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SIMULATING A READY-MIX CONCRETE PLANTS NETWORK USING MULTIMETHOD APPROACH

Jaime Alberto Sánchez Velásquez

Department of Industrial & Systems Engineering
Universidad EIA
Km 2 + 200 Vía Aeropuerto JMC, Envigado,
COLOMBIA

Maria Camila Aristizábal Isaza

Process & Information Management Coordinator
Cementos Argos, S.A.
Carrera 50 n. 14-285, Medellín,
COLOMBIA

ABSTRACT

The operation of ready-mix concrete (RMC) plants is strongly affected by the complex stochastic nature of the concrete production and delivery processes. The delivery compliance in the different building sites is one of the most significant aspects for both customer satisfaction and resource allocation in the RMC industry. To improve the decision-making process in the RMC industry, a multi-method (using a hybrid Agent-based and Discrete-Event simulation modeling technique) simulation model was created for a multinational company that produces and markets cement and ready-mixed concrete using software Arena, Rockwell Automation. The main contribution of this work is the novel approach to designing travel time to the construction sites, improving its validity and allowing us to optimize the production and delivery program. Results obtained in this project were used in the decision making process regarding the effective use of capital in installed capacity while minimizing risk.

1 INTRODUCTION

The industrialized production of ready-mixed concrete (RMC) brings many benefits, such as the efficient use of raw materials; more confidence on the product in terms of quality; waste reduction; less room needed for storing aggregates and cement; less impact on the environment, amongst others. The use of industrialized ready-mixed concrete is subject to a timely delivery of the product in agreement established with the client. This is why an appropriate planning of the supply chain is very important, so that deliveries are made on time in order to maintain the efficiency standards regarding resources. The perishable conditions of concrete make it necessary that its production system be just-in-time. The inability to store this product turns into a big challenge to the industry in terms of confidence and efficiency in its planning, production and distribution process.

There are many variables affecting the supply chain of ready-mixed concrete. There are factors affecting the supply process of raw material affected by availability, delivery and quality; production processes such as plant stops and truck mixer availability; variability of loading time and the timely return of the fleet; and deliveries such as the travel time to the destination, return to plant and the permanence of the mixer in site.

Continuous change and variability on the production and distribution process of concrete complicate understanding the variables affecting business. Uncertainty on the variables complicates the effective planning of the necessary resources for a timely delivery of the product to the client while maintaining the efficiency standards required for the financial sustainability of the business. The optimal capacity utilization rate of plants and the amount of available truck mixers that must be in the system are subject to the service level agreed with the client. The higher the service level, the higher the demand of resources, which is a situation that leads to a reduction in efficiency. On this paper, a simulation model of the supply chain is proposed, from order scheduling to the production process at the plant and the distribution of the product to different sites during the day. Variables associated to raw materials supply were not analyzed for this model. For the creation of the model, information about time at plants was gathered and a GPS data extraction procedure was carried out to analyze travel and permanence times at the different sites.

The remainder of the paper is organized as follows: Section 2 will include an overview of related literature. A multi-plant multi-site environment and the basic operations within each plant are described on Section 3. On Section 4, the Arena modeling approach is presented. Here, the modeling of the general system, the modeling of the entrances to each plant and the model validation are considered. Section 5 will include the analysis of computational results from Arena model. Lastly, conclusions will be included in Section 6.

2 LITERATURE REVIEW

To this day, reported literature studies on production and delivery of RMC are scarce. These are some papers on problems and solution methods related to this topic: Wu and Low (2007) used JIT purchasing threshold value models. Feng, Cheng, and Wu (2004), for the production and delivery of concrete, used a model based on genetic algorithms and a simulation to find the best dispatch schedule that would reduce the waiting time of trucks at construction sites. Al-Araidah et al. (2012) made a model to improve the financial performance of companies, in which the cost of production and ready-mixed concrete delivery is calculated taking into account costs related to distance, traffic, and late delivery. Matsatsinis (2004) designed a dynamic routing system for several kinds of vehicles for a daily distribution of ready-mixed concrete in a multi-plant environment with time windows. Durbin and Hoffman (2008) developed a tool to support decision making related to the scheduling and concrete delivery based on a time-space network with integer side constraints. Lu and Lam (2005) conducted research to optimize the concrete delivery scheduling and the provision of resources at a single plant with multiple locations based on a verified simulation modeling platform called HKCONSIM in order to improve productivity and the daily supply of concrete. Additionally, they used TOI (Total Operation Inefficiency) as a measurement of assessing the results (Lu and Lam 2009). Naso et al. (2007) developed a model to coordinate production and JIT transport at a group of partially independent plants to guarantee a timely delivery of concrete by using a meta-heuristic approach based on a hybrid genetic algorithm combined with constructive heuristics. Yan, Lin, and Jiang (2012) studied the RMC production problem and developed a model for planning production and truck dispatch schedules with stochastic travel times. Schmid et al (2009) and Schmid et al. (2010) proposed a solution for the ready-mixed concrete delivery problem with multiple plants, multiple construction sites and different types of vehicles, including trucks of different capacities and vehicles with specialized equipment, such as pumps. Liu, Zhang, and Li (2014), focuses more on the integrated scheduling of production and delivery of pumps and trucks and considers more practical elements, such as waiting time between vehicles and construction sites and continuity of work in construction sites, to provide an effective method for improving efficiency as well as saving costs. For a detailed review of the concrete delivery problem and its methods of solution see work of Kinable, Wauters, and Vanden (2014). Most of these papers consider a one-plant-multi-site approach and design travel times based on deterministic methods. In this paper a multi-plant-multi-site approach was used and the modeling of travel times was based on a stochastic method with time windows.

3 SYSTEM CONSIDERATIONS

The production and delivery of ready-mixed concrete in a city behaves like a single system where plants interact and support each other according to the events that occur during a day. Trucks start work from a specific plant, but not necessarily every scheduled trip starts there. Plants share trucks and transfer concrete orders when unscheduled maintenance stops occur:

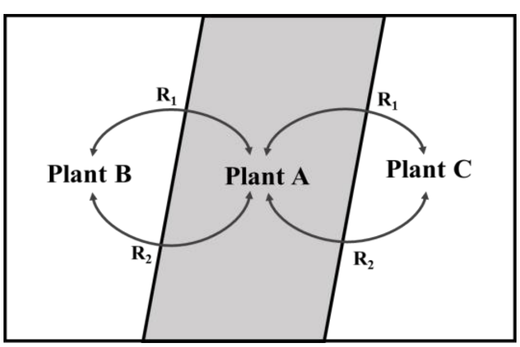
- Order scheduling. The client's order is taken the day before the dispatch and is scheduled according to resource availability at all times. Scheduling made before the dispatch constantly changes due to order cancellations and changes on scheduled travel on-site programmed times.
- Ticket printing. This is where ready-mixed concrete dispatch starts. The load sequence is established according to the schedule of the previous day.
- Loading time. The raw materials are loaded into the mixer. This time varies according to the capacity of the plant, concrete reference and order size. On the time registry the loading times vary between 5 to 20 minutes.
- Sampling. Once the product is loaded, trucks are randomly chosen for the respective sampling of concrete cylinders. This time constantly changes depending on the quality operator's experience and lab conditions.
- Mixer washing. Truck mixers must undergo a washing process of conduits to avoid waste dumping on public roads. Additionally, the concrete quality is reviewed before departing to site. This time often varies because it largely depends on the driver´s experience.
- Exit. A last check-up is made before leaving for the site.
- Travel time to site. This time depends on city traffic and distance to site, and it constantly varies during the day. Of all the causes affecting a timely delivery, this is the most impactful one because considerable changes can come up regarding expected values. Travel time to the same site can vary from 15 to 45 minutes.
- Time at site. This is the time the driver spends at the site waiting to unload and wash the truck. Although this time has no direct influence on fulfilling the timely delivery of order, it directly affects truck availability at the plant to deliver the rest of the orders to other clients.
- Return to plant. Similarly to the time spent going to the site, this time depends on the time of the day, distance and traffic. This variable affects the available trucks to be loaded at the plant.

4 MODELING APPROACH

The simulation model uses an Agent-based and Discrete-Event simulation modeling technique. For a better interaction amongst all plants, interaction logics were created from Arena's logic modules. The operation process of each plant was designed based on discrete event simulations.

4.1 Modeling of the General System

As previously mentioned, ready-mixed concrete handling in a city can be carried out by one or more plants. When there are several plants, these interact between each other and adapt to everyday events. In the initial model built for a specific city there are three production plants: A, B, and C, located in different areas. Each plant works as an agent within the integrated system of the city, and plant A supports plants B and C in case any of them experience an unscheduled maintenance stop (See Figure 1).

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R1: tickets printing

IF
STATE(B1) == −4 && STATE(B2) == −4
THEN
ROUTE TO A
ELSE
ROUTE TO B

R2: return of mixer

IF
STATE(B1) == −4 && STATE(B2) == −4
THEN
ROUTE TO A
ELSE
ROUTE TO B
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Figure 1: Interaction rules of agents.

Arena has implemented a number of features to model these sorts of agent based problems. Decision logic is typically interwoven into the main logic of the model and is used to aid in guiding the proper path for the entity or to determine whether or not it is worth proceeding and how to react to changes in the system based on system conditions. As shown in Figure 2, the allocation of tickets printing is made depending on the state of the plants (up or down). This is also the case with the return of mixers from the sites to the plants.

The Arena model also has logic controls that are logical loops that monitor the process and are used to alter logical flows, remove or redirect entities and change or update system conditions. The entities used in the control logic do not have a real physical equivalent, but are used only to impact the system.

4.2 Modeling for entry to each plant

For the operation logic of each plant, discrete-event modeling was used and the corresponding data fitting for each process was carried out. In each case, the variables that better represented the time changes were identified (see Figure 2).

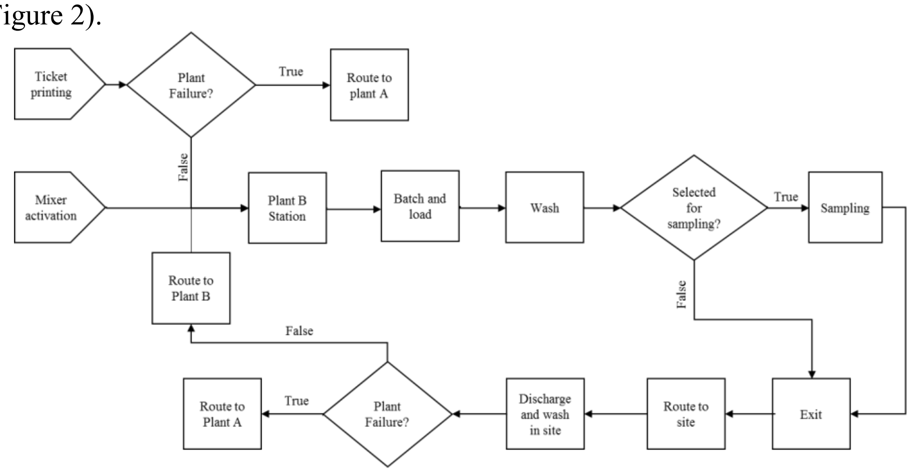

Figure 2: Operation logic Plant B.

- *Order scheduling*. Here the corresponding attributes for each ticket are included and assigned, such as load size, type of element to cast, distance to site and scheduled loading time. The ticket arrival rate is defined for each working hour of the plant according to an exponential distribution.
- *Time at plant*. For loading time, mixer wash, sampling and exit through gate the distribution fitting is made on a case by case basis according to the time registry in each plant (see Table 1).

Table 1: Distribution Fitting of Plant Processes (minutes).

Variable	Distribution	Description
Ticket Arrival	Exponential	08:00 EXPO(5.4) - 09:00 EXPO(5.2) - 10:00 EXPO(6) - 11:00 EXPO(5.7) - 12:00 EXPO(5.1) - 13:00 EXPO(5) - 14:00 EXPO(5.8) - 15:00 EXPO(8.3) - 16:00 EXPO(11.7)
Load Size	Empirical	DISC(0.170, 4.500, 0.250, 4.950, 0.350, 5.850, 0.866, 7.000, 0.955, 7.500, 1.000, 8.000)
Loading	Lognormal	4.5 + LOGN(4.53, 2.83)
Sampling	Empirical	CONT(0.400, 1.500, 0.833, 2.500, 0.933, 3.500, 0.967, 5.500, 1, 6.500)
Wash	Erlang	0.5 + ERLA(0.603, 5)
Exit	Empirical	CONT(0.067, 0.500, 0.511, 1.500, 1, 2.500)

- *Travel time*. As mentioned earlier at the end of Section 2, most of the papers related to the design of travel times are based on deterministic methods including the conditional expected travel time for any given distance by referring to urban service travel norms (Lin et al. 2010; Larson and Odoni 1981). Since the variables that have the largest impact on travel times to and from sites are distance and time of day, in this paper to appropriately represent these times a matrix was created that separates fittings according to different distance ranges between plant-site, and the time of day the truck-mixer starts its travel. This 8x5 matrix accurately represents travel times, an essential variable when assessing the necessary resources in the system (see Table 1).

Table 2: Distribution Fitting of Travel Times (minutes).

Time of Day	Distance to Site				
	0 – 4 Km	4 – 8 Km	8 – 12 Km	12 – 16 Km	Greater than 16 Km
05:00 – 07:00	9.5+EXPO(13)	9.5+WEIB(24.4, 1.6)	Empirical	UNIF(32, 77)	UNIF(50, 95)
07:00 – 09:00	9.5+49*BETA(0.623,1.82)	9.5+ERLA(6.92,3)	9.5+WEIB(29,1.82)	UNIF(45,78)	UNIF(20,89)
09:00 – 11:00	10+EXPO(13.1)	Empirical	Empirical	UNIF(17.5,95.5)	UNIF(31,106)
11:00 – 13:00	9.5+54*BETA(0.926,3.38)	Empirical	NORM(36.4,13.4)	Empirical	43+131*BETA(1.52,4.99)
13:00 – 15:00	9.5+63*BETA(0.826,3.8)	Empirical	11.5+65*BETA(1.66,2.57)	TRIA(13.5,68,84.5)	UNIF(60,100)
15:00 – 17:00	9.5+71*BETA(0.68,3.28)	13+ERLA(13.2,2)	14.5+WEIB(31.1,1.65)	Empirical	UNIF(19,89)
17:00 – 19:00	10+EXPO(13.5)	10.5+WEIB(29.6,1.49)	15.5+GAMM(15,1.58)	UNIF(17,167)	UNIF}823,138)
19:00 – 21:00	10+WEIB(5.2,0.373)	Empirical	13.5+ERLA(7.64,2)	UNIF(16,70)	TRIA(14,83.5,90.5)

- *Time at site*. This time depends on many factors, such as previous preparations at site, type of element to be casted or if pumping equipment is available at site. For this case, time modeling at site is defined according to the type of element to be casted, building a 16-field vector where fittings were made in each case.
- *Failure due to availability*. Non programmed stop times at plants are also one of the most important factors when understanding concrete plants operations. These failures create delays on order dispatches, and in many cases, their cancellation. The registration of this data was made for a six-month period and failures were detected due to operational, computing, functional and external problems. Downtime and Uptime with exponential distributions were modeled for these failures.
- *Confidence on scheduled travel times*. Travel time scheduling is of high importance for a proper resource planning. The problem when trying to achieve high levels of confidence on travel time scheduling is to accurately anticipate travel times. This variable is affected by external causes, such as traffic and weather, amongst others. Accurately scheduling these times allows to timely deliver orders. As with travel time, the confidence of travel time was modeled by a matrix of distance to site and time of day.

4.3 Model Verification

The model is primarily verified by two performance indicators: average volume of dispatches and compliance delivery. The volume is defined as the total produced volume on each plant made on a day. Delivery compliance is defined as the percentage of tickets delivered within an agreed timeframe with the client with regard to the total of tickets. These indicators allowed to contrast the created model with respect to a real operation, so that the necessary adjustments could be made.

5 OUTPUT ANALYSIS

From the Arena model, an analysis of results regarding processing times, time queues, arrival time of mixers, etc. is obtained. This information is used as a support when analyzing internal plant times with the purpose of appropriately aiming efforts and resources at time reduction in each plant.

Additionally, with the Arena initial model, different scenarios were generated on Process Analyzer to establish the optimal resource requirements. This need is determined by the scheduled volume for a specific day and the compliance delivery level of orders. A sensitivity analysis is proposed varying dispatched volumes and available mixers in order to have a look on the effects on delivery compliance. These results allowed to estimate the amount of mixers necessary to fulfil orders and the capacity utilization rate of plants according to a certain service level (See Figure 3).

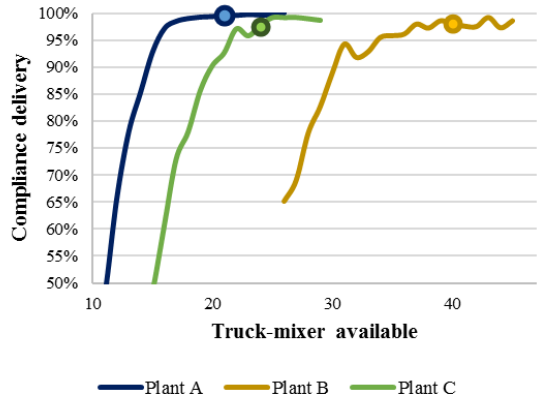

Figure 3: Compliance delivery vs truck mixer available.

Additionally, the model was able to evaluate in terms of required capital investments an optimal service level that combined the efficient use of resources but that also maintains a high level of service that represents added value for the clients (See Figure 4). Compliance levels vary according to the amount of available mixers and a determined dispatched volume. A larger amount of mixers means larger compliance with delivery. It is important to highlight that as the service level increases, every additional mixer included in the system provides little increase on the delivery compliance indicator. The difference in the amount of required mixers per plant varies according to their loading capacity and the cycle time.

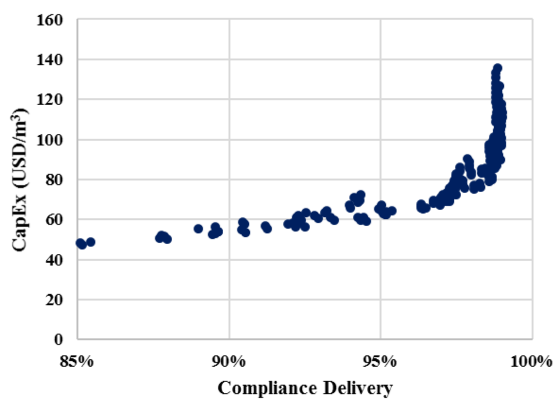

Figure 4: Compliance delivery vs Capital Expenditure.

6 CONCLUSIONS

The effective use of resources and a timely product delivery to the client are two very important pillars in the ready-mixed concrete business. A higher level of service translates into a larger demand of resources. The relationship between both variables can determine to some extent the business' sustainability in the long term. The proposed simulation model allows to find a relation between investment and delivery compliance, providing more tools when making decisions aimed at business strengthening. The proposed model provides, from its approach, information on how plants interact, allowing to build a multi-plant multi-site system. Additionally, the scheme used for travel time fittings, the hour-distance to site matrix, allows to obtain very close to reality results. This bestows much confidence in the model. Although this paper is focused on the needs of the ready-mixed concrete business, it can be adapted to other businesses with some adjustments

REFERENCES

Al-Araidah, O., A. Momani, N. AlBashabsheh, N. Mandahawi, and R. H. Fouad. 2012. "Costing of the Production and Delivery of Ready-Mix-Concrete". *Jordan Journal Of Mechanical & Industrial Engineering* 6(2):163-173.

Arena Simulation Software (Rockwell Automation, Version 14.7.) 2016.

Durbin, M., and Hoffman, K. 2008. "OR PRACTICE—The Dance of the Thirty-Ton Trucks: Dispatching and Scheduling in a Dynamic Environment". *Operations Research* 56(1):3-19.

Feng, C., T. Cheng, and H. Wu. 2004. "Optimizing the Schedule of Dispatching RMC Trucks Through Genetic Algorithms". *Automation In Construction* 13(3):327-340.

Kinable, J., T. Wauters, and G. Vanden. 2014. "The Concrete Delivery Problem". *Computers & Operations Research* 48:53-68.

Larson, R. C., and A. R. Odoni. 1981. *Urban Operations Research*. Prentice-Hall, Englewood Cliffs, NJ.

Lin, P. C., J. Wang, S. H. Huang, and Y. T. Wang. 2010. "Dispatching Ready Mixed Concrete Trucks Under Demand Postponement and Weight Limit Regulation". *Automation in Construction* 19(6):798-807.

Liu, Z., Y. Zhang, and M. Li. 2014. "Integrated Scheduling of Ready-Mixed Concrete Production and Delivery". *Automation in Construction* 48:31-43.

Lu, M., and H. C. Lam. 2005. "Optimized Concrete Delivery Scheduling Using Combined Simulation and Genetic Algorithms". In *Proceedings of the 2005 Winter Simulation Conference*, edited by M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, 2572-2580. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Lu, M., and H. C. Lam. 2009. "Simulation-Optimization Integrated Approach to Planning Ready Mixed Concrete Production and Delivery: Validation and Applications". In *Proceedings of the 2009 Winter Simulation Conference*, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls 2593–2604. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Matsatsinis, N. F. 2004. "Towards a Decision Support System for the Ready Concrete Distribution System: A Case of a Greek Company". *European Journal of Operational Research* 152(2):487-499.

Naso, D., M. Surico, B. Turchiano, and U. Kaymak. 2007. "Genetic Algorithms for Supply-Chain Scheduling: A Case Study in the Distribution of Ready-Mixed Concrete". *European Journal of Operational Research* 177(3):2069–2099.

Schmid, V., K. F. Doerner, R. F. Hartl, M. P. Savelsbergh, and W. Stoecher. 2009. "A Hybrid Solution Approach for Ready-Mixed Concrete Delivery". *Transportation Science* 43(1):70-85.

Schmid, V., K. F. Doerner, R. F. Hartl, and J. J. Salazar-González. 2010. "Hybridization of Very Large Neighborhood Search for Ready-Mixed Concrete Delivery Problems". *Computers & Operations Research* 37(3):559-574.

Wu, M. and S. P. Low. 2007. "Modeling Just-in-Time Purchasing in the Ready Mixed Concrete Industry". *International Journal of Production Economics* 107(1):190-201.

Yan, S., H. C. Lin, and X. Y. Jiang. 2012. "A Planning Model With a Solution Algorithm for Ready Mixed Concrete Production and Truck Dispatching Under Stochastic Travel Times". *Engineering Optimization* 44(4):427-447.

AUTHOR BIOGRAPHIES

JAIME ALBERTO SÁNCHEZ VELÁSQUEZ is an Assistant Professor of the Department of Industrial and Systems Engineering at the Universidad EIA (COLOMBIA) and coordinator of the Academic Area of Models and Simulation. He holds a M.Sc. in administrative engineering from Universidad Nacional, COLOMBIA. His research interests include discrete-event simulation, agent-based simulation, and their applications in social networks, service systems, transportation, energy markets, and manufacturing. His e-mail address is jasanchev@gmail.com.

MARIA CAMILA ARISTIZÁBAL ISAZA is a Civil Engineer from EIA University, currently working in Cementos Argos in the logistics planning area that seeks to implement ideas that optimize the operation of ready-mix concrete business. She is studying for the degree of MSF from Universidad EAFIT. Her e-mail address is mcamila.aristizabal@explanan.com.