STOCHASTIC MODELLING OF CONCRETE OPERATIONS

Paul Dunlop

School of Civil and Environmental Engineering
The University of Edinburgh
Crew Building
The King's Building
Edinburgh
EH9 3JN

The concrete delivery and pumping process is a stochastic system. If analysed deterministically there is the danger that the negative effects of the random distribution of events are not taken into account, leading to poor estimates of production and cost. By representing the system as a random process the construction engineer can firstly achieve improved estimates of the overall productivity and thus schedule deliveries better, and secondly, determine the effect of non-anticipated events such as excessive delivery or pour times. Research will be centred on studies of actual construction projects, which will be used to study cyclic processes in general, and concreting placing operations in particular. In addition, data will be gathered from concreting operations, which will be used as a basis for the modelling of concreting operations. These models will be developed and analysed using a number of techniques, notably discrete-event simulation, with the intention of producing software for the practical analysis of site operations. The ultimate aim of the investigation is to minimise the cost and maximise the productivity of concreting operations.

Concreting, Modelling, Queuing Systems, Stochastic Systems

INTRODUCTION

For thousands of years, concrete has been used as a construction material. However, as processes within the construction industry have been systematically modernised and allocated rigid procedures, 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 underutilisation 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 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 discussing the proposed research methodology.

OBJECTIVES

The main objective of this work is:

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

ii. To study live construction projects to gain data of cyclic processes

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

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

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

METHODOLOGY

There are two main aspects to the project; firstly, it is important to find suitable live construction sites for further study. These sites should initially allow observation of concrete operations to provide a full understanding of the procedures and activities that make them up. The factors that influence their output and the differences between contractors, geographical areas, time of year and weather. Concreting operations will also be observed on a work-study basis in order to extract raw data that can be later used as model input. Secondly, it is anticipated that it will be possible to develop numerical models of the concreting process and analyse these in a variety of ways. Discrete-event simulation has, to date, already been implemented on earthmoving processes as well as concreting processes by Smith (1998,1999). It is hoped that this technique may be used again using both commercially available software and new applications developed for this
purpose by the author; other methods will also be investigated, for example queuing
theory, regression analysis and the petri-net theory.

The analysed models will be used in two ways: firstly, to undertake parametric
experiments on the concreting process, and secondly to provide a tool for the estimation,
planning and management of concreting operations.

The research project should follow a pre-determined plan if it is to run both effectively
and efficiently. However research is a dynamic process, therefore there must be a certain
amount of flexibility – implying, although not requiring, that a contingency approach
would be helpful.

The research project is expected to follow the following route.

1. Literature Survey

An essential early stage of virtually all research is to search for and to examine potential
relevant theory and literature. Theory and literature are the result of previous research
projects.

For this particular project the literature survey has almost been completed, however, it is
fair to say that it may never be entirely finished. The survey took advantage of the
multitude of powerful search engines available on the World Wide Web and these yielded
many favourable results. The majority of research found relating to concrete operations
took place outside of the UK so from a very early stage it was noted that there was
definite research potential within the UK.

2. Model Development

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 the concreting cycle presented here we will treat it as a
single server queuing system (see Fig. 1). No account has to date been made of the
batching process as it can be considered a system in its own right and may be considered
in future work.
A queuing system consists of both customers and servers, Carmichael (1987). For each server, customers will queue until they are served and then leave. In the case of the Concrete Placing Cycle (CPC) as concrete truckmixers arrive they will join the ‘service’ (if there are no other truckmixers in the queue to be served) or join the back of the queue of waiting truckmixers. Service requires the truckmixer 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 many of the thousands of construction sites throughout the world. When the truckmixer 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 underutilization, of trucks occurred.

There are other alternative systems available to the construction industry, for example placing concrete using a crane and bucket or by using a wheelbarrow. The later is very labour intensive and dated, however, the crane and bucket method has previously been researched, Tommelein (1997).

A real system is stochastic and the events that occur within the system (e.g. the interarrival times, pump start times) take place at irregular intervals. This point has been mentioned previously but it is one that is fundamental to the Concrete Placing Cycle. 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.

As can be seen, the output of the system is dependent on the variability of the system events. What must also be considered are the factors that influence this variability. In the
majority of concrete pours it is possible to determine a number of factors that affect the effectiveness and efficiency of the Concrete Placing Cycle, such as site location, location of the supplier and the age of trucks. Establishing all of these factors may well improve the efficiency of concrete operations and so reduce wastage.

3. Data Collection

It is fundamental that for models to be a good representation of real life projects they must be based on real data. In this pilot study data were gathered from a major civil engineering project in the North-West of England. The data gathered was spread over a two-year period, however the vast majority of data was 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 $2\text{m}^3$ to $1200\text{m}^3$ of concrete. A sample of larger concrete pours provided the following data:

i. Truck arrival time,
ii. Pump start time,
iii. Pump complete time,
iv. Batching plant used,
v. Truck quantity, and
vi. Concrete slump.

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

Table 1 shows a typical example of a data sheet that provided the basis for the investigation. The data collected were summarised on a Microsoft Excel spreadsheet and the times of interest extracted.

Table 1 A typical example of a data sheet used on site to record relevant times.

<table>
<thead>
<tr>
<th>Pour Date</th>
<th>Location</th>
<th>Interarrival Time</th>
<th>Truck Wait Time</th>
<th>Truck Position Time</th>
<th>Load Pump Time</th>
<th>Pump Time</th>
<th>Operation Inactive Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch</td>
<td>Arrive</td>
<td>Start Complet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As mentioned previously, the pilot study only considered data from 63 pours. It is intended that further sites will be selected to enable a wider range of data to be sampled.
Due to the wide variety of construction sites, data will be gathered from very different site locations, for example the comparisons between rural and inner-city sites.

4. Data Analysis

Analysis may be carried out with respect to data available, the objectives and any hypothesis, so that the most robust and rigorous analytic methods will be used, thereby maximising confidence in the results (Fellows et al, 1999). It is important to consider, evaluate and plan analysis methods from the very beginning.

Analysis can begin by examining the raw data, gathered from construction sites, for patterns and relationships. It was hypothesised at the start of the literature survey that the most relevant times from the concreting system were the interarrival, position and pump times. These can now be subjected to statistical analysis and it is normal to analyse queuing systems in a non-deterministic way using methods that will be discussed below.

i. Queuing Theory. An operations research technique used in many applications. Its application to construction has been extensively researched by Carmichael (e.g. 1986, 1987) who applied the theory to earthmoving and mining operations.

ii. Simulation. Simulation involves the use a model to represent the essential characteristics of a reality, either a system or a process. So, whilst a model may be a static representation, such as an architectural model, a simulation involves some element of dynamism, if only because it models a process rather than an object (Fellows et al, 1999). This makes simulation ideal for concreting operations. By synthesising input data based on the probability distributions of actual operations, each step of an operation can be recreated. A computer can recreate each step very quickly thus allowing the simulation of lengthy, real operations.

iii. Petri Net Theory. Petri nets are used as a tool for the study of systems. Petri net theory allows a system to be modelled by a Petri net, a mathematical representation of the system. Analysis of the Petri net can then, hopefully, reveal important information about the structure and dynamic behaviour of the modelled system. This information can then be used to evaluate the modelled system and suggest improvements or changes.

iv. Neural Networks. Artificial neural networks are computational devices. Most researchers and developers at this time simulate their neural networks using software simulation. A neural network is a highly interconnected network of many simple processors each of which maintains only one piece of dynamic information and is capable of only a few simple computations. No previous work has been found exploiting the uses of neural networks in concrete operations so further research is being carried out in this area.
v. Regression Analysis. This is a statistical tool that provides equations for outputs derived from real operation data. These equations can then be used to deterministically analyse further operations. Regression analysis provides the chance to analyse the variables in pairs – one dependent and one independent. Fellows et al. state that regression analysis establish only any relationship between the realised values of the variables which occur; they do not establish causality. This may have to be taken into account at a later date.

5. Further Data Collection

After the initial data has been gathered and analysed it will be necessary to collect further data. This will involve going to different sites in order to get a wider range of data for sampling and to put right any errors which are felt may be in question from the first data collection. The process of going back on to site multiple times allows for any new ideas and thoughts to be explored.

6. Model Verification

After the model or models have been researched and put in place it is important to refine them to ensure that they are being used to their full capacity. Verification of a model involves determining whether the structure of the model is correct; this is achieved by testing the model, by examining the outputs resulting from the model under a given set of inputs. The model is verified if the outputs are appropriate, i.e. they approximate to ideas of what a good model would generate.

7. Validation

The next stage of any modelling process is validation. At this point any model that was not verified must be discarded or undergo further amendments. The validation of a model is fundamental to the achievement of one's initial aims and objectives. If the model is not an accurate representation of the system being studied then any conclusions gained from the model cannot be relied upon. When carrying out the validation stage it will be useful to test several sets of input data and known outputs over a range of conditions – including extremes. When more than one model is being used and has passed verification then it will be necessary to choose the most appropriate model.

8. Dissemination

When the final model has been chosen it is going to be important to disseminate the results and findings appropriately. This is an integral part of any research project. It is
hoped that the results of the project will show that there are definite signs of ways to minimise the cost and maximise the productivity of concreting operations.

**BENEFICIARIES**

**Potential impact of the work**

The results of this work will have the potential to:

i. Assist in the planning and estimation of concrete placing operations. Construction contractors normally have a very short period of time in which to do this when tendering and thus increased accuracy and speed would be welcome.

ii. Assist in the management of concrete placing operations. Operations on a construction site may often be conducted in a reactive way, responding to events as they happen. By increasing the understanding of planned operations, site personnel may be better placed to manage them pro-actively.

iii. Increase efficiencies, reduce wastage and increase cost effectiveness of concrete placing operations. Smith (1998) has already indicated that cost reduction of concreting operations is a possibility through a stochastic as opposed to a deterministic approach.

iv. Provide a base of experimentation and results for other internationally

**Beneficiaries of the research project**

The beneficiaries of this work are primarily expected to be construction organisations, from the increased competitiveness through the minimisation of cost and maximisation of productivity. Particular beneficiaries within the construction industry will be:

i. Contractors, who will benefit from improved planning and increased productivity; and

ii. Materials suppliers, who will benefit from reduced costs through increased utilisation of equipment.

It is expected that the academic community of workers in process modelling will also benefit.

**REFERENCES**


