COST OF CONCRETE PLACEMENT FOR CONTRACTORS

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RMC is an important construction material and the cost of placing this material is significant for a contractor. Previous research studies to minimise this cost have centred upon the cost of plant and labour, without consideration of the other costs that comprise the RMC system. The aim of this research is to define the costs that should be reduced to minimise the contractor cost in the RMC system and identify a method(s) of achieving this minimisation. The costs and the contributor(s) to these costs were identified through consultation with industrial practitioners. A quantitative analysis was performed on a data set collected from UK construction projects to determine the significance of each cost and the contributor(s) to each cost. The significant costs were the RMC material, plant hire, idleness of plant and on-site labour (placing team) and truck mixer surcharges. These costs should be reduced. A systemic cost reduction would include all of the significant costs identified and produce a larger reduction in the cost of RMC placement for contractors than focusing on plant and labour costs alone. Such a systemic would require a fundamental re-management of the RMC system such as a reconfiguration of the resource supply chain coupled with production control methods aimed at reducing plant and labour costs.

Keywords: cost, materials management, production management, ready-mixed concrete.

INTRODUCTION

Ready mixed concrete (RMC) is an important material for contemporary construction, as it is used in a variety of structures, for example in motorway viaducts, building foundations and wastewater treatment plants. The global construction industry is a major consumer of RMC, and the trend that production rates of the material are on the increase (Eurostat, 2005) signifies a growing reliance by the construction industry on the material. It is thus of concern that RMC is not being manufactured, transported and placed with a high level of efficiency and at a minimum cost to the supplier, contractor and the project client (Halpin and Woodhead, 1976; Camillo, 1996; Smith, 1998; Zayed and Halpin, 2001).

It is clear from the dates of the above publications that this problem has not only been realised in the recent past; rather it has been a continuing problem for decades. However, as stated above there is an increasing reliance on RMC as a construction material and this is the catalyst for this research, which aims to define the sources of contractor cost in RMC placement and outline a method(s) of reducing these costs. The study is presented in two parts, with this paper defining the sources of contractor

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cost in RMC placement and another paper presented by Graham et al. (2005) at ARCOM 2005 entitled 'Cost reduction through vertical integration of the in-situ concrete supply chain' outlining a cost reduction method(s).

This study concerns the RMC system when an external batch plant is acting as RMC supplier and a contractor is placing the RMC using a concrete pump – a common situation. Additionally, this study is ongoing and here it is limited to considering the costs incurred by contractors in placing concrete – a future study shall address the issue of the costs for the RMC supplier.

Previous research has suggested that a minimisation of contractor cost for placing RMC can be achieved through optimising the allocation of the required resources (truck mixers, plant, people, etc.) and thereby reducing the cost of labour and plant (for example Zayed and Halpin, 2001). This area has been focused upon because the allocation of resources is to a large degree within the control of the contractor and thus these cost reduction methods could be implemented readily. While optimising the allocation of resources would result in a decrease in the cost of RMC placing, it is felt that this reductionist view is not identifying all of the costs involved in the placement of RMC. Moreover, the cost of plant and labour may not be the most significant cost that a contractor must bear in the RMC system and thus there could be other costs that should be reduced in addition to those of plant and labour. To this end, an analysis of the data collected from real RMC pours has been made to:

- Identify and quantify the costs that exist in the RMC system for a contractor;
- Expose the contributor(s) to these costs and assess the significance of each.
- Define areas of focus for contractor cost reduction strategies.

In this article, firstly the details of the sources of the project data are presented. Next, the contractor costs within the RMC system are identified and subsequently quantified through an analysis of the project data. A comparison of this cost analysis is made with existing cost information provided by RS Means. The contributor(s) to the quantified costs are then examined. Finally, areas of focus for contractor cost reduction strategies are defined based upon the analysis performed in this study.

PROJECT DATA

The project data was collected during a time and motion study of the construction of six wastewater treatment plants in two different projects, performed by two different contractors in Scotland, UK. Project one (4 plants) had two suppliers of RMC – located at 5 and 18 miles from the project site. A total of 184 RMC pours and 14,900m^3 of placed RMC were observed in this project. Project two (2 plants) had two suppliers – located at 8 and 16.5 miles from the project site. 48 RMC pours and a total volume of 6, 200m^3 of placed RMC were observed in this project.

The information collected included: date, location (on the structure) and type of pour; weather (qualitative); truck mixer number; time batching started and finished; travel time for truck mixer; time of arrival of truck mixer on project; time that discharge began; finish time of discharge; time washout begins; time washout finishes; leave site time; travel time; time of arrival at batch plant; rejected loads; time lost due to rejected loads; time lost due to pump breakdowns; wait period of truck mixers (if any); time to position truck mixers; idle time of plant and labour due to a gap in the supply of RMC; time truck mixers spend on project site; pour duration; no. labour force in each role (e.g. plant operator); and pour volume.

For generic conclusions to be drawn from this research, it is important to ensure that the project data is evenly and well-distributed. A measure of this can be made by presenting the collected data in a histogram. In this case, the data should be well distributed in pour volume (Anson et al., 2002) and productivity (Dunlop and Smith, 2003) – two key variables of the system. A histogram of the pour volumes, with the productivities of the project data is shown in figure 1.

The histogram in figure 1 is skewed to the right – there are more pours with a volume below 150m^3 than above. When the average productivity of each of the volume categories is plotted (as in figure 1) a significant difference is shown between those pours below 80m^3 and those above; pours with more than 80m^3 volume have a higher rate of productivity. To promote generic findings from this study the project data was separated into two distinct groups, those 80m^3 or below (small pours) and those above this volume (large pours). This is because each of these groups is more evenly distributed than the data set as a whole. The small pours observed in this study totalled 6, 000m^3 performed over a four-month period.

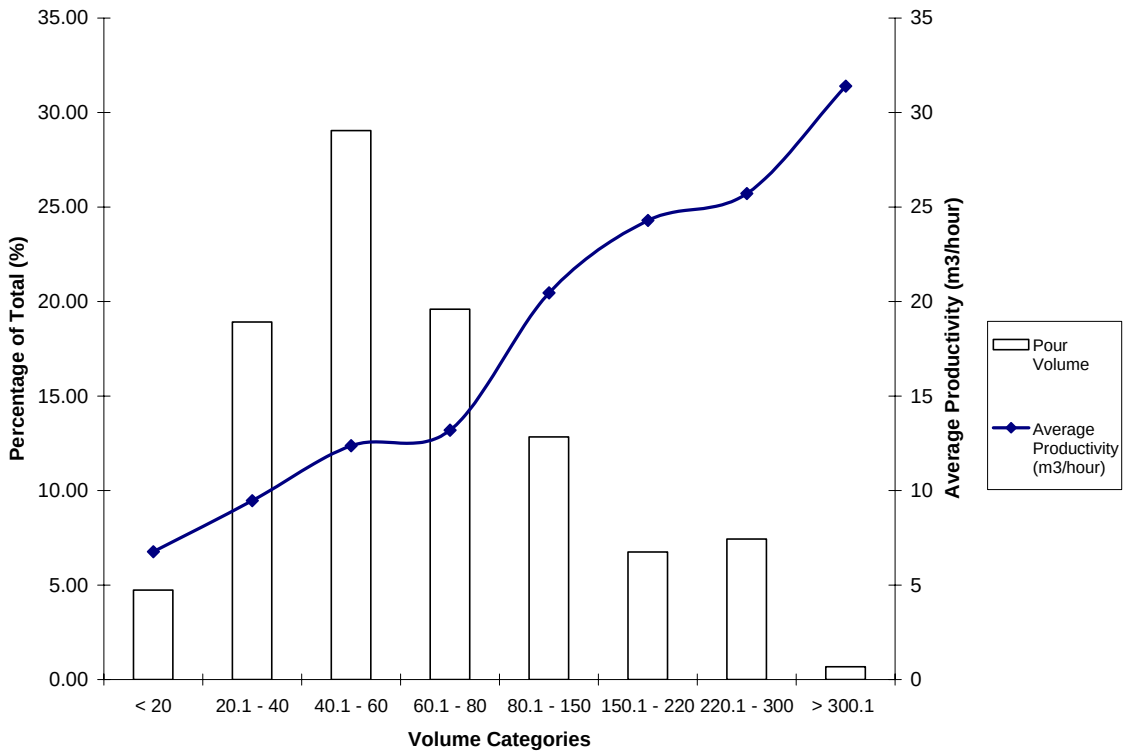

Figure 1: Project data pour volume histogram

IDENTIFICATION OF CONTRACTOR COSTS

The authors collaborated with several managers of both RMC batch plants (in USA and UK) and contractors (in UK) to identify some of the costs in the RMC system. These costs are presented in an Ishikawa or fishbone diagram (see figure 2). Note that this list is not thought to be complete. The costs for a contractor are as follows:

- RMC material costs. The price quoted by a RMC supplier absorbs a number of the supplier's costs, including raw materials prices, overheads, transportation costs and suppliers profits. These prices can vary significantly according to the design mix, but is typically in the range £30/m3 to £50/m3.

- Plant hire costs. The on-site plant required in the RMC system differs from pour to pour. However, in the studied projects there was some standard plant used in each pour, such as a concrete pump, vibrating poker units and mechanical trowels. Other pieces of plant have been included in this study and are accounted for in the quantitative analysis of costs presented in the next section. Often contractors hire the above plant, incurring hire costs that are usually charged on a fixed daily basis.
- Plant operating costs. These costs are a function of pour duration, fuel prices, plant running during idle periods and repair costs.
- Labour costs. RMC is placed by labour teams, often consisting of a ganger (or foreman), plant operator, placing personnel, general labourers and masonry specialists (for finishing) and they are usually paid at an hourly rate.
- Truck mixer surcharge. The RMC supplier often has a tolerance for the length of time that a truck mixer may remain on a project site. This tolerance is roughly 5 minutes per cubic metre. For example, a truck mixer carrying a load of 8m3 of RMC would be permitted a time of 40 minutes on a site. Beyond this tolerance, the supplier applies a surcharge of £2/ minute over the tolerance.
- Transport of material. This is a cost absorbed in the price of the material and is not directly applicable to the contractor, but could be useful in identifying ways to reduce the contractor's costs.

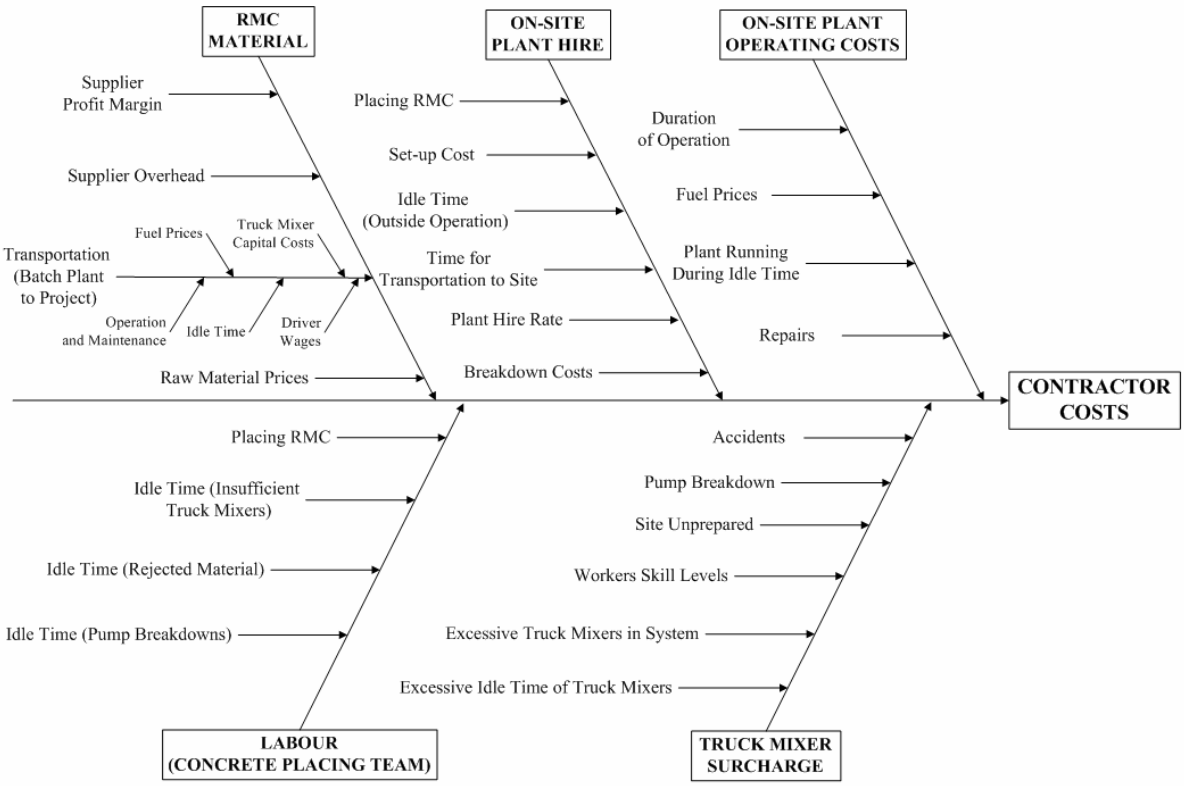

Figure 2: Ishikawa diagram of contractor costs in RMC system

QUANTIFICATION OF CONTRACTOR COSTS

The contractor costs in the RMC system identified through discussion with practitioners and presented in figure 2 were quantified for each of the 232 RMC pours to determine the largest costs in the system. These costs were calculated using the following formulae:

$$RMC\ Material\ Costs\ (£) = Unit\ Cost\ of\ RMC\ (£/m^3) \times Pour\ Volume\ (m^3) \quad (1)$$

$$Plant\ Hire\ Costs\ (£) = Daily\ Hire\ Rate\ (£/day) \times Days\ for\ Pour \quad (2)$$

$$Plant\ Operating\ Costs\ (£) = Unit\ Operating\ Cost\ (£/hr) \times Pour\ Duration\ (hrs) \quad (3)$$

$$Labour\ Hire\ Costs\ (£) = Duration\ (hours) \times \left[No.\ Persons \times Unit\ Cost\ of\ Each\ Job\ (£/hr)\right] \quad (4)$$

$$Truck\ Mixer\ Surcharge\ (£) = \begin{cases} [\text{Truck Mixer Time at Project (minutes)} - \text{Tolerance Threshold (minutes)}] * £\ 2/\text{minute} & \text{If Truck Mixer Time at Project} > \text{Tolerance} \\ 0 & \textit{If Truck Mixer Time at Project <= Tolerance Threshold} \end{cases} \quad (5)$$

where, Tolerance Threshold = 5 minutes per cubic metre of RMC to be placed.

$$Contractor\ Cost\ (£) = Plant\ Hire\ Costs + Plant\ Operating\ Costs + RMC\ Material\ Costs + ... + Labour\ Hire\ Costs + Truck\ Mixer\ Surcharge \quad (6)$$

The values for pour volume, duration of pour and labour force were recorded for each pour. The unit costs and hire rates were obtained from RMC suppliers and construction contractors and are hence at 2005 prices.

A total of 168 RMC material costs, plant hire costs, plant operating costs, labour hire costs and truck mixer surcharges were calculated for the small pour project data; and 68 for large pours. The total contractor cost was £543,000 for small pours. The amount that each of the above costs contributed to this total are shown in figure 3. In summary, 73% of the contractor cost was to pay for RMC material cost. 25% was due to plant and labour costs, while the remaining 2% was due to truck mixer surcharges. It is of note that a similar breakdown of the contractor costs in large pours was recorded.

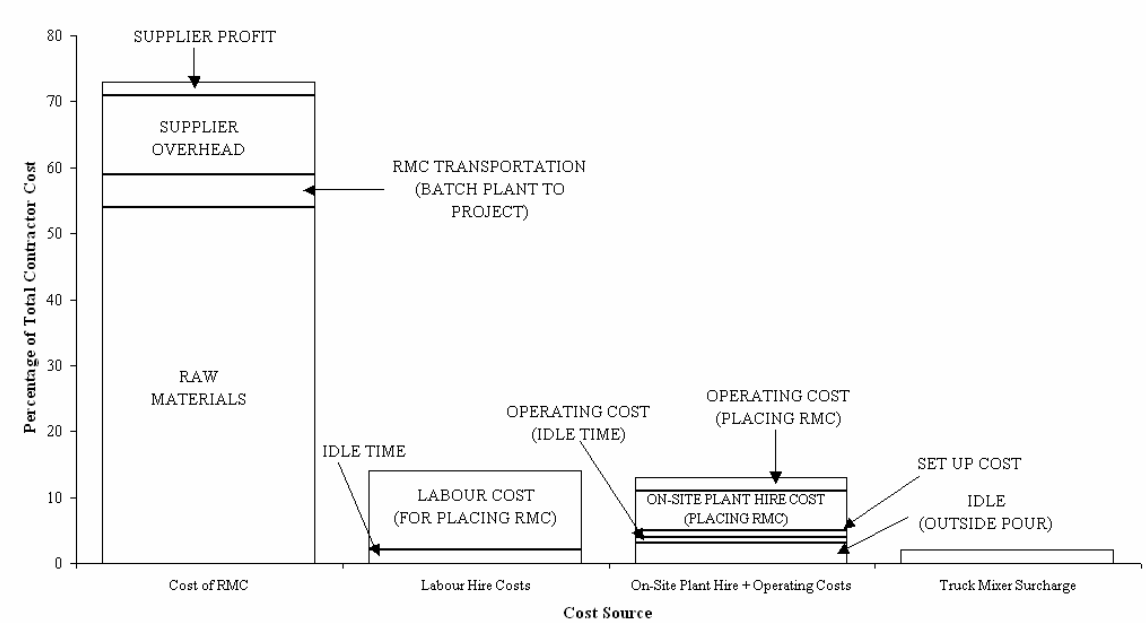

Figure 3: Contractor costs and contributors to cost in the observed small pours

COMPARISON WITH EXISTING COST INFORMATION

RS Means building construction cost data provide estimates of the breakdown of contractor costs in performing RMC operations (RS Means, 1998), and these estimates for small pours are shown in table 1. The cost breakdown from this study is similar to that presented in RS Means, which helps to provide some indication of the generic applicability of this study. However there are differences of note:

- RS Means do not recognise the impact of truck mixer surcharge on the contractor costs; a cost that was found to be significant in this study. This cost may be absorbed in the RMC material cost.
- The RS Means edition was from 1998 and is based in USA; the quantitative analysis presented here is based upon 2005 UK prices. Since 1998 the cost of RMC raw materials globally has increased (DTi, 2004). In UK this has particularly the case due to the introduction of the UK Government's Aggregates Levy in 2002 (DEFRA, 2005). Additionally, the price of crude oil has increased significantly from 1998 to 2005, resulting in increased on-site plant operating costs.

Table 1: Costs breakdown (as % of total) comparison with RS Means (after RS Means, 1998)

	Estimate Source	
Contractor Costs	Quantitative Analysis	RS Means
RMC Material	73	72
Labour Hire	13	19
On-Site Plant Hire and Operation	12	9
Truck Mixer Surcharge	2	0

CONTRIBUTORS OF CONTRACTOR COSTS IN RMC SYSTEM

The contributors to costs in the RMC system were identified through observation on project sites and quantified using the recorded data. These are presented and quantified in figure 3. The contributors to each cost in the system are discussed below.

Cost of RMC material

The contributors to RMC materials cost are as follows:

- Raw materials. Cement, fine aggregates (sand), coarse aggregates (e.g. gravel) and water are all base materials of RMC. Also, some mixes of RMC require either mineral or chemical admixtures to be added to the mix. Each of these raw materials is governed by the market price. The cost estimate of each of raw material was provided by a RMC batch plant. Raw materials account for 54% of the total contractor cost in the studied small pours.
- Transportation. When the RMC material is batched it is transported to the project in truck mixers. There are a number of factors that affect material transportation such as fuel prices, truck mixer capital, operation and maintenance costs, periods of idle time, and the driver's wages. An estimate of the unit cost of transportation was obtained from a RMC batch plant and this was used in the quantitative analysis undertaken in this research. Transportation was estimated to account for 5% of the total contractor costs (small pours).
- Supplier overhead. A number of factors contribute to the RMC supplier's overheads, such as the batch plant capital, operating and maintenance costs, labour wages, business rates, utility charges. These have been estimated to contribute to 12% of the total contractor cost in the studied small pours.
- Supplier profit. The profit margin of a RMC supplier is commonly a small percentage of the total costs. A survey of the RMC batch plants visited in this project revealed that on average the supplier's profit equates to 2% of the total contractor cost.

Labour hire cost

Labour hire costs can be broken into two groups of factors: those where labour are working on the placement of RMC (value-adding); and those where labour are standing idle for a number of reasons. For small pours, the former account for 11% of the total contractor cost, while the latter for 2% of this total cost. Three reasons for labour standing idle were identified in the observation of RMC pours: there were an insufficient number of truck mixers being used to supply the RMC resulting in gaps in the supply chain and periods were there was no RMC for the labour to place; when a load of RMC is rejected, most commonly due to failing a slump test, a gap in the supply of RMC forms as the next truck mixer will not arrive immediately – thus the labour stands idle; when the pump suffered a breakdown the labour were forced to stand idle at a cost to the contractor. The data was analysed to quantify the costs associated with these three reasons for idleness. Although idleness due to rejected loads and pump breakdowns was observed, these events occurred infrequently and thus the costs (over all the project data) associated with this idleness were negligible. It was found that 2% of the total contractor cost could be attributed to using an insufficient number of truck mixers to delivery the RMC.

Plant hire and operating costs
The contributors to plant hire and operating costs are as follows:

- Idle plant (outside pour). Plant is usually hired for a specified period of time from a specialist supplier at a fixed rate per day. Assuming that a standard working day lasts for 12 hours, plant remains on site, but idle often for significant periods of this 12 hours, at a cost to the contractor. This cost is most invisible, because of the flat-rate hire charge. It has been estimated that this causes 3% of the total contractor cost in small pours.
- Set up costs. As with any equipment there is an associated set up cost, which incorporates a 'warming up' period. It has been estimated by contractors that setting up plant could contribute 1% of the total contractor cost in a project.
- Idle plant (operating cost). When there is a gap in the RMC supply the plant is rarely switched off, thus the contractor incurs plant operating costs for this idle period. This quantity has been calculated to be worth 1% of the total contractor cost.
- Plant hire (value-adding). This is the hire cost that can be attributed to the plant being used to place RMC and thus could be called a value-adding cost. This has been estimated to equate to 5% of the total contractor cost.
- Plant operating cost (value adding). Similarly to the previous cause of cost, this is the cost (operating in this instance) that can be directly related with the placing of RMC. This cost is worth 2% of the total contractor cost.

Truck mixer surcharge
The contributor to truck mixer surcharge is the excessive idleness of the truck mixers on the project site. The RMC supplier stipulates a tolerance for the length of time a truck mixer can remain on site and to exceed this tolerance would incur the charge. There are a number of reasons for this tolerance to be exceeded, including: pump breakdown; pump operator skill level; truck mixer driver skill level; accidents on the project site; poor site access routes; site unprepared in terms of labour availability, reinforcement bars in place or formwork in place; excessive number of truck mixers being used in the system resulting in long queues of truck mixers forming on the project site, extending the time each one is present on the site.

AREAS OF FOCUS FOR COST REDUCTION STRATEGIES

A number of costs and the contributors to cost could be focused upon to achieve a reduction in the total cost of placing RMC for a contractor. These could include:

- Cost of RMC material. This is the largest single cost for the contractor in the RMC system, representing 73% and 86% of total cost in small pours and large pours, respectively. The combined value (for both pour sizes) was £973, 700 over the studied projects. From the analysis three of the causes of this cost indicate that the cost of RMC may be reduced. These are, transportation (5% total cost), supplier's overhead (12% total cost) and supplier's profit (2% total cost). If the supply chain were vertically integrated – the current external supplier were removed – it may be possible that some of these costs could be removed for the contractor. If the cost of RMC was reduced by only 1%, this would save the contractor £9, 800 – making any venture to achieve this meagre saving advantageous.

- Cost of hiring plant. A significant amount of cost (3% of total) is incurred for plant sitting idle on the project site outside of working hours, as operations rarely last for a full day. There is usually a sensible reason why pours cannot be performed continuously and thus this issue cannot be resolved. Rather it may be worthwhile for a contractor to consider re-negotiating the plant hire contract to one that allows plant to be hired on an hourly rate, allowing the equipment to be returned in some instances. The saving made by this strategy must be contrasted with the increase in costs due to additional set-up times (currently at 1% of total contractor cost). Another alternative may be for a contractor to purchase/lease the plant, given suitable market conditions (e.g. future demand for their services).
- Cost of plant and labour standing idle and the truck mixer surcharge. A balance should be achieved between using too few and too many truck mixers to delivery RMC in the system. Too few resulting in plant and labour waiting for RMC deliveries (3% total cost); and too many resulting in truck mixers queueing on site and the contractor incurring a surcharge for the truck mixers (2% total cost). A form of production control that achieves a balance in the number of truck mixers utilised to delivery RMC in a pour should be considered.

To achieve a minimum cost of RMC placement for a contractor a systemic solution to reduce costs should be applied. Such a solution would entail reducing all of the above costs as much as possible, with an obvious focus being placed upon the most significant source of cost. A possible solution is to follow the trend of aggregate producers and vertically integrate the resource (materials, plant, etc.) supply chain (Hill and Moore, 2004). Such integration is discussed further in Graham et al. (2005).

SUMMARY AND FURTHER CONCLUSIONS

This paper has presented the results of an investigation into the actual costs that a contractor incurs during RMC placement. It has been undertaken on the basis that such operations are almost always stochastic in nature, which makes planning and managing of them particularly difficult.

A further problem with the stochastic nature is that it can lead to difficulties in identifying and estimating the actual costs of a pour before it takes place. Perhaps because of this difficulty, previous studies have not attempted to fully identify all the costs of the concreting system but this paper proposed that this must be done if contractors' costs are to be reduced and allow the most significant and sensitive costs to be reduced.

Based on observations of actual concreting pours, which took place in Scotland, UK, this paper has presented the results into an investigation of where these costs lie in RMC placement. Initially, general cost areas were identified through discussion with professional practitioners: both contractors and suppliers. While the supplier costs are not specifically part of this study, it is interesting to consider where these lie. Next, actual costs sources were itemised and it is proposed that that there are five separate headings: Cost of plant idle after a pour is complete; labour cost through insufficient truck mixers; labour costs through rejected loads; labour cost through pump breakdown; and cost of placing RMC.

After analysis of the 232 observed pours it was concluded that, not surprisingly, the cost of actually placing the RMC is the principle cost for the contractor. As this is the basic cost of all resources for the duration of the actual pour, and that no idle times are considered, it is noted that cost reduction in this area would require fundamental re-management of the RMC operations such as reconfiguration of the resource supply chain. The most insignificant costs were through rejected loads and pump breakdown and thus it is proposed that these are not considered areas for improvement.

Additional contractors costs were: labour idle time caused by insufficient truck mixers and plant idle time. The second of these is difficult to consider: it was previously discussed that few suppliers would be willing to reduce the minimum hire charge period (of one day) as it would transfer the risk of under-utilisation to themselves. Reduction of this cost may be achieved through the procurement of the plant; although the under utilisation will still remain its cost will be diminished because the hire rate is likely to be greater than a repayment of a capital investment.

This leaves cost as a result of insufficient truck mixers and it has been concluded that this may be reduced by closer management and control of these resources. Contractors must work closely with suppliers to achieve this aim.

A final conclusion is that a method of reducing all of the above costs should be sought as this will result in the cost of concrete placement for contractors moving toward an actual minimum.

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