Concept of "Efficient Coordination Zone" relating to Truckmixer Deliveries Serving Construction Sites

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Abstract

Matching the provision of concrete delivered by truckmixers to the needs of the crew placing concrete on site is difficult. In general, a placing crew spends some time idle, waiting for concrete to arrive on site, and yet, at other times, on the same pour, truckmixers form a queue waiting to be unloaded. The paper presents observations deriving from many pours of concrete in Hong Kong, of the amount of enforced waiting by the placing crew and the amount of enforced truckmixer waiting on site to be unloaded. The concept of an "efficient coordination zone" is introduced, for the industry to aspire to achieve, such that no placing crew would spend more than 10% of the duration of the pour in waiting for concrete and that truckmixer provision, in waiting on site and unloading, would not exceed 150% of the duration of the pour. A new model is introduced which estimates the performance of site and plant resources matching, in relation to the pour parameters of journey round trip time, RT, and the time needed to unload a truckmixer, UL. The model assumes a fleet of N truckmixers circulates between site and plant. The model may be of practical use in aiding truckmixer schedulers.

Keywords

Truckmixer, ready mixed concrete, delivery schedule, concrete batching plant, Hong Kong.

1. Introduction

In Hong Kong, it is normal for concrete to be mixed at concrete batching plants and delivered by truckmixers to sites. As each truckmixer is unloaded on site, the concrete is placed in the formwork by the site placing crew, using placing plant such as the concrete pump, crane and skip, or other, to transport the concrete between truckmixer and formwork. Ready mixed concrete is likely to be reliably of good quality than site batched concrete on average, because the ready mixed one is mixed by concrete mixing specialists and the company maintains a good reputation for concrete quality. Ready mixed concrete is welcomed in Hong Kong construction market and used almost universally.

A batching plant usually has *N* mixing bays and *M* truckmxiers to serve *S* construction sites on any particular day. The sites are at different distances from the plant and each site. Different quantities of concrete are delivered at specific times in the day. The optimal volume of concrete that a truckmixer delivers on any one day was about 27m^3 in 2005. The values were benchmarked based on the most recent survey in Hong Kong (Tang et al. 2005). Because truckmixer drums are generally bigger today, that 27m^3 is now likely to be an underestimate.

A plant manager plans the dispatch of the *M* truckmixers to the *S* sites, according to company strategy, taking account of pour size, site requirements, and placing methods. This scheduling task is extremely difficult if truckmixers are never to be kept waiting on site to be unloaded and placing crews are to receive a continuous unbroken supply of concrete. The plant manager assigns truckmixers to any site, in "serial" dispatch mode or "circulating" dispatch mode. In "serial" mode, deliveries are made by a series of truckmixers in general, as opposed to "circulating" mode in which a small set of truckmixers circulates between plant and site until the required number of deliveries has been made.

Circulating dispatch service to a site placing crew is an example of a balance point process, a type of construction process first identified by Halpin and Woodhead (1976). The chief characteristic, is that perfect matching of resources is only possible if the potential production rate of the central operation (placing on site in our case) is an exact *integer multiple* of the production rate of a server (the truckmixer in our case). See Section 4 below for further elaboration. The truckmixer delivery cycle in the circulating case is set out in Figure 1.

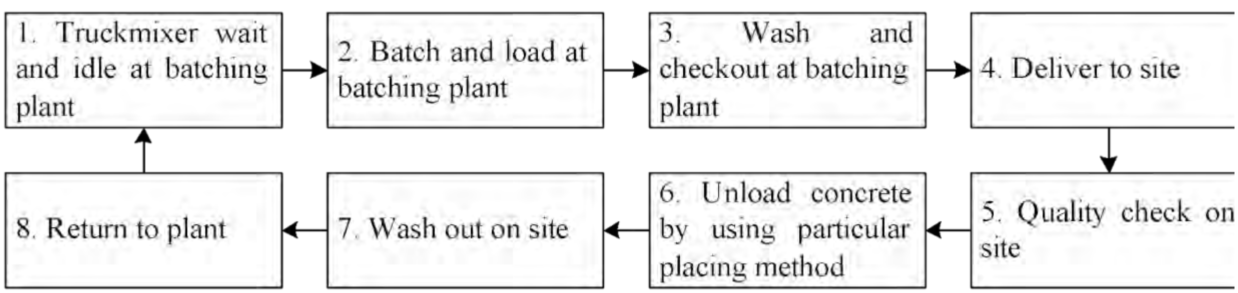

Figure 1: Truckmixer activity cycle

Once a truckmixer receives the delivery order, it moves to a plant batching bay and concrete is loaded into its drum. The truckmixer then moves to the washing and checkout area for a quality or document check, before travelling to the construction site, distant 5–25 km from the plant (Anson et al. 2002). Upon the arrival on site, the truckmixer drives to the slump and quality check area before queuing (very often), while waiting to be unloaded. Common unloading methods employ a crane and skip (tower or mobile), concrete pump, direct tip, backhoe, and others. After unloading, the truckmixer washes out on site before returning to the batching plant to await the next call. An important constraint arises from the fact that unloading should start within 1 hour 45 minutes of initial loading to avoid the risk of premature concrete setting.

The "matching" between truckmixer and crew resources achieved on sites is variable in practice and much wastage of crew and truckmixer time takes place (Anson and Wang 1998; Anson et. al. 2002; Tang et al. 2005). Too often, on the same pour, the truckmixers wait idle on site in a queue and yet, at other times, the placing crew is forced to stop work while waiting for the next delivery. Ideally, a truckmixer is unloaded as soon as it arrives on site and just as unloading of the previous truckmixer is completed.

Figures 2 and 3 are the benchmarks of the "matching" being achieved between site and truckmixer resources in Hong Kong in 1994 and 1999. The figures relate to 137 pours averaging 114 cubic metres and 118 pours averaging 69 cubic metres respectively. Perfect matching is represented by the coordinate point (0,100). Each point on the graphs represents the matching achieved on one pour. The abscissa represents crew waiting time, normalized as a percentage of the actual pour duration. The ordinate represents truckmixer time on site, both queuing and unloading, similarly normalized. The extent of the "scatter" is obvious. Only a very small proportion of pours achieve resource matching which approaches the target ideal of (0,100). This is almost certainly a measure of the difficulty of the scheduling problem, the number of economically justifiable truckmixers available in the area coupled with an inherent sensitivity of the system itself to small departures from the ideal timings.

2. Literature review

In relation to Figure 2, Anson and Wang (1994; 1998) introduced the concept of "cost efficient zone", which named as "efficient coordination zone" as marked on the figure in this research study, because the true cost effect was not determined. The plotted points within this zone represent efficient pours, where truckmixer time is not wasted excessively and waiting by the placing crew for the next delivery is similarly not excessive. All pours, for which total crew waiting is less than 10% of pour duration and truckmixers queue and unload on site for not more than 150% of pour duration, fall into this zone. The boundaries of this zone are arbitrary. It is based solely on the judgment of the researchers with reference to their studies of the concreting business and site experience. Nevertheless, in practice, it is difficult to achieve perfect matching represented by point (0,100).

For a pour of 10 deliveries taking, say, 4 hours, 10% waiting by the crew represents a wait of 2.4 minutes per delivery. This would not be seen as intolerably wasteful. The 150% "time on site" spent by the truckmixers implies roughly that when each truckmixer is halfway through being unloaded, the next truckmixer arrives on site ready to take its place. This would not seem an over-generous level of service provision by most, given that truckmixer travelling times are stochastic by nature and there can be considerable amounts of journey time variation. Just over 20% of the pours on Figure 2 fall within the "efficient coordination zone". Although arbitrary, the authors suggested that to strive for a resource matching performance within the top 20% is challenging but not daunting an aim. Accordingly, the "efficient coordination" definition for the zone as (0,100), (0,150), (10,150), (10,0) may be useful in practice. Figure 2 also shows the influence of particular unloading methods. Notably, pours unloaded by crane were generally more efficient than those unloaded by concrete pump in terms of resource coordination.

Anson et al. (2002) summarized 295 pours placed in 1999/2000, a data set derived from months of intense observation by the second author during twenty weeks spent observing the concrete delivery activities on 7 Hong Kong concrete plants (Figure 3). Only 49 of the 295 pours fell within the "efficient coordination zone". They found that 12% of large pours and 20% of small pours fell within the zone. Of course, for small pours, which need only a few deliveries, a higher proportion of all deliveries are likely to arrive in timely fashion because the early deliveries to any pour, large or small, are more likely to be dispatched close to the scheduled time. An additional factor is the high probability of an unforeseen disruption to pours of greater size and duration.

Tang et al. (2005) introduced RMCSIM (Ready Mixed Concrete SIMulation) software platform which simulated a whole day of batching plant and truckmixer activities with statistical distributions (e.g., of journey times, etc.) derived from the 1999/2000 dataset of Anson et al. (2002). As above, they found that the optimal concrete volume that a truckmixer should carry on any day is $27m^3$, and that unsatisfactory concrete delivery performances are often due to site difficulties in precise planning, and other, rather than poor scheduling at the concrete plant. Lu et al. (2003) investigated how to optimize matching performance by introducing HKCONSIM, which is a computer system for the simulation modeling and analysis of the production of the Hong Kong ready mixed concrete market. Inter alia, they simulated the performance of matching between truckmixer delivery and site demands based on the dataset of Anson and Wang (1998). 17% of their simulated pours were classified as "good" matches, thereby validating HKCONSIM. The program was then used to make experimental runs allowing some recommendations on how to achieve good matching.

To add some perspective, the optimization of resource matching, as above, is only one useful objective. For example, Matsatsinis (2004) developed an optimizing model for truckmixer travel routes and timings, for a given fixed number of truckmixers serving pumped pours on a number of different sites in Greece. The timings of the pours were varied to achieve an optimum compromise between customer service and delivery costs. Naso et al. (2004, 2007) introduced a model for a multi-plant, multi-site scenario using a genetic algorithm to produce schedules minimizing truckmixer costs including those of truckmixer outsourcing and overtime. They validated the model by a case study in the Netherlands. Wang and Halpin (2004) allocated the available truckmixers to multiple projects using simulation, regression, and mathematical models in their US study. The optimum number of truckmixers was allocated to each site such that the overall pouring rate of concrete was maximized.

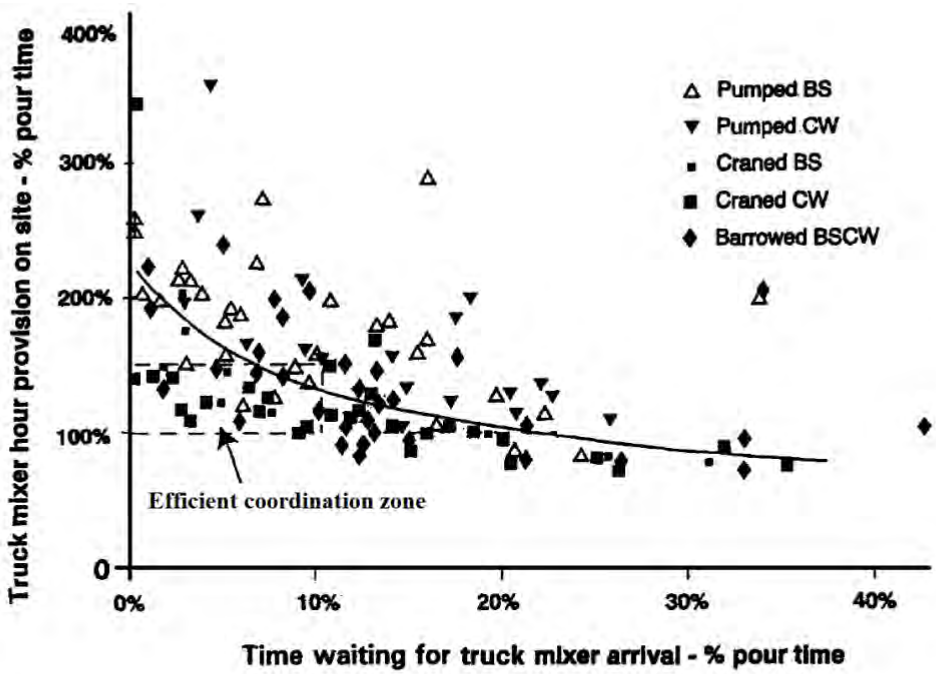

Figure 2: Truckmixer hour provision on site versus waiting for truckmixer arrival (137 pours) in 1994

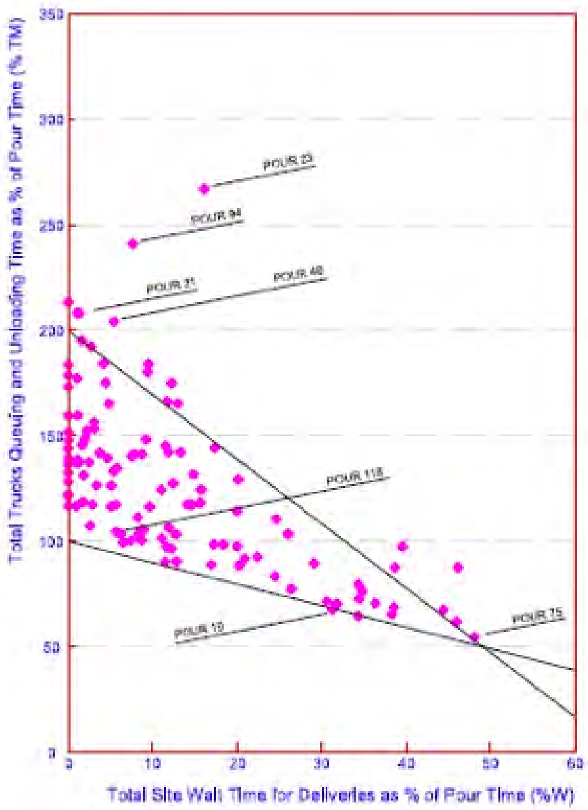

Figure 3: Matching of truckmixer queuing and unloading on site versus placing crew waiting for truckmixer deliveries (118 pours) in 1999/2000

3. Efficient coordination zone in Figure 2 and Figure 3

In both Figures 2 and 3, the lower boundary to the data distributions is governed by the equation %TM+%W=100. No point can plot below this line. It is a genuine lower bound. For points plotted on that line, no truckmixer ever has to queue and truckmixer time on site (TM) is spent wholly in unloading. But the total pour time must be TM plus the time spent by the crew in waiting for truckmixers to arrive (W), so, %TM+%W=100. Any point plotting above the lower boundary means that some queuing took place on that pour. Only for the points exactly on the line experienced no queuing.

Similarly, we can note that a number of points on Figure 3 plot exactly on the left hand boundary, %W=0, though only a few on Figure 2. Such plots represent pours where the placing crew had fresh concrete at its disposal throughout the pour.

The upper boundary is drawn arbitrarily on Figure 3 as it includes most of the points in the sample. The governing equation is %TM+3×%W=200. Thus, in general for any point in that sample (%TM+%W)>100 and (%TM+3×%W)<200. Unfortunately, if the same upper bound line were to be drawn on Figure 2, a significant number in the sample would lie above the line.

4. Efficient coordination zone for circulating dispatch

In this research study, circulating dispatch is of particular interest. As above, a set of N truckmixers circulates between plant and site until the pour is completed. The site's actual placing rate dictates the intervals between truckmixer departures from the site and hence strongly influences the intervals separating their returns to site after refilling with concrete. The result, theoretically, is better coordination as measured by %TM and %W. On the other hand, as a balance point process, we know that perfect matching is impossible unless the ratio of site production rate to truckmixer production rate is exactly an integer. If UL is the time it takes to unload a truckmixer and RT is the truckmixer round trip time (finish unload until arrive back on site), the ratio is represented by RT/UL. If N is chosen as 1+RT/UL, perfect matching occurs if RT/UL is indeed an integer. Otherwise, if N>1+RT/UL, %TM is always >100 and %W=0. If N<1+RT/UL, both %W and %TM are >0 and the two sum always to 100.

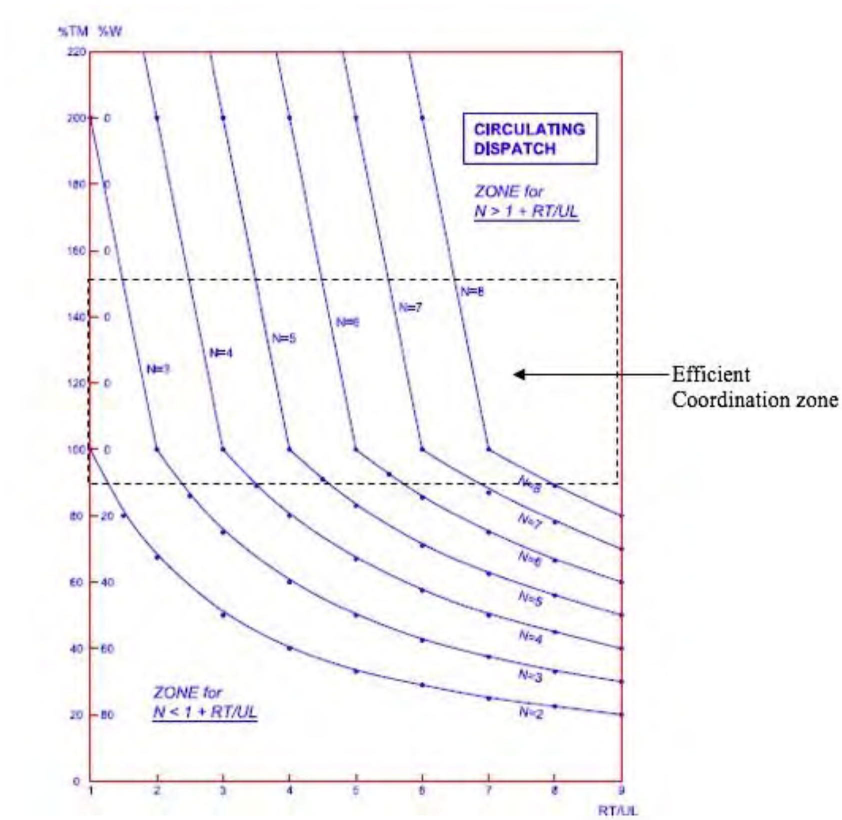

Figure 4: Circulating dispatch relationships between RT/UL, N, %W and %TM

A newly derived set of curves is plotted in Figure 4 (currently, under journal review). The curved lines are expressed by %W=100×[1–N/(RT/UL+1)], and the straight lines by %TM=100×(N–RT/UL). The diagram complements the balance point diagram of Halpin and Woodhead (1976). It augments the theory to the extent that the productivity of the server units (truckmixers) is directly provided as well as that of the central process (placing concrete in the forms). For various values of RT/UL and a given N, a graph can be plotted giving a direct read off of the resource wastage indicators %TM and %W. Figure 4 includes curves for values of N between 2 and 8.

The upper part of Figure 4, relates to N>1+RT/UL, the lower part to N<1+RT/UL. The discontinuities where the upper straight and the lower curved lines join occur when RT/UL takes integer values. These correspond with perfect matching predictions of %TM=100 and %W=0 on the left hand axis. A square is plotted on Figure 4. All points on the graphs within the “efficient coordination zone” represent efficient matching performance.

The curves are of practical use. For example, if a projected site estimates an unloading time, UL, of 25 minutes and the concrete plant manager estimates a round trip time, RT, of 50 minutes, then RT/UL is calculated as 2. As such, 3 truckmixers will be assigned to circulate with predicted perfect matching if RT and UL were to somehow remain constant for all deliveries. If, however, the site had predicted a UL of 20 minutes, 1+RT/UL would be 3.5, not an integer. The plant would assign either 4 or 3 truckmixers to circulate. If 4, there is an oversupply and %TM is 150 which can be directly read off from Figure 4. If 3, there is an undersupply and %W=14 and %TM=86 as given by Figure 4.

The curves in Figure 4 assume RT and UL both remain constant throughout the pour. This ideal scenario produces matching predictions that only lie either on the left hand axis of Figure 3 or on the lower bound line. Nevertheless, the authors proved that the plotted points do move off the boundary lines and into the "wedge" of Figure 3 by simulating the stochastic characteristic of the delivery process associated with individual truckmixers. However, it is not within the scope of this paper.

5. Conclusions

In connection with the complex problem of planning the supply of a string of concrete truckmixer deliveries to a construction site, the concept of "efficient coordination zone" is introduced. The points within the zone indicate the efficient plant and site coordinations such that the truckmixers do not wait excessively on site to be emptied and placing crews do not wait excessively for the arrival of the next delivery.

This zone is marked on Figure 2 and Figure 4 and is defined by the following two conditions:

1. The total amount of time spent by the site concreting crew in waiting for concrete deliveries is within 10% of the overall duration of the pour concerned.
2. The total amount of time spent on site by truckmixers in queuing and unloading (being emptied) is not greater than 150% of the pour duration.

These percentages are arbitrary but are potentially useful to the Hong Kong industry because a new coordination benchmark is produced. It is possible, though by no means certain, that coordination has improved over the last 20 years. In fact, the concept of the "efficient coordination zone" is important. The actual zone "dimensions" would differ from place to place. It is not likely that a practical definition of an "efficient coordination zone" would be the same for a rural region of England, say, as for the dense city of Hong Kong.

The paper introduced a analytical model, applicable only to deliveries made in circulating mode, which predicts %TM and %W values for any given ratio of RT/UL, whether an integer or not, and any value of N, the number of circulating truckmixers. RT and UL are constant throughout the pour. RT is the round trip time defined as "finish unloading on site until return to site having refilled with concrete. UL is the time it takes to unload a truckmixer. It is suggested that the managers of batching plants and construction sites might formally take account of the expected RT and UL values when planning the allocation of truckmixers to significant pours and use the model to choose a value for N likely to minimise truckmixer and placing crew time wastage such that its point will fall within the "efficient coordination zone".

Notably, there are outliers in Figure 2 and Figure 3 may have particular underlying causes other than the pour parameter and scheduling aspects discussed above. In future, a range of possible reasons for detecting and classifying the outliers will be studied by using the techniques of simulation and statistical analysis.

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