# SIMULATION ANALYSIS OF THE UK CONCRETE DELIVERY AND PLACEMENT PROCESS –: A TOOL FOR PLANNERS

**Paul G. Dunlop and Simon D. Smith**

*School of Civil and Environmental Engineering, The University of Edinburgh, Kings Buildings, West Mains Road, Edinburgh, EH9 3JN, UK*

The UK construction industry continually strives to improve previous performance and increase financial efficiency in terms of labour, plant and materials. Construction projects are very rarely made up of one activity or process and in most cases projects involve a multitude of task specific and intricate processes. In order to achieve desired goals, such as better productivity rates, it is fundamental that an improvement is witnessed in the performance of each and every process.

One such process is the delivery and placement of ready-mixed concrete. Evident in the vast majority of major civil engineering projects in the UK, concrete is a very valuable material, and one that requires meticulous planning in order to successfully get it to site and into the required formwork. The successful completion of many construction projects, on time and within budget, can be decided by the effectiveness of the concreting phase. So, therefore, why in the UK are very few tools available for the efficient planning and completion of concrete operations?

It is proposed that by using simulation to model the concrete process it will be possible to plan and manage productivity rates of concrete operations. The factors that influence the concrete system can be summarised as: truck mixer interarrival time, truck mixer position time, concrete load pump time and truck mixer volume. This paper will look at a model of the above factors, based on over 300 'real' concrete pours. The random variability of these factors can be incorporated into a model by using the gamma probability distribution for the interarrival time, the exponential probability function for the position time and finally the inverse Gaussian probability distribution for the pump time. The development of the model and the simulation runs carried out will be described. The main results of the experimental process will aid planners in optimising the concrete process by maximising productivity and minimising cost.

Keywords: concrete operations, cyclic construction processes, Monte Carlo simulation, probability distribution functions.

## INTRODUCTION

The UK construction industry is continually striving to improve previous performance and increase financial efficiency in terms of labour, plant and materials. The realisation that this has to be done has been apparent for many years; now, due to increasing global competition within the industry, it is one that is finally being embraced. Latham (1994) in his review suggested that productivity improvements in the UK of up to 30% were necessary to face the challenges of the next millennium. Egan (1998) added to this building on Latham's earlier work and suggested that productivity be increased by 10% per year. At the time of this report productivity was increasing by an average of 5% per year with the best projects demonstrating

Roy, R, Waller, J and Low, M (2002) Development of a process documentation system for the house-building industry. *In:* Greenwood, D (Ed.), *18th Annual ARCOM Conference*, 2-4 September 2002, University of Northumbria. Association of Researchers in Construction Management, Vol. 2, 791-800.

increases of up to 15%. These figures reflect the current improvements in the UK construction industry today, though there is still room for further improvements.

Construction projects are complex: they are very rarely made up of one activity or process and in most cases they involve a multitude of task specific and intricate processes. In order to achieve desired goals, such as better productivity rates, it is fundamental that an improvement is witnessed in the performance of each and every process. One such process is that of ready mixed concrete delivery and placement, which is common to many of the UK's construction projects. The successful execution of this process is essential if a project is to be managed efficiently due to the high cost of not only the material but also the labour and plant used.

In order to achieve this it is useful to study past UK concrete pour records and make improvements on some key aspects. The concreting process has in the past been subjected to much research (Anson 1989, 1998 and Smith 1998, 1999), however the findings may have been geographically specific and little has been carried out in the UK. Although this work has been published on the subject of modelling the concreting process few contractors in the UK seem to use such methods and continue to resource and plan their concreting contracts using the experience from past projects. This paper will outline a computer based simulation, using probability distributions, which can be used at both the tender and implementation stage as an estimation and planning tool. The developed simulation is based on the study and observation of nearly 400 "real" UK concrete pours spread over 6 multi-million pound projects.

## THE CONCRETE DELIVERY AND PLACEMENT PROCESS EXPLAINED

Concrete is a complex material and due to its short shelf life it is important that careful consideration of concrete supplier is made. In the UK, it is usual that the concrete supplier will transport the concrete to the required site using his own truck mixers under instructions by the contractor, such as delivery time, dispatch time between trucks etc. These instructions are often not carefully planned and by simulating concrete processes it may be possible to be more accurate with these.

Figure 1 shows a flow diagram of the concrete process. It can be seen that it consists of two distinct cycles: one at the batching plant and one on the construction site. Both of these are cyclic and can be treated as single server queuing systems. A queuing system is characterised by three components: arrival process, service mechanism, and queue discipline. Specifying the *arrival process* for a queuing system consists of describing how customers arrive to the system. The *service mechanism* for a queuing system is articulated by specifying the number of servers, whether each server has its own queue or there is one queue feeding all servers, and the probability distribution of customers' service times. For the purpose of this paper it is assumed that only one server is available. The *queue discipline* of a queuing system refers to the rule that a server uses to choose the next customer from the queue (if any) when the server completes the service of the current customer (Law and Kelton 1991). In the case of concrete operations customers are normally served in a first-in, first-out manner (FIFO) due to the nature of concrete's shelf life.

For a detailed description of the concreting process see Dunlop and Smith (2000).

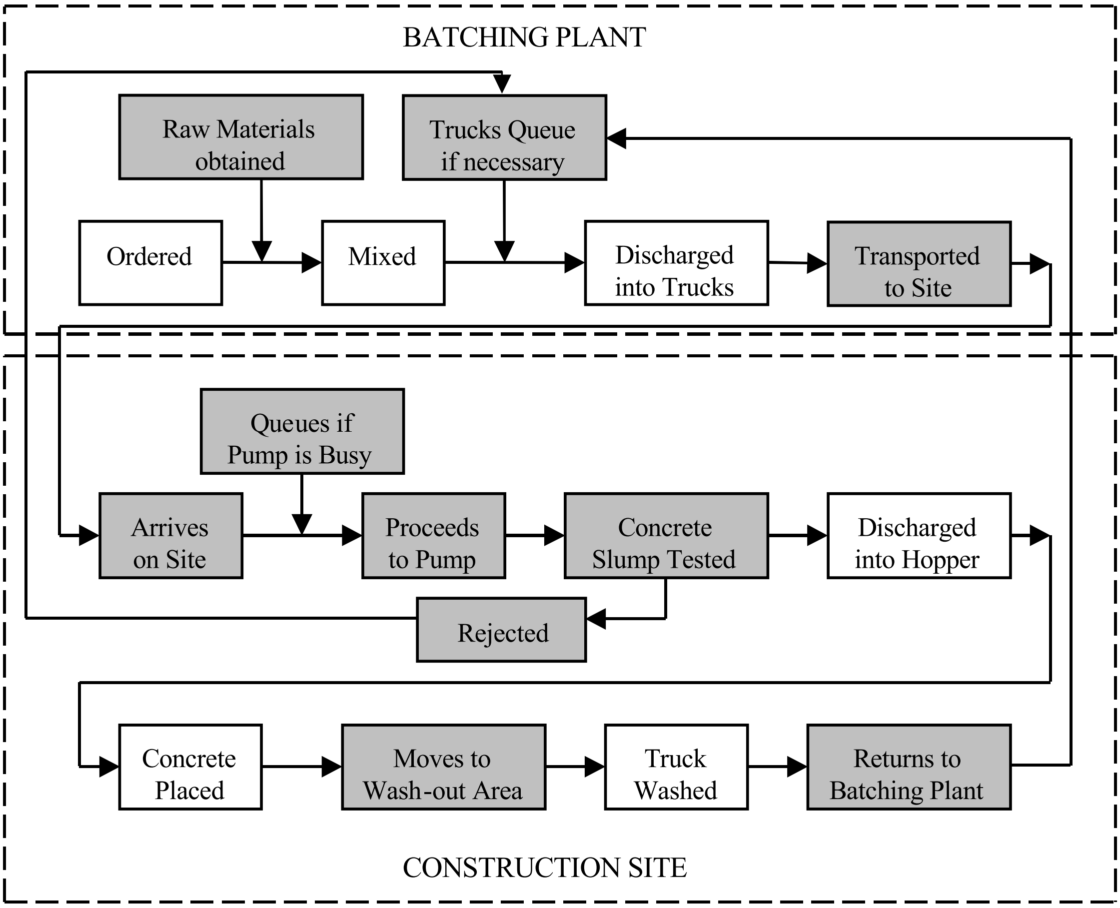


**Figure 1**: Flow diagram of the concrete process

## MODEL FOR INVESTIGATION

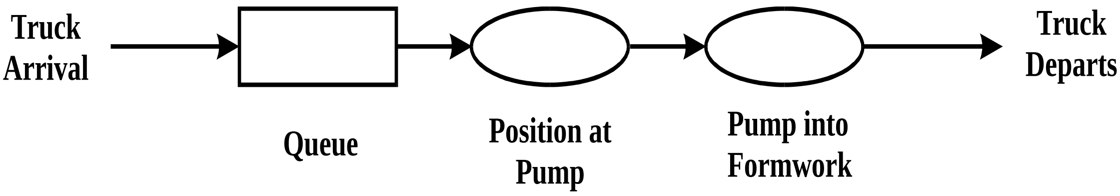


**Figure 2**: Simplified schematic diagram of the concrete delivery and placing process

Due to the constraints of this paper, no detailed account of the batching process will be given in the simulation model. If figure 1 is simplified, as in figure 2, the model will only deal with events that take place on the construction site.

As with all modelling exercises, whether physical or numerical, the main aim of this study is to represent the concreting system in a way that can be investigated practically, economically and safely. The real concreting process is a very expensive undertaking, which limits the amount by which the underlying relationships in the process can be determined. If a model of the system is valid, i.e., it represents satisfactorily the real system; results obtained via the model can be interpreted and applied to a real situation with confidence.

## Data Collection

In order to produce a valid model it is essential to investigate the nature of the real system. Data was collected from 6 different projects from a total of 396 separate concrete pours. Each pour used a concrete pump as the placing method. Details of the 6 projects can be seen in Table 1.

**Table 1**: Details of studied projects

| Project | Year of completion | Type of project | Location | Number of concrete pours observed |
|---|---|---|---|---|
| 1 | 1994 | Motorway viaduct strengthening and widening | Cheshire, England | 63 |
| 2 | 2000 | Wastewater treatment plant | Dundee, Scotland | 54 |
| 3 | 2000 | Wastewater treatment plant | Aberdeen, Scotland | 202 |
| 4 | In progress | Transportation | Falkirk, Scotland | 48 |
| 5 | 2001 | Wastewater treatment plant | Inverness, Scotland | 29 |

Table 2 shows the statistics that have been derived from the data, giving the interarrival time (i.e. the lapsed time between truck mixer arrivals), the position time (i.e. the time the truck mixer takes to move from the queue, position itself at the hopper of the pump and prepare itself for unloading) and the pump time.

**Table 2**: Summary of the data gathered from the observed projects

| | Interarrival time /secs | Position time / secs | Pump time / secs |
|---|---|---|---|
| Mean | 1215 | 435 | 796 |
| Standard Deviation | 1013 | 572 | 580 |
| No. of Observations | 4692 | 4679 | 5077 |

## Probability Distribution Functions

In order to carry out a simulation using random inputs such as interarrival times, their probability distributions have to be specified. Pritsker (1995) defined probability distributions as “any rule which assigns a probability to each possible value of a random variable.” In this case, theoretical distributions are being used to represent the observed data, namely interarrival, position and pump times and to level any data irregularities that may have been derived from the observations.

The data, collated from the time studies, is used to fit a theoretical distribution using heuristic procedures or goodness-of-fit techniques. These smooth irregularities of an empirical distribution, allowing the possibility of sampling extreme values, and represents the most compact and timesaving procedure for performing simulations (Law and Kelton 1991).

Computer software programs have been developed that automatically assess the goodness-of-fit of observed data to theoretical distribution functions. The program Bestfit is used in this study. Bestfit compares the observed data to 26 different distributions (Bestfit 1993). With the Bestfit program the parameters for each theoretical distribution are compared to the sample data using maximum likelihood estimators; then they are optimised and the chi-square, the Kolmogorov-Smirnov (K-S), and the Anderson-Darling (A-D) goodness-of-fit test statistics are calculated. Table 3, shows only the valid distributions from the 26 tested using the Bestfit software for the three input data. The initial test involved a visual analysis and from this it was possible to eliminate distributions with a poor fit. Each distribution was then ranked using the chi-squared, K-S and A-D test statistics. For each of the distributions tested the lower boundary was set to zero (that is, it is impossible to have a negative time value) which immediately eliminates certain distributions.

**Table 3**: Ranked valid distributions for the three input data sets

| Input | Valid distributions | *Rank* Chi-squared | A-D | K-S |
|---|---|---|---|---|
| Interarrival time | Erlang | 1 | 1 | 2 |
| | Exponential | 2 | 2 | 3 |
| | Gamma | 3 | 3 | 1 |
| | Rayleigh | 4 | 4 | 4 |
| Position time | Gamma | 1 | 3 | 3 |
| | Exponential | 2 | 2 | 1 |
| | Erlang | 3 | 1 | 2 |
| | Rayleigh | 4 | 4 | 4 |
| Pump time | Pearson VI | 1 | 1 | 3 |
| | Loglogistic | 2 | 4 | 4 |
| | Lognormal 2 | 3 | 2 | 5 |
| | Inverse Gaussian | 4 | 3 | 1 |
| | Pearson V | 5 | 5 | 2 |
| | Exponential | 6 | 10 | 10 |
| | Gamma | 7 | 6 | 7 |
| | Erlang | 8 | 7 | 8 |
| | Weibull | 9 | 8 | 6 |
| | Rayleigh | 10 | 9 | 9 |

It can be seen that the ranks according to the three separate goodness-of-fit tests are markedly different: which test to use? All three have unique advantages and disadvantages. Whilst the chi-squared is widely used it does appear to have a major weakness in that there are no clear guidelines for selecting intervals, leading to discrepancies in the same input data. The K-S does not depend on the number of intervals, which makes it more powerful than the chi-squared test. A weakness of the K-S test is that it does not tail discrepancies very well (Bestfit 1993). The A-D test is similar to the K-S test in that it does not depend on the number of intervals, but it does place more emphasis on the tail values. Even at this stage it is very difficult to select which goodness-of-fit test to use so it is useful to look at what other researchers have used in construction based research. AbouRizk and Shi (1994) have used the K-S test, however, stated that the chi-squared can be reliably used with large data sets (AbouRizk and Halpin 1990). In earlier research, Clemmens and Willenbrock (1978) used the chi-squared test. The A-D test has not been widely used in construction based research. Due to the fact that there is no test that will give you the "best" results it has been decided to use the K-S test in order to avoid the problems associated with class intervals.

On the basis of these results Figure 3 (a, b and c) can be plotted which show the optimum fitted distributions for interarrival, position and pump times. The gamma distribution is used for the interarrival, the exponential distribution for the position time and the less familiar inverse Gaussian distribution is used for the pump time. Bestfit also provides the parameters of these fitted distributions (Table 4.)

**Table 4**: Parameters of the probability distributions of best fit.

| Distribution | Gamma | | Exponential | *Inverse Gaussian* | |
|---|---|---|---|---|---|
| Parameter | α | β | β | μ | λ |
| Interarrival time | 1.9482 | 632.17 | | | |
| Position time | | | 434.95 | | |
| Pump time | | | | 795.83 | 1589.5 |

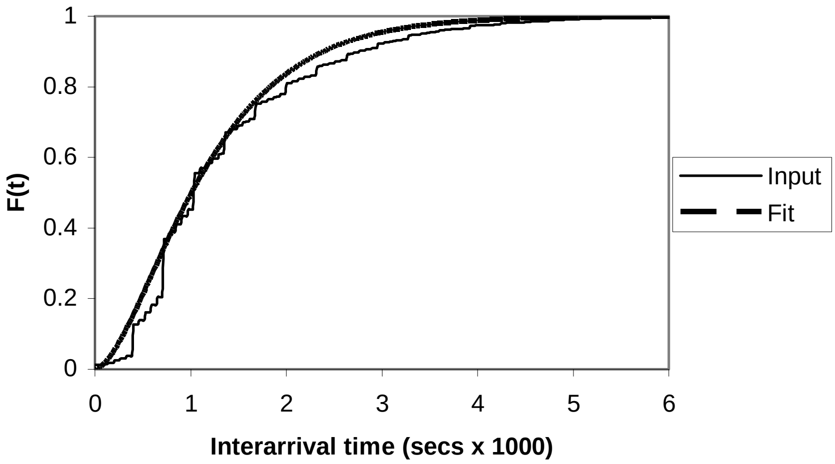


**Figure 3a**: Fitted gamma distribution to interarrival time of truck mixers

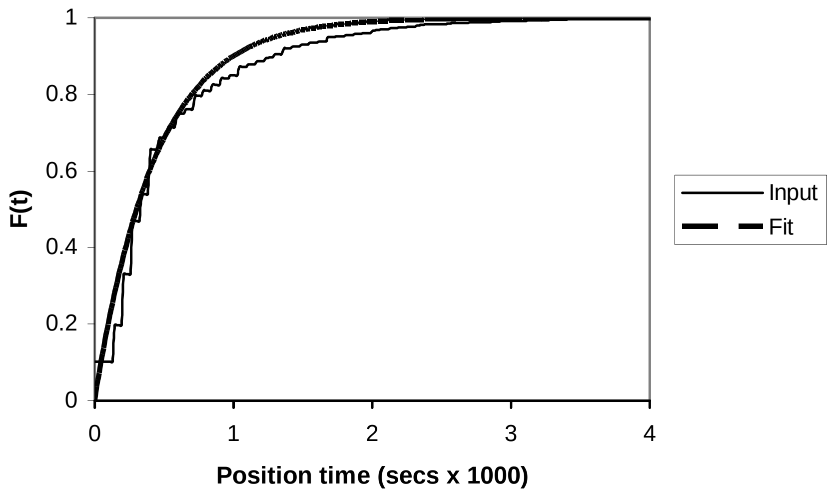


**Figure 3b**: Fitted exponential distribution to position time of truck mixers

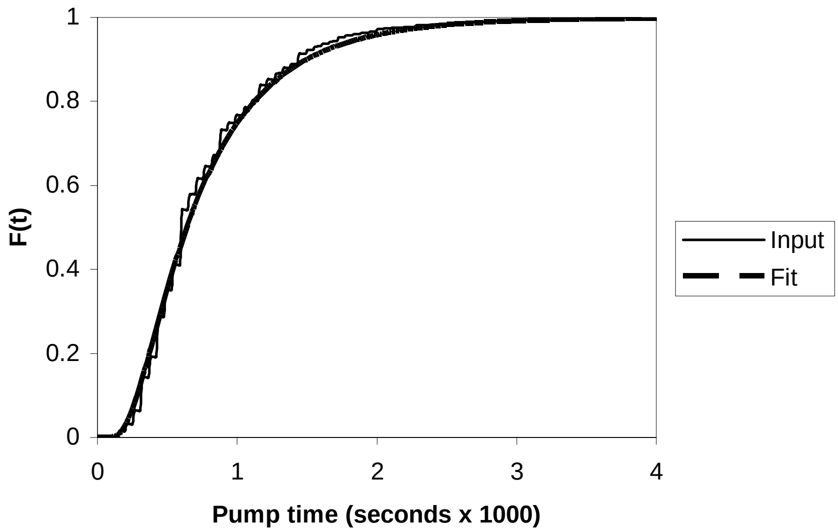


**Figure 3c**: Fitted inverse Gaussian distribution to pump time of truck mixers

## SIMULATION OF CONCRETE DELIVERY AND PLACEMENT

Simulation is a well-established technique to analyse models within construction research (see, for example, Tommelien 1997 and Smith 1998). It details the system as it develops over time and its fundamental principle is to reflect the changes of the state of the system as they occur at discrete-events. In this case the events would be either an arrival or a departure of a truck mixer in the system. Only these two events can effectively change the nature of the system that is represented by the state variables. In this model, these are the arrival time of the next arrival, the departure time of the next departure, the state of the placing team and equipment and the number of trucks in the queue. The heart of a simulation is the generation of random variates and in this case three must be considered, the gamma, exponential and inverse Gaussian algorithms to generate the gamma, exponential and inverse Gaussian variates.

There are various ways in which to carry out simulation analysis. For example a dedicated computer program that specifically carries out simulations for a particular model; or alternatively one can use commercial software. In this study the Microsoft Excel add-in @RISK was used. @RISK uses Monte Carlo simulation to carry out "what if" scenarios on specific data and it describes the risk involved with probability distributions.

### Parameters of the Simulation Model

One of the drawbacks of Monte Carlo sampling is that it creates noise and in order to reduce this the experiment should be repeated many times. Crandall (1997) proved that simulation results would be accurate if a minimum of 1,000 iterations were conducted in the simulation. With this in mind the system was instructed to carry out 1,500 iterations. It was also decided that 120 events are sufficient in order to represent a typically large concrete pour with 60 arrivals and 60 departures of truck mixers. This represents a pour of approximately $360m^3$ as the average truck mixer will have a capacity of $6m^3$ (although this actually exceeds the maximum pour in any one day recorded during data collection.)

Other parameters of the @RISK Monte Carlo simulation model are :

- *Event number* is the number of the event, which can be either an arrival or departure. This is set to 120 events.
- *Event type* identifies the event, whether it is an arrival or a departure of truckmixer.
- *Interarrival time* is the time between successive arrivals of truckmixers on site.
- *Position time* is the time taken by a truckmixer to move from the queue, position at the concrete pump and prepare to discharge the concrete. If no queue is present, it will be the time taken by the truck mixer to position at the pump and prepare for discharging only.
- *Pump time* is the time required for the truckmixer to unload the completely.
- *Time* is the amount of time into the concrete pour.
- The *status* of the concrete pump, where 0 means that the pump is idle and 1 indicates that the pump is busy.
- The number of truckmixers queuing, waiting to be unloaded.
- The time of the next arrival of truckmixer
- The time of the next departure of truckmixer. If the concrete pump is idle, this is set to 9999.
- Number in system is the number of truckmixers on site.

### Simulation Results

There are several operating characteristics that can be considered in concreting operations; four of interest in this study are:

- The utilisation of the concrete pump,
- The number of truckmixers in the system,
- Number of departures, i.e., the number of trucks that have been served, and
- The total operation time.

These are fundamental to the effective planning of concrete operations and being able to predict these early greatly increase the chance of the operation running smoothly. Table 5 shows the simulation results. The results show the concrete pump is utilised 90.83% of the time from the arrival of the first truck to the departure of the last truck. The average number of truck mixers on site was found to be 4.511. The simulation provided results for 55 departures in a time of 1279 minutes.

**Table 5**: Key characteristics of the simulation model

| Statistics | Pump Utilisation (%) | Number of Truckmixers | Number of Departures | Total Time (mins) |
|---|---|---|---|---|
| Simulation Results | 90.83 | 4.511 | 55 | 1279 |

A sensitivity analysis was carried out in order to find the most significant of the three inputs in the simulation model, i.e. interarrival, position and pump time. The interarrival time was found to be the most significant: by varying the interarrival time the utilisation of the concrete pump can be significantly affected and it will be possible to find the optimum interarrival time.

### Optimum Truckmixer Interarrival Time

The simulation model can easily be adapted so that it is possible to vary the interarrival time. Instead of using the gamma distribution the interarrival time was replaced with times ranging from 1 to 23 minutes. The operating characteristics can be seen in Table 6.

**Table 6**: Varying interarrival times in the simulation model

| Interarrival Time (minutes) | Number of Truckmixers | Utilisation of Concrete Pump | Number of Serviced Trucks / 120 events | Total Operation Time (minutes) |
|---|---|---|---|---|
| 1 | 56 | 100 | 5 | 114 |
| 3 | 47 | 100 | 14 | 315 |
| 5 | 37 | 100 | 22 | 485 |
| 7 | 31 | 100 | 30 | 623 |
| 10 | 17 | 100 | 43 | 760 |
| 12 | 16 | 100 | 44 | 900 |
| 14 | 13 | 100 | 49 | 980 |
| 16 | 9 | 100 | 53 | 1066 |
| 17 | 5 | 99 | 56 | 1071 |
| 18 | 4 | 98 | 56 | 1137 |
| 19 | 3 | 98 | 58 | 1159 |
| 20 | 3 | 96 | 59 | 1200 |
| 21 | 3 | 92 | 59 | 1260 |
| 22 | 2 | 85 | 58 | 1320 |
| 23 | 1 | 80 | 60 | 1378 |

When choosing the optimum interarrival time several factors have to be considered such as financial viability. It can be seen that having an interarrival time of 1 minute obtains maximum utilisation of the concrete pump - however in order to have such a short interarrival time it is necessary to have 56 trucks on the job. This would not only be very costly but practically impossible. In addition, for the 120 events simulated only 5 of these were departures. Generally, shorter interarrival times result in high utilisation levels of the concrete pump but this is achieved at the expense of many truckmixers being idle on site. An interarrival time of 23 minutes would allow the concrete pour to be carried out by only one truck however the concrete pump utilisation is the lowest of all of the times. This suggests that the truckmixer could have its concrete discharged, travel to the batching plant and uplift the next load and then return to the site within 23 minutes, which would be highly unlikely. The optimum interarrival time from the simulation model would be 19 minutes as this returns a high utilisation level of 98% with an average of only 3 truckmixers present on site.

## CONCLUSIONS

Simulation has been shown to be a very useful tool for planners when matching the concrete supply to site requirements. By doing this it should be possible for the contractor to concentrate on bettering performance on site without the worry of the logistics of concrete delivery. Interarrival time of trucks is an essential characteristic of concrete pours and taking this into account at an early stage in a project can greatly increase the utilisation level of the concrete placing equipment and minimise the number of trucks on site. In this study the optimum interarrival time was found to be 19 minutes resulting in a high utilisation of 98% with an average of only 3 truckmixers present on site.

The simulation tool used in this study was the Microsoft Excel add-in @RISK, which was found to be easy to use and should therefore present no problems for contractors to use. It can be easily manipulated to cater for many different pour sizes and operating conditions. It also allows contractors to continually improve the input data by using pours from on-going projects. Finally, simulation allows contractors to investigate the effects of altering the three inputs quickly, without great financial loss and effectively in order to find the optimum operating characteristics for specific concrete pours.

## REFERENCES

AbouRizk, S. M., and Halpin, D. W. (1990) Probabilistic simulation studies for repetitive construction processes, *J. Constr. Engrg. And Mgmt.*, ASCE, 116(4), 575-594.

AbouRizk, S. M., and Shi, J. (1994) Automated construction-simulation optimisation. *J. Constr. Engrg. And Mgmt.*, ASCE, 120(2), 374-385.

Anson, M., and Wang, S. Q. (1998) Performance of concrete placing in Hong Kong Buildings, *J. Constr. Engrg. And Mgmt.*, ASCE, 124(2), 116-124.

Anson, M., Aston, D. E., and Cooke, T. H. (1989) Concrete pumping in the U.K. and West Germany, *Proc., Inst. Of Civ. Engrs.*, U.K., Part 1, 41-57.

*Bestfit software on-line help*. (1993) Palisade Corp., Newfield, N.Y.

Clemmens, J. P., and Willenbrock, J. H. (1978) The SCRAPESIM computer simulation, *J. Constr. Div.*, ASCE, 104(4), 419-435.

Crandall, K. C. (1977) Analysis of schedule simulations, *Journal of Construction Engineering and Management*, 103(3), 387-394.

Dunlop, P. G., and Smith, S. D. (2000), A non-deterministic investigation of the concrete placing system, *Proc. 8th Ann. Conf. Intl. Group for Lean Constr.*, IGLC-8, 17-19 July 2000, Brighton, United Kingdom.

Egan, J. (1998) *Re-thinking construction*. Report of the construction task force. DETR, London.

Latham, M. (1994) *Constructing the team: procurement and contractual arrangements in the UK construction industry*, HMSO, London.

Law, A. M., and Kelton, W. D. (1991) *Simulation modelling and analysis*, McGraw-Hill, New York.

Smith, S. D. (1998) Concrete placing analysis using discrete-event simulation, *Proceedings of the Institute of Civil Engineers*, Structures and Buildings, 128(4), 351-358.

Smith, S. D. (1999). Modelling and Experimentation of the Concrete Supply and Delivery Process, *Civil Engineering and Environmental Systems*, Vol 16, 93-114.

Tommelein, I.D. (1997) Discrete-Event Simulation of Lean Construction Processes, *Proc. 5th Ann. Conf. Intl. Group for lean Constr.*, IGLC-5, 16-17 July at Griffith Univ.: Gold Coast Campus, Queensland, Australia, 121-135.