numbers, not in pictures - Numbers (stats) are often more useful than display
Comments from 2D Respondents - Analysis and communication of results play a greater part than visual presentation

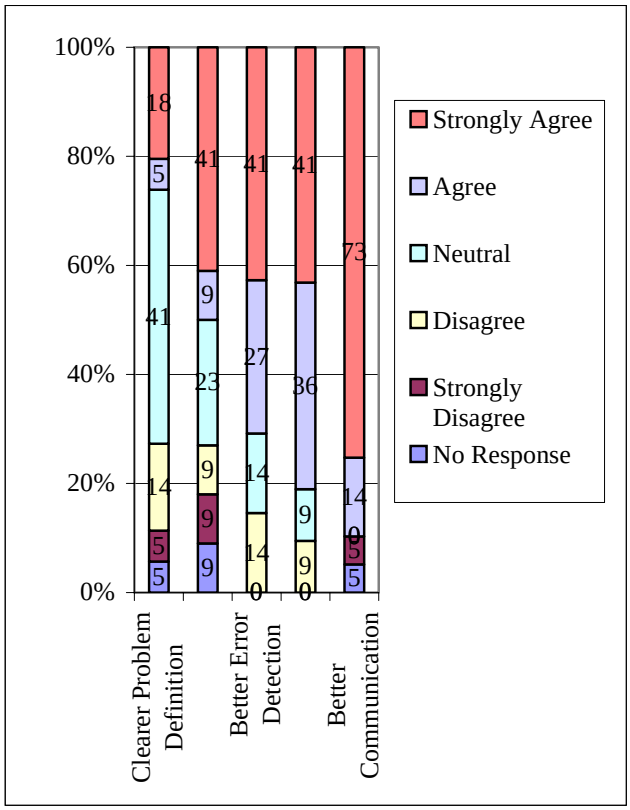

Figure 1a: The Opinion of 22 Users of 3D/VR Application about the Five Major Claims of 3D/VR Modeling

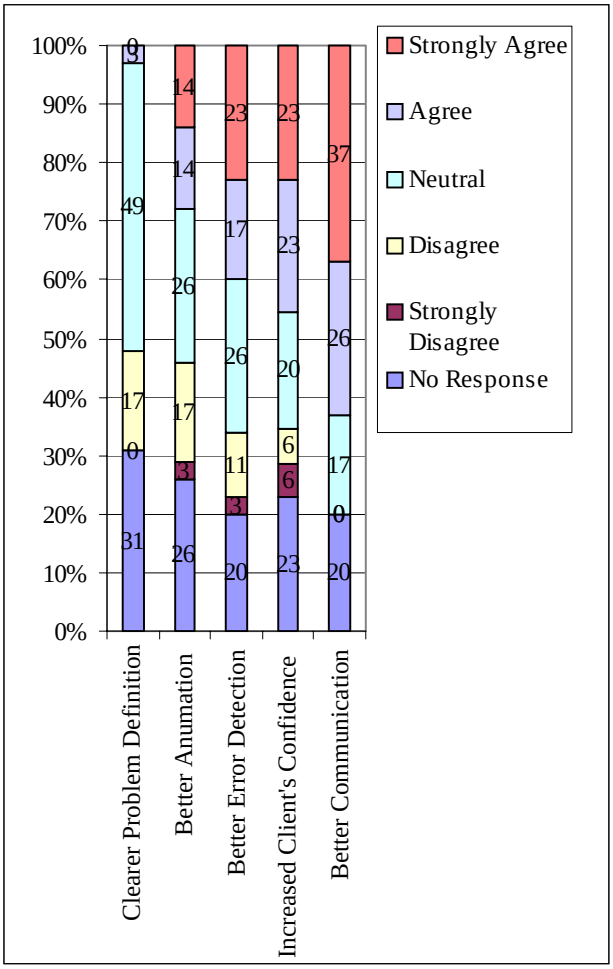

Figure 1b: The Opinion of 35 Users of 2D Application about the Five Major Claims of 3D/VR Modeling

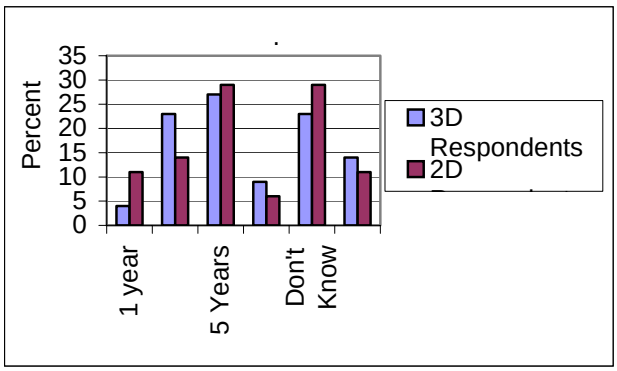

Figure 2: Respondents' Prediction on When VRSIM is likely to be Widely Used

Table 13: Limitations of VRSIM and Reasons for Non-Use

Comments by Respondents	Mentions*
Complexity of 3D modelling	
• More difficult and time consuming to define 3D shapes	8
• Harder to build 3D models	3
• Wastes modellers' time, as customers want "disney production" rather than numbers	1
• 3D models is more complex to develop and takes longer time.	32
3D Hinders the Modelling Process	
• Graphics may actively get in the way of seeing the problem	2
• Working from a specific 'life like' rather than 'logical' perspective can make it possible to overlook the important aspects of the model	1
• Too much effort put into display rather than tackling the problem.	1
• Too much information is a distraction from main issues.	1
Limited Functionalities of current 3D Software Packages	
• The future adoption of 3D by users depends on providing better tool support to simplify the 3D model-building process and quick and easy ways of creating elements	6
• Immature Technology	1
• Need to integrate 3D software with Virtual Reality Tools (e.g. HMDs, Gloves).	1
Additional modelling cost	
• Large development overhead for no significant analysis benefit, just aesthetics	2
• Long learning curve: It requires time to train in new skills.	2
Longer run time of 3D model	
• Run speed can be slower than 2D.	3

* Some respondents offered more than one reason.

4.2 Summary of Findings and Discussion

This section presents a brief discussion of the key issues from the survey. The conclusions drawn from the study are based on the views of majority of the respondents.

4.2.1 VRSIM Improves the Accuracy of Simulation Model

This survey has provided valuable insights about the effectiveness of visual display in detecting error in simulation model, although this is less mentioned in the literature. In Visual Interactive Modelling (VIM) practice, most people now use visual display for model testing and validation

compared to other modelling activities as cited by majority of modellers/users (31% and 28% of 3D/VR and 2D respondents respectively – see Table 7). For the 2D Display, its use for checking of errors in simulation model has become far more popular than its usefulness in model demo, which was the case in the initial study of VIM activities (see Bell et al., 1999; Kirkpatrick & Bell, 1989) just over a decade ago.

Regarding the impacts of VRSIM on model accuracy, most people cited 3D/VR display as being more effective than 2D in spotting errors in simulation model. This is witnessed in two ways:

i. Majority of respondents who have used both the 3D/VR and 2D applications (57% - see Table 9) indicated that, VRSIM makes it easier to spot errors in simulation model than 2D display.

ii. Significant majority of respondents (73% of 3D/VR users and 84% of 2D - see Tables 10a & 10b) stated that, testing and validation is shorter with 3D/VR than 2D.

4.2.2 VRSIM Enhances Excellent Communication with Clients

The study strongly supports the claim that VRSIM enhances better communication between the model builder and the decision-maker about the problem than 2D display. Seventy-three percent of the 3D/VR respondents and thirty-seven percent of the 2D respondents (majority) viewed that VRSIM greatly improves communication with clients than 2D display during model demo, and made simulation results more convincing to the customers. More than half of VRSIM modelers and users cited excellent communication capability of the 3D display that most greatly influenced their decisions to adopt 3D Modeling. This may indicate a possible danger where the stakeholders extol the novelty of a pretty interface of model over technical (statistical) accuracy. However, its impacts on model acceptance cannot be overlooked.

The survey also revealed a high level of discontent with the use of 2D display as communication tool, given that majority of the 2D users indicated their preference for VRSIM for this purpose. Current advances in computer graphics in which the use of 3D images has become very popular and common, making the use of 2D animation inadequate explains this development.

4.2.3 VRSIM Improves Clients' Understanding of the Modelled System

Previous studies on the impacts of visual display in simulation modelling established that VIM (then referred to 2D display) enhances user understanding of the various aspects the simulation problem (Hurrion, 1981; Hurrion, 1985; Kirkpatrick & Bell, 1989). This study however shows a different outcome. A significant majority (59% of the 3D participants and 34% of the 2D respondents) indicated that VRSIM makes it easier for managers, decision-makers and non-technical personnel to understand the modelled system, than when using 2D display. It is interesting to note that, although fewer respondents considered users' ability to understand the model to be independent on the type of display, no respondent considered 2D display to enhance a better understanding of the modelled system than VRSIM.

4.2.4 VRSIM Increases Client's Confidence in the Simulation Model / Results

This study lends strong support to the claim that VRSIM increases confidence in the simulation results than if the 2D display is used. A vast majority of the 3D modellers or users (77%) indicated that they either 'strongly agree' or 'agree' to this assertion. A good number of the 2D respondents supported this claim though less convincing which can be explained by their lack of practical experience in VRSIM modelling.

The increased confidence in the simulation results therefore greatly facilitates credibility and acceptance. However, over reliance on simulation results based on a pretty interface rather than statistical correctness of the result raises a serious concern and poses the danger of rejecting a technical sound model with less convincing interface for a less sound model but with a visually pleasing display.

4.2.5 VR Model is More Difficult to Build and Takes Longer Time to Develop

The most serious concern about VRSIM modelling that was re-echoed throughout this study is the difficulty in building 3D model, the longer time required to build the model and the associated costs compared to the 2D model. Fifty percent of the VRSIM users indicated that it is more difficult to develop 3D model compared to 2D, while sixty-four percent indicated that it takes significantly longer time to develop a 3D model. On the other hand, majority of non-VRSIM users (31%) also cited complexity of 3D modelling and longer time required to build 3D model as the main reason for non-use. A number of VRSIM modellers cited technical problems associated with current VRSIM applications (such as problems encountered when building 3D shapes), and suggested the need to improve

current software packages to make it easier to build 3D models.

4.2.6 Modeling Process Takes Longer to Complete with VRSIM

The study investigated the time taken to complete the entire decision-making process (that is, between the problem definition stage and decision-making). A significant majority of 3D respondents (46%) viewed that the process is shorter with 2D than with VRSIM. The results implies that, the longer time taken to build 3D/VR model overshadows the time saved at the model testing/validation and implementation stages, thereby making the overall time taken to complete the model building process to be longer when VRSIM is used than when using 2D.

4.2.7 VRSIM is the Future of Simulation

The views of respondents investigated about the time period before VRSIM become widely used. Majority of VRSIM and 2D modellers and users (27% and 25% respectively) indicated that 3D/VR modelling can become popular within the next five years, although the 3D respondents were slightly more optimistic than the 2D participants. Furthermore, the general enthusiasm of respondents, especially the over 70% who indicated their willingness to be contacted for further VRSIM research as well as requested the results of this survey indicates that VRSIM has come to stay.

4.2.8 Limitation of the Survey

The selection of the survey sample did not follow any formal statistical procedure such as probabilistic sampling, hence the need for careful generalization of its conclusions.

Furthermore, the sample size of VRSIM users was smaller than those of 2D, which could limit the validity of the comparison of responses between the two categories. However, the smaller sample of 3D/VR users was largely due to fewer number of practitioners at present.

Nevertheless, this study has expounded the body of knowledge and provide empirical evidence about the benefits of VRSIM, indicate the aspects of simulation modelling where the benefits can be attainable and state the pitfalls to avoid.

5 CONCLUSION

This study has provided empirical evidence regarding the various claims of VRSIM based on the views of simulation practitioners. Generally, the simulation community seems enthusiastic about the application of VR technology in DES but many remain cautious, guarding against possible exaggeration of the claimed benefits. The survey results show that majority of 3D/VR modellers/users (and 2D modellers/users) are aware of the significant set-up costs, possible long learning curve for 3D modelling/software and the new modelling methodology of VRSIM. Despite these limitations, most simulation practitioners remain enthusiastic about VRSIM as an inevitable next step in simulation modelling process.

Finally, the curiosity of participants in this survey, especially by non-users (evidenced by the high number of request for the summary of this survey) is an indication that even the current skeptics can adopt the technology if the benefits are clear, realistic and convincing.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance received from Lanner PLC by contacting its customers on our behalf and encouraging them to take part in the survey.

REFERENCES

Astheimer, P. 1999. A Business View of Virtual Reality. IEEE Computer Graphics and Applications, vol. 19, pp. 28-29

Barnes, M. 1997. An Introduction to Quest. In: Proceedings of the Winter Simulation Conference. Eds. S Andradottir, K Healy, D Withers & B Nelson.

Bennaton, J and Sivayoganathan, K. 1995. The Usefulness of 3D Discrete Event Simulation. In: Proceedings of the 31st International MATADOR Conference, 20th – 21st April, Manchester, 99 – 103

Hlupic, V. 2000. Simulation Software: An Operational Research Society Survey of Academic and Industrial Users. In Proceedings of the 2000 Winter Simulation Conference, J A Joines, R R Barton, K Kang, and P A Fishwick, eds.

Jacob, R. K, Deligiannidis, L and Morrison, S. 1999. A Software Model and Specification Language for Non-WIMP User Interfaces. ACM Transactions on Computer-Human Interaction, vol. 6, pp. 1-46, 1999.

Jones, N. 1992. Manufacturing Simulation using Virtual Reality. Master's Thesis.

Kamat, V R & Martinez, J. C. 2000. 3D Visualization of Simulated Construction Operations, Proceedings of the 2000 Winter Simulation Conference. J A Joines, R R Barton, K Kang & P A Fishwick eds.

Kirkpatrick, P and Bell, P. C. 1989. Visual Interactive Modelling in Industry: Results from a Survey of Visual Interactive Model Builders. In Interfaces, 19:5, Sept – Oct., pp.71-79.

McKay, K., Colquhoun, P., Bramall, D et al. 2002. An aggregate resource model for the provis digital mock-up within a distributed manufacturing planning system.

Mesquita, R et al. 2000. Usability Engineering: VR Interfaces for the next generation of production planning and training systems. Online Access.

Munro, A. J. et al. 1999. Social Navigation of Information Space. Springer, London.

Shannon, R. 1975. Systems Simulation: The Art and Science, Prentice-Hall, Englewood Cliffs, NJ.

Smith, R. 2000. Simulation: The Engine Behind the Virtual World. Volume 1 in the Simulation 2000 series.

Smith, S and Duke, D. J. (1999) "Virtual Environments as Hybrid Systems," presented at Annual Conference Eurographics UK Chapter, Cambridge, 1999.

AUTHOR BIOGRAPHIES

Justice Ikpe Akpan studied Software Development at Leeds Metropolitan University, UK, where he received his MSc in 2001. Currently, he is finishing his PhD Thesis on the impacts of Virtual Reality on Discrete-Event Simulation at Lancaster University. He is a member of British Computer Society, UK and has worked as Software Developer, Web Programmer, and Developer of Virtual Learning Environment (VLE) in the USA and UK. Email to: <J.Akpan@lancaster.ac.uk> Website at: <www.lancs.ac.uk/postgrad/akpan/>.

Dr Roger J Brooks is a lecturer in the Department of Management Science at Lancaster University. He has research interests in the methodology and the applications of simulation. Email to: <Roger.Brooks@lancaster.ac.uk>, website at <http://www.lums.lancs.ac.uk/profiles/147/>.