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Benchmarking site-plant resource matching performance of ready-mixed concrete delivery and placing

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ABSTRACT

Since on-time concrete delivery is important to both contractors and suppliers, performance benchmarking of the concrete delivery process, as actually achieved in practice, is a worthwhile undertaking of potential benefit to the construction industry. However, there has been no thorough such benchmarking in Hong Kong for 20 years, since the study by Anson et al. (2002). This research study has provided an up-to-date benchmark of the site/supplier resource matching, or coordination, performance for big building superstructure pours, based on study of the records of 77 pours placed on five buildings under construction in Hong Kong. This research study also aimed to assess whether there was any evidence to suggest that site/plant coordination performance has improved since 2000, not least due to the adoption of advanced technologies, which nowadays monitor the locations of truckmixers in real time throughout the day. Of great importance to the industry, however, and the most significant finding arising from this study, is that there is no support for the proposition that site/supplier resource coordination has improved over that 20-year interval. Truckmixer position tracking systems need to be capitalised upon with the introduction of data analysis simulation software and optimising scheduling applied in real time.

KEYWORDS RMC delivery; resource matching performance; resource matching; matching performance; building projects
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1. Introduction

Ready-mixed concrete (RMC) is produced off-site and delivered by RMC plant-based truckmixers to construction sites. The quantity of RMC needed and the ingredient proportions (i.e., cement, water, sand, aggregates and admixtures) are custom-made to client requirements and specifications (Shah et al., 2014). The key features of consistent high-quality concrete and the saving of space on site have made RMC the favoured choice for contractors, especially in Hong Kong, as congested sites are very common. For these reasons, RMC is much more commonly used than site-mixed concrete on construction projects in general.

In Hong Kong, contractors, as the purchasers of RMC, are generally required to place orders with RMC plants three days before the date that concrete will be poured. The RMC suppliers may confirm the contractors' orders the day before the required delivery date (Lu and Lam, 2009). In general, each RMC plant in Hong Kong serves multiple sites, scattered geographically, in meeting demand on any particular day. According to Anson et al. (2019), the number of deliveries each truckmixer makes in Hong Kong is generally four to six per day, and the truckmixer fleet based at the typical RMC plant may serve 15 to 25 sites, all at different distances from the plant. Adding further scheduling complexity is that pours vary considerably in size, requiring only one delivery at one extreme and up to perhaps 25 deliveries at the other.

RMC suppliers generally play a dual role during the RMC delivery process, acting as the concrete manufacturer and logistics planner at the same time. The suppliers have to design an efficient schedule to match the on-site concrete activities and capacities, giving consideration to the resources existing, including the availability of truckmixers and batching equipment. Balancing both plant resource allocation and client capability and placing rate capacity is a most challenging task for RMC suppliers. Further, RMC delivery times need to be well-determined and controlled due to the perishable property of RMC. Wet concrete will have already started to harden if the duration between concrete placing on site and the introduction of mixing water at the plant is too long, though a suitable admixture can be added to RMC to extend, to some extent, the viability of concrete in its fresh state (Tommelein and Li, 1999). A safe duration is suggested to be within one hour and 30 minutes or within 300 revolutions of the drum (ASTM C94/C94M, 2020). In Hong Kong practice, RMC is generally unloaded on site within a maximum of one hour and 45 minutes (Lu and Lam, 2009). Beyond that time, contractors have the right to reject the RMC and require a replacement delivery, but this undoubtedly seriously interrupts the plant's schedule and on-site concreting progress, adding to both the RMC supplier's and contractor's costs.

A productive RMC process requires a high standard of coordination between concrete supply and demand. The productivity of concrete placing depends on punctual concrete supply and the ready availability of on-site placing crews and their placing equipment. The productivity of RMC delivery is governed by the logistic schedule, which is based on the site orders received and site factors such as queueing time (Anson and Wang, 1998). Placing crews are idle if RMC delivery is delayed. Therefore, optimisation of RMC productivity must take into account both the RMC supply system and the site's concrete placing resources, requiring good cooperation and communication on both sides (Anson and Wang, 1998). An optimum RMC process balances both concrete supply and concrete placing productivities benefitting both RMC suppliers and contractors. The ideal matching of resources is achieved when concrete truckmixers never queue on site waiting to be unloaded and the concrete placing crews are never idle waiting for concrete to arrive on site.

The studies related to benchmarking of RMC resource matching performance are comparatively few, in Hong Kong and internationally. "RSMeans" is the most comprehensive database for cost and time estimation commonly used in North America and worldwide (RS Means Co., 2020). However, the database does not have productivity benchmarks for RMC delivery. Notably, "Daily output" is not available in RSMeans. Therefore, that omission warrants this benchmarking study.

2. Literature review

The references cited were mainly found through Google Scholar, HKPolyU, OneSearch, and the reference lists of related journal articles. As this research study focused on the benchmarking of resource matching performance, the literature review only relates to the methods of data collection and actual past benchmarking of concreting in Hong Kong. The vast array of literature on simulation and optimisation studies, for example, is only of tangential relevance to the work involved in this study.

2.1. Technologies for collecting RMC delivery process data

Lu et al. (2004) conducted two experiments in Hong Kong to assess GPS performance in high density urban areas. One experiment was carried out in which a cellphone with an embedded GPS receiver was installed on the truckmixer's dashboard and transmitted truckmixer positions to the control centre by SMS. However, positioning performance was found to be unsatisfactory, as real-time location and truckmixer activity could not be accurately determined. They stated that possible reasons were satellite signal blockages and/or multi-path signals due to reflections off adjacent buildings and structures on site. This problem was especially significant in urban areas of high density. After identifying these GPS system limitations at that time, Lu et al. (2007) developed a more comprehensive navigation system for RMC delivery tracking, which integrated GPS with Dead Reckoning (DR) and Bluetooth Beacon (BB). Their experiments showed that DR did allow continuous location records even though GPS signals were blocked, records which closely matched the actual path followed (Lu et al., 2007). As this integrated system was combined with the Global System for Mobile Communication (GSM)/General Packed Radio Service (GPRS) network technology, it allowed the transmission of key event data to the control centre in real time through SMS for further monitoring and analysis. This system proved to be reliable during a one-year field experiment conducted by Lu et al. (2007). RMC companies, however, to control costs, prefer to adopt a simple GPS tracking system by installing a GPS Blackbox on the truckmixer. When a GPS signal blockage problem occurs, a common solution is to either call the driver directly, if possible, or to contact the site manager to ascertain the truckmixer's status.

In the benchmarking studies of 20 years ago, three key event times (i.e., arrive on site, start unloading, finish unloading) were recorded manually through direct observation. However, the adoption of advanced technology nowadays has greatly enhanced data collection efficiency, allowing these data to be collected and stored automatically into a database. To record the time "arrive on site", a geo-fencing technique is adopted. According to Rahate and Shaikh (2016), geo-fencing associated with a GPS system enables the users to define a zone on a map to form a virtual barrier. Once the device enters or leaves the specified area, notification is made to the users and the status of the device is therefore determined. The RMC supplier can define a geo-fenced area as the site boundary. Thus, the time "arrive on site" is automatically recorded when the truckmixer enters the geo-fenced site boundary. The times "start unloading" and "finish unloading" are recorded by a magnetic rotation sensor installed on the truckmixer drum. A clockwise rotation represents the start of unloading and anti-clockwise the end of unloading. The rotation sensor is compatible with Wi-Fi and GPRS technology and can be integrated with the existing GPS tracking system to transfer the "start unloading" and "finish unloading" data to the control centre. This data can then be used for further analysis and real-time scheduling using simulation and optimisation techniques.

3. Past performance benchmarking of RMC delivery in Hong Kong

According to Anson et al. (2019), benchmarking reveals the existing standards being achieved and helps to identify those key factors which govern productivity standards. The first benchmarking study of RMC with a relatively large sample in Hong Kong was conducted by Anson and Wang (1994). Direct observation data on site for 137 concrete pours on multi-storey buildings were recorded manually in 1991–1993. These pours were divided into pumped pours, crane and skip pours, and hoist and borrow pours. In order to assess the impact of the different placing methods on concrete placing rates, Anson and Wang (1994) also investigated the effect on placing rates of pour size and pour shape such as deep wall and column elements versus shallow beam and slab pours. To benchmark the performance of RMC delivery in terms of good matching of plant and site resources, there was proposed the concept of a "cost-efficient zone". For a pour to fit within the zone, *%TM*, the total time spent on site by all truckmixers expressed as a percentage of actual pour duration, must be less than 150% and *%W*, the total time waiting for concrete with no truckmixers on site, must be less than 10% of the actual pour time. Lower *%TM* values mean less TM queuing and less interference with the supplier's multi-site delivery schedule, while low *%W* values represent good continuity in the placing process. In fact, of the 137 pours, more than 80% fell outside the cost-efficient zone, with many well outside.

Anson et al. (2002) similarly investigated a more representative Hong Kong sample in 1999–2000. The study included 295 concrete pours placed over 15 days and based on four RMC plants. The pours covered building, civil and geotechnical engineering projects divided into 118 larger pours averaging 70 m^3 (pour size > 20 m^3) and 176 smaller pours (size < 20 m^3). Large pours were thought likely to exhibit more queuing on site by truckmixers, simply because more deliveries would be made. The results of the study showed this to be the case. Truckmixers queued for more than 10 minutes on average on 52% of the large pours, but for only 37% of the small pours. In addition, the larger pours were less cost-efficient than the smaller pours, with only 12% of pours falling within the cost-efficient zone compared with 20% of the smaller pours. Note, nevertheless, that both types of pour displayed poor matching of site and plant resources. Of the 295 pours, as many as 83% fell outside the cost-efficient zone.

A recent study by Anson et al. (2019) reported an attempt to understand the reasons underlying the poor matching of resources for those 118 larger RMC pours reported in 2002, of four or more deliveries, averaging 11 deliveries per pour. The pours took place on building, geotechnical, and civil engineering sites. The number of building projects involved was not identified by the authors. The concept of the "resource wastage distribution graph" was first raised. This distribution pattern was wedge-shaped. The smaller the area of the "wedge", the better would be the coordination between suppliers and contractors. For those 118 pours, the distribution pattern, with its obvious high degree of variability, shows the apparently poor matching actually occurring in Hong Kong at that time, a pattern very similar to that applied to the 137 pours of the earlier study (Anson and Wang, 1994). Those authors inferred that the wedge graph visualisation of resource matching performance helps us to understand the importance of the coordination factor in achieving good concreting productivity and provides a way of measuring and presenting the effects of future attempts by the industry to improve coordination.

4. Nomenclature

4.1. Definitions of technical terms

Table 1 shows the definitions of technical terms.

Table 1. Definitions of technical terms.

Variable	Definitions
Pour duration	The total time interval between "start unloading" for the first delivery and "finish unloading" of the last delivery for that pour.
%TM	TM as a percentage of pour duration (or equivalent pour duration defined as below).
Interruption of concrete supply (W)	The total duration of idling time of on-site placing crews waiting for concrete. The calculation of W is the sum of the intervals between "finish unloading" for each delivery and "start unloading" for the next delivery.
Total truckmixer provision on site (TM)	The duration of truckmixers waiting to be unloaded after the arrival on-site plus on-site unloading times. Thus, the calculation of TM for each pour is the interval between "arrive on site" and "finish unloading".
%W	W as a percentage of pour duration (or equivalent pour duration defined as below).

4.2. Equivalent pour duration

During the 77 building pours studied by the authors in the case study of this paper, it was observed that sometimes two, three, and occasionally even four truckmixers were unloaded concurrently. For calculation of the values of *%TM* and *%W*, these simultaneous unloadings need to be taken into account if comparison is to be made with the sample of 2002 when truckmixers were unloaded sequentially, one by one. The concept of the "equivalent pour duration" is proposed, defined by Equation (1), as partial compensation for the additional allocation of site unloading resources compared with the normal pour.

Equivalent Pour Duration = Actual pour duration + Total duration of 2 truckmixers unloading concurrently + 2 × (Total duration of 3 truckmixers unloading concurrently) + 3 × (Total duration of 4 truckmixers unloading concurrently). (1)

Calculations of *%TM* and *%W* derived from Equation (2) and Equation (3).

%TM = Total truckmixer provision on-site (TM) / Equivalent pour duration × 100%. (2)

%W = Interruption of concrete supply (W) / Equivalent pour duration × 100%. (3)

5. Methodology

Figure 1 is a flowchart of the method used in this benchmarking study. The study data was provided by simple GPS tracking. GPS Blackboxes were installed in all truckmixers and positional data transferred back to the control centre by GPRS. The three key event times, mentioned above, were obtained in this way for each truckmixer delivery. Table 2 shows the full database structure in Excel format, as extracted from the control centre database of the RMC supplier assisting the study. Columns 4, 5 and 6 are the three event times required for construction of the performance wedge. The RMC supplier who kindly provided the data for this study had installed and implemented a truckmixer tracking system in 2013. The RMC supplier emphasises that all truckmixer delivery records could be provided to the research team, if required. Nevertheless, the datasets of the five very similar building superstructure designs selected for this study were comprehensive and reliable, and likely to give a realistic coordination benchmark measure for this particular type of concrete pour. The concrete design features of the five buildings were similar and the construction method identical in each case. The concrete deliveries, from project start dates to project end dates, were all subject to minimal "noise" interference (e.g., GPS errors due to interference from neighbouring buildings) and none of the projects were much affected by the social unrest occurring at that time or by COVID-19.

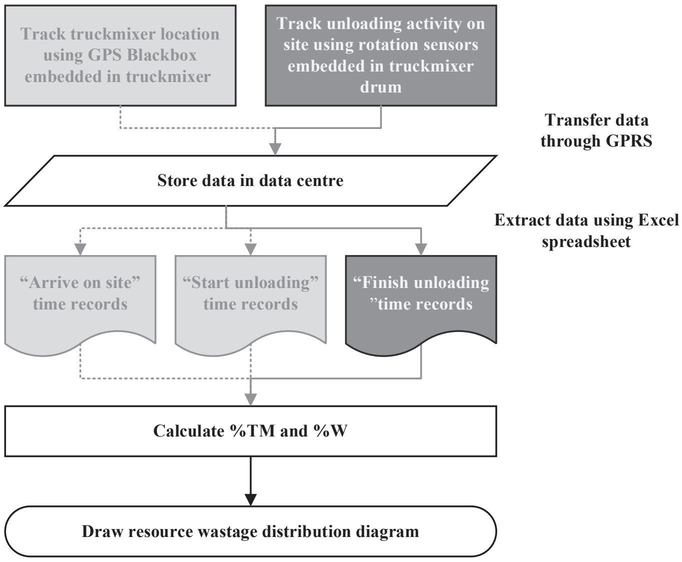

Figure 1. Method used to obtain benchmarking productivity data.

Table 2. Structure of extracted dataset.

I. Concrete plant	II. Delivery date	III. Delivery number	1. Delivery quantity	2. Start time	3. Leave plant	4. Arrive site time
1	5/2/2019	1	4.3	07:30	7:58	8:44
1		2	4.5	10:22	10:35	11:08
1	5/3/2019	3	1	12:10	12:20	12:54
1		4	8	12:12	12:26	12:58
1		5	8	12:38	12:54	13:26
1		6	7.5	13:14	13:35	14:15
1		7	8	13:32	13:47	14:23
1		8	8	13:52	14:08	14:42
1		9	8	14:04	14:19	14:54
1		10	8	14:47	15:01	15:34
1		11	8	14:57	15:20	15:47
1		12	8	15:12	15:27	15:58
1		13	5	08:41	8:53	9:47
⋮	⋮	⋮	⋮	⋮	⋮	⋮
I. Concrete plant	II. Delivery date	III. Delivery number	5. Start unloading time	6. Finish unloading time	7. Leave site time	8. Dispatch point
1	5/2/2019	1	9:10	11:43	11:49	B3
1		2	12:14	14:18	14:19	B3
1	5/3/2019	3	13:05	13:25	13:30	B1
1		4	13:03	13:38	13:49	B1
1		5	13:31	13:55	14:05	B1
1		6	14:25	14:45	15:00	B1
1		7	14:28	14:57	15:09	B1
1		8	14:50	15:25	15:31	B1
1		9	15:00	15:42	15:47	B1
1		10	16:11	16:14	16:19	B1
1		11	15:50	16:14	16:25	B1
1		12	16:04	16:42	16:50	B1
1		13	9:52	10:35	10:51	EXT
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Based on the calculation of all key variables above, the resource wastage distribution wedge graph was constructed to review the resource matching performance. Figure 2 is an example deriving from this study. The y-axis gives *%TM* and the x-axis gives *%W*. The truckmixer provision on site, TM, includes only the durations for queueing plus unloading, not any other component of time on site. The bottom line of the results wedge connects the Coordinate (0, 100) and Coordinate (80, 20), represented by the equation "*%TM*+*%W*=100", as it is impossible for any point to appear below this lower bound line. For comparison purposes, the arbitrary upper line is positioned in the same place as the line of Anson et al. (2019), drawn from the point (0, 200) to the point (50, 50). In spite of the differences in the method of calculation of *TM* and *W*, the wedge diagram results of this study are compared below with the wedge diagram of the 2002 studies (Anson et al., 2019) to ascertain whether there is evidence of any improvement in coordination since 2002. Improvement might well be expected because of improvements in technology over the last 20 years. Because of the GPS systems mounted on truckmixers nowadays and because of sensors on truckmixer drums and wireless information transmission technology improvements, detailed real time knowledge can be obtained of truckmixer locations and when truckmixers are actually discharging concrete, meaning that more optimal and better coordinated control of truckmixer movements is potentially possible today in real time. Also, perhaps, because the study sample pours were all similar in type, unlike the 2002 pours, less variability between them in coordination performance might be expected.

One major difference between the 2002 and 2020 research studies is the method of recording the timing of truckmixer movements. For the 2002 sample, manual recordings based on direct observation by research personnel and by driver records were made. For the dataset used by this paper, sensors and GPS tracking technologies provided for automatic tracking and timing of truckmixer activities.

Nowadays, all such data would be transferred to the cloud database. The raw data can be extracted and exported easily. The human error involved in data collection in this research study was thus minimised thanks to the advancement of technology. Tracking systems began to be adopted by some Hong Kong RMC suppliers in about 2006. The data provider for this 2020 study adopted such a system in 2013, eight years ago.

6. Results

For this paper, access was obtained to 2018–2020 site and plant timing data relating to superstructure pours on buildings in Hong Kong. This section presents the resource matching performance achieved on the five building projects in Hong Kong in 2020, totalling 77 pours (each pour > 20 m^3) and 931 truckmixer delivery trips. The average pour size was 87 m^3, approximately 12 deliveries per pour on average. All were building superstructure pours. Information about each project is given in Table 3. The resource matching coordination performance achieved on each project is given in Table 4. The resource matching coordination performance achieved on all project is given in Table 5.

Table 3. Information on the five building projects.

Project	First day of concrete placing	Last day of concrete placing	No. of large pour involved	Total no. of truckmixer trips involved
A	01-Apr-2019	30-May-2019	34	440
B	01-Aug-2019	15-Aug-2019	12	178
C	20-Jan-2018	24-Mar-2018	13	99
D	01-Aug-2020	15-Aug-2020	8	83
E	01-Nov-2019	15-Nov-2019	10	131
Total			77	931

Table 4. Performance of each project.

Project no.	Average pour size (m^3)	Mean *%W*	Mean *%TM*	Average truck idle per delivery (minutes)
A (34 Pours)	92.8	14%	119%	13.04
B (12 Pours)	103.5	30%	118%	14.81
C (13 Pours)	58.6	43%	94%	12.26
D (8 Pours)	75.8	31%	133%	19.69
E (10 Pours)	93.2	21%	116%	13.4

Table 5. Performance of all projects.

All pours	Average pour size (m^3)	Mean *%W*	Mean *%TM*	Average truck idle per delivery (minutes)
All projects (77 Pours)	87	24%	116%	13.92

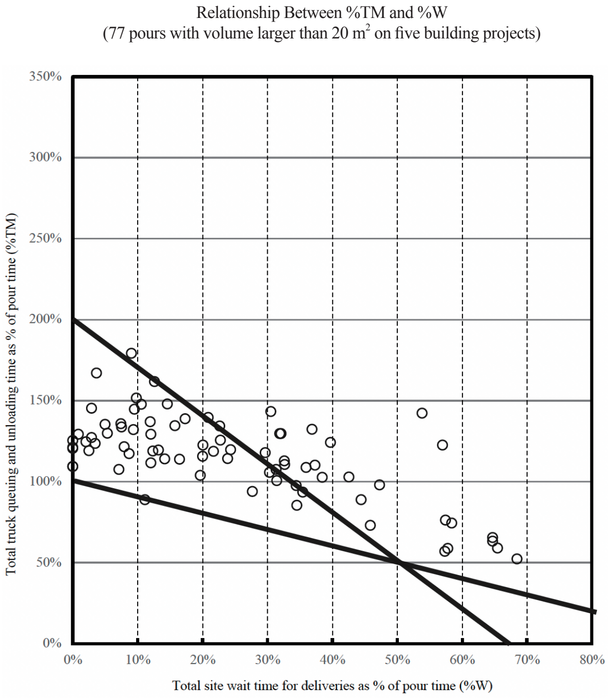

Figure 2. Resource wastage distribution for 77 pours on five building projects.

The results of this study are mainly compared with the 118 pours of 2002 (Anson et al. 2019). The average pour size of those 118 pours was 69 m^3, similar to the 77 pours of this 2020 study, which averaged 87 m^3. The 2020 result, Figure 2, shows a pattern broadly similar to that of the study of Anson et al. (2002) in that the scatter, or variability, in the coordination performance of different pours is still very considerable, even though this study took place within the era of GPS tracking systems, computer simulated system behaviour analysis and computer produced truckmixer delivery schedules. These technologies have the potential to improve resource matching between RMC suppliers and contractors, partly because real-time data and the status of each delivery is available to both parties and the data records are available for performance analysis and prediction.

In contrast with the past study (118 pours in 2002), this study (77 pours in 2020) shows no significant improvement in RMC resource matching performance. Table 6 and Figure 3 compare *%W* and *%TM* values for the 2020 study and the 2002 studies.

Table 6. Comparisons of *%W* and *%TM* based on 2020 study and 2002 study.

Benchmarks	Criteria	2020 (77 pours)	2002 (118 pours)
%W	Average *%W*	24%	13%
	%W < 40%	82% of pours	95% of pours
	%W < 10%	30% of pours	57% of pours
%TM	Maximum *%TM*	179%	200%
	Average *%TM*	116%	127%
	%TM < 150%	95% of pours	80% of pours

The average *%W* of the 77 pours is 24%, much higher than the 13% for the 118 pours of 20 years ago. 82% of the 77 pours achieved interruptions in concrete supply, *%W*, of less than 40%, not as good as 95% of the 118 pours of 20 years ago. Only 30% of the 77 pours achieved a *%W* performance lower than 10%, compared with 57% of the 118 pours of 20 years ago.

On the other hand, the maximum *%TM* of the 77 pours is 179%, lower than the 200% for the 118 pours of 20 years ago. The average *%TM* of the 77 pours is 116%, also better than the 127% for the 118 pours of 20 years ago. 95% of the 77 pours achieved a *%TM* performance of less than 150%, compared with 80% of the 118 pours of 20 years ago.

Thus, a reduction today in queuing time by truckmixers on site is countered by increased waiting for concrete to arrive on site. It cannot be said, therefore, that this study indicates any improvement in the matching of site and plant resources (coordination performance) due to the advanced technologies in use today. But, it might be very tentatively inferred, on this particular comparison, that the new technologies that the concrete supply industry has invested in might have resulted in improved truckmixer utilisation rates – but at the expense of more placing crew idle time.

A factor to report, which affects truckmixer scheduling, is a particular company practice which puts a constraint on the scheduler's freedom to achieve optimum truckmixer utilisation. Since payments to a truckmixer driver depend on the number of deliveries made, and because some of the drivers themselves own their truckmixers (though painted in the company's colours and displaying its logo), care is taken that all drivers make roughly the same number of deliveries in the day. Owner drivers are not treated differently from company drivers in this respect. Simulation studies could readily be made to ascertain the degree of significance of this practice.

In a focus group meeting that included two project managers with 30+ years of experience in scheduling concrete delivery in a partnering company, the experts agreed that the concreting scheduling problem can be visualised using the truckmixer tracking system. However, in practice, decision-making systems able to predict and rectify potential delays in good time have not been installed. Any truckmixer re-allocation is made by plant managers based purely on their own personal experienced judgement.

If the next development of truckmixer tracking systems includes the functionalities of concrete delivery simulation and optimisation, this would be extremely valuable to the concrete industry both locally and internationally.

One concern is the difference between the 2002 and 2020 samples. Like is not being strictly compared with like. Firstly, the 2002 sample was more representative of the full range of types of pour. The 2020 sample was confined only to pours on big buildings and to only superstructure pours at that. Secondly, in the case of the 2020 data, the site was able to unload two, three, and occasionally even four truckmixers concurrently through the provision of additional concrete placing crew and equipment, no doubt to speed-up overall concreting progress when needed. For instance, one of the pours of Project E used both a concrete pump and a crane and skip for concrete placement for some of the time, enabling two truckmixers to unload simultaneously. Naturally, this provision of additional unloading resources would reduce overall truckmixer waiting time on site, resulting in lower TM values. In this study, for 78% (60/77) of the pours, some degree of parallel unloading took place from time to time, a factor contributing to the improved *%TM* performance of the 2020 sample.

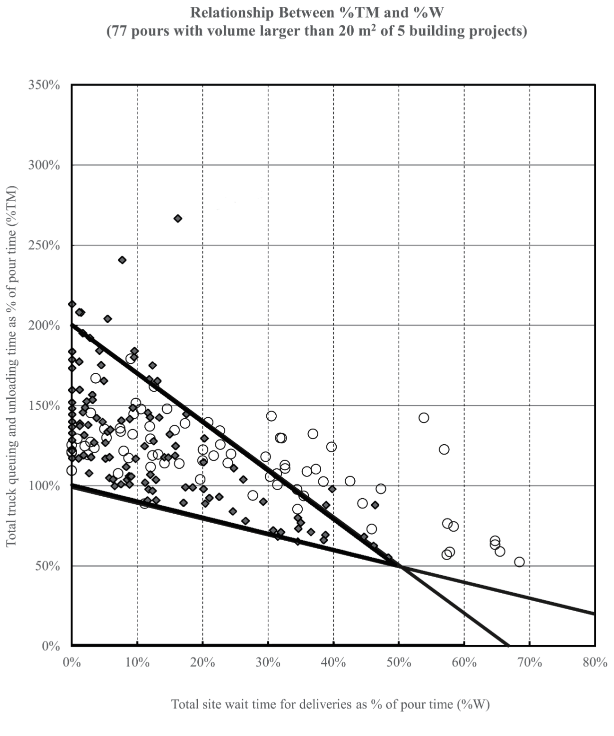

Figure 3. Similar pattern between the 2002 results of Anson et al. (2019) (diamonds) and this study (circles).

7. Conclusions

The academic contributions of this study are: (i) highlighting the differences between modern GPS and sensor-based methods of tracking truckmixer positions in real time and the laborious, more error-prone methods based on direct observation of 20 years ago; (ii) re-introducing the graphical wedge-shaped visualisation diagram which provides an immediate picture of resource coordination performance – ideal for comparing past and present performances very quickly and recommended as a way of presenting future benchmark measurements; (iii) making clear the urgent need for future research to develop simulation and optimisation software for use in real time, linked with truckmixer tracking systems, to improve the productivity performance of the concrete supply system.

One practical contribution of this study is the provision of an up-to-date benchmark for a sizeable sample of building superstructure concrete pours in Hong Kong, which enables practitioners to compare their own performance with the benchmark, with the view to improve on it. The sample was compared with a benchmark of 20 years ago to see if there is any evidence that the plant and site coordination performance measured then has improved, perhaps as a result of the GPS systems and the simulation-based scheduling software available today. There has been no benchmarking of coordination in Hong Kong during those 20 years. A further contribution of the study, probably the most significant, is that there was no such evidence of coordination performance improvement, a cause for some concern, given the investments made in the various tracking technologies. The fact that similar patterns of coordination performance are seen for both 2002 and 2020 is a disappointment. The modern ability to know exactly where every truckmixer is located in real time, not possible 20 years ago, should enable real time decision-making to occur aimed at reducing waiting by placing crews for concrete to arrive on site and reducing truckmixer time wasted when bunched on site waiting to be emptied. In addition, this study has shown the potential engagement of practitioners in advancing the current research study by routinely supplying truckmixer tracking data to help in developing scheduling-simulation and optimisation engines and increasingly accurate concrete delivery tracking. This research study also provides an improved methodology for deriving concrete resource usage benchmarks by taking account of the fact that, in general, truckmixers might be unloaded by more than one placing crew on a particular pour, rather than purely sequentially as in the 2002 data set.

The results do indicate some reduction in truckmixer overprovision, but this is at the expense of site productivity, as placing crews waited for concrete for longer periods than was the case with the 2002 dataset. In fact, the 2020 sample of pours related to more flexible concrete unloading arrangements than the sample of 20 years ago, when truckmixers were unloaded one by one in sequence, with no cases of two or more truckmixers being unloaded simultaneously. It is only to be expected that time lost to truckmixer queuing on site would be reduced by any ability to unload truckmixers simultaneously from time to time with the consequent improvement in *%TM*, as was measured in the 2020 dataset. It cannot be inferred, therefore, that the observed improvement in truckmixer overprovision is a consequence of the new technologies in use.

Even though it is difficult to make precise comparisons between the old and new sets of results, since the 2002 data set is representative of pours of all types whereas the 2020 date applies only to broadly similar building superstructure pours, it might be expected that the 2020 results would be more consistent than those of 2002, because of the reduced element of human error in recording truckmixer movements and because the 77 pours are much more like each other than the 118 pours of 2002. Moreover, assuming that the 77 building superstructure sample of pours is big enough to detect whether there has been an improvement over the 20 years in plant/site resource coordination, and also is enough for a realistic 2020 benchmark to be attained for concrete superstructure pours in Hong Kong, then it is all the more striking, and important to note therefore, that the study found no evidence to support the hypothesis that plant/site resource coordination has improved over the last 20 years.

Advanced technologies can potentially enhance the efficiency of scheduling and management, and facilitate communication between contractors and RMC suppliers, but the tracking outputs need first to be linked in real time with modern simulation software and an optimisation engine, for starters, capable of predicting both resource shortages and overprovisions an hour or two ahead and recommending resource reallocation decisions to alleviate those shortages and overprovisions. Perhaps when such capabilities are used to their full extent, more positive coordination and productivity outcomes will result.

Further work is needed for more rigorous comparison with the benchmark of 2002, requiring a 2020s study sample which includes a wide range of representative pour types and pours supplied by different RMC suppliers. There is, as yet, no evidence that new technologies are improving the productivity of the site concreting system. It is necessary to check into this question further and to study the extent to which the new capabilities might be the most effectively utilised.

This research study has revealed a practical constraint to be taken account of in seeking optimum solutions: the practice in Hong Kong to pay drivers based on deliveries made, not on the time they are available to the plant. One set of computer-produced schedules, therefore, should aim to give similar delivery opportunities to all drivers on duty that day. There is also future research work to be done to make sure that the industry, with the help of modern real-time scheduling software, learns to capitalise on the fact that the locations of all truckmixers based at a plant are known at all times, and that when they reached those locations is also known.

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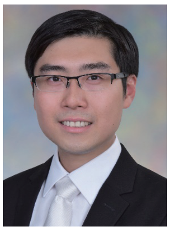

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