COGNITIVE 'VISUAL' PROCESSING AND MANUAL DEXTERITY: THE INFLUENCE OF EYE-TO-HAND COORDINATION ON A PLANT OPERATOR'S APTITUDE

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Findings obtained from a recent plant professional questionnaire revealed that eye-to-hand coordination may influence a plant operator's ability to operate their machine efficiently and effectively. In addition, it is hypothesised that measuring eye-to-hand coordination can also determine whether the operator is likely to retain sufficient skills required to become competent. This paper reports upon the findings of seminal research work which used an excavator simulator to monitor the eye-to-hand coordination of plant operators within the Royal School of Military Engineering, UK Ministry of Defence. The simulator sought to elicit information on the operator's ability to first load an object (a sphere) and then discharge it onto a dump target; this action was repeated ten times prior to test conclusion. Pearson's correlation was then used to measure the strength of relationship between recorded times and hit rates. Some correlation ($r = - 0.51$) between the time taken to complete the test and the hit rate was evident; this would illustrate that eye-to-hand coordination is an important measurement that could be used to test an operator's aptitude. The test group of operators (that is, those who were exposed to simulator training) were then compared to a dummy group (those who were not exposed to simulator training) to determine whether there was any significant difference in the time taken to complete a predefined excavation 'test dig' exercise. Results of a t-test ($p = 0.05$) revealed that a significant difference was apparent between the two sub samples. Future work is proposed which will investigate this area further and prove these initial findings conclusively.

Keywords: off-highway plant simulation, T-test, correlation, backhoe wheeled loaders, Royal School of Military Engineering.

INTRODUCTION

Virtual reality simulators are an embedded feature of construction and civil engineering management research work and have been successfully used to: determine the impact of turbidity currents on reservoir sedimentation (De Cesare, *et al.*, 2001); teach construction management (Jaafari, *et al.*, 2001); simplify modelling through

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integration with 3D CAD (AbouRizk and Mather, 2000); and simulate temperature and stress fields during roller-compacted concrete dam construction (Luna and Wu, 2000).

However, within the realms of construction operative training and competency development, simulators have attracted considerably less academic attention. The lack of this 'blue skies' technology is most notable within the off-highway plant and equipment sector. This is principally because simulators are already an integral component of training courses for plant operators in other 'advanced' industries (for example, rail, road and aviation) (Cabahug and Edwards, 2002). It is therefore difficult to provide reasons which preclude simulation technology in the plant and equipment sector, particularly since operators have such a fundamental role in realising optimum machine performance (measured in terms of production, running and maintenance costs and so forth).

Traditional plant and equipment research work has focused efforts on: plant and equipment selection (Haidar, *et al.*, 1999); earthwork optimisation (Jayawardane and Harris, 1990); earthwork analysis (Smith *et al.*, 1995; Lambropoulos, *et al.*, 1996); productivity (Edwards and Holt, 2000); direct cost prediction (Edwards, *et al.*, 1999a; Edwards, *et al.*, 2000); total cost prediction (Edwards *et al.*, 1998); or mechanical reliability (Moubray, 1995). To date, limited empirical research has been undertaken to determine plant operators' operational competency, even though operators can be responsible for (up to) a staggering 50 percent reduction in machine output (Edwards and Holt, 2000). Instead, plant performance research has focused either upon measuring site output generally (as opposed to individual work tasks in isolation) (Anon, 1999a) or benchmarking UK construction industry productivity as an integral whole (Anon, 1999b). However, a recent survey (which sought to 'profile' operator competence) revealed that industry professionals (trainers, instructors and plant managers) view eye-to-hand coordination skills and cognitive visual processing as important yard sticks with which to measure operator ability (Cabahug, *et al.*, 2002). This research work aims to test this theory using excavation simulation software. In achieving this aim the following objectives will be simultaneously realised:

1. determine whether simulation can assist less capable apprentice operators learn plant operation at an efficient and effective rate;
2. assist with the delivery of plant operation training during inclement weather conditions; and
3. improve the all round performance of apprentices and thus better prepare them for real site conditions.

The demonstrable benefits associated with the aforementioned are difficult to quantify. Nonetheless, plant managers and foreman could expect improvements in machine productivity, reduced training costs and improved quality of candidates.

OPERATOR SELECTION AND TRAINING

New recruits to the army are assessed and classified according to their general overall aptitude and ability. Those with a higher standard of education and intellect are selected and recruited into the Royal Engineers (RE) whilst those with lesser ability often join the infantry. RE recruits then undergo a twelve-week programme of common 'basic' military syllabus training (phase one) that includes drilling, marching, shooting, camouflage, teamwork, a physical assessment etc. The recruits are then passed out to become 'sappers' (private soldier) in the RE corps. Whilst at basic training a Personnel Recruitment Officer will provide advice on the numerous trades that are available within the RE corps (for example, bricklayer, carpenter, heating and electrical engineers and so forth). Having selected a trade, candidates are then moved to Minley to complete phase two training. Phase two consists of a fourteen week course of combat engineer skills training such as bridge construction, mine fields clearing, field defences, camp maintenance and so on.

Plant operator training

If selected as a plant operator mechanic (POM), the POMs will be move to Leconsfield to receive basic driver training such as B License (car driving), C license (new Heavy Goods Vehicles ‘HGV’) and C plus E license. In addition, POMs will also obtain their B3 driver RE training which includes vehicle camouflage, maintenance and off highway driving. At this stage POMs are transferred to the Construction Engineering School to receive a twenty-week off-highway plant training course.

The twenty-week training course consists of individual modules taught consecutively. The first module is four weeks in duration and introduces the POM to a tractor dozer. This machine is both simple to operate and robust and thus enables the POM to gain invaluable operational experience on off-highway machines whilst simultaneously reducing the risk of damaging a more fragile plant item (for example, a tracked 360° excavator). Module two incorporates a four week mechanical phase and aims to introduce the POMs to machine components and compartments *a priori* to learning basic maintenance techniques such as: bleeding the fuel system; taking oil samples; replacing filters; and general machine cleanliness. The third phase consists of a one week course which teaches the POM how to conduct a full 1,000 hours service. This is particularly important in a military setting because vehicles used in a theatre of combat are often remote from service workshops. Under such conditions, the POM is responsible for both machine maintenance and operational performance; failure to adhere to strict maintenance guidelines (subsequently resulting in breakdown) could result in severe negative outcomes for any given task or mission.

Phase four is aptly entitled the ‘wheeled phase’ since it introduces the POMs to operating backhoe loaders. Candidates spend approximately two weeks on each of the aforementioned machine types and are trained and tested on their operation (cf. Table 1). During phase four, a scientifically designed ‘physical assessment’ test was developed and implemented to determine whether simulators could measure the eye-to-hand coordination skills of the POM as a means of assessing operational aptitude.

RESEARCH DESIGN

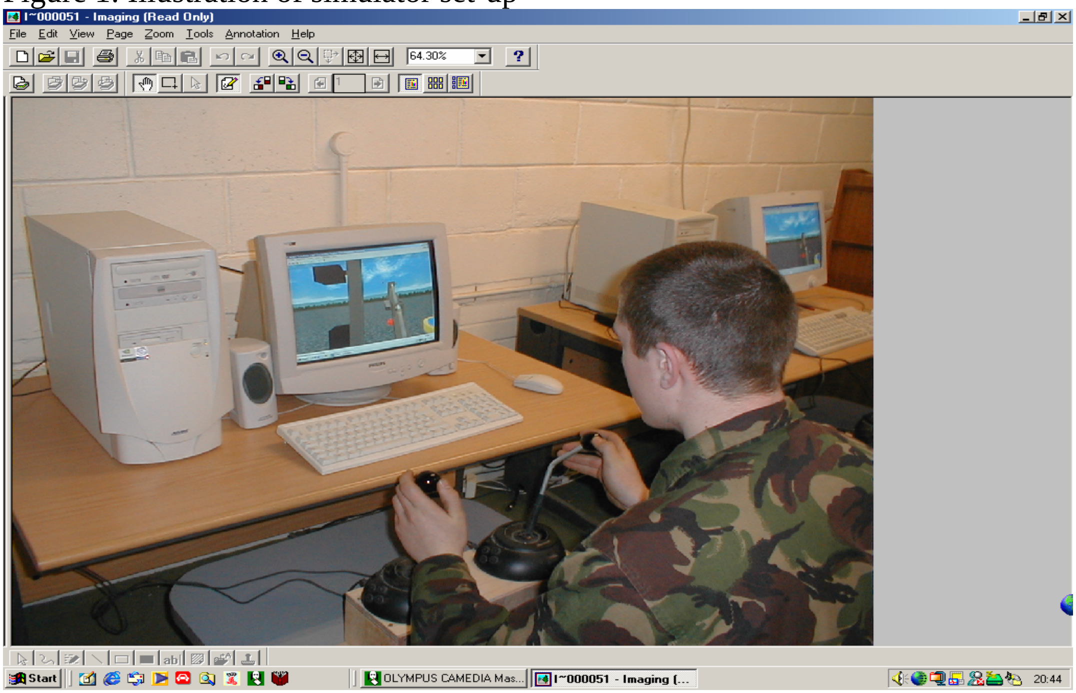
For this research experiment, simulation software developed by AIMS Solutions was utilised. Two dichotomous groups of twelve POMs were selected and trained independently at the RE Construction Engineer School in Wainscott. The first ‘test’ cohort (hereafter referred to as Group A) received tuition on an excavator simulation ‘training’ package (in addition to traditional training). Conversely, the second ‘dummy’ cohort (Group B) were trained in the traditional manner alone (that is, without simulator exposure). At the end of training, both groups would then undertake a ‘test dig excavation’ to determine whether the POM could operate the machine to an acceptable standard. Failure to complete the test dig to defined standards meant that the candidate operator would be rejected as a POM. Two tests were conceived and implemented. Test one would examine the eye-to-hand coordination skills of Group A.

Table 1 – Outline of the wheels phase of RE POM training

Day	Description of training received
1	Introduction to then Hydrema 806 wheeled backhoe loader, for example, cabin controls, start and stop procedures, mechanical adjustments and operating techniques.
2	Demonstrations of the Hydrema 806 and road travel.
3	Practical operating procedures with the loading shovel to include excavating vehicle pits.
4	Practical operating procedures with the loading shovel to include tipper loading (dump to a dump target) and stock piling.
5	Fundamentals of backacter excavation techniques and practical operation of the machine.
6-8	Detailed backacter excavations techniques and assessment dig*.
9	Use of ancillary equipment to include forks, winch, theory and practical.
10	Oil testing and machine service.

Test two sought to determine whether POMs within Group A could complete training up to the ‘test dig’ standard at a faster rate than POMS within Group B. In order to ensure that bias was not introduced into the experiment, a double blind trial was conducted where neither the operator or the instructor (where the latter would record the time to complete training and the test dig excavation) were aware that the data would be used as part of a scientific test. Neither would the first group of POMs (Group A) be aware that the second group (Group B) would not receive the simulation experience prior to conducting the excavation (and visa versa). The simulator was set up in training buildings near the training grounds and consisted of a personal computer screen and joystick controls that mimicked the excavator controls. Speakers where also provided to ensure a realistic engine sound (cf. Figure 1).

Figure 1: Illustration of simulator set-up



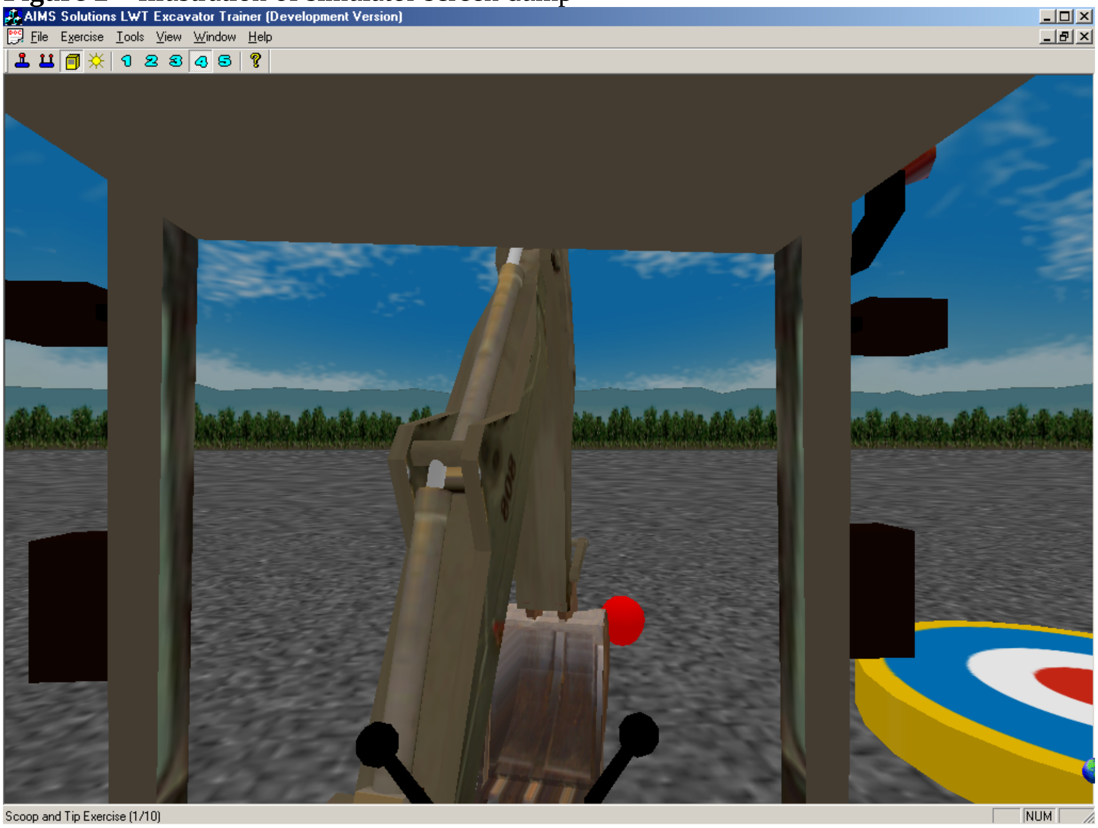
Exceptions to realism were: a lack of ‘judder’ within the controls; and a general lack of sensory perception stimulation in terms of ‘smell’, atmosphere and all round visibility. These aforementioned exceptions were however deemed to be acceptable considering the exploratory ‘embryonic’ nature of the research. Each candidate in

Group A would receive the same exposure time on the simulation package before attempting the trial pit excavation on the training ground. The only variation occurred in actual time taken by POMs to complete the simulation test itself.

Simulation test design

Four simulation exercises were presented to each candidate. The first three aimed to introduce the POM to fundamental machine operational techniques such as grading and loading. This type of iterative machine familiarisation process is typical within any training regime and enables the POM to build confidence and develop core operational skills. The forth test built upon basic operational principles and presented the first test that would measure cognitive visual processing and manual dexterity. Test configuration consisted of an object (more specifically, a globe) that was lifted into the machine bucket and discharged onto a dump target (cf. Figure 2).

Figure 2 – Illustration of simulator screen dump



The time taken to load, slew and dump (an iteration) was recorded together with dump target accuracy. Once this iteration was complete, a new target and globe would appear (both in a different position on the screen) and a further nine iterations performed. Therefore, a total of ten iterations were recorded; these formed the basis for subsequent correlation analysis.

Two complementary hypotheses were generated from the test design, namely:

1. Within Group A there is a significant correlation (p = 0.01) between the continuous variables of time to complete the test (in seconds) and hit rate (in percentage). Hence simulation can be used to measure operator ability.
2. Simulation training can enhance traditional training regimes and reduce training time to the test dig exercise.

For the first hypothesis, Pearson's correlation was used. The second test however, aimed to test the null hypothesis that several group means are equal in the population, by comparing the sample variance estimated from the group means to that estimated within the groups (Puri, 1996). To this end, the relatively simplistic t-test presented itself as the ideal means with which measure whether there is a significant difference in excavation times between the two groups of POMs, at the 95 percent level of confidence.

RESULTS

Within the simulation group, time to complete the test and hit rates were observed to be moderately negatively correlated with $r = -0.51$ (that is, as simulation time increased, hit rate accuracy decreased). In addition, this correlation was observed to be significant (two tailed test, $p = 0.05$). Anecdotal evidence also suggests that those operators who performed poorly on the simulator (hit rates less than 80 percent) also performed poorly on the test grounds and in some instances, candidate POMs failed the course.

Training times leading up to completion of the test dig were then analysed. Table 1 presents the training times recorded for both groups A and B.

Table 1 – Simulator data

Time up to test standard		
With simulator (hrs) Group A	Without simulator (hrs) Group B	
18.5	22.0	
19.0	23.0	
15.5	21.0	
19.0	20.0	
18.0	23.0	
15.5	17.0	
19.0	17.0	
26.0	19.0	
18.0	23.0	
18.0	23.0	
18.0	17.0	
19.5	17.0	
18.7	20.2	Mean average

The distribution of times for both groups were broadly normally distributed hence, the usage of parametric techniques is validated. The fastest training time was 15.5 hours whilst the slowest was 26 hours. In addition, initial perusal of sample means reveals a difference of 18.7 and 20.2 hours for groups A and B respectively.

Data for the two test groups were analysed using a t-test (specifically, a two-sample t-test assuming unequal variances). Analysis results are presented in Table 2. Disappointingly, the *p*-values revealed no significant difference between the two sample means at the 95 percent level. Hence, it would appear from this analysis that the simulator does not influence (positively reduce) operators' training time.

However, further investigative research revealed that the one candidate in test Group A consumed a maximum of 26 'allowable' hours for training leading up the test dig. Subsequently, the candidate failed the test dig and was deemed to be an unsuitable POM. Indeed, instructors described the candidate as being an extremely weak operator who lacked fundamental eye-to-hand coordination skills. This operator was therefore deemed to be an outlier and removed from the data s*et al.*ong with a candidate selected at random from Group B. The remaining training time data for the eleven POMs in each group was then re-analysed to determine whether a significant difference between sample means existed (having removed the suspect outlier).

Table 2: t-test: Two-Sample Assuming Unequal Variances

	With Outlier		**Without Outlier**	
	Group A	Group B	Group A	Group B
Mean	18.77	20.17	18.00	20.27
Variance	7.67	7.06	1.80	7.62
Observations	12.00	12.00	11.00	11.00
T stat	1.39		2.46	
P(T(=) one tail	0.09		0.01	
T Critical one-tail	1.72		1.76	
P(T(=) two tail	0.18		0.03	
T Critical two-tail	2.07		2.14	

Table 2 illustrates that once the outlier is removed the variance exhibited by Group A changes significantly from 7.67 to 1.80. Furthermore, the sample mean for Group A has also reduced to 18.00 hours whilst Group B has hardly altered. Resultantly, this variance impacts on the t-test results obtained and subsequently, a significant difference between the two groups is now apparent ($p = 0.05$).

PALPABLE BENFITS OF SIMULATION TECHNOLOGY: SOME FURTHER DISCUSSION

The underpinning rationale for the apparent growth in simulation adoption as an operator training aid can be attributed to an abundance of palpable benefits. Some of the main benefits are:

1. Cost reductions – training operatives to operate plant and equipment is an expensive exercise particularly when one considers that the capital cost of a 20 tonne machine is £100,000. On top of this capital expenditure, other additional costs incurred by training providers include: buildings, maintenance, running costs, supervisors and external assessors and so forth. The summation of these aforementioned costs (whilst not exhaustive) can be considerable. Simulation technology usage could significantly reduce these costs whilst simultaneously, separating the able from the less able candidate.

2. Practicalities – many contractors train operators in-situ using site machines that could be otherwise used to increase production rates. Such a problem is not encountered with simulators and therefore interference with production is avoided. This not only leads to greater production but also (conveniently to point iii).

3. Safety – arguably, the formative years of an operator's working life (one to two years) are potentially the most hazardous. Simulators offer a safe, reliable, and inexpensive means for testing operational capacities without exposing the operator themselves to any risk.

Whilst not exhaustive, the aforementioned benefits provide demonstrable evidence that simulators have obvious benefits for industry.

Analysis results emanating from this research provide some evidence that simulation technology can improve the training experience of plant operators. However there are two concessions. First, a larger sample of plant operators is required to determine whether tentative research findings are reliable and robust. Second, correlation results illustrate that whilst a significant (and moderate) correlation exists between time taken to complete the simulation exercises and hit rate, other factors clearly influence operator aptitude. Future work is therefore required to excoriate these other additional factors in order to fully comprehend and measure operator aptitude. A new hypothesis stemming from this work would suggest that:

"The potential for an operator to pass the end of training 'test dig' can be reliably predicted using simulation results augmented with multivariate analysis".

Research work designed to explore and test this hypothesis has already commenced and will be available within the next year.

CONCLUSION

Plant operators have the potential to greatly influence plant performance rates (measured in terms of production, health and safety and running costs). Despite this observation, training programmes have stagnated somewhat and tend to rely upon traditional teaching methods and rarely embrace new technologies such as simulation. Yet, simulation is widely used in other 'plant reliant' industries to improve operator performance in a safe and efficient environment.

This paper has presented pioneering research that is currently being conducted by a collaborative team consisting of representatives from the UK MOD and Loughborough University. Fundamental aims sought to improve training regimes and POM selection processes. A bespoke virtual reality simulation software package was used to test the natural acumen of potential trainees. To determine if the software positively impacts operator training efficiency, t-tests and correlation statistical analysis procedures were employed. T-tests identified that, after removing an outlier, there was a statistically significant difference between operators who had used the simulation software and those that had not. Within the simulation cohort, a moderate negative correlation between time to complete the test and hit rate was also observed ($p = 0.05$). In combination, results of this seminal research work suggest that simulation can improve operators' operational capability and moreover, that potentially weak candidates can be identified. It would however, be erroneous to conclude definitively that the excavator simulator produces a 'significant' enhancement of current training mechanisms. Rather, this tentative research work is encouraging.

To date, the UK MOD has been to sole user of simulation software usage for plant operator training and selection: no other training providers have embraced this training procedure. Evidence presented indicates avenues that could be exploited by the mass operator training market to improve operator selection procedures whilst simultaneously removing domains where excessive training costs (excessive machine wear, lost productivity etc.) are incurred. Before these benefits can be fully realised, future research work is required to assess a larger population of POMs and apply multivariate analyses to the new data collected. This process of meticulous self-scrutiny of the experiment has already begun and should be complete within the next twelve months. Whatever the results of this loner term study, initial research and observations have raised a new hypothesis and subsequently new avenues of work.

REFERENCES

AbouRizk, S. and Mather, K. (2000) Simplifying simulation modelling through integration with 3D CAD, *J of Construction Engineering and Management*, **126**(6), 475-483.

Anon. (1999a) CALIBRE: the measure of success, centre for performance improvement in construction, *Building Research Establishment*, http://www.bre.co.uk/bre/calibre/index.html

Anon. (1999b) Productivity and cost improvement, *Construction Industry Board*, http://www.ciboard.org.uk/pci.htm

Cabahug, R.R, Nicholas, J. and Edwards, D.J. (2002) Mapping operator competence. A Paper Currently being Refereed.

Cabahug, R.R. and Edwards, D.J. (2002) Maintenance Skills Training of UK Construction Plant Operatives: A Pilot Survey, *Journal of Structural Survey*, **20**(1), 22-30.

De Cesare, G., Schleiss, A. and Hermann, F. (2001) Impact of turbidity currents on reservoir sedimentation, *Journal of Hydraulic Engineering*, **127**(1), PL/SQL 6-16.

Edwards, D, Holt, G. D. and Harris, F.C. (1999a) Predicting maintenance expenditure on construction plant: model development and analysis, *Journal of Financial Management of Property and Construction*, **4**(1), 31-45.

Edwards, D.J., and Holt, G.D. (2000) ESTIVATE: A model for calculating hydraulic excavator productivity and output costs, *Engineering, Construction and Architectural Management*, **7**(1), 52-62.

Edwards, D.J., Holt, G.D. & Harris, F.C. (2000) A Model for Predicting Plant Maintenance Costs, *Construction Management and Economics*, **18**, 65-75.

Edwards, D.J., Holt, G.D. and Harris, F.C. (1998) *Maintenance management of heavy duty construction plant and equipment*, Oxford: Chandos Publishing, Oxford.

Haidar, A., Naoum, S. Howes, R. and Tah, J. (1999) Genetic algorithms application and testing for equipment selection, *Journal of Construction Engineering and Ma*nagement, **125**(1), 32-38.

Jaafari, A. Manivong, K.K. and Chaaya, M. (2001) VIRCON: interactive system for teaching construction management, *Journal of Construction Engineering and Management*, **127**(1), PL/SQL 66-75.

Jayawardane, A.K.W. and Harris, F.C. (1990) Further development of integer programming in earthwork optimization, *Journal of Construction Engineering and Management*, **116**(1), 18-34.

Lambropoulos, S., Manolopoulos, N. and Pantouvakis, J.P. (1996) SEMANTIC: smart earthmoving analysis and estimation and cost, *Construction Management and Economics*, **14**, 79-92.

Luna, R. and Wu, Y. (2000) Simulation of Temperature and Stress Fields during RCC Dam Construction, *Journal of Construction Engineering and Management*, **126**(5) 381-388.

Moubray, J. (1995) *Reliability-centred Maintenance*, Butterworth Heinemann, London.

Puri, B.K. (1996) *Statistics in Practice*, Arnold Publications, London.

Smith, S.D., Osborne, J.R. and Forde, M.C. (1995) Analysis of earth-moving using discrete-event simulation, *J of Construction Engineering and Management*, **121**(4), 388-396.