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The Multiple Roles of Discrete Event Simulation in the Workplace*

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Computer simulation has been around as an operations management tool for several decades and is seen by many as a means for solving complex transaction processing problems, particularly when flow paths are convoluted and/or server processing times irregular. However, experience gathered from many industrial case studies suggests that simulation serves another purpose, that of educating engineers and other employees about the operations of their own facilities. In fact, it appears that this education process is often the primary advantage of embarking on a simulation study. The trend in commercial simulation languages to provide more and better visualisation and animation tools has particularly heightened the value of simulation as an education tool, not just for production engineers but also production workers and non-technical senior management. This paper presents a brief discussion of some recent Australian case studies to support these views.

INTRODUCTION

Simulation, particularly Discrete Event Simulation (DES), has been available as an operations management technique in the manufacturing industry for around 50 years [1][2]. The basic principal of building a computer model that tracks the changes in a system's state with time has changed little in this period, although many special purpose languages have been developed to aid in the design, execution and analysis of such models. Most modern simulation languages, such as GPSS, SIMAN, SLAM and SIMSCIPT, have changed little in structural terms since their early inception, but, in many cases, significant changes have been made to the user interface.

Typically, simulation models were built in text editors and then executed from a command line prompt to produce a text-based result file of primarily statistical output. This statistical data formed the basis of the analysis and provided a means to both describe and assess the performance of the system and also build confidence in the validity of the simulation model being used.

Consider, for example, the following trivial tool crib case study, which is often used as an introductory problem in simulation courses.

> *In a particular factory, a single clerk works at a tool crib. The clerk checks out tools to mechanics who use them to repair failed machines. This arrangement is necessary because the tools involved are too numerous and expensive for each mechanic to have his or her own set.*
>
> *There are two different types of mechanic.*
>
> - *The time between arrivals of type 1 mechanics is 420 ± 360 sec.*
> - *The time required to serve a type 1 mechanic is 300 ± 90 sec.*
> - *The time between arrivals of type 2 mechanics is 360 ± 240 sec.*
> - *The time required to serve a type 2 mechanic is 100 ± 30 sec.*
>
> *All of these times are uniformly distributed. The crib operates on an 8 hour day.*
>
> *Current practice is for the mechanics to*

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> *queue at the tool crib while the clerk serves them on a first come first served basis.*
>
> *It has been suggested that since type 2 mechanics can always be served faster than type 1 (see service time data above) that the operation would be more efficient if type 2 mechanics were accorded a higher priority and served first. It is argued that this will result in a shorter average queuing time for all mechanics and would hence cut costs because mechanics would waste less time waiting and machines would be repaired and back in production faster.*
>
> *Would this change in service order, from First Come First Served (FCFS) to Shortest Processing Time (SPT), reduce the average waiting time and, if so, by how much?* [3].

Schriber's GPSS/H model for the SPT configuration is shown in Figure 1, along with an extract of sample output from running the model [4]. While it offers a useful solution to the initiated expert, this form of model and results presentation is very technical in nature and is hence likely to make diminishing degrees of sense as it is passed from the simulation analyst to the industrial engineer to the operations manager and, finally, the company board. Similarly, it is generally incomprehensible to shop floor workers and, hence, they are excluded from the process.

This difficulty in understanding the implications of simulation results as the client becomes more remote from the technical details of the company's operations, can undermine management confidence in the results and thus limit the potential of simulation as a tool to improve operations. This is particularly true for small businesses where the cost of employing the necessary in-house technical expertise may be prohibitive.

However, developments in computer hardware and software have had one obvious impact on the underlying functionality of specialist simulation languages in that there has been a substantial advance in the quality of tools available to allow visualisation of the system. In particular, the past decade has brought significant improvements in the quality and utility of 2-dimensional and, more recently, 3-dimensional animated representations of the physical system being modelled [1][5]. Such systems bolster confidence sometimes lacking in *black-box* systems, such as the GPSS/H model presented above.

Figure 2 presents the same model built in a dedicated simulation package known as *Arena*, produced by Rockwell Software [4]. While there is an underlying text-based program conceptually similar to GPSS/H, the entire model was built graphically by adding and connecting high-level elements, such as servers and sources. However, what is important from the client's point of view is that, in addition to the traditional statistical output, this model's output includes animation of the graphical elements used to construct it (see Figure 3).

It can be convincingly argued that the addition of animation does little or nothing to improve the numerical accuracy of the simulation and its resultant system analysis, but it has nevertheless added a new dimension to the usefulness of such models in industrial application. There is evidence to suggest that simulation study clients, such as industrial engineers and operation managers, see simulation animation as a value-added component of the traditional study [5-7].

While discrete event simulation is seen as primarily a tool for analysing, and hence solving complex transaction processing problems, this article argues that it also has a significant educational role to play in industry. Furthermore, this role is substantially enhanced by the inclusion of animation in the study.

Qualitative evidence to support this assertion is presented by way of a collection of recent Australian case studies where discrete event simulation models were commissioned to solve various industrial problems.

CASE STUDIES

All of the case studies presented here involved the construction of simulation models using either of the specialist simulation language systems *QUEST* (produced by Delmia Corp., formerly Deneb Robotics) or *Arena* [8].

QUEST is designed for the construction of discrete event simulations that model the overall flow of resources through and between work cells and is thus well suited to reviewing the performance of production lines. *QUEST*, like *Arena*, includes graphical model construction and run-time animation. *QUEST* presents a detailed and dimensionally accurate 3-dimensional animation of the system as part of its output, as opposed to the 2-dimensional animation of *Arena*. However, as a consequence, *Arena* is considerably more computationally efficient in terms of run speed than *QUEST* and so each tool suits its own set of modelling problems.

```
LINE# STMT#  IF DO  BLOCK#  *LOC OPERATION     A,B,C,D,E,F,G  COMMENTS

    1     1                      SIMULATE                                   Case Study 9A
    2     2                 *                           A Tool Crib System (SPT Service Order)
    3     3                 *                                        Base Time Unit: 1 Second
    4     4                 *******************************************************************
    5     5                 *        Model Segment 1 (Type 1 Mechanics)                      *
    6     6                 *******************************************************************
    7     7                 *
    8     8            1             GENERATE   420,360,,,5    Type 1 mechanics arrive
    9     9                 *                                  (Priority 5)
   10    10            2             QUEUE      TOOLWAIT       start TOOLWAIT Queue membership
   11    11            3             SEIZE      CLERK          request/capture the clerk
   12    12            4             DEPART     TOOLWAIT       end TOOLWAIT Queue membership
   13    13            5             ADVANCE    300,90         service time
   14    14            6             RELEASE    CLERK          free the clerk
   15    15            7             TERMINATE  0              leave the tool crib area
   16    16                 *
   17    17                 *******************************************************************
   18    18                 *        Model Segment 2 (Type 2 Mechanics)                      *
   19    19                 *******************************************************************
   20    20                 *
   21    21            8             GENERATE   360,240,,,10   Type 2 mechanics arrive
   22    22                 *                                  (Priority 10)
   23    23            9             QUEUE      TOOLWAIT       start TOOLWAIT Queue membership
   24    24           10             SEIZE      CLERK          request/capture the clerk
   25    25           11             DEPART     TOOLWAIT       end TOOLWAIT Queue membership
   26    26           12             ADVANCE    100,30         service time
   27    27           13             RELEASE    CLERK          free the clerk
   28    28           14             TERMINATE  0              leave the tool crib area
   29    29                 *
   30    30                 *******************************************************************
   31    31                 *        Model Segment 3 (Run-Control Xact)                      *
   32    32                 *******************************************************************
   33    33                 *
   34    34           15             GENERATE   28800          control Xact comes after 8 hours
   35    35           16             TERMINATE  1              reduce the TC value by 1,
   36    36                 *                                  ending Xact movement
   37    37                 *
   38    38                 *******************************************************************
   39    39                 *        Run-Control Statements                                  *
   40    40                 *******************************************************************
   41    41                 *
   42    42                          START      1              set TC = 1; start Xact movement
   43    43                          END                       end of Model-File execution


         --AVG-UTIL-DURING--
FACILITY TOTAL  AVAIL  UNAVL     ENTRIES   AVERAGE   CURRENT  PERCENT  SEIZING  PREEMPTING
         TIME   TIME   TIME               TIME/XACT  STATUS   AVAIL    XACT     XACT
  CLERK  0.903                      142    183.097    AVAIL             145


QUEUE    MAXIMUM   AVERAGE    TOTAL    ZERO     PERCENT   AVERAGE    $AVERAGE    QTABLE   CURRENT
         CONTENTS  CONTENTS   ENTRIES  ENTRIES  ZEROS     TIME/UNIT  TIME/UNIT   NUMBER   CONTENTS
TOOLWAIT    6        1.501     146      26       17.8     296.093     360.246                4


  RANDOM    ANTITHETIC    INITIAL    CURRENT     SAMPLE   CHI-SQUARE
  STREAM      VARIATES    POSITION   POSITION     COUNT   UNIFORMITY
     1             OFF     100000     100290       290       0.93
```

Figure 1: Sample GPSS/H program and output [1].

Case 1: Automotive Production Line

With the introduction of a new model, an automotive plant must generally undergo significant re-tooling. In this case, the addition of various new features and options on upcoming new models meant that some significant changes needed to be made to the operation of the final stages of the production line. The simulation models the final stages of the production process. Vehicles, upon reaching the end of the assembly line are driven onto, or into the limited queue space for, one of the wheel and headlamp alignment stations and then, after completion of the alignment process, onto the test rolls. At the test rolls, a bank of tests are performed on each vehicle at speeds of up to 120 km per hour to ensure that the vehicle is performing to specification. Once again, should all of the test rolls be occupied, vehicles need to wait in the limited queue space between the alignment rigs and the test rolls.

The production line had been operating smoothly for some years but considerable uncertainty was about to be introduced due to the introduction, for the first time, of Independent Rear Suspension (IRS) to certain models. This necessitated the installation of a new, separate, laser wheel alignment station, thus

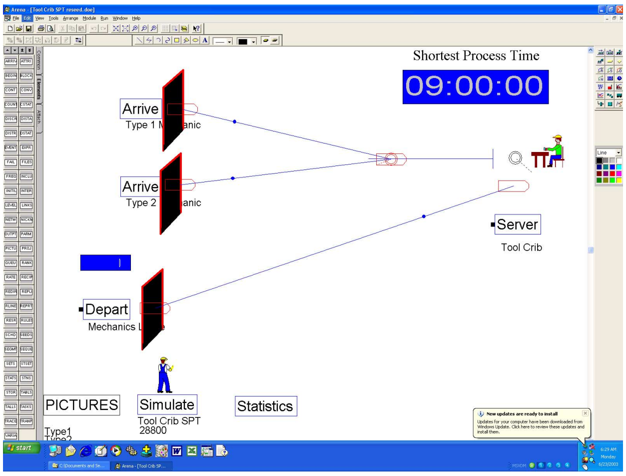

Figure 2: SPT Tool Crib Simulation built in *Arena*.

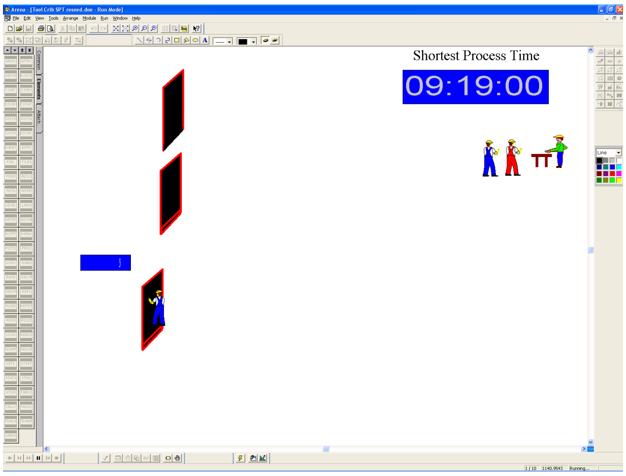

Figure 3: SPT Tool Crib Simulation running with animation in *Arena*.

adding the following complications to the system:

- The addition of this third rig, while being an extra alignment resource, was the only station capable of aligning IRS vehicles, and so complicated the process of assigning vehicles to alignment stations as they came off the production line.
- The time to align IRS wheels on the new rig was three times that of traditional vehicle suspension and was therefore a potential resource bottleneck.
- The test rolls' traffic patterns, and hence the necessary traffic flow rules for operators, would be altered unpredictably by the new alignment process and hence test roll cycle times may need to be revised in order to ensure smooth operation.
- The limited space for vehicle queues meant that there was little scope for accommodating even transient bottlenecks, because once the wheel alignment queues filled, the production line would need to be stopped with lost retail production value of around $40,000 per minute.

A simulation model (a still picture taken from the output is presented in Figure 4) was used to study the operation of the wheel alignment, wheel balancing, headlamp alignment, test rolls, final inspection, detailing and water testing of vehicles.

Major objectives of the study included:

- Determination of target cycle times for these processes;
- Determination of the preferred location for the construction of new balance rolls;
- Investigation and identification of potential traffic congestion problems;
- Confirmation that existing labour levels would be sufficient;
- Testing of proposed rules for selecting which aligner and test rolls each vehicle should use.

The model was successfully used to determine workable traffic flow rules and determine target values for station cycle times and IRS vehicle build rules (the minimum number of non-IRS vehicles that must roll off the production line between two IRS vehicles). However, it transpired that the study had additional benefits to the client.

An obvious advantage of animation in this case study occurred in the model validation process. In building a simulation model, it is necessary to make decisions about the scope and level of the model. The modeller must judiciously disregard the parts of the system (scope) and the details (level) that will have zero or negligible impact on the objectives of the study.

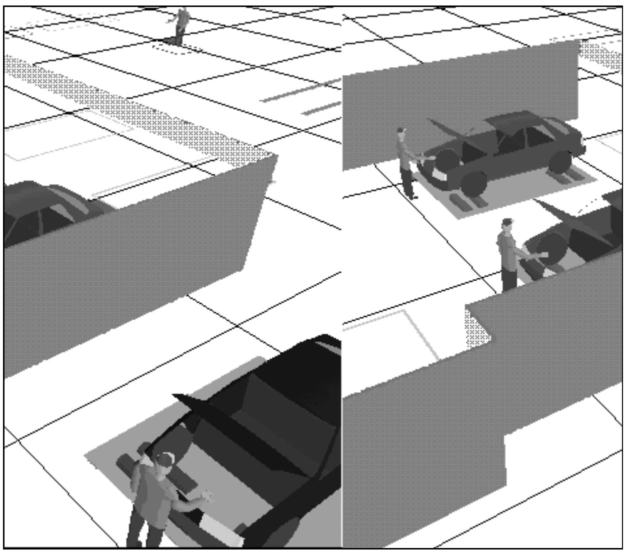

Figure 4: Detail from simulation of automotive production line showing wheel alignment work cells.

However, in doing this, assumptions are being made about the system's performance and so there is always the chance that such assumptions, and hence the model, are invalid. For this reason, model validation is a vital (though often neglected) part of the process of conducting a simulation study.

A sometimes-useful technique for model validation is the Turing test, where model output data sets are mixed with real system data and an expert, such as the operations manager, is given the task of determining which are which [2]. The inclusion of animation, and the ability to control its playback speed so that an entire shift could be viewed in real-time or in a few minutes, allowed a variation of the Turing test. Plant engineers were able to watch the animated operation and judge whether or not it was operating within the same parameters as the real plant. However, using animation, rather than numeric output, meant that shop floor operators – and not just graduate industrial engineers – were able to contribute to this process.

The most obvious educational advantage of this study came about during the model-building phase. At this point, the analyst needs to get a detailed understanding of how the production line operates so that an accurate model can be built. A significant part of this process involves interviewing the relevant engineers and asking a series of detailed questions. What became apparent in this process was that there were many operational details about which the engineers were unsure or where their views were not self-consistent. This often came as a revelation to the engineers concerned and led to many visits to the line to study just how it did operate. Hence, the process of simply trying to build a model had positive educational outcomes for the engineers.

Animation also meant that factory floor staff, such as supervisors and leading hands, could be involved in the design and decision making process. The proposed new system was presented to them via the animation and several suggestions and improvements to the operating rules of the line were made. These workers, normally excluded from operational decision-making, were able to make useful contributions and the company thus benefited from a knowledge base not often enough tapped.

In fact, this process of involving production staff in the model building exercise further served as education for the engineers in that it allowed production workers to watch the plant operating as the engineers believed it did and correct their misconceptions. For example, it turned out that the rules given by the engineers for how drivers choose which of the test roll stations to move each vehicle onto were inefficient, even unworkable, and that shop floor workers had long ago changed the rules. Without the animated model, the engineers would never have learned about their misconception.

Indeed, it could also be argued that the contribution of factory floor staff might have saved the whole simulation study. During development, they were able to point out areas of deficiency in the model in terms of operating procedure details that may have rendered the model inaccurate, or at least remained undetected for some time.

The completed model then served a further educational role in that it was used to train plant operators on the new procedures when the new model re-tooling was completed.

Case 2: New Plant Layout

The purchase of new plant is very often a major expenditure and decisions such as these cannot be made lightly. Simulation without animation has served as a useful tool in assessing the operation of proposed new plant in the past but, at the end of the day, it can hope to do little more than convince the engineers. The decision makers at board level are often faced with approving a multi-million dollar capital expenditure whose operation is largely a mystery and of which they have little or no visual conception.

Visualisation via traditional 2-dimensional engineering drawings is difficult enough for experienced engineers but is nearly impossible for most general managers. This is sometimes overcome by building a physical scale model of the system. However, such models give little or no insight into plant operation and are generally difficult to amend as the project develops.

Animated simulation models were built for several new plant projects, including a high volume fastener manufacturing plant and a proposed bottle refilling plant (see Figure 5). The final layout of the bottle filling plant was reached through many iterations and varied significantly from the original conception. The animation included every pallet and every bottle in the plant and so, by watching the plant's operation, engineers were able to ensure that their operating procedures were viable and identify potential bottlenecks more easily.

Yet while the engineers developing the proposal readily admitted the value of such a simulation in their design process, they expressed even greater enthusiasm for the animation as a tool for their final presentation to the board. The team pointed out that, despite their working for many months on the project, approval for such expenditure in industry was often granted or denied by senior managers based upon a brief written

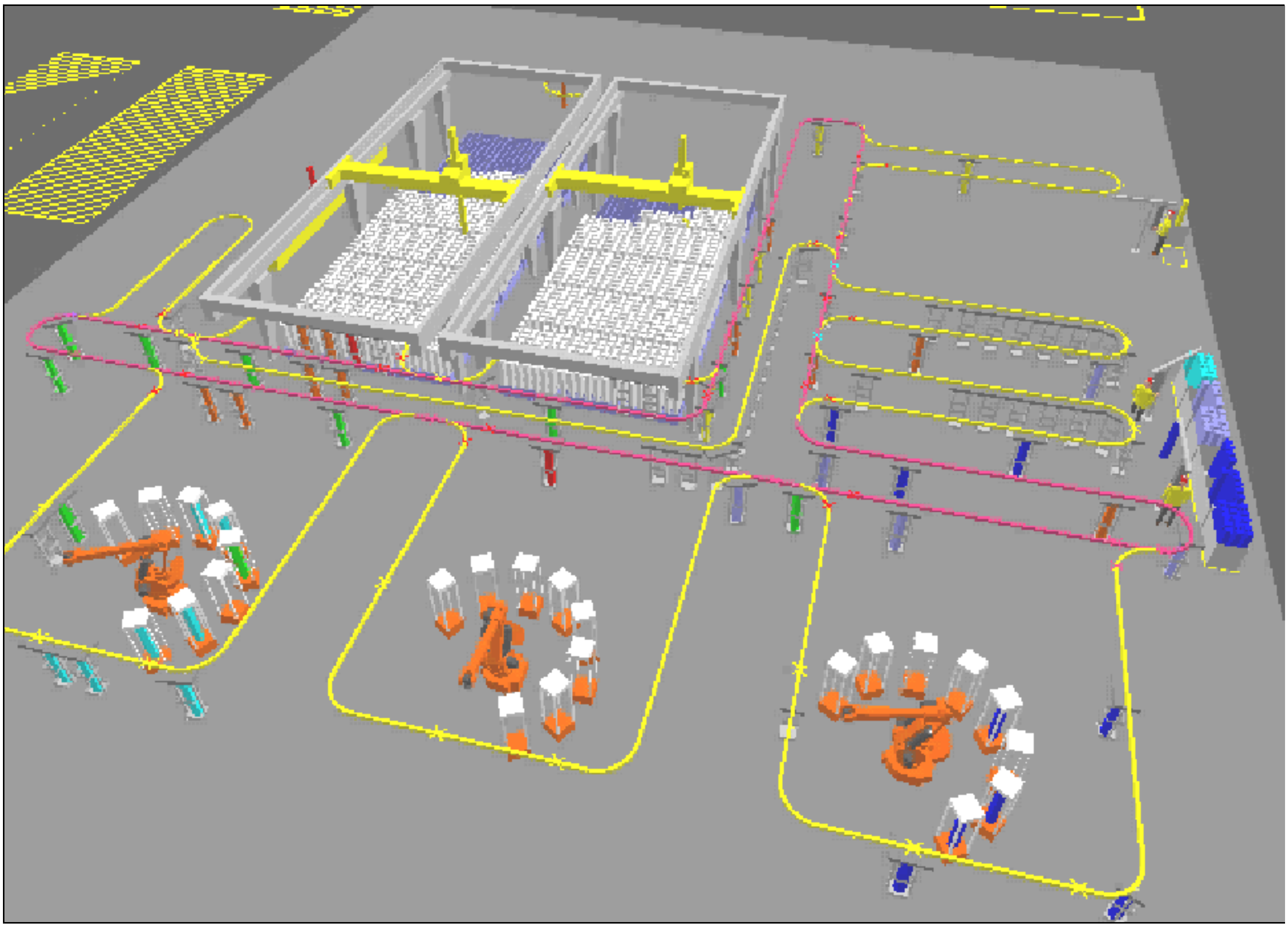

Figure 5: Green field gas bottling plant.

executive summary and a 15-minute presentation to the board. They felt that the ability to give their board a vivid dynamic image of exactly what they would be getting for their money would significantly enhance their chances of gaining support.

Case 3: Baggage Handling System

A similar story relates to the construction of a major airport baggage handling system, a detail from which is shown in Figure 6. While the simulation study was able to prove that the proposed system would meet throughput requirements, this was never really in doubt. The primary purpose was to produce a video presentation of the system, complete with explanatory voice over, so as to present to senior managers for final approval.

Case 4: Data-driven Communications Network

The new manager of a large telecommunications system commissioned a study of the processes involved in implementing changes to the database that drives the network. Large and small changes in the data occur at a rate of thousands per month, presenting a significant management problem. The study was commissioned in the hope that a more efficient, or at least controlled, operation could be designed. The core of this study was the construction of a simulation of the change control process from commissioning through design, construction, testing and final implementation.

This study was a classic example of education through being forced to answer the right questions.

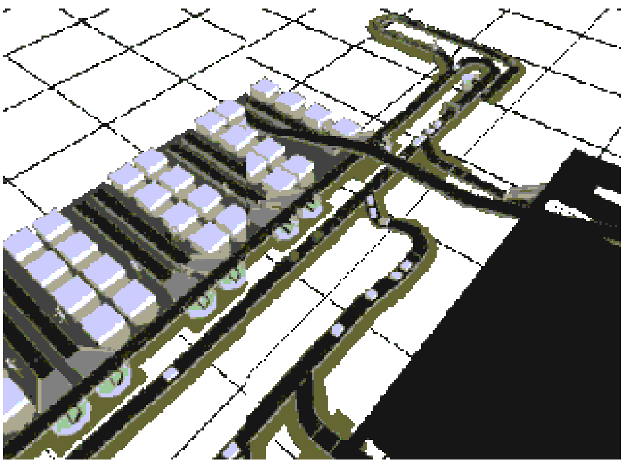

Figure 6: Part of a proposed baggage handling system.

The manager was an engineer who was not familiar with the processes involved in managing the network. Unfortunately, none of his subordinate engineers had a strong understanding of the operation outside their own area and so getting an overview of the system was not easy. The need to build an accurate model for the study rapidly became the driving force in the process of building a detailed picture of what was actually going on in the operation.

By the time the model was completed and had undergone preliminary testing, the project was terminated. Terminated, not as a failure but rather as a resounding success because its educational value had clarified the system enough for the manager to feel confident about managing further operations without the need for a simulation model. The process of building the model had revealed that the underlying system was not extremely complicated but that large volumes of data involved obscured its inherent simplicity.

DISCUSSION

While the major incentive for industrial simulation projects is the normally solution of some specific operation or design problem, these case studies show that the process results in substantial educational outcomes at various levels of the organisation. In fact, these educational outcomes can sometimes be of greater value than the original objectives of the study.

As can be seen from the descriptions above, a particularly common outcome of such studies is a much greater understanding of the organisation's operations, which results from being asked the necessary questions in order to build the simulation model. While this outcome may seem obvious, it is often quite unexpected. This highlights the fact that engineering staff are often not aware of just how much they do not know about what happens in their operations. In the automotive case study, this was apparent and in the communications network study, this outcome turned out to be the primary measure of success for the project.

In addition to the new understanding brought about by this questioning process, these studies have often served to clarify or correct long held management misconceptions about operational details. Once again, this was made apparent in the automotive case study where the simulation exercise served as the communication catalyst between shop floor and technical management staff. This is a valuable channel of communication often under-utilised in industry. In many cases, office-bound engineering managers can learn much from those whose livelihood and safety depend upon understanding the operational details of what goes on around them.

Physical engineering models are often used as training tools, particularly when trying to build familiarity with the layout of a system. However, this type of simulation model has the added dimension of being dynamic and can therefore show not just a static system view, but graphically represent the way system components interact and change over time. The accurate 3-dimensional animation of *QUEST* allows the user to *fly through* the system and view any part of it from any angle while it continues to operate. This gives a much better view of the space limitations involved in a plant than traditional simulation studies. These factors significantly enhance the models utility as a training tool for both management and shop floor employees.

Indeed, the ease with which complex systems can be understood via detailed animation, particularly at the macro level, has made simulation a useful tool for educating non-technical managers, clients and customers in system operations. This has proven particularly useful in marketing new plant proposals, both in-house and externally.

In both the baggage handling and new plant case studies discussed here, the primary stated aim was to determine system throughput but, in fact, these figures were already known from other engineering calculations performed as part of the system design process. As the projects progressed, it became apparent that the engineers and sales staff who commissioned the studies were far more interested in animation as a sales tool. The fact that the animation was driven by a realistic engineering simulation particularly enhanced its credibility. The model could be presented and perceived not as a cartoon mock up, but as a credible tool for educating customers about plant operations.

The developers of *QUEST*, Delmia Corp., produce another 3-dimensionally animated simulation program called *IGRIP*, which has the primarily function of assisting in the design of industrial robot work cycles and then automatically generating the necessary robot control code. A major industrial robot vendor in Australia now uses *IGRIP*, not to develop robot programs, but as a pre-sales marketing tool to allow customers to visualise the vendor's robots in their own factories. Animated models of work cells are routinely developed as part of the tendering process for new clients and are also used as *attention getters* at trade shows. The senior sales and management staff within the company have repeatedly expressed the view that such animations give them a significant competitive advantage.

CONCLUSIONS

While education is rarely the stated primary aim in commissioning a simulation study, it is nonetheless a common benefit from the exercise. As these case studies indicate, the educational outcomes can take many forms. These including the following:

- Increased understanding by asking or being asked the right questions;
- Correction of engineers' misconceptions of operational details;
- Provision of a training tool;
- Presenting complex systems to non-technical decision makers;
- Passing shop floor knowledge up to the engineering department.

In some cases, the process of model building can impart so much extra understanding and insight that the simulation model never needs to be used as a decision making tool. In such cases, it would appear that education is the major outcome.

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BIOGRAPHY

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He has since worked as a bond market Business Analyst for Credit Suisse First Boston in London, a Research Scientist at BHP's Melbourne Research Laboratories, as well as a member of the School of Management Information Systems at Deakin University. More recently, he has spent time as a computer simulation, software development and multimedia consultant and project manager in industry, working with clients including Ford, Boeing, ABB, Pacific Dunlop, the NSW RTA and the CSIRO.

Peter joined the School of Business Systems in the Faculty of Information Technology at Monash University, Melbourne, Australia, in 1999 and teaches the commerical applications of computer modelling, simulation and project management.