PLANNING ROAD CONSTRUCTION USING SIMULATION

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It appears that as in manufacturing, intense competition may compel the construction industry to seek new tools to improve planning and control of construction processes. Enormous benefits have come from applying 'discrete event simulation' within the manufacturing industry, often using a process based simulation methodology. In stark contrast, there exist only a few documented applications of simulation in the construction industry. Of these applications the majority have been developed using CYCLONE, or one of its derivatives, which are based upon activity cycle diagrams. The purpose of this research paper is to investigate how simulation can be used as a planning and decision support tool within road construction. The suitability of *Activity Cycle* and *Process Based* simulation methodologies for solving road construction planning problems will be examined. The advantages of using process based simulation are highlighted. Experiments are performed with the results documented emphasising the potential benefits of applying simulation in this area.

Keywords: Activity cycle, earth works, discrete-event simulation, process based.

INTRODUCTION

Clients, designers and contractors all require plans. The client is interested in the completion dates of major activities, since altering the construction schedule affects cash flow. The duration of these activities is typically measured in terms of weeks or months. Designers produce plans to manage their own resources to ensure contractual documents are submitted on time for tendering purposes. Plans produced at tendering detail both the duration of and the dates on which major activities shall be undertaken. The contractor produces his plans based upon those of the designers detailing the resources required to achieve the completion date specified by the designers. The activities are resourced on a weekly, daily or half daily basis. Of the three (client, designers and contractors), planning has the greatest significance for the contractor and as such it is for him that the simulation models are intended.

"The results of a well planned carefully monitored and controlled contract reflect directly on the profitability of the contract and the company." Harris (1989)

If the accuracy of planning construction operations can be improved, then all concerned with the project shall benefit. The current economic climate necessitates the submission of tenders on a near zero profit basis. Hence, the significance of each delay upon the viability of the project has increased to a critical point.

It has been observed that 'there has been a substantial increase in the number and magnitude of delays in the construction of highway projects' Herbsman (1985).

The increased significance of each delay has necessitated the investigation of planning techniques not currently utilised in road construction, but available in other sectors.

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The manufacturing industry experienced many problems in production planning. Jobs were neither completed on time nor within budget. Simulation was at first frowned upon. Opponents argued that the technique was too complex and full of unknowns. But gradually, as simulation was proven to be beneficial it gained wider acceptance. In the established manufacturing environment simulation has typically been used for; capacity planning and bottleneck analysis; evaluation of production management decisions; conceptual design and specification of manufacturing facilities, Wu (1994: 233).

Construction and manufacturing have many similar operational characteristics. However; best practices (Just In Time, Material Resource Planning, Simulation etc.) developed in manufacturing have rarely been used in the construction industry. Among the many best practices that exist, Halpin (1993), argues that computer simulation would provide an excellent opportunity to improve productivity, reduce cost and shorten lead times in the construction industry. For example, at present, conventional project planning tools are used to plan and manage construction projects. These are *static models* and do not take the dynamic nature of construction processes into account. Also resources are allocated to activities on an aggregate basis. These over-simplified models can often provide inaccurate performance data, hence managers and planners make ill-informed decisions. Consequently, project targets are missed and additional expenses incurred.

In contrast, *dynamic models* such as computer simulation models can take time variations into account (as in real construction projects) and the use of resources can be more accurately represented. Simulation models provide detailed performance data, improving the quality of decision making. Using simulation models, realistic 'what-if' analysis can also be carried out.

Unlike the manufacturing industry, simulation has rarely been used for planning construction operations outside the sphere of academia.

Halpin, understanding the benefits of applying simulation in the manufacturing industry, for improved planning, sought to develop a simulation methodology that was appropriate to construction. To this end, Halpin (1972) developed *Cyclone* an activity scanning based simulator. Activity scanning methodology is considered suitable for construction because of it closely represents construction site activities.

Since then, his students: Oloufa (1994), AbouRizk (1993), Vanegas (1994), Huang (1995), have documented applications and developed new software based on the activity cycle methodology.

Others used his methodology, including Ioannou (1992), in developing both COOPS and STROBOSCOPE.

Of these researchers, the main application for their software is earth-moving. The earthwork described typically involves: the excavation of material from a static location, transporting it over a static distance, and discharging the material in a static fill, this process shall here on in be considered as mining.

The argument presented: is that mining and earthworks encountered in road construction, share similar characteristics but differ in several important ways.

This paper aims to evaluate the importance of these differences, assessing whether it is necessary to include them in future models; and hence whether further models should be developed using activity-scanning, or process based simulators.

CHARACTERISTICS OF MINING AND EARTHWORKS.

Mining is the predominant application for demonstrating both the ease and applicability of applying simulation to the construction industry. Mining and earth-moving for road works share similar characteristics as shown. Table 1.

Mining	Earthworks
Excavators are used to extract one type of material and load trucks	Excavators are used to extract many types of material and load trucks
Dumper trucks (usually all the same size) are used to transport material	Dumper trucks (often differing in size) are used to transport material
Transport material along an unpaved haul road.	Transport material along an unpaved haul road.
The point of excavation is static	Excavation of material takes place over a series of chainages.
The movement of dumper trucks are not restricted	The movement of dumper trucks are often impeded by traffic lights, bridges and other construction activities. Causing bunching of trucks and the potential for trucks to overtake.
The type of material to be excavated remains constant	The quantity and type of material to be excavated can vary at different chainages.

Table 1: Characteristics of Mining and Earthworks.

The factors examined in this paper are those that are responsible for queuing along the haul road, i.e. traffic lights and different truck types. If queuing along the haul road significantly reduces production output then future simulation models shall have to be modelled using a Process based simulator, since it is difficult if not impossible to assess haul road queuing using Activity cycle methodology.

The greatest difficulty with Activity Cycle Diagrams is encountered when activities are required to stop prematurely, i.e. when following truck wants to travel faster than the truck in front and is prevented from overtaking.

"There are systems which do not easily fit the activity cycle notion - though enthusiasts would argue that they can be made to fit. One such type of system is where the interruption of an active state may occur before it reaches its scheduled termination." Pidd (1992).

NB. Earth moving contractors do not allow their trucks to overtake as it is considered too dangerous.

EARTH-MOVING FOR ROAD CONSTRUCTION

In preparation for a road to be constructed, material (common earth) has to be removed from a strip of land. The quantity of material to be excavated has been determined as 65000m^3, with the layout is as shown in Figure 1.

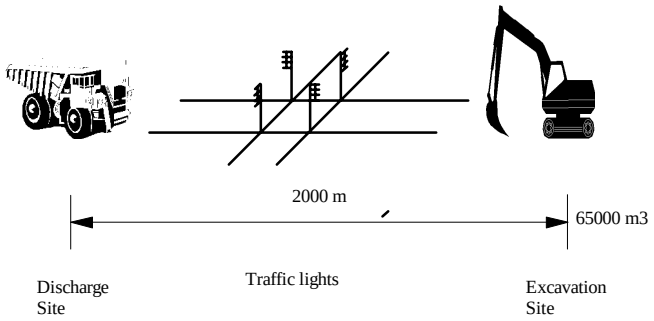

Figure 1, Diagrammatic representation of earth-moving

An earth moving contractor requires that two (Cat 350's) excavators are serviced by D400's, however this is not always possible and D300's are often used to supplement the available number of dumper trucks.

At the start of each working day all the dumper trucks are located near to the two excavators. The time required to fill each is a function of it's capacity. For excavating common earth observations have determined that the time required to fill each truck as 149 and 129 seconds for D400's and D300's respectively. Once filled the trucks proceed along the haul road where there is a 50% probability that the trucks shall have to wait at the traffic lights. On reaching the discharge site the material is deposited 'on the hoof' before returning to the excavation site. Sufficient machinery is available at the discharge site that the trucks are not unnecessarily delayed, hence the spreading and compacting equipment shall not be modelled.

MODEL DEVELOPMENT

To assess the importance of modelling queuing along the haul-road two almost identical simulation models were developed, the only difference was that in one model overtaking was allowed, as is the case in activity cycle diagrams, in the other overtaking was not permitted, achieved using logic found only in Process based simulators.

Table 2 shows the characteristics of the available resources.

Dumper trucks			***Excavators***	
Models	D300	D400	Model	350
Capacity	$13m^3$	$16.5m^3$	Bucket size	$2.2m^3$
Haul speed full, 6% grade	13.06	11.828	Cycle time (sec)	0.33
Haul speed empty, 6% grade	6.25	5.288		

Table 2: Equipment Data

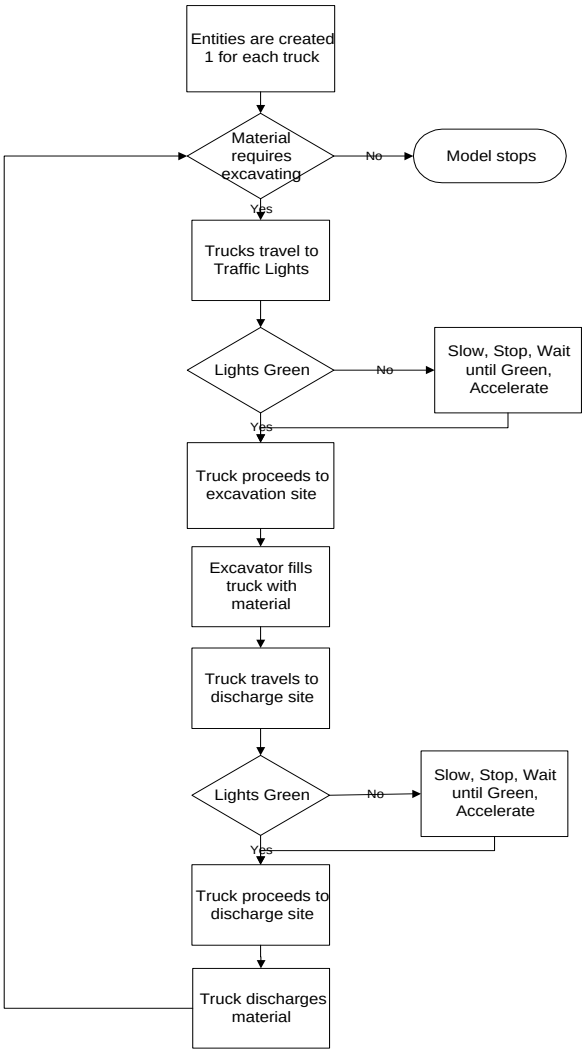

Figure 2. Flow chart model of an excavation site with traffic lights along the haul road.

To assist in the process of building the models a flow chart and a mathematical model were developed to clarify the sequence of activities and assist in validating the models. To ensure that the simulation models were valid they were checked using simple static numbers ensuring that the entities controlling the movement of trucks and execution of the model were processed in the correct order and the times obtained were as calculated. The model was then run under dynamic conditions initially using one truck, since no queuing should occur in the system the average predicted completion time should be very similar to the time predicted using mathematical calculation. This was the case, with a difference between the simulation results and calculation being 0.52 and 0.28% for 1 and 2 D400's respectively.

EXPERIMENTS

Experiments were performed on the simulation models to evaluate the time required to excavate, transport and dispose of material (common earth). For each experiment the number of available dumper trucks was incremented by one, from one to fifteen with the delay encountered at the traffic lights increased from 0 to 90 seconds. To minimise any bias caused by the use of a particular string of random numbers, five replications for each experiment were performed.

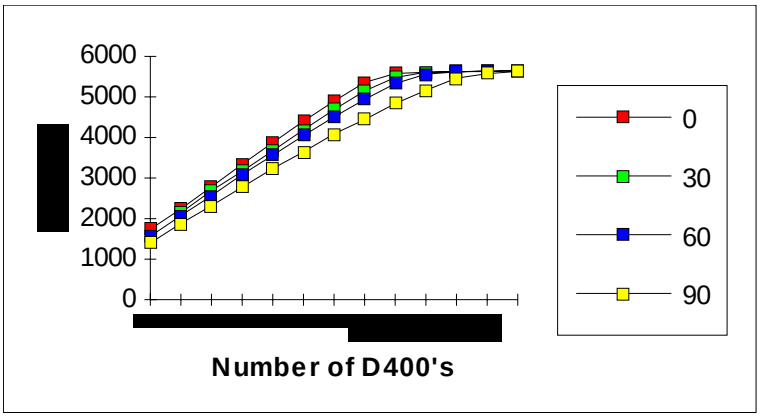

Figure 3, Productivity m3/per day

It is clear from the graph figure 3, that output per day increased steadily as the number of available dumper trucks was increased, reaching a maximum when there is no delay at the traffic lights and 11 dumper trucks are used, i.e. the excavators are under utilised when less than 11 trucks are used.

As the delay at the traffic lights is increased, to say 90 seconds there is a corresponding reduction in output per truck with the number of dumper trucks required to achieve maximum output increasing to 15.

There is clearly the need to simulate earthworks. Had the contractor used 11 trucks he would have expected an output far greater than is attainable. Indeed figure 4 shows that his production estimate could be between 3.8% and 29.5% greater then is achievable. The size of this discrepancy is dependant upon the length of delay experienced at the traffic lights and the associated congestion this causes along the haul road. The knock-on effect would be enormous, since earthworks are central to the construction of a new road any delay experienced at this stage could easily increase the project duration incurring additional on-site and penalty costs.

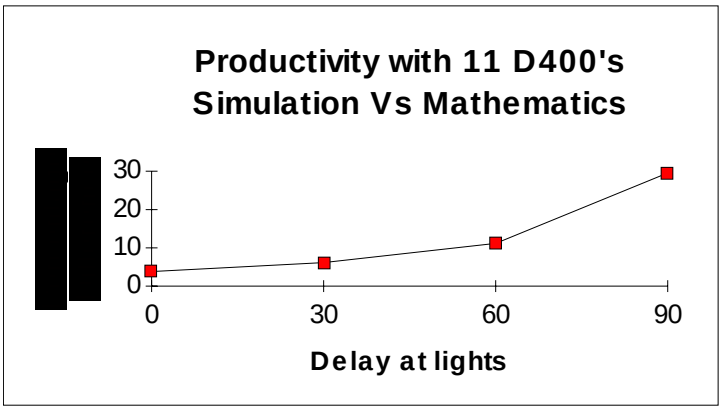

Figure 4 Percentage reduction in output predicted by simulation

Figure 5 shows that the amount of queuing encountered along the haul road differs not only with the number of trucks utilising the haul road but also the length of delay encountered at the traffic lights. With the greatest difference occurring when fewer then the optimum number of trucks are used. It is at this point that queuing along the haul road has the greatest detrimental effect on the excavators output.

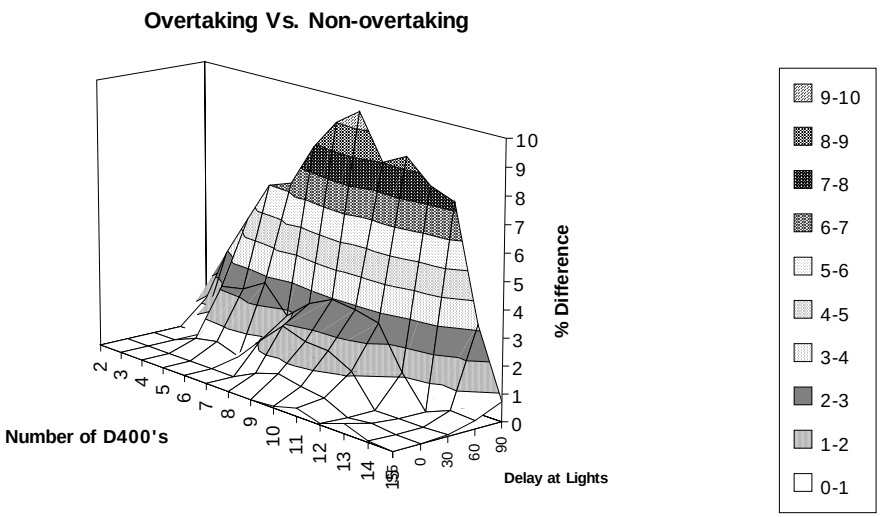

Figure 5 Percentage difference in output per day, between not allowing and allowing overtaking along the haulroad.

Haul road congestion is further increased if the contractor is unable to obtain the required number of identical trucks. As stated earlier the contractor that assisted in the development of these models has access to both D400's and D300's. From figure 6 it can be seen that utilising trucks with non-identical characteristics (e.g. loading time, haul velocity) increases haul road congestion for a given number of trucks, once again this has the effect of increasing project duration and costs.

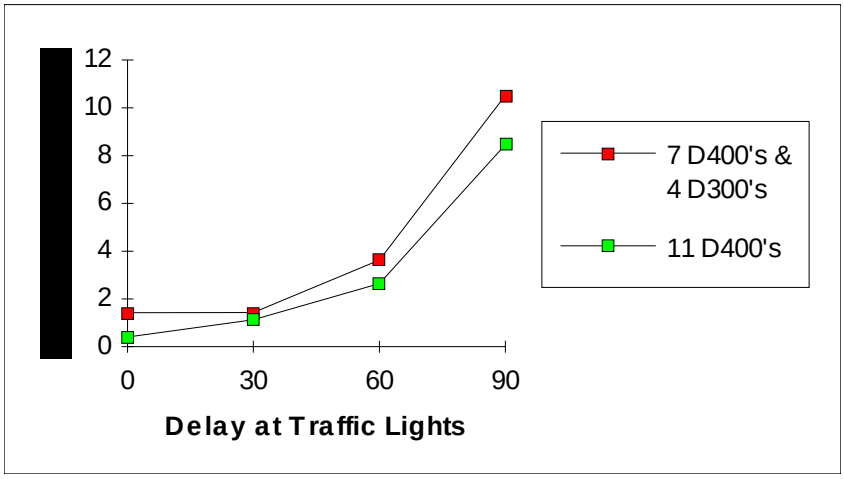

Figure 6, Increase in congestion experienced when trucks of dis-similar characteristics are used.

It is clear from the simulation results that the time taken to excavate material is greater when the dumper trucks are not allowed to overtake, the amount of which is proportional to the congestion along the haul road.

CONCLUSIONS

In the light of this research it is clear that simulation offers contractors the ability to plan earth moving operations with greater accuracy than is feasible using static mathematical models. Furthermore, where there is the likely-hood of congestion

being an important factor, as is the case when there are obstructions along the haul road, the simulation model builder should utilise a suitable methodology, i.e. a process based as oppose to an activity based simulator. Hence, if space is restricted and trucks cannot overtake then it is important to model the haul-road process with this in mind.

As simulation practitioners attempt to produce more accurate representations of road construction processes, incorporating other activities that occur in parallel, it becomes increasingly important to model how these resources utilise the available space. Thereby enabling the maximum output to safely be obtained with minimal congestion, hence minimising the cost and the likely hood of delays.

In the light of these findings it is necessary for model builders to reconsider the appropriateness of applying Activity cycle and Process based simulators when developing simulation models for use in the construction industry.

REFERENCES

AbouRizk, S.M. and Dozzi, S.P. (1993) Application of computer simulation in resolving construction disputes. *Journal of Construction Engineering and Management*, **119(**2), 335-373.

AbouRizk, S.and Shi, J. (1994) Automated construction-simulation optimisation. *Journal of Construction Engineering and Management.* **120(**2), 374-356.

Halpin, D.W. (1993) Process-based research to meet the international challenge, *Journal of Construction Engineering and Management*, **119(**3), 417-425.

Harris, F.C. and McCaffer, R. (1989) *Modern construction management*, 3rd edition, pp.10., Blackwell.

Herbsman, Z.J. (1985) *Evaluation* of scheduling techniques for highway construction projects, *Transportation Research Record 1126*, 110-1126.

Huang, R., Grigoriadis, A.M. and Halpin, D.W. (1994) *Simulation of cable-stayed bridges using DISCO*, Proceedings of the 1994 Winter Simulation Conference.

Huang, R. and Halpin, D.W. (1995*)* POLO: Planning and optimization for linear operations. *Computing in Civil Engineering*, **2**, 1126-1133.

Ioannou, P. G. and Liu, L.Y. (1992) COOPS-Construction object-oriented process simulation system. *The 9th International symposium on automation and robotics in construction*, June 3-5, Tokyo, Japan.

Oloufa, A.A. (1994) A user-oriented approach to construction simulation of buildings, *Microcomputers in Civil Engineering*, **9**, 425-433.

Pidd, M. (1992) *Computer simulation in management science*, 3rd edition, John Wiley & Sons Ltd.

Vanegas, J.A., Bravo, E.B. and Halpin D.W. (1993) Simulation technologies from planning construction processes. *Journal of Construction Engineering and Management*, **119(**2), 336-354.

Vanegas, J.A., Halpin, D.W. and Abourizk, S (1994*)* Integrated process simulation into construction engineering education. *European Journal of Engineering Education*, **19(**1), 51-67.

Wu, B. (1994) *Manufacturing systems design and analysis*, 2nd edition, Chapman & Hall.