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OPTIMIZED CONCRETE DELIVERY SCHEDULING USING COMBINED SIMULATION AND GENETIC ALGORITHMS

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ABSTRACT

The research presented is mainly focused on how to simultaneously optimize concrete delivery scheduling and resource provisions for ready mixed concrete (RMC) plants based on a valid simulation modeling platform resulting from research, called HKCONSIM. Combined discrete-event simulation and genetic algorithms (GA) are applied in HKCONSIM to model and further optimize the one-plant-multisite RMC plant operations in Hong Kong. Logistics planning practices of RMC businesses in Hong Kong are introduced, and interfaces, features and functionalities of HKCONSIM described. The potential industry impact of the research effort is demonstrated with a case study based on one-day operations data obtained from a Hong Kong RMC plant. It is concluded that the GA-integrated simulation platforms specifically designed for RMC companies such as HKCONSIM will potentially assist managers in making optimal decisions on concrete production and delivery scheduling, thus enhancing productivity, resource utilization and concrete supply service in day-by-day operations.

1 INTRODUCTION

The benefits of ready mixed concrete (RMC) in light of attaining consistent quality standards, being environmentally-friendly and occupying less working space in site account for an increasingly high proportion of concrete consumed on infrastructure and residential building projects worldwide. The batching and delivery operation of RMC industry is a classic example of Just-In-Time (JIT) construction system due to the perishable nature of concrete (Tommelein and Li 1999). And site customers demand JIT concrete delivery service at competitively low prices. Yet, problems associated with logistics planning of a RMC plant in producing and delivering concrete to multiple sites –such as shortage in raw materials supply, truckmixers waiting on site and tardy concrete deliveries–have undermined not only efficiency and service of the RMC business, but also productivity and quality of concrete construction in building sites. High uncertainties in regard to site concreting operations and plant-to-site travel times coupled with broad fluctuation of site orders in terms of timing and quantity dictate that current practices for scheduling concrete production and marshaling concrete-delivery resources (truckmixers) in the RMC industry are the use of trial-and-error tactics and largely dependent on managerial experiences. There is a lack of effective support by scientific, analytical, or systematic methodologies.

Compared with heuristic methods and conventional mathematical programming techniques, the simulation technology holds the potential to provide a useful decision-support tool in tackling the complicated, stochastic problem of scheduling concrete production and delivery with limited truckmixer resources. In previous research, Alkoc and Erbatur (1998), Sawhney et al (1999), Zayed and Halpin (2001) and Feng et al (2004) respectively developed simulation methods and applications to model concrete batching plant operations. The present research is mainly focused on how to simultaneously optimize production and delivery scheduling and truckmixer resource provision for concrete plants based on a valid simulation modeling platform resulting from recent research, called HKCONSIM (Lu et al 2003). Combined discrete-event simulation and genetic algorithms (GA) were applied in developing the upgraded version of HKCONSIM (Lu et al 2004) so as to model and optimize typical one-plant-multisite RMC plant operations in Hong Kong. The remainder of this paper first introduces logistics planning considerations and practices of a RMC business in Hong Kong, and describes features and functionalities of HKCONSIM. The potential industry impact of the research efforts is further demonstrated with a case study based on one-day operations data obtained from a Hong Kong RMC plant. Conclusions are given in the end.

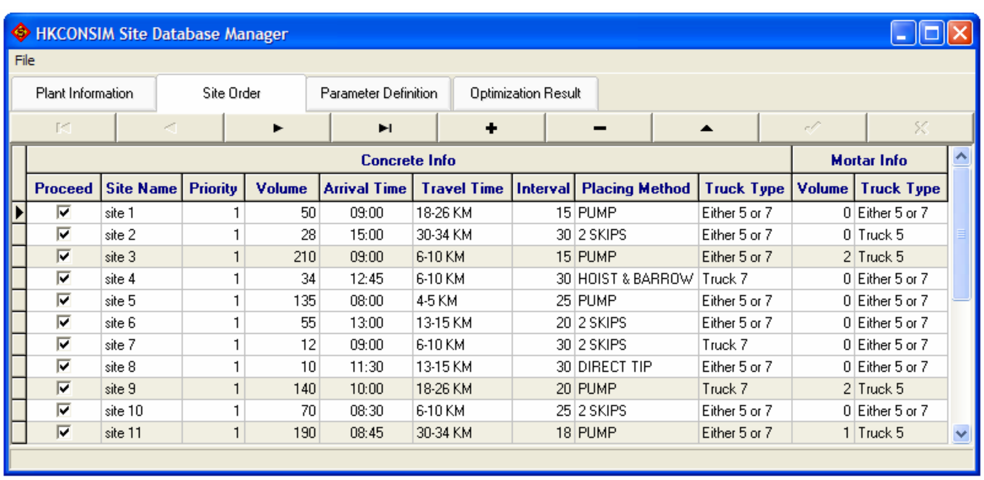
2 CONSIDERATIONS AND PRACTICES FOR RMC LOGISTICS PLANNING

The scheduling of concrete production and delivery is essentially a problem of materials logistics planning, which is a decision process for strategically managing the procurement, movement and storage of raw materials, finished product inventory and the related information flows throughout the organization and its marketing channels in such a way that the current and future profitability are maximized by cost-effective fulfillment of orders (Christopher 1992). Considerations and practices for RMC logistics planning in Hong Kong in relation to (1) procurement of raw materials and (2) production and delivery of concrete were investigated through direct observation and interviews with relevant personnel at concrete plants and construction sites. In Hong Kong, advance notices were generally required for ordering concrete delivery service. The lead time was typically three days, with the order confirmed one day before the actual pour date. RMC producers implemented a JIT pull system, which was responsive production scheduling driven by customer demand. Raw material stocks at a plant were commonly replenished on a daily basis. And RMC plants transformed raw materials into concrete in their production facilities and supplied concrete to construction sites using truckmixers at the supply rates as required to match the on-site concreting progress. It was observed that raw materials supply and quality control for concrete production were on the whole well managed; by contrast, concrete deliveries by truckmixers were far from achieving logistical efficiency and productivity in site concreting operations.

For a RMC plant, its delivery service is largely governed by plant resources available, traveling distances or times from the plant to each site, contractors' placement methods and particular pour-start schedules and progress rates on each pour, as well as the subtle interactions between those factors. The delivery process not only requires a great deal of capital investment in running a fleet of truckmixers, but also directly affects the service level as perceived by site customers. Hence, truckmixer dispatching and delivery scheduling is among the most critical and challenging management responsibilities. Anson (1996) highlighted the importance of proper coordination between RMC plants and site contractors, which had significant effects on the productivity of concreting processes. The relatively poor matching performance between the concrete supply and the site requirements also caused the serious underutilization of plant resources – an average of 37.6% in terms of truckmixer working percentage was reported as of Hong Kong experience (Anson et al 2002). Thus, the business goal of the RMC industry in regard of achieving timely concrete deliveries while utilizing limited truckmixer resources to the fullest warranted research efforts into developing a simulation system that was instrumental in coping with critical management tasks, including (1) sequencing the processing of concrete orders from multiple sites, (2) deciding on the amounts of truckmixers of each type (e.g. volume capacity), (3) scheduling truckmixers' site deliveries, and (4) estimating travel times and site unloading times.

3 HKCONSIM SIMULATION SYSTEM

The HKCONSIM software system was designed to allow the RMC plant management to enter site order attributes through a simple site demand assignment form (as shown in Figure 1). As such, through simulation and optimization, the plant management could readily and analytically determine the number and type of truckmixers required and the time intervals between truckloads on each site so as to maintain continuous concrete supply. The simulation model for one-day operations of a concrete plant in serving multiple site clients was automatically generated after taking order inputs as shown in Figure 2.



Proceed	Site Name	Priority	Volume	Arrival Time	Travel Time	Interval	Placing Method	Truck Type	Volume	Truck Type
☑	site 1	1	50	09:00	18-26 KM	15	PUMP	Either 5 or 7	0	Either 5 or 7
☑	site 2	1	28	15:00	30-34 KM	30	2 SKIPS	Either 5 or 7	0	Truck 5
☑	site 3	1	210	09:00	6-10 KM	15	PUMP	Either 5 or 7	2	Truck 5
☑	site 4	1	34	12:45	6-10 KM	30	HOIST & BARROW	Truck 7	0	Either 5 or 7
☑	site 5	1	135	08:00	4-5 KM	25	PUMP	Either 5 or 7	0	Either 5 or 7
☑	site 6	1	55	13:00	13-15 KM	20	2 SKIPS	Either 5 or 7	0	Either 5 or 7
☑	site 7	1	12	09:00	6-10 KM	30	2 SKIPS	Truck 7	0	Either 5 or 7
☑	site 8	1	10	11:30	13-15 KM	30	DIRECT TIP	Either 5 or 7	0	Either 5 or 7
☑	site 9	1	140	10:00	18-26 KM	20	PUMP	Truck 7	2	Truck 5
☑	site 10	1	70	08:30	6-10 KM	25	2 SKIPS	Either 5 or 7	0	Either 5 or 7
☑	site 11	1	190	08:45	30-34 KM	18	PUMP	Either 5 or 7	1	Truck 5

Figure 1: Site Order Demand Assignment Form

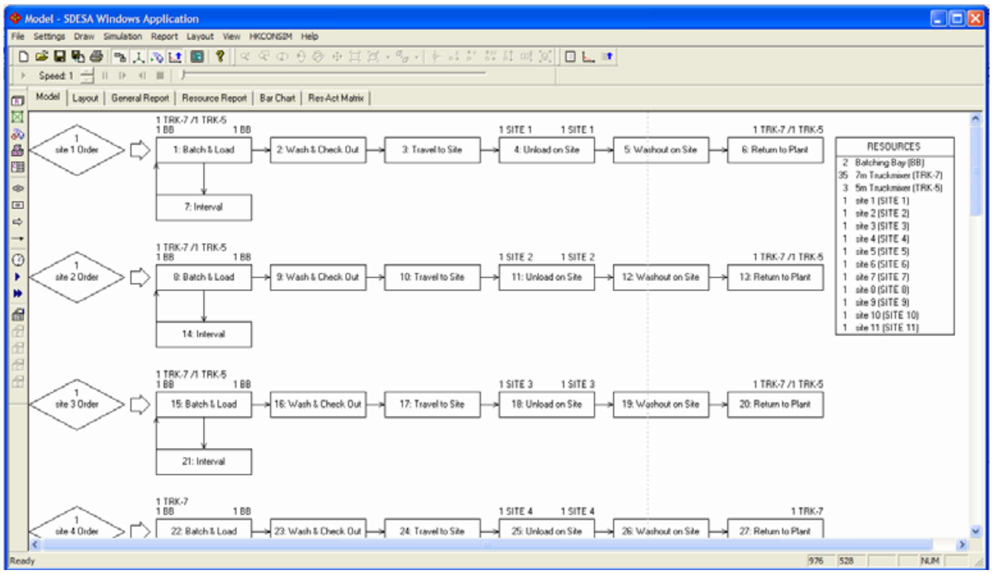


Figure 2: Screenshot Captured from HKCONSIM's Model View

3.1 Concrete-Placing Methods

The methods employed for unloading concrete vary widely from site to site, depending on site conditions, characteristics of the pour and availability of the placing equipment. Six concrete placing methods as commonly seen in Hong Kong were classified by the leading placing equipment used (Lu et al 2003; Lu and Anson 2004); they were (1) backhoe, (2) direct tip, (3) hoist and barrow, (4) pump, (5) crane & 1-skip and (6) crane & 2-skip. In particular, in recent years the "pumping" method has gained increasing popularity in Hong Kong's building sites thanks to its flexibility and efficiency.

When employing the pumping method for placing concrete, site contractors would order a batch of mortar, which is a mixture of sand, cement and water (no coarse aggregate), to lubricate the pump and pipeline before the concreting operations started (Panarese 1987). The rule of thumb was to pump 0.1 cubic meter of mortar for every 60m-long 100mm-hose pipe section, and lesser amounts for hoses of smaller diameter (Dobrowolski 1998). Note no such "lubricant" orders were required when the site clients practiced the other five concreting methods. Given the RMC plant had two batching bays in operation, the mortar (the amount was generally less than 5 m^3 and took up one truckload only) and the first truckload of concrete ordered for a pumped pour were batched simultaneously. In case of one batching bay available, the first truckload of concrete would be mixed immediately following the batching of mortar at the plant, and two truckmixers –the first one for mortar delivery and the second for concrete– would depart for the same construction site at the same time. On the site, the mortar-flushing of the pump could start with the first truckload of concrete standing-by. Upon all the mortar being unloaded into the receiving chamber of the pump, unloading concrete commenced at a slow speed. And when concrete flowed out of the discharging end of the hose, pumping proceeded at the normal speed (Panarese 1987). The HKCONSIM allows modeling the mortar batching, delivery, and flushing processes for a pumped concrete pour, as explained in the following section.

3.2 Scheduling Mortar Order in Simulation

The small amount of lubricating mortar (1-2 m^3) renders the processing time of unloading mortar from a truckmixer

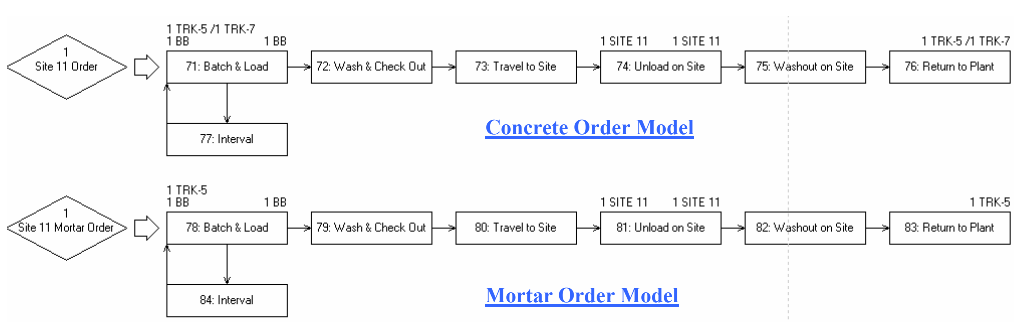


Figure 3: Simulation Models of Concrete Order and Mortar Order

Table 1: Processing Information of HKCONSIM Model

Activity	Control Variable		Remarks
	Conditions for Initiating Act.	Modification at End Act.	
Mortar Order Entity Flow			
- Act. 78 “Batch & Load”	- NIL	- Site11_MortarDone = 1	- Site11_MortarDone is initialized as 0, at end of Act 78, is set as 1, denoting mortar batching being completed
- Act. 81 “Unload on Site”	- NIL	- Site11_MortarDone = 2	- Site11_MortarDone is, at end of Act 81, is set as 2, denoting mortar unloading being completed
Concrete Order Entity Flow			
- Act. 71 “Batch & Load”	- Site11_MortarDone = 1	- NIL	- Site11_MortarDone being equal to 1 or 2 is prerequisite for initiating Act. 71 and 74 respectively, ensuring the precedence logic.
- Act. 74 “Unload on Site”	- Site11_MortarDone = 2	- NIL	

relatively short as compared with that for a normal truckload of concrete. However, the mortar does occupy the truckmixer resource in traveling to and from the construction site in a similar way as a full truckload of concrete, and as a result, the mortar handling processes should be incorporated into the concrete-delivery simulation model subject to definite truckmixer resources available. Based on the site demand data entered, the latest version of HKCONSIM can automatically generate the SDESA simulation model for a pumped pour requiring mortar flushing, as shown in Figure 3. Note that the logical sequence of mortar flushing activities preceding concrete pumping activities was specified using internal control variables of the model (shown in Table 1). On any particular day, a RMC plant in Hong Kong is engaged in serving a large number of sites. Thus, the one-plant-multi-site simulation model was created integrating the pumped pour with other multiple sites, as illustrated in Figure 4.

4 FINETUNING HKCONSIM INPUT MODELS

In a HKCONSIM simulation model, activity times (such as truckmixer batching and loading, traveling, unloading and washing) are uncertain by nature. The default probability distributions for activity times were fitted onto truckmixer operations data obtained from the twenty-week plant observations of mixing, transportation, placing of RMC during 1999/2000 periods (Anson et al 2002). Yet, the high variability in travel times and site unloading times still necessitates the fine-tuning of those default distributions with up-to-date information on specific sites, simply by resorting to past records or experiences in serving the same or similar site (e.g. for accurately modeling the concrete unloading rate and travel times, either checking past delivery tickets provided a reliable source of timing and quantity information or subjectively estimating given the most current information on site progress and traffic).

5 HKCONSIM SIMULATION AND OPTIMIZATION ANALYSIS

The HKCONSIM simulation began by compiling orders from all sites into an order-dispatching list according to pour start times and estimated progress rates for unloading concrete on each site. This list could be regarded as a first-arrive-first-serve queue of jobs (orders) with the estimated start-batching time being each job’s arrival time at the plant. Through simulation analysis, HKCONSIM produced

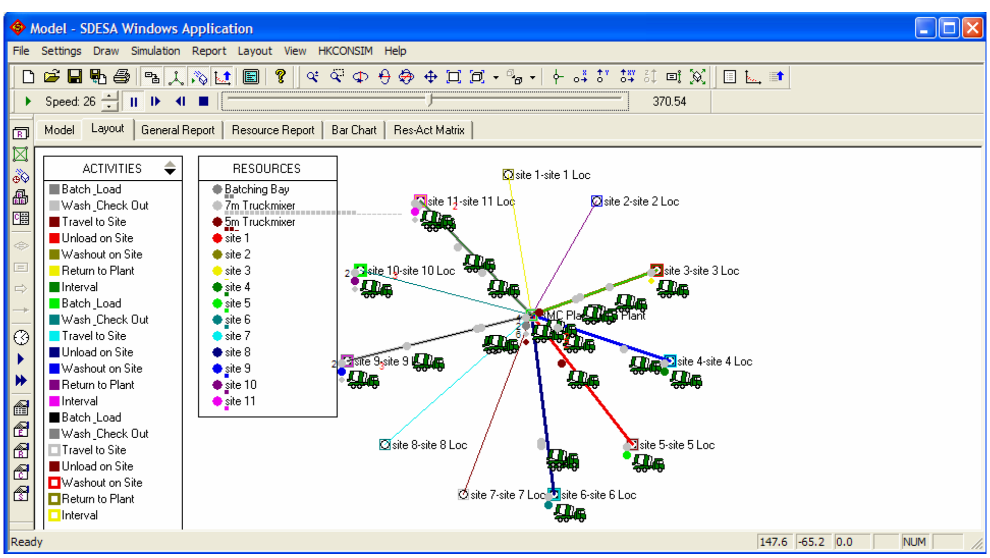


Figure 4: Animation Screenshot Captured from HKCONSIM’s Layout View

two types of performance measures: (1) a diagrammatic measure (service performance plot) –a plot relating truck-hour provision over pour duration percentage against site waiting for truckmixers over pour duration percentage for each individual site (Anson and Wang 1998); and (2) numerical measures such as the site service level (SSL, i.e. the summation of crew idle times due to tardy concrete deliveries on all sites being served), the total operations inefficiency (TOI, i.e. the summation of crew idle times due to tardy concrete deliveries plus truckmixer queuing time on all sites being served) (Lu 2002), and resource utilization rates for truckmixers deployed.

Once an objective (performance measure) was set, HKCONSIM relied on the steady-state genetic algorithm (GA) engine embedded to search for the optimum on the objective by adjusting input variables (i.e. the amounts of truckmixers of different types, and the estimated concrete supply rate in terms of truckmixer inter-arrival times on site) (Lu et al 2004). The GA engine randomly generated an initial "population" of chromosomes, each having a combination of values sampled from the likely ranges of input variables. Then the fitness score for each chromosome in terms of the objective function (e.g. the SSL or TOI values) was evaluated by averaging over Monte Carlo duplications, which was intended to downplay the effect of random sampling on the variability of a simulation output. Next, two chromosomes with higher fitness scores were selected from the population to reproduce offspring chromosomes by either crossover or mutation operations, resulting in two new chromosomes being added to the population. The population was then ranked by the fitness score of chromosomes, and the two with the lowest fitness scores were dropped. The stopping criteria for the optimization were as: (1) no improvement on the objective function evaluation was observed over a preset number of consecutive generations or (2) a maximum of iterations was reached, whichever came first.

Most RMC plants in Hong Kong run on two batching bays to allow two independent batching processes at the plant. It is found that the batching process required relatively short time in comparison with traveling and site unloading and seldom presented "availability" constraints on concrete production and delivery. Yet, the resulting high productivity in RMC production and flexibility in plant operation and maintenance come along with the expense of underutilization of plant resources (mixers and batching bays). Our interviews with the managerial staff of concrete companies revealed the fixed cost of operating one additional batching bay was not considerable high, thus causing no serious concern over underutilization of batching bay resources. What indeed baffled the plant operator was about the utilization of delivery resources –how many truckmixers to hire to cope with site demand on the next day so no oversupplying or undersupplying of truckmixer resources would occur, and how to reduce the on-site queuing time of truckmixers to a minimum while avoiding tardy concrete deliveries and the resultant interruptions on site operations?

Statistics can be readily collected from the HKCONSIM simulation for the measure of TOI–which takes into account the total idle time incurred on all sites inclusive of truckmixers queuing and crews idling. Hence, the TOI could be taken as the fitness score or objective function in GA optimization. On the other hand, optimization based on the SSL measure was merely concerned with keeping the crews idling time to a minimum with no regard to underutilization (queuing) of truckmixers. In the following case study, SSL-based optimization experiments were also performed on HKCONSIM to contrast with the TOI-based scenario.

6 CASE STUDY

In this case study, HKCONSIM was tested on one day real operations at a local plant serving 11 pours with 2 batching bays and 35 truckmixers. In the actual case, the truckmixer fleet consisted of 10 of 5 m^3 and 25 of 7 m^3, and the total volume of concrete ordered was 934 m^3. Details on each pour are given in Table 2. Simulation and optimization experiments were performed on two scenarios: the first used the default activity duration distributions fitted with historical data and the second retrieved up-to-date operations data to fine-tune the activity durations. Results were compared in detail.

6.1 Fine-tuning Activity Time Distributions with Current Data

Facilitated by a truckmixer driver and a local concrete plant, data were obtained from tracking one truckmixer's activities in Hong Kong over 89 typical operational days during the 2004-05 periods, covering 187 pours on 17 different on-going sites and involving 266 truckmixer trips. 8 out of the 11 sites were dealt with in the collection of operations data. Therefore, the data obtained provided more precise and current information for estimating truckmixer activity durations in simulation modeling. As shown in Table 2, the collected data were used to establish updated statistical distributions for duration of three main activities (i.e. travel to site, unload on site & return to plant) in the simulation model. Because site-specific factors (such as site working progress, site layout, height of pouring, shape of pour, type of structural element) determine the concreting productivity, the concrete-unloading rates vary on different construction sites employing the same concrete-placing method. In Short, distributions for truckmixer unloading times/rates on particular sites deserve special scrutiny for ensuring actual site productivity performances are properly reflected.

Table 2: Summary of Updated Time Distribution Parameters

Site ID	Dist. (km)	No of Trip Observed	Placing Method	TM Req.	Distribution Data: Go to Site (min)	Distribution Data: Return to Plant (min)	Distribution Data: Placing Rate (min/m3)
1	18	20	Mobile Pump	*either*	*triangular (30,42,35)*	*triangular (20,35,25)*	*triangular (2.1, 4, 2.9)*
2	32	13	Crane & Skip	*either*	*triangular (39,55,50)*	*triangular (28,42,35)*	*triangular (2.9, 4.1, 3.6)*
3	7	66	Mobile Pump	*either*	*triangular (20,32,28)*	*triangular (18,27,20)*	*triangular (1.3, 3.2, 1.6)*
4	6	13	Hoist & Barrow	*7m*	*triangular (26,41,34)*	*triangular (17,28,25)*	*uniform (4.1, 7.6)*
5	5	2	Mobile Pump	*either*		*Not equal sample data*	
6	12	5	Crane & Skip	*either*		*Not equal sample data*	
7	6	11	Crane & Skip	*7m*	*triangular (23,38,33)*	*triangular (18,25,20)*	*uniform (5, 8)*
8	16	5	Tremied or Chuked	*either*		*Not equal sample data*	
9	25	78	Mobile Pump	*7m*	*triangular (35,51,38)*	*triangular (25,40,30)*	*triangular (1.9, 5.7, 2.9)*
10	6	17	Crane & Skip	*either*	*triangular (17,30,22)*	*triangular (16,25,20)*	*triangular (2.4, 6, 4.8)*
11	38	27	Mobile Pump	*either*	*triangular (51,67,57)*	*triangular (30,45,40)*	*triangular (1.5, 3.9, 2.4)*

Note: Triangular (min, max,mode); Uniform (min, max)

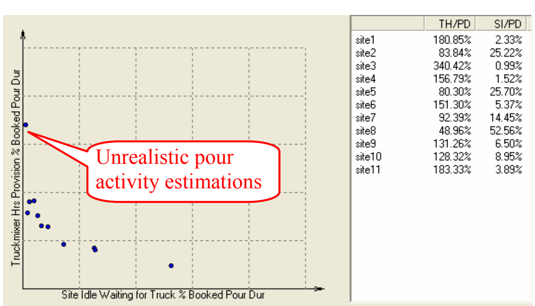
HKCONSIM simulation experiments were conducted for the "default" scenario based on the default time distributions, and for the "updated" scenario, in which the updated distributions (Table 2) were model inputs. The simulation results obtained for the two scenarios were compared in Table 3. Note the total busy time on all sites resulting from the "default" scenario (3563 min) was 20% higher than the "updated" scenario (2569 min). That the five-year-old default site unloading times were actually much longer compared with current site situations has caused the oversupply (and underutilization) of truckmixers on site, as indicated by the lower utilization rates of truckmixers and the much larger TOI measure on the "default" scenario–in contrast with the "updated" scenario. The simulation-produced service performance plots for the two scenarios are given in Figure 5. The unrealistic estimation of unloading times in the "default" scenario was clearly exposed in Figure 5 (a); the outlying dot with 340% truckmixer hour provision over pour duration ratio pointed to one site would experience serious truckmixer queuing. Thus, deriving input models with up-to-date, accurate site productivity information is critical to conducting valid HKCONSIM simulations.

Table 3: Summary of Simulation Results based on Different Time Distribution

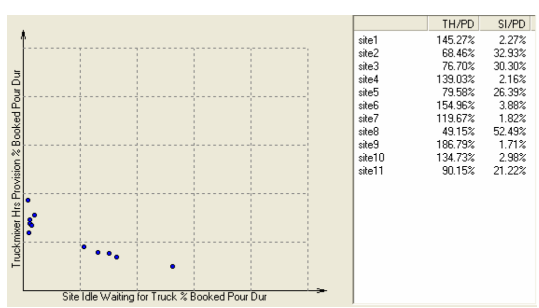
Scenario	Simulation on Original Case: Scenario 1: Default	Simulation on Original Case: Scenario 2: Updated
No of 5 m^3 truckmixer	*10*	*10*
No of 7 m^3 truckmixer	*25*	*25*
SSL	*346.50*	*593.33*
TOI	*3153.29*	*1659.59*
Resource Utilization Rate		
• **Batching Bay**	***35.61%***	***35.80%***
• **5 m^3 Truckmixer (busy/idle times)**	***51.64%*** *(3695/3460)*	***62.53%*** *(4252/2548)*
• **7 m^3 Truckmixer (busy/idle times)**	***62.15%*** *(10614/6465)*	***67.69%*** *(11010/5255)*
• **Sites (busy/idle times)**	***92.97%*** *(3563/269)*	***82.71%*** *(2969/621)*

6.2 Optimization Analysis: SSL-minimum Scenario

From the standpoint of RMC producers, providing in-time delivery of high-quality concrete to site is paramount to their reputation and competitiveness. The concrete plant, therefore, often bunched up two or three truckmixers on site for a large pour that demanded stringent continuity in concrete supply (e.g. a bored pile site). Under such a cir-



a) Service Plot using default time distribution



b) Service Plot using updated time distribution

Figure 5: Service Plot using Different Time Distribution

cumstance, the HKCONSIM optimization objective could be set as improving the site service level (SSL) such that the total site idle time was minimized. In this case study, the optimization results revealed the majority of dots were pushed to the left, toward the ideal level at 0%-site idle waiting/booked pour duration, but also upward along the "truckmixer hour provision" dimension, as shown in Figure 6.

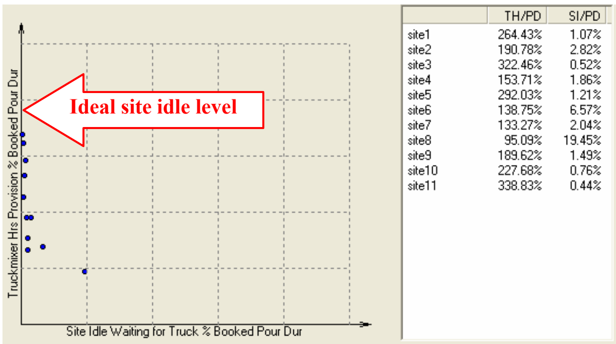


Figure 6: Service Plot of Optimal SSL-minimum Scenario

When the system reached the optimum state in regard to SSL, a total of 42 truckmixers were needed to attain the high service level –SSL of 52min and 97% of site resource utilization rate (Table 4). The inter-arrival times of truckmixers at each site, the mix of truckmixers of different volume capacities are also given in Table 4. In practice, the concrete plant may rent extra truckmixers from other plants or hire out their surplus ones to others in coping with fluctuations of site demand in their day-by-day business. It is expected that HKCONSIM can provide managerial staff with an effective aid in adjusting the size of the truckmixer fleet in response to the changing site demand on a daily basis.

6.3 Optimization Analysis: TOI-minimum Scenario

The oversupply of truckmixers to guarantee continuous site operations concurs with excessive queuing time experienced by truckmixers on site, which not only results in underutilized resources but also increases chances of concrete being overdue and unworkable. Note that the Hong Kong's General Specification for Civil Engineering Works (1997) required RMC to be manufactured, inspected, transported and placed at the customer location within 105 minutes for quality control purposes. Besides, it is more likely that RMC plants are constrained by availability of truckmixers in light of their high capital and operational costs. As a result, deploying less truckmixer resources and marshalling then more efficiently in running its daily operations would bring in both quality and cost benefits. And cost-effective management of limited truckmixer resources for achieving the highest delivery service level possible is the more practical objective of RMC businesses. As such, it is more appropriate to set the optimization objective as minimizing the TOI measure in HKCONSIM optimization experiments. As shown in Table 4, both the number of truckmixers deployed and the TOI measure decreased in comparison with the SSL-minimum scenario and the original (actually tracked) scenario, while utilization rates for truckmixers and site crews still remained at the high levels.

Table 4: Site Demand and Optimization of Case Study

Site ID	**Total Concrete Quantity (m^3)**	**Distance (km)**	**Placing Method**	**Spec. Truck**	**First Arrival**	**Interval Time**		
						Original Scenario	**SSL-min Scenario**	**TOI-min Scenario**
1	*50*	18~26	Pump	*either*	*90*	*15*	*9*	17
2	*28*	30~34	2 Skips	*either*	*450*	*30*	*7*	23
3	*210* & *2m³ mortar*	6~10	Pump	*either* *5m*	*90*	*15*	*8*	12
4	*34*	6~10	Hoist & Barrow	*7m*	*315*	*30*	*24*	39
5	*135*	4~5	Pump	*either*	*30*	*25*	*14*	18
6	*55*	13~15	2 Skips	*either*	*330*	*20*	*20*	22
7	*12*	6~10	2 Skips	*7m*	*90*	*30*	*18*	51
8	*10*	13~15	Direct Tip	*either*	*240*	*60*	*5*	10
9	*140* & *2m³ mortar*	18~26	Pump	*7m* *5m*	*150*	*20*	*18*	23
10	*70*	6~10	2 Skips	*either*	*60*	*25*	*19*	30
11	*190* & *1m³ mortar*	30~34	Pump	*either* *5m*	*75*	*18*	*11*	16
				No of 5 m^3 truckmixer		10	12	3
				No of 7 m^3 truckmixer		25	30	29
				SSL		*593.33*	52.20	293.08
				TOI		*1659.59*	4601.76	1300.25
				Utilization Rate				
				• Batching Bay		***35.80%***	**43.01%**	**38.50%**
				• 5 m^3 Truckmixer		***62.53%***	**56.86%**	**78.99%**
				• 7 m^3 Truckmixer		***67.69%***	**66.89%**	**76.80%**
				• Sites		***82.71%***	**97.09%**	**94.95%**
				Opt-Process Time			1 hr	1 hr

The service performance plot resulting from the TOI optimization is given as Figure: 7, with the majority of dots settled in the “cost efficient zone” of the plot, bounded by truck-hour provision of pour time between 100% and 150% and an interruption in supply of no more than 10% of pour time (Anson and Wang 1994). Note a particular pour ended up into the cost efficient zone only if the interruption in concrete supply to a site and the queuing time of truckmixers on site were both low relative of the overall pour duration.

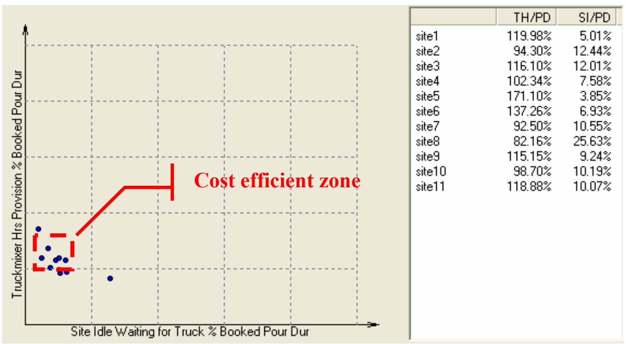


Figure: 7: Service Plot of Optimal TOI-minimum Scenario

7 CONCLUSIONS

An effective, analytical approach to concrete production and delivery scheduling is indispensable for ready mixed concrete (RMC) businesses to provide just-in-time concrete delivery service and achieve efficiency, competitiveness and customer satisfaction. To address the practical needs as identified, the PC-based simulation tool of HKCONSIM has been developed in house for modeling and optimizing concrete plant operations in a one-plant-multisite setting. Through simulation experiments, the plant managers can decide on the optimal numbers of truckmixers of each type to be deployed together with an optimal schedule for batching and delivering concrete to multiple sites on any particular day, aimed at minimizing total operation inefficiencies (TOI) under limited resource availability constraints imposed. In addition, the research underscored the importance of fine-tuning input models in the HKCONSIM simulations by collecting up-to-date, accurate site productivity data to ensuring the validity of simulation results. It is concluded that the GA-integrated simulation platforms specifically designed for the RMC companies such as HKCONSIM will potentially assist managers in making optimal decisions on concrete production and delivery scheduling, thus enhancing productivity, resource utilization and concrete supply service in day-by-day operations. Finally, the computing time requirements for running optimization on the HKCONSIM simulation models were one to two hours on a Pentium IV PC, which could be further reduced by resorting to emerging optimization techniques that outperform GA in terms of both quality of optimum obtained and optimum-searching time in tackling stochastic simulation systems.

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