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KEY ENABLERS IN THE DEVELOPMENT OF SIMULATION

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ABSTRACT

The awareness of simulation technologies within the UK is relatively small when compared with the USA. Subsequently several large US companies have been able to overcome the difficulties in adopting new technology into their business and introduce simulation. This paper investigates the problems encountered and the practices helping to successfully implement simulation into a company environment. Details of a major survey conducted to determine the approaches taken by large automotive and aerospace companies within these two countries are outlined. The survey highlighted differences in the development of simulation within twelve large companies, the extent of the difference and the reasons why these differences exist.

1 INTRODUCTION

Simulation is an increasingly powerful tool for planning and process improvement within the manufacturing industry. Several large companies around the world have successfully adopted these improved simulation tools as an integral business tool. The Boeing Company for example have a major internal program, 'Design, Manufacturing and Producibility Simulations,' making significant reductions in production development, etc. (Price 1998) Discrete Event Simulation (DES) is the most mature and most widely used tool. However, the application of simulation across the business is becoming increasingly popular with the new range of simulation tools available, such as assembly simulation. Large companies are finally recognising the importance of simulation as an important tool to remain competitive. (Barth and Algee 1996, The Manufacturing Report 1998) Simulation is now being used across the business from design to manufacture to assembly and support. (The Boeing Company 1995)

A questionnaire survey was used in a pilot study to investigate simulation practices within UK and US companies. (Murphy 2000) Key differences were identified between the two countries, which prompted further research into the extent of these differences and the factors contributing to them. As part of this wider investigation, company visits and collaborative work was conducted, to ascertain the introduction of simulation into large companies and to understand the circumstances leading to this introduction. Large aerospace and automotive companies were targeted and studied from both the UK and the USA. The majority of the companies had been able to introduce simulation into their company through the development of distinct simulation practices and objectives.

This paper presents the findings from the major survey conducted within these large companies, delving into the type of data collected, the benchmarking and analysis of company data captured and the conclusions derived from these analyses. Benchmarking exercises were conducted to investigate development of simulation activities within each case study and identify any trends in the way large companies have approached the adoption of simulation. The paper will also highlight the differences in simulation development across each company studied and the key factors contributing to these differences. Successful practices leading to and problems encountered in the implementation of simulation into a company are evaluated. Detailed analyses of the information gathered from company visits have revealed distinct factors in the way simulation has been successfully introduced, established, practised and developed within a company. The key enablers facilitating the adoption and integral use of simulation have been captured and structured into a list of 'best practices'.

2 DATA COLLECTION

2.1 Case Study Development

In the development of case studies for each of the large aerospace and automotive companies, appropriate contacts were established with industrial practitioners. Formal meetings were set-up with these contacts to discuss the way in which their respective companies had approached and set-up their simulation activities. (Bengt and Ostblom

1993, Cross 1996, Stake 1995, Yin 1994) These large companies were targeted because they were frequent users of simulation and able to introduce and develop simulation within their business. Three UK companies and nine US companies were chosen for case study investigation via company visits. (Bogan and English 1994)

Issues over the company's approach, set-up, development, etc. of simulation would be discussed, rather than their specific application of simulation. (Marshall and Rossman 1999, Porter and Coggin 1995) The main aim of the meeting were to ascertain and identify any major factors contributing to problems experienced and successes achieved in implementing simulation into a company.

The structured case study reports were then sent back to their respective companies for approval, clarification and validation of the information. (Stake 1995, Yin 1994)

3 BENCHMARKING

3.1 Benchmarking Objectives

The differences in UK/US practice identified by the pilot study were investigated further through benchmarking exercises, proposed to highlight the extent of these differences. The objectives of the benchmarking exercises were to analyse and determine the important factors contributing to the development of simulation within each of the twelve companies studied. The analyses included individual company benchmarking, a full UK/US company benchmarking and a UK/US comparison benchmarking exercises. The individual company benchmarking focused on the internal factors of a company's simulation development and priority. The exercise considered many different aspects of simulation and their importance within the company. The full UK/US company benchmarking compared all twelve companies against one another to highlight the variation in the levels of simulation development. Finally, the UK/US comparison benchmarking was aimed at determining the overall difference in the level of simulation development between the two countries, and the reasons why such differences exist.

3.2 Benchmarking Criteria

A 'mind mapping' procedure was used to address the issues of using simulation within a company environment. The information gathered from the company visits was structured into the case studies using a set of criteria covering all different aspects of simulation. The criteria consisted of a list of detailed categories, focused on the way simulation is set-up, organised and utilised within a business. Each company was individually profiled and assessed under this set of criteria, shown in Table 1. (Murphy 2001).

The individual company analysis used a scoring method to represent the level of development and priority of each criterion within the company. A score from 1–5 (Low – High) was given to each of the sub categories reflecting the stage of development, and thus giving an overall score to each of the main categories.

Table 1: Benchmarking and Assessment Criteria

Main Categories	Sub Categories
Team Organisation, set-up & role of simulation experts	History, Size, Structure, Role, Responsibilities, Promotion, Profile, Recruitment, Career & Funding
Software Range of software selected, used & developed	Use, Selection, Aspects, Interface, Development, Benchmarking, Support & Future
Applications Application areas of simulation within the business	Range, Objectives, Development, Standards & Future
Projects Procedures for using simulation within projects	Formulation, Approach, Methodology, Time Scale, Management, Support, Results & Standards
Models Range, management & use of simulation models	Size, Storage, Levels, Merging, Reuse, Management & Future
Model Building Model building process, management & development	Approach, Time Scale, Management, Model Data, Templates, Flexibility & Experimentation
Data Collection, management and integrity of model data	Source, Type, Collection, Integrity & Integration
Knowledge Capture & transfer of simulation knowledge	Sharing, Training, Expertise, Collaboration & Standards
Users Types of simulation user	Type
Problems/Solutions Problems encountered in the use of simulation	Introduction, Development & Practice
Success Issues Key factors leading to the successful simulation	Introduction, Development & Practice

A weighting was also allocated to each of the main categories, in a similar manner, depending on their importance in the successful development of simulation. The weightings were based upon the results of company visits and the collaborative work conducted. For example, it was considered vitally important to establish a team structure of simulation experts to conduct key simulation work, but not essential to introduce new domain simulation users. Therefore high and low weightings were allocated to both 'Team' and 'Users' categories respectively. A weighted table was used, based on a 'house of quality' method, to rank each of the criterion in terms of the company's internal development. (Cross 1996) The graphical representation of the individual company benchmarking is shown below in Figure 1. The individual benchmarking exercise shows segments, ranking the company's development within each of the criterion. (Bengt 1995) To supplement the analysis findings, a list of strengths and weaknesses were also identified contributing to their relative development levels.

The full UK/US company benchmarking exercise used the findings from each of the individual benchmarking exercises to compare and benchmark the companies against one another. This was aimed at highlighting the varying stages of simulation development, the most developed companies within each criterion and the reasons why. The individual segments again represented the assessment criteria making up each company's relative stage of simulation development. (Bengt 1995) This is graphically shown below in Figure 2.

A UK/US comparison benchmarking exercise was carried out to obtain an overall perspective of the gap between the UK and US companies in terms of their general simulation development. An overall comparison between the UK and US combined the data of all the companies from their respective countries. The results obtained reflected the overall country's stage of development within the benchmarking criteria, based on the companies studied. This analysis highlighted the extent of the gap between the UK and the US companies. (Bengt 1995) This comparison is shown below in Figure 3.

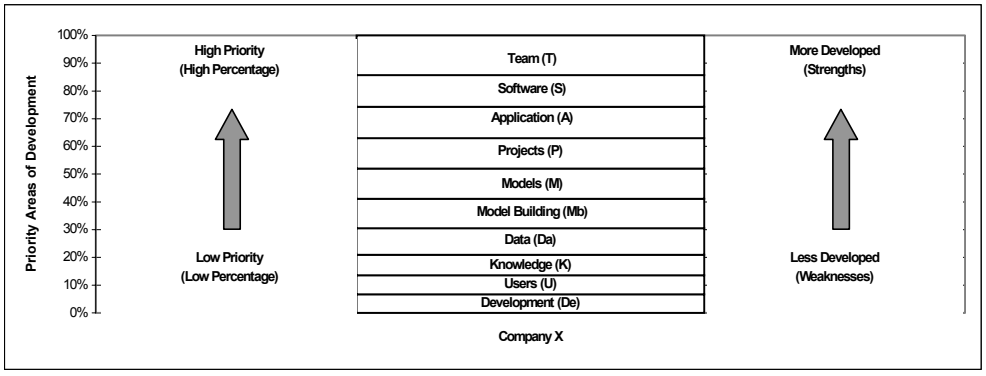

Figure 1: Individual Company Benchmarking

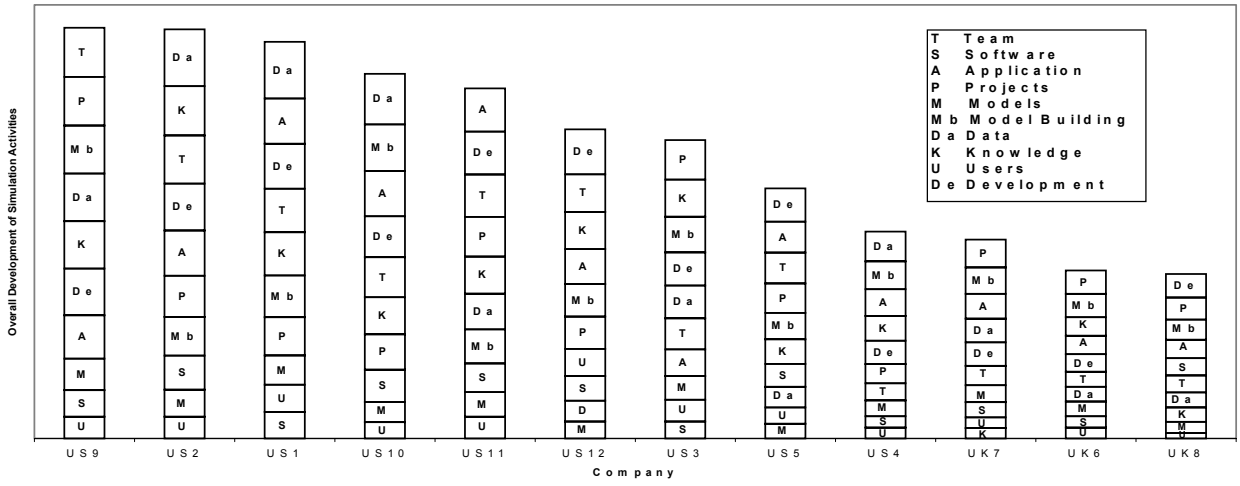

Figure 2: Full US/UK Company Benchmarking

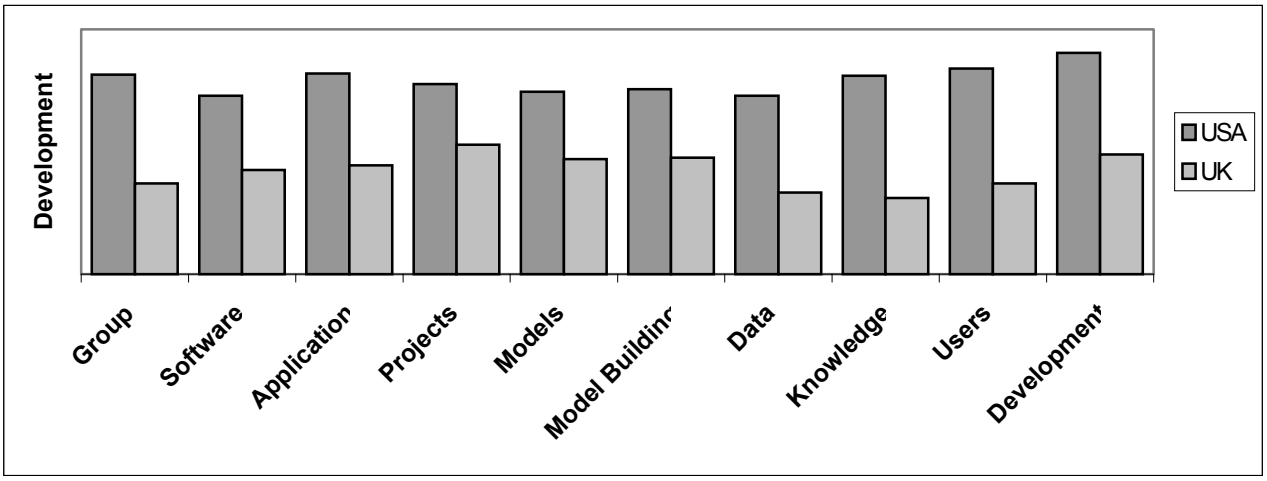

Figure 3: UK/US Comparison Benchmarking

4 ANALYSIS OF DATA

4.1 Comparison of Company Practices

Results suggested some significant differences in way simulation is practised between UK and US companies, due to their differing stages of simulation development. Many of the US companies studied have evolved their simulation activities and practices for many years, whilst the UK companies are relatively immature in their use of simulation technology. Key global factors have played a major role in the differing development between these two countries. Factors hindering simulation development within the UK and contributing to the huge gap between the two countries are shown below in the fishbone diagram in Figure 4 and explained in Table 2. (Murphy 2001)

Major and minor factors for the successful practice of simulation were identified from a detailed analysis of all the case study material. (Murphy 2001) Many of the US companies exhibited some 'major' success factors and some of the more developed US companies displayed some 'minor' success factors, shown in the fishbone diagram in Figure 5.

4.2 Major Factors for Successful Simulation

- Build a structured team of simulation experts and engineers to conduct model building, model analysis and project management. Support all simulation activity and steer the development of simulation as an integral business tool.
- Develop and use effective mechanisms of promotion to spread the awareness, visibility and benefits of simulation as an important business tool, across the company. Create a greater interest in the capabilities of simulation.
- Utilise in-house expertise to form the simulation team, rather than external consultants, to ensure the company's internal control of simulation projects. Allowing simulation experience to be retained within the company.
- Create a custom-built model input/output interface to facilitate the ease of model building for both experts and non-skilled users. Enabling the easy input and change of model data and allow end-users to conduct experimentation.

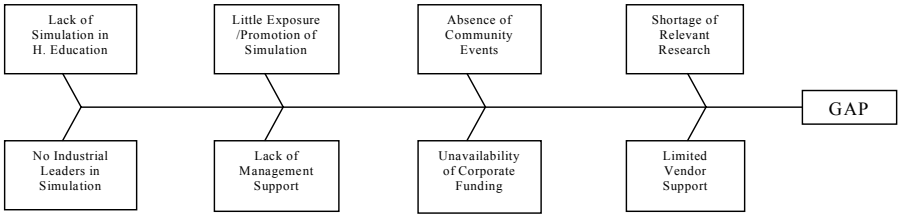

Figure 4: Key Limitation Factors for UK Simulation Development

Table 2: Cultural Differences between the UK and USA

UK	US
Simulation education at an undergraduate/ postgraduate level is very limited because simulation is perceived not to be needed by industry and so little requirement to educate the technology.	Simulation is a significant part of some undergraduate courses, i.e. Industrial Engineering, because there has been a need identified by industry in the use of this technology.
There are very few mechanisms of promotion leading to industry's lack of exposure and unawareness of the potential applications and importance of simulation.	Various promotion mechanisms through papers, journals and vendor publications, have documented and highlighted many previous and potential industrial applications of simulation.
The absence of a simulation community and events has seriously limited the growth of simulation within industry, and thus prevented any sharing of simulation experience.	Vendors and industry have both managed to create a community of practitioners and conferences actively developing, practising and promoting simulation throughout industry.
The shortage of relevant research within universities and especially industry has come from the low priority and awareness of simulation and restricted its adoption within industry.	The research into simulation by universities and industry has played a major role in evolving and supporting the development and practice of simulation within the industry.
No presence of any company leader(s) showing other companies the benefits of simulation, the potential applications within industry and its importance as a business tool.	There are several companies leading the way in the use of simulation, enabling other companies to recognise the practical capabilities and benefits of applying simulation.
Lack of company management support and confidence in simulation, plus scepticism of its benefits stemming from their limited education and experience in the previous use of simulation.	Through the awareness of simulation by company managers, either from previous education or earlier project successes, the benefits of using simulation are known and support it as a business tool.
There is no corporate funding available to investigate the capabilities of simulation because many companies do not have the resources to develop unknown technologies.	The capabilities and benefits of simulation are proven, so often there is corporate policy and funding available to further apply simulation into new areas of the business.
There is a lack of software vendors located in the country, which has presented limited support and close contact needed for companies wishing to introduce and utilise simulation.	The abundance and resources of software vendors located in the country has offered the much-needed support in the introduction and adoption of simulation within company.

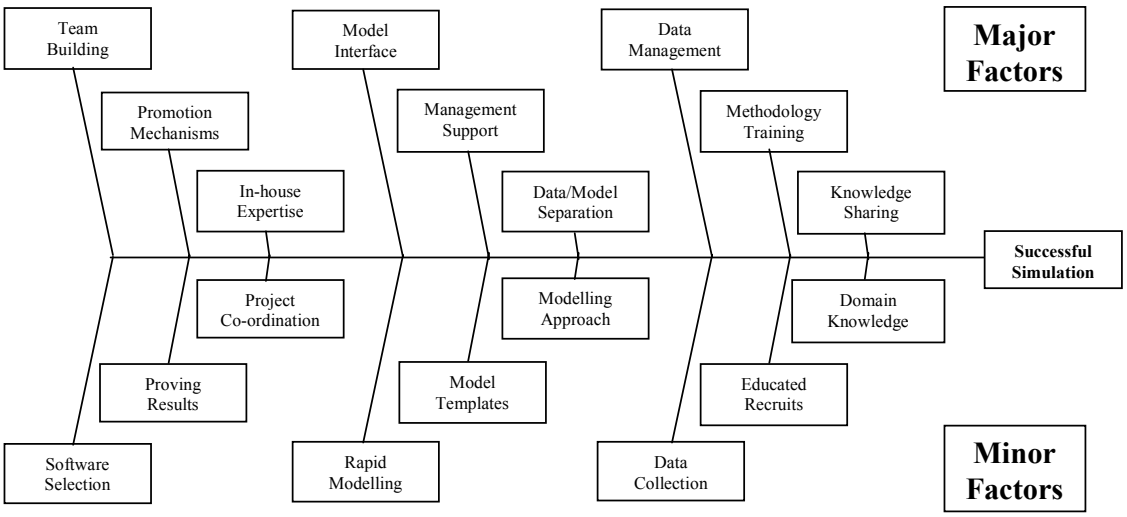

Figure 5: Major and Minor Factors for Successful Simulation

- Involve all project team members from project conception to completion, allowing them the input into the project formulation. The project will then receive all levels of support, from top management to project leaders to shop floor engineers.
- Separate the input data from the model logic, so the model can be updated with new data without massive complication. Separating the data and the model, retains the flexibility of the model for experimentation and reuse.
- Ensure the integrity and management of input model data with constant communication between domain application experts, management and customers. Use meetings, reviews and presentations with all project members to indicate any changes made to the model or the model data.
- Provide simulation methodology training to all simulation users to supplement their software training, by developing standard methods and procedures within all simulation activities. These standards can then be

used to co-ordinate and manage all simulation projects throughout the company.
- Actively share knowledge and experience between all simulation users, gained from past projects and modelling exercises. Capture, retain and develop a knowledge base, through model and project documentation, which can be used in future projects by all existing and new simulation users.

4.3 Minor Factors for Successful Simulation

- Select software depending on application, capabilities and future integration.
- Prove the benefits and capabilities of simulation by past project successes.
- Co-ordination of all project members to ensure project aims and objectives.
- Practice rapid modelling to satisfy all customers with quick, reliable answers.
- Create a library of generic objects to limit recoding for each new model built.
- Pre-plan the model building approach to avoid unnecessary re-modelling.
- Integrate simulation with business systems to facilitate model data collection.
- Access to pre-educated recruits for a simulation team and new domain users.
- Simulation users possessing the domain knowledge of the model application.

4.4 UK/US Company Comparison in Simulation Development

The differences between the US and UK companies can be attributed to some key enablers and internal factors of success. These factors have lead to the successful introduction, establishment, practice and development of simulation within US companies, but not as yet in UK companies. This is detailed in Table 3. (Murphy 2001).

Table 3: UK/US Differences in Simulation Practice and Development

UK	US
Companies generally having one or two simulation experts because of the limited application of simulation within the company, the lack of corporate funding and educated recruits.	Developed a structured team of competent simulation experts and engineers, because of the company's emphasis on team building and the availability of resources and educated recruits.
The lack of corporate funding for research and development of simulation, and limited support from vendors has restricted the success of introducing this new technology into large companies.	The selection of software is influenced by the level of support from software vendors to help with introducing, establishing, developing and integration of simulation with other new software.
There are only isolated applications of simulation across the company business because of the lack of evidence that simulation has been successfully introduced and applied by similar companies.	With the presence of company leaders able to prove the benefits of simulation, with many companies repeatedly applying simulation to their business and experiencing successful project results.
Simulation has a low company profile and is only used as an optional project tool because of the limited awareness of the technology and the lack of project successes and proven results.	Simulation is used as an integral project tool within the business process and major projects, through its high company profile, past project successes and the strong management support.
There is no evidence of companies reusing models, only model coding, for other applications because of the limited number of applications carried out by the few experts in the company.	Evident reuse of models, modules and coding for new model applications, through the extensive use of simulation, model management, model flexibility and the easy access to models by all users.
Not yet identified the need to supply customers with fast model results from rapid modelling, thus not developing an important model interface, generic model templates or the profile of simulation.	There is an increasing importance on rapid modelling using model interfaces and templates, because of the growing need to keep customers satisfied with fast model results.
No integration link has been established between simulation and business systems to facilitate the efficient collection of model data and the effective updating of models.	Much emphasis is given to the importance of model data collection, management and the integrity of the model using integration links with the principal sources of valid and real data.
Knowledge sharing is not seen as a priority due to the few simulation experts within the company and the extensive use of consultants for outsourcing their modelling work.	Retaining and sharing knowledge throughout the company's in-house expertise and focussing efforts on the development and management of a simulation knowledge base.
The use of simulation doesn't extend past the few simulation experts because of the small demand to use simulation within many projects, the availability of experienced users and lack of training provided.	There are increasing numbers of new simulation team recruits and domain users, due to the transfer of knowledge and understanding across the company to domain engineers and customers.
No development of any standardised procedures, methodologies or techniques in the most effective manner of setting-up, organising and approaching simulation activities within a company.	Developed simulation methodologies and standards to guide all existing and new simulation users in the effective approach to modelling, data management, project management and personal development.

5 BEST PRACTICES

A list of 'best practices' could be determined by identifying the manner in which the US companies have successfully supported, managed, standardised and planned their future simulation activities. (Murphy 2001) The capture of these 'best practices' can help guide large UK companies to implement simulation successfully throughout their organisation. The following list of practices have proven to be successful in large US aerospace and automotive companies.

5.1 Introducing Simulation

The effective introduction of simulation into a company needs the correct support, resources and infrastructure in place in order to be successful and some of these are as follows:

- Build confidence and support of management in the use of simulation, by proving the results from successful projects and provide awareness training to all levels of management to secure the funding for the initial investment.
- Build a team of experts and engineers able to conduct both modelling and management roles. Recruit team members with domain knowledge of model applications and provide the appropriate software and modelling training.
- Carry out a comprehensive software selection to determine the correct tool(s) for the model application(s). Choose the software with consideration of future application and the potential growth and integration of other simulation types.
- Establish effective mediums of communication with the software vendor to deal with any potential problems effectively and promptly. Encourage the vendor to allow the company to influence any future software developments.

5.2 Establishing Simulation

In establishing simulation within a company there needs to be a full co-operation in adopting simulation into the business, and the setting of objectives and targets to frequent and spread the use of simulation across the organisation.

- Promote simulation enterprise-wide as an important and effective business tool for all domain experts from management to shop floor. Use workshops, seminars and the Intranet to disseminate the benefits of using simulation.
- Procure the financial support for the team and develop a separate budget for simulation activities within projects, rather than depending on the allocation of funding from each individual project for any simulation work required.
- Encourage the integration of simulation as part of the business process by insisting on the mandatory use of simulation within major projects and successfully applying to and improving many different areas of the business.
- Provide customers with fast model results to keep them satisfied and increase their opinion of simulation as an effective modelling tool. Eliminate the scepticism of simulation through the efficient and accurate delivery of reliable and relevant answers.

5.3 Practising Simulation

Simulation teams can use simulation efficiently and to the best of its modelling potential with a set of pre-defined methods and techniques. These procedures will aid the modeller in the regular use of simulation and enable them to keep their customers satisfied.

- Develop a model interface to the simulation software to separate the data from the model to reduce the complication of changing model details. The model flexibility and experimentation will both be enhanced and the model building process will be eased.
- Educate all simulation users in modelling and experimentation procedures to ensure the correct interpretation of results. This will allow end-users to experiment with models to better understand the model application and encourage them to play a more active role in the experimentation process.
- Ensure the integrity of the model data by establishing integration links with business systems and other databases to facilitate the collection of the data from the prime source. This model data can then produce a model representation of the real world and produce valid model results.
- Create and use a library of generic model constructs/templates to assist in the rapid model building process. Customers can be provided with fast model results, which will keep them satisfied and increase their opinion of simulation as an effective modelling tool.
- Increase the reusability of models, coding and logic for use in further applications across the business. Do not discard models after they have been used for their original purpose; rather store the models within a database on the Intranet for other users to utilise in future projects.
- Enhance the effectiveness of the modelling process by utilising familiar and widely used programming language, such as Visual Basic and C++. This will increase the flexibility and the

range of models that can be created, and the realism of the domain application models.

5.4 Developing Simulation

In the development of simulation technology and activities, a level of funding for research and development should be available for setting business procedures, methodologies and standards in the mainstream use of simulation.

- Provide simulation methodology training in model building and project management for team experts and engineers. Set objectives and targets for all modelling exercises and the development of all team members.
- Prepare and develop a simulation 'introduction pack' to aid the growth of new domain users or new team recruits and their understanding of simulation and modelling procedures. This pack will supplement the level of mentoring, supervision and software training provided by the simulation team.
- Set standards in the use of simulation within projects by implementing project procedures and coordination to involve all project members in the understanding, practical application and potential capabilities of simulation.
- Actively share knowledge and expertise amongst team members and other simulation teams within the organisation. Utilise forums and internal user groups to enable all existing and new simulation users to contribute and benefit from a simulation knowledge base.

6 CONCLUSION

The evidence presented in this paper emphasised the growing importance of using simulation across the business within automotive and aerospace industry. In order to remain competitive, large UK companies need to follow the lead of their US counterparts. Considering the support and resources allocated for the development of simulation across large US organisations, UK companies should now actively be adopting and practising simulation to compete. The education and exposure of simulation throughout the USA have been key enablers in companies adopting simulation and these cultural factors need to be addressed by UK universities and industry alike.

Identifying the key enablers and major factors influencing the success of implementing simulation might go some way in bridging the gap between the leading US companies and trailing UK companies. However, US companies have established their use of simulation over many years and the lagging UK companies will also need the time to develop their own effective methods of simulation practice and capabilities. Realistically, there is not going to be a sudden surge in the adoption of simulation by large UK companies, but by addressing the issues surrounding its adoption, management might encourage the use of simulation more openly.

REFERENCES

Barth, T. and Algee, J. 1996. Proving and Improving Your Process with Simulation. In *International Industrial Engineering Conference Proceedings*, Institute of Industrial Engineers 522-525.

Bengt, K. 1995. *Benchmarking Workbook*. Chichester: Wiley.

Bengt, K. and Ostblom, S. 1993. *Benchmarking A Signpost to Excellence in Quality and Productivity*. Chichester: John Wiley & Sons.

Bogan, C. E. and English, M. J. 1994. *Benchmarking for Best Practices, Winning through Innovation Adaptation*. USA: McGraw-Hill, Inc 1994.

Cross, N. 1996. *Engineering Design Methods, Strategies for Product Design*. 2nd Edition. Chichester: John Wiley & Sons.

Marshall, C. and Rossman, G. B. 1999. *Designing Qualitative Research*. 3rd Edition. California: Sage Publications.

Murphy, S. P. 2000. Application Library. [Internal Working Document]

Murphy, S. P. 2000. Questionnaire Survey. [Internal Working Document]

Murphy, S. P. 2001. Case Study Directory. [Internal Working Document]

Murphy, S. P. 2001. Case Study Benchmarking & Analysis Report. [Internal Working Document]

Murphy, S. P. 2001. Best Practice List. [Internal Working Document]

Porter, L. R., and Coggin, W. 1995. *Research Strategies in Technical Communication*. Canada: John Wiley & Sons.

Price, A. M. 1998. Virtual Product Development 'Case Study of the T-45 Horizontal Stabilator', American Institute of Aeronautics and Astronautics, 3041 –3050.

Stake, R. E. 1995. *The Art of Case Study Research*. Sage Publications.

The Boeing Company. 1995. Boeing 777 Digital Design Process Earns Technology Awards. Boeing News Releases [online]. Available from: `www.boeing.com/news/releases/1995/news.release.950614-a.html`

The Manufacturing Report. 1998. 'AUTOFACT97: Virtual Manufacturing Has Become a Reality'. TMR Show Reports [online]. Available from: `http://www.lionheartpub.com/tmr/showreviews98/122697autofact.html`

Yin, R. K. 1994. *Case Study Research Design & Methods*. 2nd Edition. Sage Publications.

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