STOCHASTIC MODELLING OF CONCRETE OPERATIONS

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Processes within the construction industry have for many years been systematically modernised and allocated rigid procedures. However, this has not been the case with concrete placing operations. These have been left to evolve naturally and to develop in a piecemeal manner. As a result inefficiencies have become established in concrete operations that have led to wastage in terms of time and money. In a forward-looking industry, in which we are constantly striving to modernise its procedures, it is remarkable that such an area where significant financial savings can be made has been overlooked. There are undoubtedly opportunities for development in this area. Accordingly, this paper considers the amount of wastage involved in the concrete placement process. Results are presented using data gathered over a two-year period from a major civil engineering project in the North-West of England. The data consists of over seventy individual concrete pours. The majority of concrete operations observed involved concrete being pumped into formwork, which was seen to be a complex queuing system. The data collected from actual observations has been analysed using a model that deals with the many factors encountered in concrete placing operations. In this paper the aim is to look, briefly, at queuing systems in general as well as reporting on some of the main findings from the investigation into concrete processes.

Keywords: concreting operation, probability distribution, queuing system, stochastic modelling, process.

INTRODUCTION

For many years now, construction contractors have been using concrete as a construction material. Processes within the construction industry have been systematically modernised and allocated rigid procedures; however, this has not been the case with concrete placing. The process of concrete batching, transport and finally placement is subject to interruption, irregularity and fluctuation for which there can be very little control. Due to their random nature it is possible to treat concrete placement operations as a stochastic system. This random nature suggests that in many cases there is a variable nature to the rate at which material is delivered, which may result in an under-utilisation of plant and labour or an additional cost for storage of raw materials. By representing the processes as queuing systems, they can be analysed by a multitude of techniques that are available to the systems analyst, for example queuing theory, regression analysis and simulation. Indisputably it will be advantageous for the industry as a whole to encourage workers to apply management techniques to construction to increase its productivity and effectiveness.

This paper reports on the findings of a pilot study undertaken by the University of Edinburgh in collaboration with Tarmac Civil Engineering (now Carillion plc.). Real

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construction data were obtained from large concrete pours on a major UK motorway viaduct project, and this provides the basis for the case study in this paper. This paper will look, briefly, at queuing systems in general as well as reporting on some of the main findings from this investigation into concrete processes. This research area is also supported by EPSRC funds: the future development of the project will be discussed.

OBJECTIVES

The main objectives of this work are:

To investigate and provide a better understanding of cyclic construction processes with particular reference to concreting operations

To study live construction projects to gain data of cyclic processes

To examine methods to assist in the planning and estimation of cyclic construction processes

To examine systems which enable construction engineering organisations to better manage cyclic construction processes, in terms of the efficiency and effectiveness of resources

To provide systems which ultimately minimise the costs, in financial, material and human effort contexts, and maximise the productivity of concrete placing operations.

STOCHASTIC QUEUING SYSTEMS

In the concreting cycle presented here we will treat it as a single server queuing system (see Figure 1), due to the fact that no account has yet been made of the batching process which can be considered a system in its own right. This means that the only part of the process that must be considered is on site.

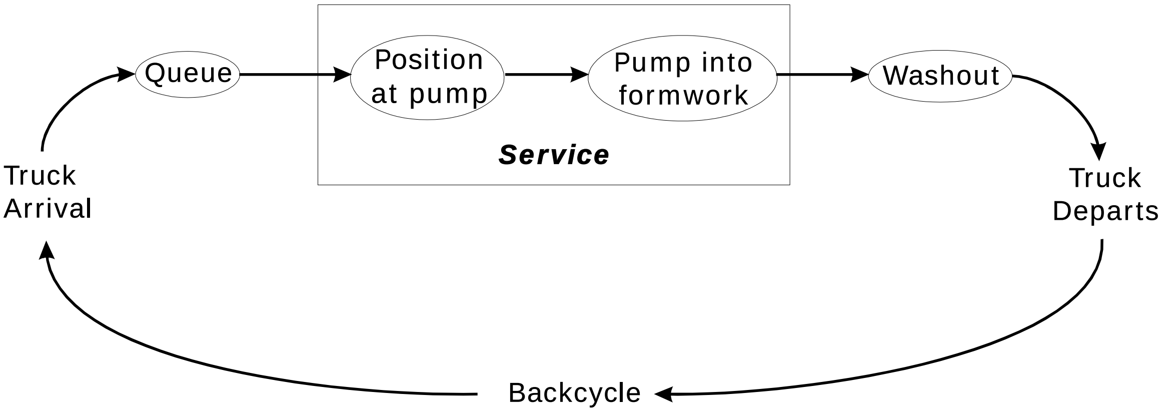

Figure 1: Schematic diagram of a general Concrete Placing Cycle

The concreting process represented here will involve pre-ordered concrete arriving from a batching plant to site. The queuing system will consist of both customers and servers. For each server, customers will queue until they are served and then leave. In the case of the concrete placing process as concrete truck mixers arrive they will join the “service” (if there are no other truck mixers in the queue to be served) or join the back of the queue of waiting truck mixers. Service requires the truck mixer manoeuvring into position then discharging the concrete into the hopper of the pump, which then pumps the concrete into the required formwork. This operation is common to thousands of construction sites throughout the world. When the truck mixer has been served it will then join the backcycle until they rejoin the system – again queuing if the server is busy. In an ideal system the rate at which trucks arrive, position and have their concrete pumped would be constant. Therefore, it would be possible to determine the time between arrivals (the interarrival time) of the trucks in order that no queuing, and thus under utilisation, of trucks occurred.

A real system, however, is stochastic and the events that occur within the system will take place at irregular intervals. Queuing of trucks can be expected, as it is unlikely that the interarrival time will be both regular and at such a rate that trucks arrive just when the previous one departs. If trucks arrive late, there will be a lengthening of the process, with plant and labour becoming inactive. The rates at which trucks are used are also dependent on the speed at which they are positioned and the concrete is pumped.

Although no account, as yet, has been made of the backcycle it is important to appreciate what happens during this time. When the truck mixer is finished discharging the concrete into the hopper it will then have the drum of the mixer washed and then leave the site. After departure the truck mixer will make its way to the designated batcher and then queue again, if necessary, to receive the next batch of concrete.

Identifying uncertainties

When dealing with the concreting system it is important to realise that there are many random factors or uncertainties that will affect its final productivity and effectiveness. The time variables in question have already been introduced and they are namely truck interarrival, position and pump times. Figure 2 shows how these factors affect the whole system. The factors that affect the time variables are limitless and it will be necessary to identify and manage as many of these as possible. Crombie (1999) calculated as many as 44 factors (see Table 1), both technical and managerial, and although he did not make any suggestions as to how to manage them the findings can be used as a very useful starting point.

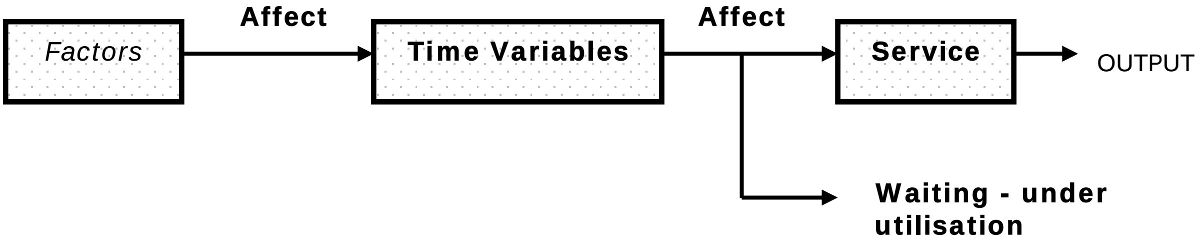

Figure 2: Schematic diagram of the effects that unknown factors have on the concreting placing process

Some of the more obvious factors that may affect the time variables are discussed below.

Site location
Site location is a very important factor in concrete operations, as the locality of the site will influence the ease at which the concrete can be transported to site, and finally pumped into the required formwork. Time delays can occur if the distance between

the batcher and site is too great. It is also important to consider the effects of sites in rural or inner-city locations.

Location of Supplier
As with site location it is important that in any concreting project a suitable supplier is chosen. The location of the supplier is fundamental to the success of all concreting operations. It must be within a realistic radius of the site – both because the quality of concrete deteriorates with time and also because the delivery cost is proportional to distance. Larger projects will quite often use on-site batchers, which greatly reduce the travel time.

Age of Trucks
This is an area where no research has, as yet, been carried out. However, it is acknowledged that this could be quite an important factor in the process. Many people within the construction industry feel that the age of trucks may influence the quality of service and concrete being provided; however, this is mostly anecdotal.

Site Congestion
This may seem an obvious factor but it is one that is not always eliminated. Site congestion can lead to many problems considering the fact that trucks are continually arriving on site and, ideally, should not be held up in anyway.

As can be seen from Table 1, there are a multitude of factors that affect the process. Probably the most imperative aspect, if the concreting process is to be a success, is that the contractor has a good relationship with the concrete supplier. To a certain extent the contractor is placing great importance on the supplier’s integrity. Without a reliable supplier the contractor may be faced with large delays, which will ultimately lead to a poor utilisation of resources. Both contractor and supplier have a vital role to play; firstly, the contractor must order the correct amount and type of concrete for each job and secondly, the supplier must deliver the concrete on time and to the required specifications. This is only one scenario, what must be remembered is that each party will have a large team of workers to manage in order to maximise effort and effectiveness.

Modelling Concreting Operations

As with all modelling exercises, whether physical or numerical, the main aim is to represent the concreting system in a way that can be investigated practically, economically and safely. In modelling the concrete placing process described above, it is necessary to replace the three time components, interarrival, position and pump times, with a probability distribution. It is not necessary to model the queuing time of a truck, as this is a factor of the other time components.

In order to analysis such a system it will be necessary to use techniques available such as queuing theory, simulation, regression analysis, petri-net theory and neural networks. For this paper the data collected has been analysed using discrete-event simulation (for example, Smith et. al. 1996 and Tommelein 1997), where the time components are then represented by probability distributions. These distributions can then be ‘sampled’ and used to recreate a typical cycle of truck arrival, queue, position and pour. In order that such a system is realistic, it is necessary that it based on actual data from actual site operations; the more real data collected, the more realistic the model becomes.

Table 1: Factors that can affect the efficiency of a concrete operation. (Crombie, 1999)

TECHNICAL FACTORS	MANAGERIAL FACTORS
1. GRADIENT OF THE SITE	22. PLANNING
2. SITE CONGESTION	23. PROGRAMME
3. OTHER SITE ACTIVITIES	24. RATE OF PROGRESS REQUIRED
4. ACCESS CONDITIONS	25. TIME RESTRICTIONS
5. SITE LOCATION	26. COMPANY STRUCTURE
6. PLACING METHOD	27. COMPETENCY OF MANAGEMENT TEAM
7. LOCATION OF SUPPLIER	28. ENGINEER'S EXPERIENCE AND INTUITION
8. POUR SIZE	29. MOTIVATION OF ENGINEER
9. POUR LOCATION	30. ENGINEER’S MANAGEMENT SKILLS
10. POUR SHAPE	31. SKILL OF PLACING TEAM
11. HEIGHT OF POUR	32. EXPERIENCE OF SITE TEAM
12. AGE OF TRUCKS	33. MATURITY OF PERSONNEL
13. SUITABILITY OF PLANT FOR JOB	34. MOTIVATION OF PLACING TEAM
14. FORMWORK	35. JOINER AND STEEL-FIXER EFFICIENCY
15. SEQUENCE OF POURS	36. MAINTENANCE OF PLANT
16. ACCURACY OF TAKE-OFF	37. TIMELY SUPPLY OF CONCRETE
17. TESTING	38. SUPPLY OF MATERIAL
18. CONCRETE SPECIFICATIONS	39. QUALITY OF PLANT
19. OUT OF SPECIFICATION DELIVERIES	40. SUPPLIER’S OTHER CONTRACTS
20. SPILLAGE	41. RESOURCES OF SUPPLIER
21. VANDALISM	42. LABOUR REQUIREMENTS
	43. ACCIDENTS
	44. WEATHER CONDITIONS

Discrete-event simulation modelling

Full details of the discrete-event model can be found in Smith (1998 and 1999) but to summarise the steps involved are as follows:

Data collection. The model must be based on real data collected from actual construction sites. This is discussed further below.

Fitting probability distributions. The real data is used as the basis for probability distributions – the ‘best-fit’ distribution is then used in further analysis. This is also discussed below.

Generation of random variates. A random variate is a value generated at random from within the probability distribution chosen. Assuming a good fit between actual distribution and probability distribution the random variate is a true representation of an actual value.

Use random variates to synthesise ‘events’. An event is something that changes the state of the concrete placing system. In this case it is either an ‘arrival’ or a ‘departure’ of a truckmixer into, or out of, service.

Model operations. A real operation is a series of events, the timing of which determine its attributes (for example, productive output, plant utilisation). These attributes can therefore be determined for a simulated operation.

Investigate system. The real concrete placing system is too large to experiment with – but the simulation model of the system can be investigated in many ways.

Data Collection

In order to determine the probability distributions that are used to model the concrete placing process, data were gathered from a major civil engineering project in the North West of England. The data gathered were spread over a two-year period, the vast majority of it being collected during the summer months. The project involved the construction of a motorway viaduct and widening and involved pours ranging, for the whole project, from 2m^3 to 1200m^3 of concrete. A sample of larger concrete pours provided the following data:

Truck arrival time,

Pump start time,

Pump complete time,

Batching plant used,

Truck quantity, and

Concrete slump.

The overall volume of the sampled operations ranged from 33m^3 to 470m^3 with an average of 180m^3. The average number of truckloads was 31 and the average delivery volume was 6.15m^3 for the 63 pours sampled.

The data gathered were summarised on a Microsoft Excel spreadsheet and the times of particular interest were extracted. It is necessary to inspect the nature of the distributions of these times prior to fitting any kind of theoretical probability distributions to them. Examples of cumulative distributions of the interarrival, position and pump times can be seen in Figure 3.

Data fitting and analysis

After determining the observed cumulative distributions (for example as shown in Figure 3), it is then extremely important to represent this observed input data within the model in the form of mathematical probability distributions. It is important that the input data in this form are a good representation of the system – otherwise any output will not be reliable and the model will give ambiguous results.

If the sampled data is to undergo analysis by simulation then it will be important to consider various distributions. From first inspection of the cumulative distributions shown in Figure 3 the normal, uniform, triangular and exponential distributions can be discounted. It is anticipated that it will be preferable to use mathematical distributions such as the beta, gamma and Weibull distributions. The Erlang distribution is another commonly used distribution (for example consider Smith et. al. 1996 and Carmichael 1987), which is a special case of the gamma distribution. It is useful if a good fit is obtained, as it can be quick to generate random variates from.

For the purpose of this paper no comparisons have been made of the different distributions that best fit the data. It is anticipated that this will be possible in the future when more data has been gathered.

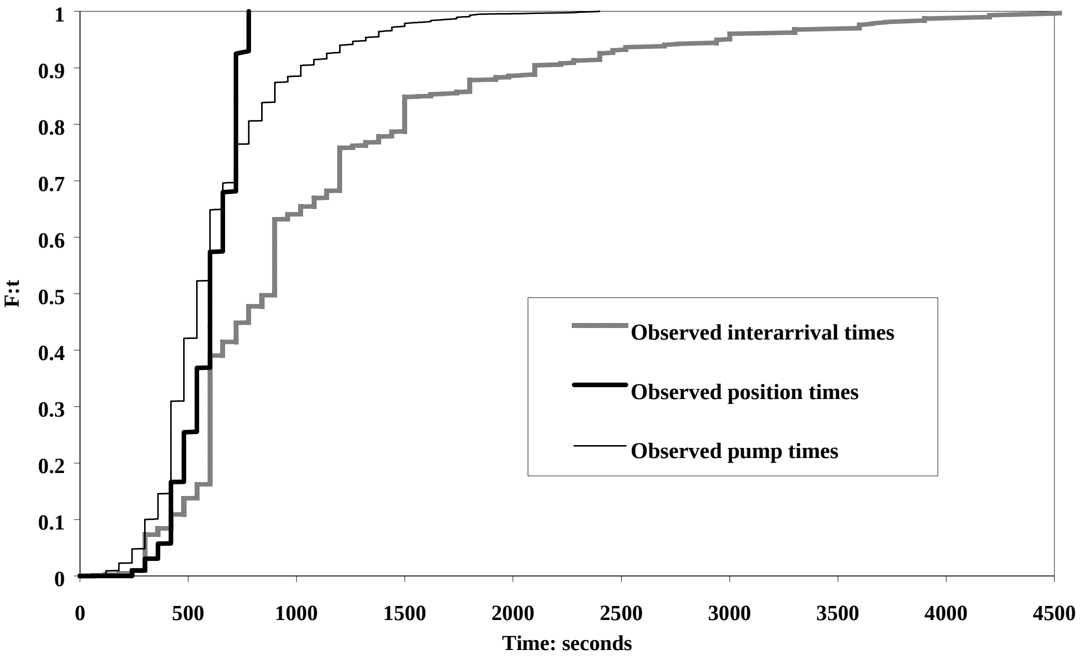

Figure 3: Cumulative distributions of the sampled data

CONCLUSIONS

This study has been carried out at a very early stage of the research project and combines early theory with the early stages of data collection and data analysis. Although no 'concrete' results have been found the paper sets about introducing the research topic and some of the methodologies that will be used in the future. From the paper it is possible to show the following conclusions:

The study shows that the concrete placing process, common to many thousands of construction sites, may be considered a stochastic system – it can be quite clearly seen from figure 3 that the system is in no way deterministic or non-random. This is a central to the analysis of concreting operations: the random nature of the system's events result in very different characteristics to systems that are considered to be deterministic.

The concrete placing operation can be treated as a queuing system, which we encounter in our everyday life, such as at a supermarket or a bank. The queuing system in question will consist of both customers (truck mixers) and servers (concrete pump). From the queuing system it was possible to calculate the length of time each customer spent within the system. The batching process is also a queuing system that, although not considered in this paper, can be treated in a similar manner.

Many random factors affect the productivity of the system. These random factors (for example site location, supplier location and site congestion) all have a knock-on effect and affected the time variables – truck interarrival time (time between arrivals), truck position time (the time it takes a truck to move into position so that it is ready to discharge it's load into the pump hopper) and the pump time (the time taken to pump the concrete into the formwork). This will inevitably cause a certain degree of time delays within the system that will result in wastage, both in financial and human contexts.

It is possible to analyse such systems using a variety of techniques such as regression analysis, simulation, queuing theory, petri-net theory and neural networks

Data from a large civil engineering project was used as a pilot study at the beginning of the research. From the data collected it was possible to calculate the three most relevant times and the average number of truckloads, which was found to be 31. The average delivery volume was found to be 6.15m^3 for the 63 pours sampled. The cumulative distribution of the raw sample data was calculated and this is what would form the basis of the model analysis. It was concluded that the four most obvious distributions to consider are the beta, gamma, Erlang and Weibull distributions.

FURTHER WORK

This area of study has a large potential for future research; it is intended that the following directions will be pursued:

To take forward the initial studies and apply the data collected to probability distributions.

The initial studies only used data from one site collected in the summer months. It is anticipated that further studies can be conducted using multiple sites, with varying conditions (such as type of pour and ‘urban’ or ‘rural’ for example) and data collected at different times in the year.

Investigations shall take place into effects of different contractors and concrete suppliers. As mentioned in the paper the relationship between the two parties is critical so it will be necessary to investigate how each rely and support each other.

As mentioned in the paper, the model used simplifies the actual process by ignoring the batching stage and backcycle so it may be necessary to take these into account in the future.

As discussed there are limitless numbers of factors which affect the system so further work will have to be carried out to identify many more of these uncertainties.

In ideal situations, all of the concrete delivered to site would meet all necessary requirements but unfortunately this is not the case. Every batch of concrete’s slump is tested and unless this is within the set limits it is rejected. This delays the process and has a knock on effect further down the line. Studies will be carried out to determine the effects this has on the process as a whole.

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