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Deterministic and Simulation Modeling of the Production of Ready Mix Concrete Batch Plant Industry in Nahr El Maout, Lebanon

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Deterministic and Simulation Modeling of the Production of Ready Mix Concrete Batch Plant Industry in Nahr El Maout, Lebanon

Nabil Semaan

Abstract

The Ready Mix Concrete (RMC) batch plant is an industrialized plant, where concrete is mixed from cement, coarse and fine aggregates, water and admixtures. Then, it is delivered to the construction site using a transit truck mixer. Calculating the productivity of RMC batch plants in the combined operation of concrete mixing in the plant and the delivery to the site is a complex task. RMC batch plants researchers or managers try to limit the production evaluation to that of the mixer alone. This approach fails to look at the batch plant production as a whole system, thus it fails to assess the bottle necks, querying and idleness in each part of the plant system.

This paper analyzes the production of the RMC batch plant mixing and its delivery to the site. The productivity is evaluated using two approaches: a deterministic and a stochastic. The deterministic approach develops a general production model and assesses a deterministic productivity. On the other hand, a stochastic approach to productivity evaluation uses probabilistic activity durations and assesses a probabilistic productivity. The simulation model is based on the Monte Carlo simulation technique applied to MicroCyclone web-based software. Both, the deterministic and stochastic models are applied to the HOLCIM plant in Nahr El Maout, Lebanon.

The deterministic model found the batch plant production to be 63 m^3/hr, while the truck mixers vary between 6 and 36 m^3/hr. depending on the truck cycle time and the number of the trucks. The stochastic model simulated the batch plant process with truck delivery to site for 30 iterations, and utilized probabilistic activity durations. It was found that when a steady state is reached it results to a productivity of 55 m^3/hr. The simulation model identified that the aggregates, cement and admixture transfer to the central mixer are 95% idle.

This research paper is relevant to both the academic field and the industry.

Keywords: Cycle Time, Deterministic Production, MicroCyclone, Monte Carlo Simulation, Queue, Ready Mix Concrete, Stochastic Production.

Introduction

A concrete batch plant is a well-developed and industrialized plant, where the concrete is combined before transferring it to the site using transit mixer and ready to be placed (Utranazz, 2008). In the 1930s, the first Ready Mix Concrete (RMC) factory was constructed but the industry was not used frequently until the 1960s and then it expanded gradually (Feghali and El-Imadi, 2011).

According to Alkoc and Erbatur (1997), the purpose of a production system is to examine the interaction between operations, in order to determine the idleness of resources, to locate the bottlenecks and to estimate the production of the system.

The RMC batch plant managers always try to limit the production evaluation by the mixer productivity solely. True a certain extent, this approach fails to look at the batch plant production as a whole system. For instance, the aggregates transfer from the bins to the mixer is not considered. Similarly the cement transfer from the silo to the mixer is not considered as well. This approach fails to evaluate the different systems (in a batch plant) production, and points at the bottle necks, queuing and idle system in the plant.

The objective of this project is to determine the productivity of a concrete batch plant using both deterministic and stochastic approaches. The deterministic model is a general production model. In this model, the duration and the factors affecting each activity are considered to be constant in order to calculate the productivity. The stochastic approach is done using first a queuing model, then a MicroCyclone model. Thus the following sub-objectives are identified:

1. Develop a deterministic model of the production.
2. Evaluate the deterministic productivity.
3. Develop a production model using MicroCyclone.
4. Evaluate the MicroCyclone productivity.
5. Perform sensitivity analysis of the MicroCyclone model.
6. Analyze the results of the models.

Ready Mix Concrete Batch Plant

A ready mix concrete batch plant is a plant that is used to produce concrete and transport it to the site using a transit mixer. Controlled by the usage of computers where the constituents of concrete are measured accurately. Hence, the main advantage of the ready mix concrete is to increase the quality of concrete (Mark, 2010).

The combination of sand, Portland cement, aggregate and water forms the concrete. The addition of small quantity of admixture may be used to decrease the permeability of liquid, amplify the strength, change color, adjust concrete viscosity, delay or increase the speed of the setting time, entrain the air, or diminish the water requirements. The concrete batch plant combines Portland cement, sand, aggregate and water together in order to get a ready mixed concrete according to a certain mix.

The Ready mix concrete batch plant can be either a central or transit mix type, or dry and wet type mix, or mobile and permanent type of plant, thus the ready mix concrete batch plant can be divided into four categories (Atlantic, 2011a):

i) Dry mobile transit mix,
ii) Wet mobile central mix,
iii) Dry permanent transit mix,
iv) Wet permanent central mix.

The permanent batching plant, in general, contains silos, bins, concrete batchers, conveyors, and control tools. Whereas the mobile batching plant includes frameworks with batchers, conveyors, scales, organize supplies and tiny silos that are transferred from one site to another. These supplies save large amounts of money and time that improve the efficiency at the construction site (Utranazz, 2008). Mobile concrete plants permit the contractors to produce concrete at the construction site, hence reducing order and transportation costs (Atlantic, 2011b).

On the other hand, the batch plant can has a transit (or truck) mix or central mix. In a transit mix operation, the dry components (aggregates, cement and admixture) are placed into a mixer truck, and then water is added volumetrically in the truck mixer, hence the concrete mix is formed in the truck mixer on the way to the construction site. Whereas, using a central mix operation, the dry components of concrete (aggregates, cement and admixtures) are mixed with water in a central batch plant mixer before pouring the mixed wet concrete in the transit truck. The transit truck is used, in this case, for transportation purposes only (Atlantic, 2011c).

Several researchers examined the production of concrete batch plants and concreting operation in general. Wand and Anson (2000) gathered lot of site/plant data for plants in Hong Kong, and performed a statistical analysis in order to draw conclusions. Ying et al. (2005) used the data collected by Wang and Anson (2000) and manipulated them in order to use them in a simulation model.

Simulation of Concrete Batching Operations

Simulation is used in construction operation before the construction begins to manipulate a model, which is a simplified representation of the real system, in order to seek the unforeseen problems and optimize the system performance: maximize production, and minimize the cost (Maria, 1997).

MicroCyclone is a simulation system developed by Halpin in 1973, and published in his book in 1992 (Halpin, 1992), which can model and simulate an operation where the duration of work tasks are randomly defined. The cyclone method of modeling is based on the development of cyclical networks of queues and activities (Alkoc and Erbatur, 1997). Halpin developed three MicroCyclone modeling elements: the active state, idle state, and direction of entity flow. One of the most important characteristics of MicroCyclone is the sensitivity analysis technique. This feature allows the user to change the number of resources and to know the productivity for a different number of resources (Chung, 2009).

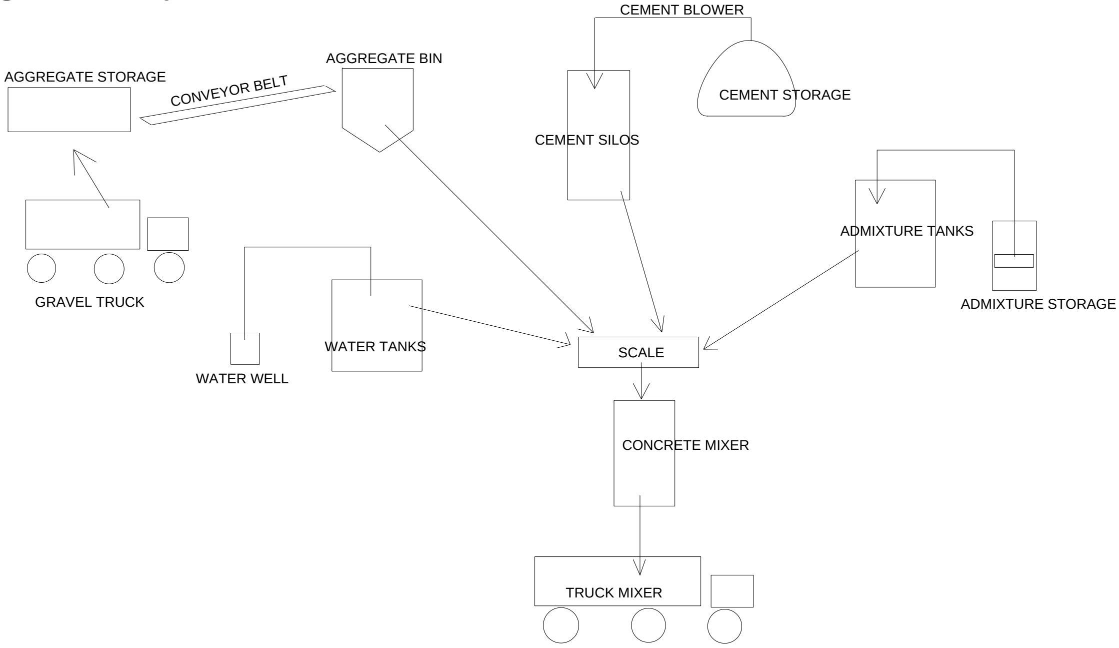
Several researchers have used MicroCyclone in the construction industry and the concrete production specifically. For example, Alkoc and Erbatur (1997) have developed a cyclone simulation model of the concrete casting operation. However, they did not study the batch plant as an independent system. Tang et al. (2005) have developed a simulation model based on cyclone framework, but more advanced, entitled the Ready Mixed Concrete SIMulation (RMCSIM). The RMCSIM simulates a whole day of activities for a concrete plant with several mixing bays, several trucks with variable capacities and serving several sites (with variable distances to plant). Their model was limited to Hong Kong. Furthermore, it can be applied only in academic circles since it requires complex mathematical background. Zayed et al. (2005) developed a productivity and delays assessment model for concrete plant–truck mixer operations using simulation with artificial Neural Networks (ANN). Their work was limited to academics.

It is observed that while worldwide research is advanced in this topic, (1) link to industry is still missing, (2) Lebanese academic research and industry is way behind, and (3) current industry methods are based on common engineering practices, prone to plan-as-you-go mis-management.

Ready Central Mix Concrete Batch Plant Process

Mixing concrete in a ready mix batch plant follows a specific process. The central mix batch plant process requires that all raw materials (sand, coarse aggregate, cement, water, and admixtures) are mixed in the central mixer prior to delivery to transit trucks. Hence, the whole process consists of moving the raw material from stock places to the mixer. Coarse and fine aggregates are either stockpiled or stored in bins. The aggregates are transported to the central mixer via conveyor belts. On the other hand, cement is stored in silos to keep it away from moisture, and it is transported to the central mixer via either pipes or a conveyor belt. Water is stored in tanks, and transported to the central mixer via pipes. Finally, the admixtures are also stored in tanks, and transported to the central mixer via pipes. Figure 1 illustrates the ready mix concrete batch plant.

Figure 1. *Ready Mix Concrete Batch Plant Process*



The central mixer role is important, since it mixes (according to ratios) all the raw material in order to produce concrete. After mixing the concrete, the central mixer unloads the concrete in a truck fleet that transport it to the construction site.

Deterministic Production Model

Generic Deterministic Model

Production is defined as the output per unit of time. A deterministic production for a concrete batch plant is equal to the volume of concrete produced divided by the cycle time, as defined in Equation 1.

$$P_{BP_i} = \frac{V_{CM}}{CT_{BP}} \qquad (1)$$

Where P_{BPi} *is the ideal batch plant productivity* (m^3/hr.)

V_{CM} *is the volume capacity of the central mixer* (m^3),

CT_{BP} *is the batch plant Cycle Time (hr.) it takes to:*

i) Move the raw material to the central mixer,

ii) Mix in the central mixer

The batch plant cycle time (CT_{BP}) defined in Equation 1 is evaluated using Equation 2, as follows.

$$CT_{BP} = CT_{gravel} + CT_{sand} + CT_{cement} + CT_{water} + CT_{admix} + CT_{mix} + CT_{unloading} \quad (2)$$

Where CT_{BP} *is the batch plant cycle time (hr.),*
CT_{gravel} *is the cycle time to move the gravel (coarse aggregate) from bins to central mixer (hr.),*
CT_{sand} *is the cycle time to move the sand (fine aggregate) from bins to central mixer (hr.),*
CT_{cement} *is the cycle time to move the cement from silo to the central mixer (hr.),*
CT_{water} *is the cycle time to move the water from tank to central mixer (hr.),*
CT_{admix} *is the cycle time to move the admixtures from tanks to central mixer (hr.),*
CT_{mix} *is the cycle time to mix the raw material in the central mixer (hr.),*
$CT_{unloading}$ *is the cycle time to unload the concrete from the central mixer in the transit trucks (hr.).*

The ideal batch plant productivity, as defined in Equation 1, is affected by many factors that reduce it. Hence, the actual batch plant productivity is defined in Equation 3.

$$P_{BP_a} = P_{BP_i} \cdot \prod_{j=1}^{n} f_j \quad (3)$$

Where P_{BPi} *is the ideal batch plant productivity* (m^3*/hr.),*
P_{BPa} *is the actual batch plant productivity* (m^3*/hr.),*
f_i *are reduction factors, j = 1 to n, n = total number of reduction factors.*

Now, the actual transit truck productivity is defined in Equation (4)

$$P_{TR_a} = \frac{V_{TR}}{CT_{TR}} \quad (4)$$

Where P_{TRa} *is the actual transit truck productivity* (m^3*/hr.)*
V_{TR} *is the volume capacity of the transit truck* (m^3*),*
CT_{TR} *is the transit truck Cycle Time (hr.) it takes to:*

- *iii) Load from the central mixer,*
- *iv) Travel from batch plant to construction site,*
- *v) Manoeuver and wait to unload in the construction site,*
- *vi) Unload in the construction site,*
- *vii) Travel back empty to the batch plant.*

The transit truck cycle time (CT_{TR}) defined in Equation 4 is evaluated using Equation 5, as follows.

$$CT_{TR} = CT_{load} + CT_{travel\ full} + CT_{wait} + CT_{unload} + CT_{travel\ empty} \quad (5)$$

Where CT_{TR} *is the transit truck cycle time (hr.),*
CT_{load} *is the cycle time to load concrete in the truck (hr),*

$CT_{travel\ full}$ is the cycle time to travel (full) to the construction site (hr.),
CT_{wait} is the cycle time to manoeuver and wait to unload in the site (hr.),
CT_{unload} is the cycle time to unload concrete in the site (hr.),
$CT_{travel\ empty}$ is the cycle time to travel back empty to the batch plant (hr.),

Now, the whole process productivity is governed by the lease one. Thus, if the batch plant is less productive, truck have to wait in queue in order to be loaded. On the other hand, if the trucks are less productive (long cycle time, for example), the batch plant is idle most of time, waiting for the truck to come back. The optimum productivity of the whole system is reached when a balance point of the productivity is planned for, i.e. have a balanced (optimum) number of trucks in order to have the batch plant productivity equal (or very close) to the trucks productivity. The Balance Point (B.P.) is defined in Equation 6.

$$\boldsymbol{B.P.} = \frac{\boldsymbol{P_{BP_a}}}{\boldsymbol{P_{TR_a}}} \qquad (6)$$

Where B.P. is the Balance Point or the required number of transit trucks in order to reach optimum productivity,
P_{BPa} is the actual batch plant productivity,
P_{TRa} is the actual transit truck productivity.

Nahr el Maout Holcim Plant Deterministic Productivity Evaluation

Holcim is a renowned European cement and concrete production industry; it has several concrete batch plants in Lebanon serving the construction industry. Nahr el Maout batch plant is localized near the Lebanese capital, Beirut, and serves the surroundings. Nahr el Maout batch plant consists of the following:

- Aggregates (gravel and sand) bins: 3 bins, 45 m^3 capacity each; and 2 bins 48m^3 capacity each.
- Cement silos: 3 silos, 67 m^3 capacity each.
- Water tank: 4 tanks, 260 m^3 capacity.
- Admixtures tanks: 6 tanks, 3 m^3 capacity each.
- Central mixer: 1 mixer, 2 m^3 theoretical capacity.

Nahr el Maout uses a fleet of trucks, and each truck has a capacity of 9 m^3. Table 1 shows the actual schedule of concrete production for two cycles.

Table 1. *Actual Batch Plant Schedule*

Task	Cycle No.	Task Starts at Time *[sec]*	Task Duration *[sec]*	Task Ends at Time *[sec]*	Cycle Time *[sec]*
Batching Aggregates	1	0	19	19	
Discharge Aggregates	1	19	34	53	
Batching Cement	1	0	32	32	
Discharge Cement	1	47	8	55	
Batching Water	1	10	21	31	
Discharge Water	1	40	14	54	
Batching Admixture	1	0	41	41	
Discharge Admixture	1	41	14	55	
Mixing Concrete	1	55	30	85	
Discharge Mixer	1	85	34	119	**119**
Batching Aggregates	2	76	20	96	
Discharge Aggregates	2	102	36	138	
Batching Cement	2	55	32	87	
Discharge Cement	2	125	8	133	
Batching Water	2	85	21	106	
Discharge Water	2	120	14	134	
Batching Admixture	2	55	41	96	
Discharge Admixture	2	120	14	134	
Mixing Concrete	2	138	33	171	
Discharge Mixer	2	171	34	205	**86**

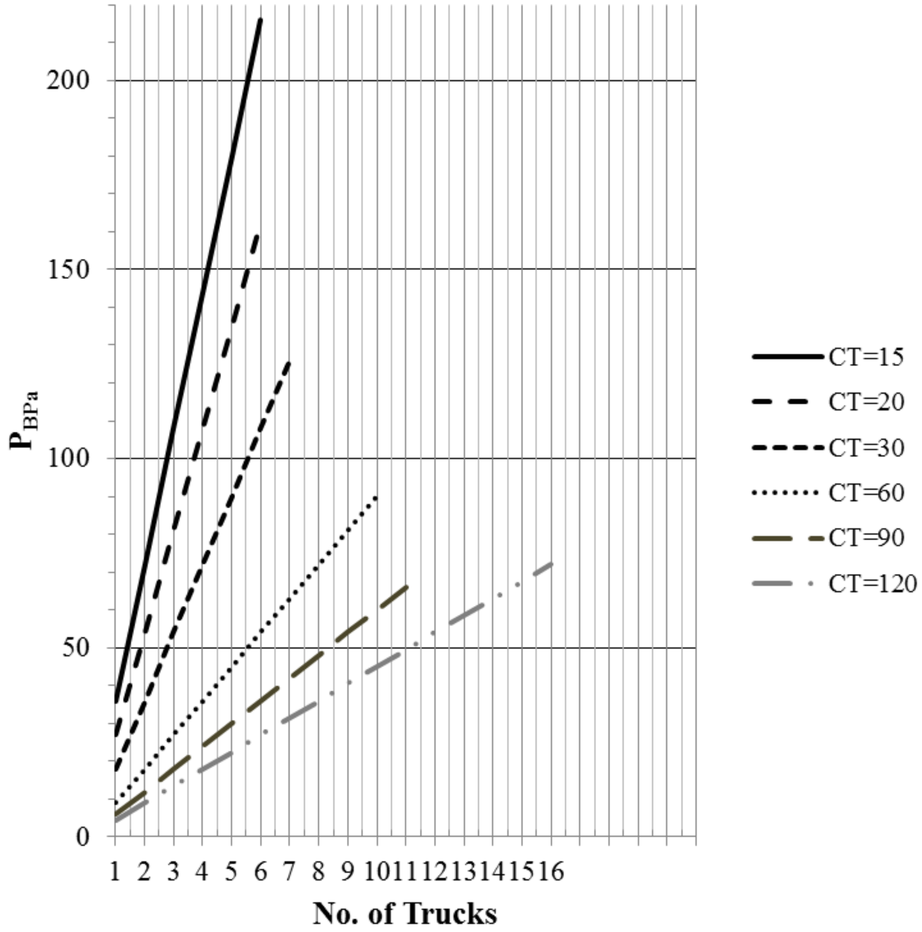
Applying Equations 1 to 4, and using batch plant cycle time duration of 86 sec (from Table 1), with variable truck cycle time, Table 2 show the results of the deterministic productivity calculation, with the Balance Points (BP).

Table 2. *Deterministic Batch Plant/Trucks Systems Productivity Results*

CT_{TR} *[min]*	P_{TRa} *[m^3/hr.]*	P_{BPa} *[m^3/hr.]*	BP	Required No. of Trucks
15	36	63	1.75	2
20	27	63	2.33	3
30	18	63	3.5	4
45	12	63	5.25	6
60	9	63	7	7
90	6	63	10.5	11
120	4.5	63	14	14

Figure 2 illustrates deterministic productivity curves for the Nahr el Maout production.

Figure 2. *Batch Plant Productivity Plot for Nahr el Maout*



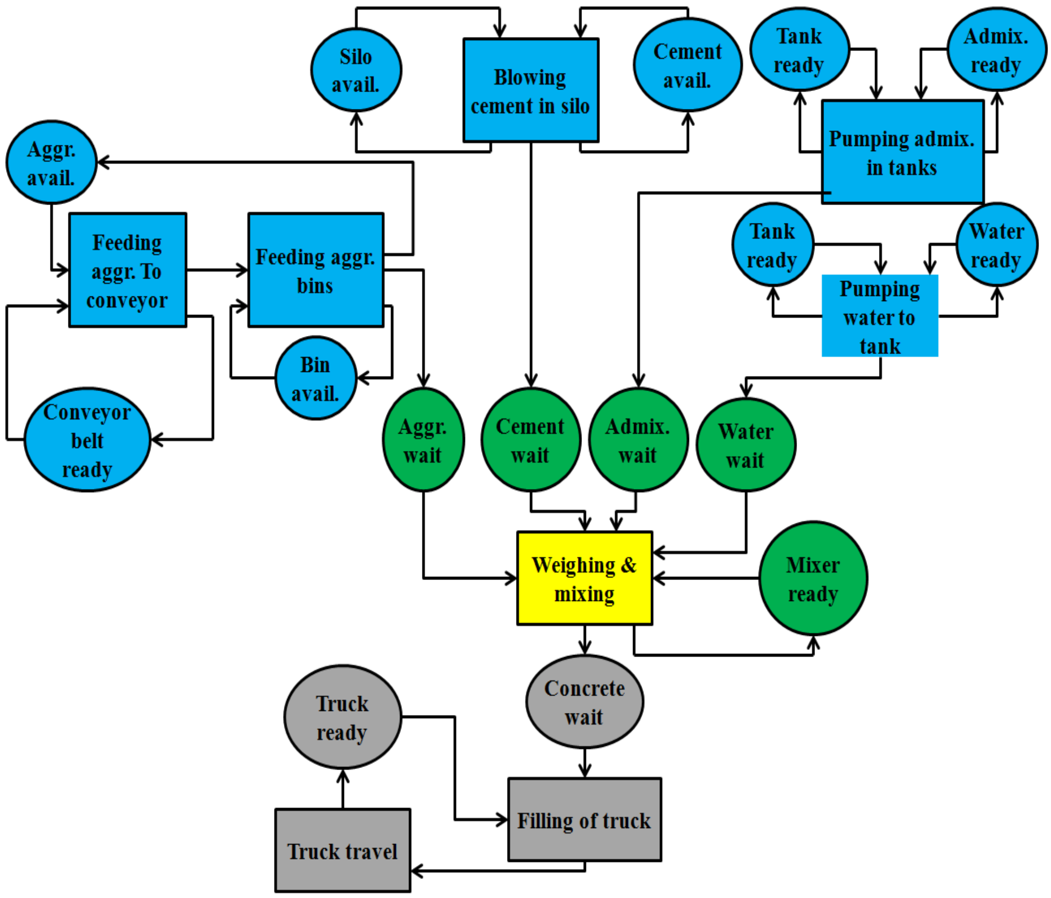
Both Table 1 and Figure 2 are a very important output of the deterministic model. Plant manager can now read the plant productivity for a specific truck number and truck cycle time. The manager, depending on the location of the construction site can evaluate the truck cycle time, which is equal to the time to load the truck mixer, travel full, unload at the site and return empty. When the truck cycle time is evaluated, the manager can either decide on the number of trucks for a certain plant production, or can regulate the plant production depending on the fleet of trucks that is available.

The main drawback of this deterministic production evaluation is its lack to incorporate the uncertainties in the production process. Only stochastic modeling allow including uncertainties in the production evaluation.

Stochastic Simulation Production Model

The MicroCyclone model of the concrete batch plant production is represented in Figure 3. The resources are the aggregates, the cement, the admixture, the water, the aggregate bins, the cement silos, the admixture tanks, the water tanks, the mixer, and the trucks. The process is divided into 3 cycles: i) 1st cycle (feeding aggregate conveyor then feeding aggregate bins, blowing cement in silos, pumping admixtures in tank, pumping water in tank), ii) 2nd cycle (weighing and mixing aggregate, cement, admixture, and water in the mixer), and iii) 3rd cycle (loading the truck, truck travelling to site, unloading, and returning empty).

Figure 3. *MicroCyclone Model for the Concrete Batch Plant Production*



The power of simulation is that it can model the activities durations as probabilities. MicroCyclone uses probabilities to represent the activity durations. Several site visits were done, and different activity durations were recorded. Then, histograms of the different activity durations are developed, and the probability distribution function for each one is developed as well. Triangular distribution is chosen since it represents best activity durations. Table 3 shows the different activities probabilistic durations.

Table 3. *Batch Plant MicroCyclone Model Activities Probabilistic Durations*

Task	**SET**	**Probabilistic Duration** *[sec]*
FEED AGGR BIN	1	Triangular (42, 53, 64)
BLOW CEM SILO	2	Triangular (32, 40, 48)
PUMP ADMX TANK	3	Triangular (38, 55, 72)
PUMP WATER TANK	4	Triangular (27, 35, 41)
MIX CONCR	5	Triangular (21, 30, 39)
FILL CONCR TRUCK	6	Triangular (20, 34, 55)
TRUCK TRAVEL	7	Triangular (900, 2700, 7200)

The MicroCyclone is run for 30 cycles (iterations). Table 4 shows the productivity result.

Table 4. *Productivity Simulation Results*

Concrete Batch Plant Production		
Productivity Information		
Total Sim. Time Unit	Cycle No.	**Productivity** *[Per Time Unit]*
98.5	30	0.3044

Referring to Table 4, the stochastic batch plant production (after 30 cycles) is equal to (0.3045*3600) / 20 [m^3/sec] = 54.81 m^3/hr., which is lower than the 63 m^3/hr. that resulted from the deterministic productivity evaluation. Now, looking at the different resources (queues) and their respective idleness, Table 5 shows the queues statistics.

It is observed from Table 5 that the aggregates are idle for 51% of the time which means 49% efficiency. For the cement, the idle time is 57% which means 43% efficiency. For the admixtures, the percent of idleness is 13.1%. This means that the admixtures are not idle most of the time. However, the percent of idleness for water is 72% which is very large. The mixer is spending 67.97% of the time waiting. Therefore, the efficiency of the mixer is only about 32.3%. For the concrete ready, only 12% of the time is idle which means the efficiency is about 88%. The trucks are most of the time idle (87%). For this reason, it is better either to use a smaller fleet of trucks or use trucks with lower capacity.

Table 5. *Cyclone Queues Statistics Information*

Concrete Batch Plant Production								
Cyclone Passive Elements Statistics Information								
Type	No.	Name	Average Units Idle	Max. Idle Units	Times Not Empty	% Idle	Average Wt. Time	Units At End
Queue	1	Aggr Avail	0.0	1000	0.0	0.00	0.0	0
Queue	2	Aggr Bin Wt.	1250.0	2250	98.2	99.67	16.3	1250
Queue	4	Cement Avail	0.0	540	0.0	0.00	0.0	0
Queue	5	Cem Silo Wt	1460.0	2000	98.5	99.97	11.1	1460
Queue	7	Admx Avail	970.0	1000	97.7	99.15	1.9	970
Queue	8	Admx Tank Wt	0.0	30	0.0	0.00	0.0	0
Queue	10	Water Avail	700.0	1000	98.5	100.00	19.0	700
Queue	11	Water Tank Wt	0.0	300	0.0	0.00	0.0	0
Queue	13	Aggr Ready	283.3	972	50.1	50.85	5.4	972
Queue	14	Cement Ready	237.9	577	55.8	56.67	10.0	577
Queue	15	Admx Ready	0.5	10	12.9	13.10	1.3	5
Queue	16	Water Ready	278.9	642	71.1	72.16	25.4	642
Queue	17	Mixer Wait	24.2	30	67.0	67.97	27.0	0
Queue	20	Concr Ready	0.6	10	11.9	12.07	0.0	10
Queue	21	Truck Wait	18.3	20	85.5	86.78	39.1	0

A sensitivity analysis using MicroCyclone is also performed, in order to check if different mixer sizes affect the production. Thus, the size of mixer was changed in order to know the production for each size of mixers and select the best productivity. Table 6 shows the sensitivity analysis results.

Table 6. *Sensitivity Analysis Results*

# Of Mixer Wait At Mixer Wait	Productivity Per Unit Time
30	0.3034
31	0.2822
32	0.3030
33	0.3015
34	0.3123
35	0.3055
36	0.2889
37	0.3112
38	0.2878
39	0.2967
40	0.3043

From the Table 6, it is observed that changing the number of mixer do not improve the production a lot.

Conclusions

Evaluating the productivity for a concrete batch plant is one of the most important tasks that a manager should take care of. The productivity measures the performance of work and gives a clear idea for the manager to know where the bottle-neck occurs and how to solve it. The production of the concrete batch plant is calculated using two models: the deterministic model and the stochastic model. The deterministic model is based on the general production model and uses deterministic time. However, the stochastic model is done the MicroCyclone simulation model. The stochastic model resulted in a batch plant productivity of 55 m^3/hr, while the deterministic model gave a batch plant production of 63 m^3/hr., higher by 15%. The reason behind the difference is the inability of the deterministic model to consider resource utilization (queues and idleness). Thus, the deterministic model fails to consider both the different inner (aggregates, cement, water and admixtures) resources of the batch plant – but focuses on the mixer only – and the truck(s) cycle time in the batch plant production. The MicroCyclone model works better in evaluating idleness of the different inner resources of the batch plant, and considers the truck production as an integral part of the whole batch plant/truck system.

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