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

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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 (VRSIM) 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 lack of empirical evidence establishing any clear benefits over the conventional 2D modelling.

The current literature seems to be dominated by fairly superficial assessment of the novelty of 3D/VR simulation 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).

The survey results presented in this paper therefore attempts to address this important question about the added value of VRSIM over the conventional 2D modelling practice.

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. The paper also presents the findings of this research about the impacts of VRSIM and speculates about the future of 3D modeling.

2 CLAIMS ABOUT VRSIM

The current literature speculates a number of benefits of VRSIM. This section states some modeling activities and relevant claims of VR.

2.1 Problem Definition

VR/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 and Benyon 1999).

2.2 Model Validation

It is easier to identify errors in 3D model than 2D, thus improving model accuracy. This is made possible by the excellent visualization capability of VRSIM. The 3D display also enhances easy understanding of model behaviour during simulation runtime (Kamat and Martinez 2000, McKay et al. 2002, Mesquita et al. 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 (Bennaton and Sivayoganathan 1995).

2.4 VRSIM Enhances Communication with Clients and Model Presentation

VR or 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

VR/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 and Jacob 2001, Jacob et al. 1999, Kessler 1999).

2.6 Improving the Quality of Managerial Decisions

The 3D/VR display is more intuitive than 2D. It also provides detailed information to decision-makers or model users, and improves understanding of the modeled system reasonably. This enables the decision-maker to base important decisions on accurate and plausible simulation feedback instead of resorting to experience and personal judgment. This can enhance prudent business decisions.

Furthermore, by bridging the communication gap between model developer and management or 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, 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 Table 1).

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.

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.

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}*			

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 Characteristics of Respondents

Tables 2, 3, 4, and 5 show a summary of the main characteristics of the respondents such as respondents' business sector / organizations, job titles, simulation software used, etc. Table 6 shows the types of problems tackled by respondents using the software listed in Table 5.

Further details about respondents' can be found on these tables. Also, this paper does not establish any relationship between the characteristics of respondents and their views.

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%]
Decision-maker/Manager	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 [61%]	3 [27%] {9, 27%}
6 – 10	6 [33%]	4 [22%] {7, 21%}
11 – 15	-	1 [6%] {5, 15%}
16 – 20	-	1 [6%] {4, 12%}
21 - 25	-	3 [17%] {5, 15%}
26 - 30	1 [6%]	1 [6%] { - }
31 - 35	-	-
36 - 40	-	1 [6%]
Over 40	-	4 [22%] {3, 9%}
Notes: i. A few respondents did not answer the question ii. {}: 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
	%	%
Facility Layout	29	12 {16}
Facility Planning	19	23 {19}
Long term Planning	4	8 {11}
Operational Control	10	16 {21}
Resource Allocation	12	14 {7}
Capital Investment Decision	14	16 {20}
Business Process Simulation	4	4 {3}
Budgeting	-	7 {3}
Invalid Choices	8	- {1}
{} = values from 2D respondents. ** Respondents listed more than one type of problem*		

4.2 Summary of Major Findings and Discussion

This section presents a brief discussion of the key issues from the survey. The relatively small size of the survey means that it can only provide an indication of the views within simulation community.

4.2.1 VRSIM Improves the Accuracy of Simulation Model

This survey provides valuable insights about the effectiveness of visual display in detecting errors in simulation model, although this is less mentioned in the literature. The overall results from both the 3D and 2D users indicate that it is easier to spot errors in 3D/VR model than in 2D. The evidence is given by 73% of respondents who have used both the 3D/VR and 2D applications (see Table 10) and 84% of the 2D users (see Table 11) stating that testing and validation is shorter with 3D/VR display.

The results also indicate that, most people now use visual display for model testing and validation compared to other modelling activities as cited by majority of modellers/users (82% and 66% 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 Visual Interactive Modelling (VIM) activities (see Bell et al. 1999, Kirkpatrick and Bell 1989) just over a decade ago.

Generally, 57% of the 3D/VR users (see Table 9) indicate that 3D display is better in spotting errors in simulation model than 2D. This also explains the reason why a good number of respondents now use 3D display for model testing and validation (see Table 8).

Table 7: The Use of Visual Display

Modelling Activities	Using 3D Display		Using 2D Display	
	Count*	%	%	%
Model Building	14	64	16 [73]	21 {60}
Model Testing & Validation	16	73	18 [82]	23 {66}
Model Run	15	68	16 [73]	21 {60}
Model Experimentation	11	50	17 [77]	22 {63}
Demo to Clients	17	77	10 [45]	13 {37}
{} = 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]
Experimentation	4 [29]	5 [35]	4 [29]	1 [7]
Demo to Clients	13[93]	0	0	1 [7]

Table 10: VRSIM Users' Opinion on Time Taken 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: Some respondents did not answer the question			

Table 11: 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 [36]	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 [23]
Decision-making process	10 [59]	2 [12]	5 [29]
Note: About 16 respondents did not answer the question			

4.2.2 VRSIM Enhances Excellent Communication with Clients

The survey results support the claim that VRSIM enhances better communication between the model builder and the decision-maker about the problem than 2D display (see Table 12 and 13). Eighty-four percent of the 3D/VR respondents and forty-five percent of the 2D respondents (majority) viewed that VRSIM greatly improves communication with clients than 2D display during model demo.

Most VRSIM modelers and users also cited good communication capability of the 3D as the major reason that influenced their decisions to adopt VR technology. For example, 77% of 3D/VR users (see Table 7) use 3D display for model demo as it enhances communication with clients.

Furthermore, the results from the 2D respondents indicates that, although they may be reasonably happy with the 2D display, they still thought that 3D/VR would be better.

However, notwithstanding the good impression about the 3D/VR display in enhancing communication with clients, there is need to exercise caution to avoid any danger of extolling the novelty of a pretty interface of 3D model over technical correctness and statistical accuracy. In any case, the popularity of VRSIM among respondents appears too strong than can be overlooked.

Table 12: 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: 3 out of the 22 respondents did not answer the question				

Table 13: 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: 6 out of the 35 respondents did not answer the question				

4.2.3 VRSIM Improves Clients' Understanding of the Modeled System

Previous studies on the impacts of visual display on 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 and Bell 1989).

The results of this study also indicate a similar trend. Significant majority (68% of the 3D participants and 41% 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 2D respondents considered users' ability to understand the model to be independent on the type of display, none

thought that 2D display can enhance a better understanding of the modelled system than VRSIM (see Table 13).

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

The survey lends strong support to the claim that VRSIM increases clients' confidence in the simulation results than if the 2D display is used. Most respondents who have used 3D applications (77% - see Figure 1) either 'strongly agreed' or 'agreed' to this assertion. Similar view was popular among the 2D respondents with 60% (see Figure 2) strongly agreeing or agreeing to the claim.

The implication of this result is that, the increased confidence of clients in the simulation results when 3D/VR display is used can further facilitates model credibility and acceptance. However, the over reliance on simulation results based on a pretty interface rather than statistical correctness of the result can pose a danger of rejecting a technically sound model with less convincing interface for a less sound model but with a visually pleasing display.

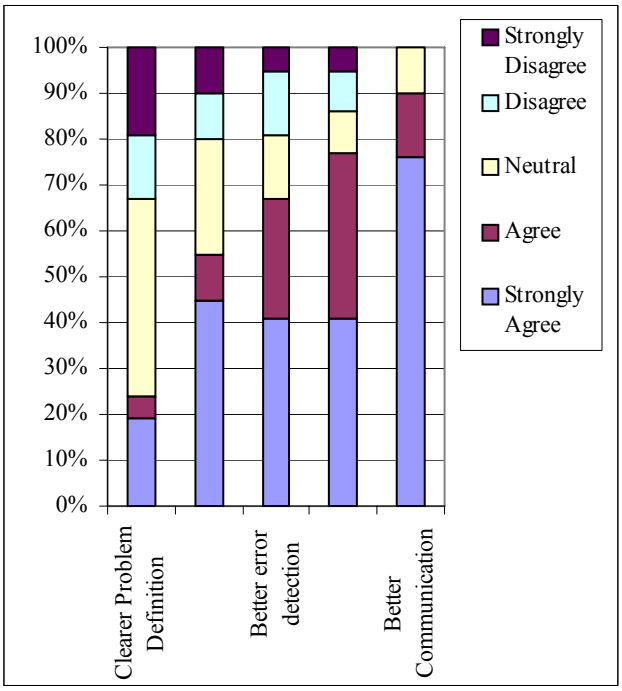

Figure 1: Users' Opinion about the Claimed Benefits of 3D/VR Modeling, (a) VRSIM

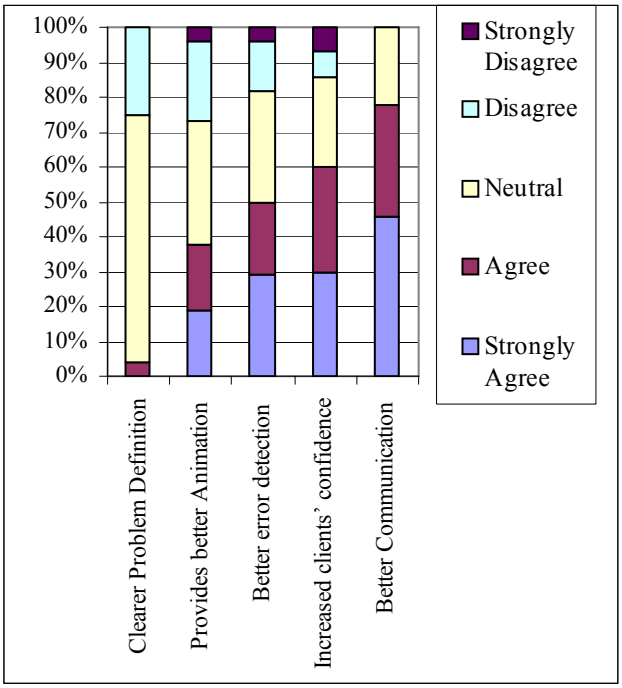

Figure 2: Users' Opinion about the Claimed Benefits of 3D/VR Modeling, (b) 2D

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

One of the concerns 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. Over 90% of the 3D/VR modellers (Table 10) indicated that it is more difficult to develop 3D model compared to 2D. Also, most respondents emphasised the complexities of 3D modelling. For example, the issues raised by respondents about the limitations of 3D/VR display and reasons for non-use of the VR technology (see Table 17) indicate 32 'mentions' of the difficulties in building 3D model, followed by 8 'mentions' about longer time required to build the model.

Technical problems associated with current VRSIM applications (such as problems encountered when building 3D shapes) was also highlighted by respondents. This suggests the need to improve current software packages to make it easier to build 3D models.

4.2.6 VR Does Not Guarantee Better Solution from Simulation

The 3D/VR and the 2D respondents have divergent views on the impacts of VRSIM on simulation solutions. Majority of the VRSIM users (69% - Table 14) viewed that VR can enhance better solutions. This result was rather surprising as one would expect simulation solutions to be inde-

pendent of the display type as identified by majority of the 2D respondents (57% - see Table 15).

Some of the convincing reasons why the type of model display is not likely to affect simulation solution as offered by the 2D respondents is that, the simulation solutions "is in numbers, not pictures" (see Table 17).

Table 14: 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: 4 out of the 22 respondents did not answer the question				

Table 15: 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: 7 out of the 35 respondents did not answer the question				

4.2.7 Modeling Process Takes Longer to Complete with VRSIM

The study also 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 (77% - see Table 10) viewed that the modeling process is shorter with 2D than with VRSIM.

The results implies that, the longer time taken to build 3D/VR model (as discussed in Section 4.2.5) overshadows any time saved at the model testing/validation and implementation stages (see Section 4.2.1), thereby lengthening the overall simulation modeling process compared to when 2D is used.

4.2.8 VRSIM is the Future of Simulation

The survey asked respondents to speculate about the future of 3D modelling. The results show majority of VRSIM and 2D modellers and users (27% and 25% respectively) indicating that, 3D/VR modelling is likely to be widely used within the next five years. The 3D respondents were however slightly more optimistic than the 2D participants (see Figure 3).

Furthermore, the general enthusiasm of respondents indicated by over 70% who indicated their willingness to be contacted for further VRSIM research as well as requesting the results of this survey indicates that, a good number of modellers and uses have develop some form of interest in the VR technology within the DES community.

4.3 Limitations of the Survey

As indicated in Section 3.2, 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.

However, it is believed that, the approach in which only experienced simulation practitioners were involved in the survey indicates a fair representation of the simulation practitioners.

Finally, this study has expounded the body of knowledge and provide some empirical evidence about the benefits of VRSIM. The study has also highlighted the aspects of DES modelling where VR can be beneficial as well as indicates the pitfalls to avoid when modelling in 3D.

Table 16: 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

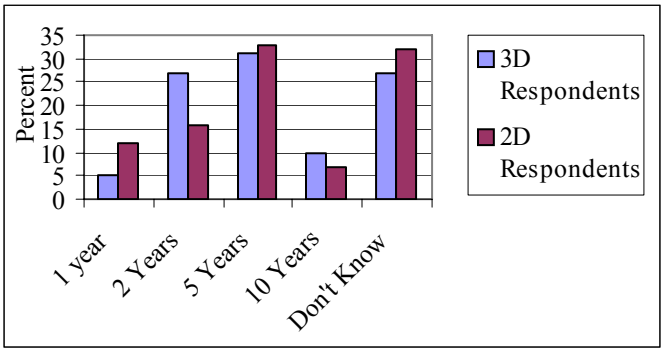

Figure 3: Respondents' Prediction on the Future of VRSIM Practice

Table 17: 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.*	

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 in the course of undertaking this research.

REFERENCES

Astheimer P. 1999. A business view of virtual reality. *IEEE Computer Graphics and Applications.*

Barnes, M. 1997. An introduction to Quest. In *Proceedings of the Winter Simulation Conference*. Eds. S Andradottir et al.

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.

Hlupic, V. 2000. Simulation software: An Operational Research Society survey of academic and industrial users. In *Proceedings of the 2000 Winter Simulation Conference*. Eds. J A Joines, et al.

Hurrion**,** Robert D. 1981. An visual interactive visual simulation system for industrial management. In *European Journal of Operational Research*, Vol 5. No.4 pp138 – 144.

Hurrion**,** Robert D. 1986. Visual interactive modelling. In *European Journal of Operational Research*.

Hurrion**,** Robert D. 1985. Implementation of a visual iInteractive consensus decision support system. In *European Journal of Operational Research.*

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*.

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*. Eds. J A Joines et al.

Kirkpatrick, P. and Bell, P. C. 1989. Visual interactive modelling in industry: Results from a survey of visual interactive model builders. *In Interfaces.*

McKay, K. 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*, London.

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. In the *Simulation 2000 series*.

Smith, S and Duke, D. J. 1999. Virtual environments as hybrid systems. Paper presented at *Annual Conference, Eurographics*, UK Chapter, Cambridge.

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