International Journal of Science, Environment and Technology, Vol. 5, No 1, 2016, 7 – 16
ISSN 2278-3687 (O)
2277-663X (P)

STOCHASTIC PRODUCTIVITY ANALYSIS OF READY MIX CONCRETE BATCH PLANT IN KFARSHIMA, LEBANON

Nabil Semaan
Assistant Professor, P.E.
Civil Engineering Department, Faculty of Engineering, University of Balamand
Kelhat, El-Koura, North-Lebanon, Lebanon, P.O. Box: 100 Tripoli
Email: nabil.semaan@balamand.edu.lb

Abstract: Evaluating the productivity of a ready mix concrete batch plant is one of the most challenging tasks of a plant manager and engineer, since it involves lot of uncertainties, thus risks. Hence, a stochastic productivity model is deemed important. This paper analyzes the production of ready mix concrete batch plant using two stochastic models: i) a queuing model, and ii) a simulation model. The queuing model is based on both the Queuing Theory (QT) and a Markov Chain (MC) model. While the simulation model is based on the Monte Carlo simulation technique performed by MicroCyclone web-based software. Both models are applied to the HOLCIM plant in Kfarshima, Lebanon. This paper is relevant to both the academic field and the industry.
Keywords: Ready Mix Concrete, Stochastic Production, MicroCyclone, Monte Carlo Simulation, Queue, Cycle Time.

1. 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. 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. Evaluating the production of the Ready Mix Concrete (RMC) batch plant is not obvious and straight forward, since it involves lot of uncertainties in evaluating durations of each process. These uncertainties are due to many factors, such as: operations management, equipment conditions, operators skills, weather conditions, and others.

The objective of this paper is to determine the productivity of a concrete batch plant using a stochastic approach, but with i) a queying model, and ii) a simulation model. Thus the following sub-objectives are identified:

1. Develop a queuing productivity model.
2. Evaluate the queuing productivity model.

*Received Dec 8, 2015 * Published Feb 2, 2016 * www.ijset.net*

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

2. READY CENTRAL MIX CONCRETE BATCH PLANT PROCESS

Mixing concrete in a ready mix concrete 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 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 process.

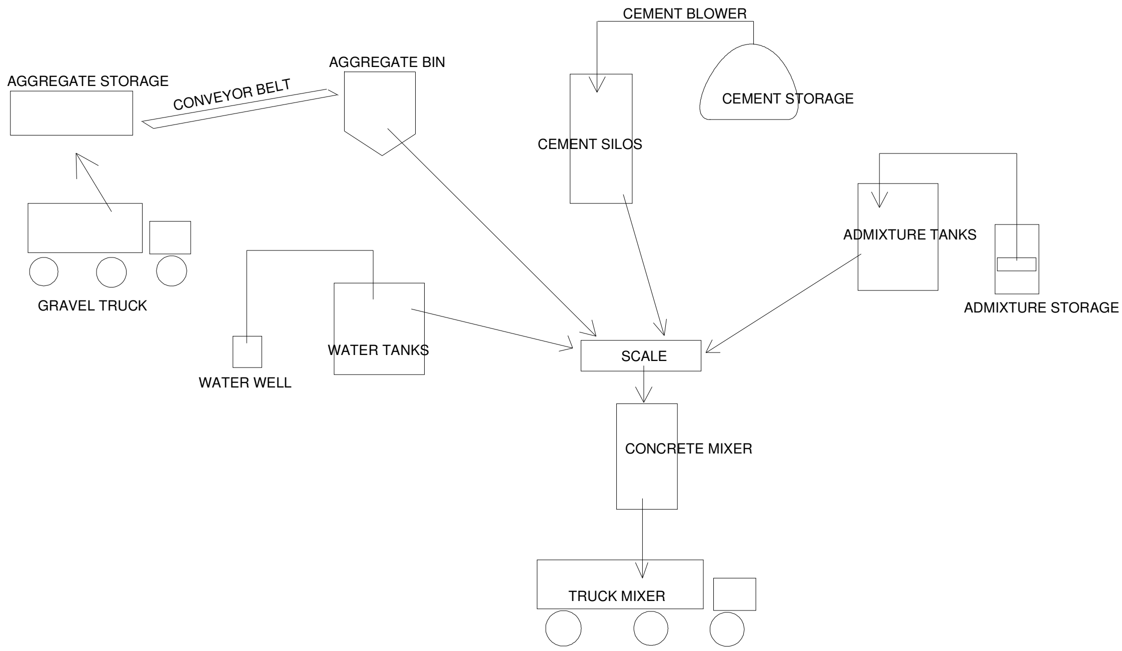

Figure 1. Ready Mix Concrete Batch Plant Process

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.

Holcim, one the leading RMC industry has several batch plants across a small country like Lebanon. Holcim batch plant in kfarshima area is one of the biggest plants, and serves a big surrounding region. Raw material data from the kfarshima plant are collected, and tabulated in Table 1.

Table 1. Raw Material Data of Kfarshima Batch Plant

Kfrashima Plant	Storage	Weighing system	Dosing device	Material transfer
Aggregate	5 bins (45 m^3)	Weighing conveyor belt	2 batching gates per bin	Conveyor belt + feeder skip
Cement	2 silos (200 m^3)	Weighing container	1 speed screw conveyor per silo	By gravity in the mixer
Admixture	4 tanks (3 m^3)	Weighing container	pump	By gravity in the mixer
Water	1 tank (300 m^3)	Weighing container	2 pneumatic valves	By pumping in the mixer

3. THE QUEUING MODEL

A queuing model is a stochastic model that is used to represent the process of a construction process and estimate its production and cost. In the queuing model, a generic construction process has a server and auxiliary units. The server is the one who does the main work and serves the units. However, the auxiliary unit is the one who is being served and helps in completing the work.

In the concrete batch plant, the server is the batch plant mixer and the trucks are the auxiliary units. When a truck arrives to the batch plant and the mixer is loading another truck, it has to wait until the mixer is idle. The time, when the mixer is serving the truck is called service time. However, the back cycle time, which is the time a truck stays outside the plant is called arrival time. Hence, service rates and arrival rates in a qeuing model are evaluated as probability distributions following Erlang exponential distribution. The most likely rates are defined in Equations (1) and (2):

Service rate: $\mu = 1/T_{Service}$ (1)

Arrival rate: $\lambda = 1/T_{Arrival}$ (2)

Where: $T_{Service}$ = *Service time – follows an exponential distribution.*

$T_{Arrival}$ = *Arrival time – follows an exponential distribution.*

The service and arrival rates are very important in order to determine if there is a queue in the system (truck is waiting) or if the server is idle (batch plant is waiting) as follows:

- If $\lambda > \mu$, then there is a queue problem in the system.
- If $\lambda < \mu$, then the server is idle.
- The optimum production occurs when $\lambda = \mu$

The Queuing model uses Markov Chain (MC) in order to model the change of the system from one state to another. S_0 is defined as the state where no transit mixer truck is waiting in queue to be served by the central mixer. Thus, S_3, for example, is the state where 3 transit mixers are being served by the central mixer. Hence, the Markov Chain model is illustrated in Figure 2, for 3 transit trucks (as an example).

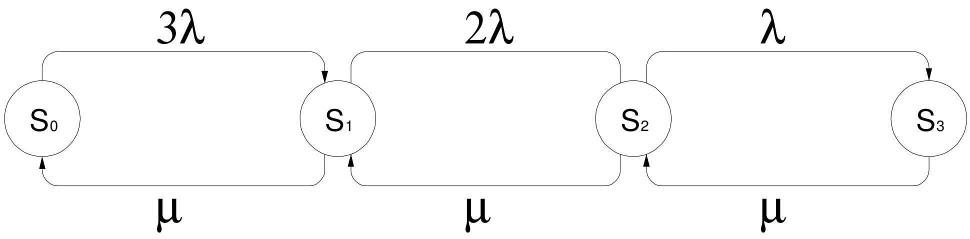

Figure 2. Markov Chain Model for 3 Transit Trucks

Now, for each state S_i, the associated probabilibty of the the trucks being served in P_i. Hence, P_0 is the probability of no trucks being served. A Productivity Index (PI) is the equivalent loss in productivity, or the presence of queues (which decrease the productivity), hence the inverse of the state of 'no queues' in the system, or $1-P_0$, as defined in Equation (3):

Productivity Index: $PI = 1 - P_0$ (3)

Therefore, the system productivity is evaluated using Equation (4):

Batch Plant/Truck System Productivity: $P = \mu . PI .C$ (4)

Where: μ is the service rate,

C is the central mixer capacity,

PI is the Productivity Index,

In Kfarshima batch plant, there is one server which is the batch plant mixer. And, the most likely service time is of the mixer is evaluated as:

$T_{Service} = 356$ sec = 5.93 min.

Hence, the service rate (μ) is evaluated as per Equation (1) as:

□ $= 1/T_{Service} = 1/5.93 = 0.168$

The auxiliary units are the trucks. The arrival time is the cycle time of a truck minus the service time ($T_{Arrival} = CT_{Truck} - T_{Service}$).

Different truck arrival times are considered based on different site locations. Thus, different truck arrival times are evaluated. Table 2 shows the arrival rate over the service rate versus the varying truck cycle time.

Table 2. Service and Arrival Rates

CT_{Truck} *[min]*	$T_{Arrival}$ *[min]*	**Arrival Rate (λ)**	**Service Rate (μ)**	**λ/μ**
15	9.066	0.110	0.168	0.65
20	14.06	0.071	0.168	0.42
30	24.06	0.041	0.168	0.24
45	39.06	0.025	0.168	0.15
60	54.06	0.018	0.168	0.11
90	84.06	0.011	0.168	0.07
120	114.0	0.008	0.168	0.05

It is observed that $\mu > \lambda$ for all CTs, thus the server is always idle. Therefore, it is better to get more trucks. PI is a factor that reflects the efficiency of production and is affected by both λ/μ and the number of trucks (units) by applying Equation 3. Figure 3 illustrates the different PI for the varying number of trucks and arrival cycle times.

The Productivity (P) can be evaluated for the different values of PI. Thus, using Figure 3 and applying Equation 4, the productivity P is evaluated, as illustrated in Figure 4.

Figure 4 is an important output of the queuing model. The manager/engineer can easily estimate the plant production for known number of trucks and truck cycle time. However, the queuing model has also lot of drawbacks summarized as follows:

- The production is assumed steady, which in real life is not the case.
- The First In First Out (FIFO) principle for trucks being served is assumed, which is also very difficult to have in real life.
- The service and arrival rates are assumed to follow Erlang exponential distribution, which might not be the case in real life.

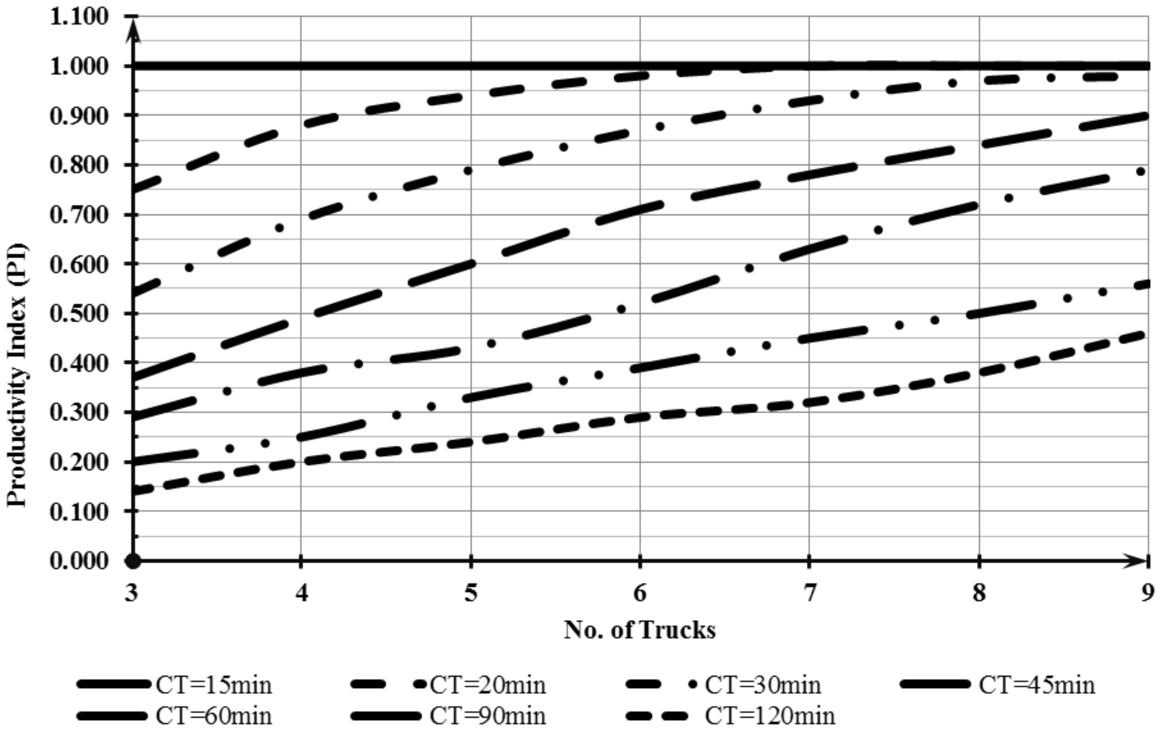

Figure 3. PI for Different Number of Trucks and Different CT

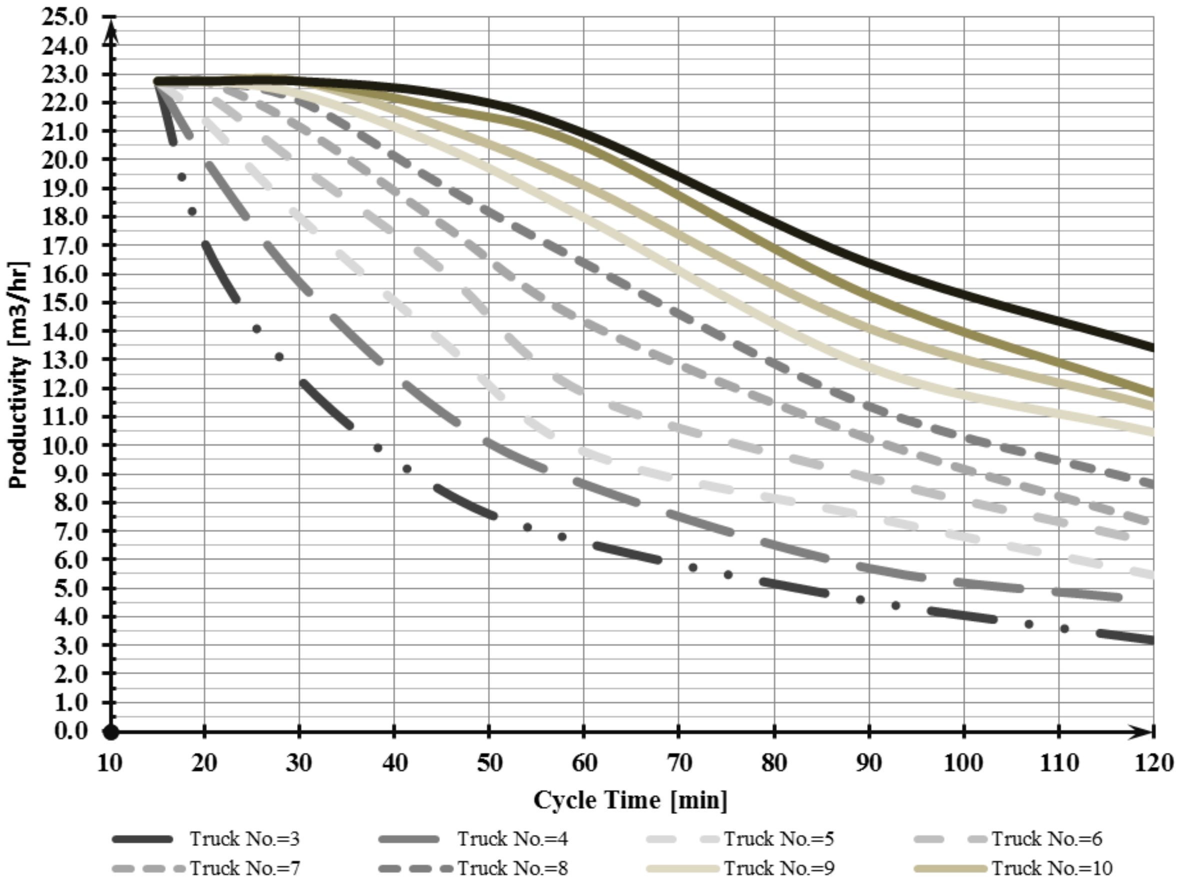

Figure 4. Concrete Batch Plant Productivity Graph

5. SIMULATION PRODUCTION MODEL

Simulation is a graphical/mathematical representation of the real system, in order to seek the unforeseen problems and optimize the system performance: maximize production, and minimize the cost. 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. Halpin developed three MicroCyclone modeling elements: 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 analyze the respective productivities.

The MicroCyclone model of the concrete batch plant production is represented in Figure 5. 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).

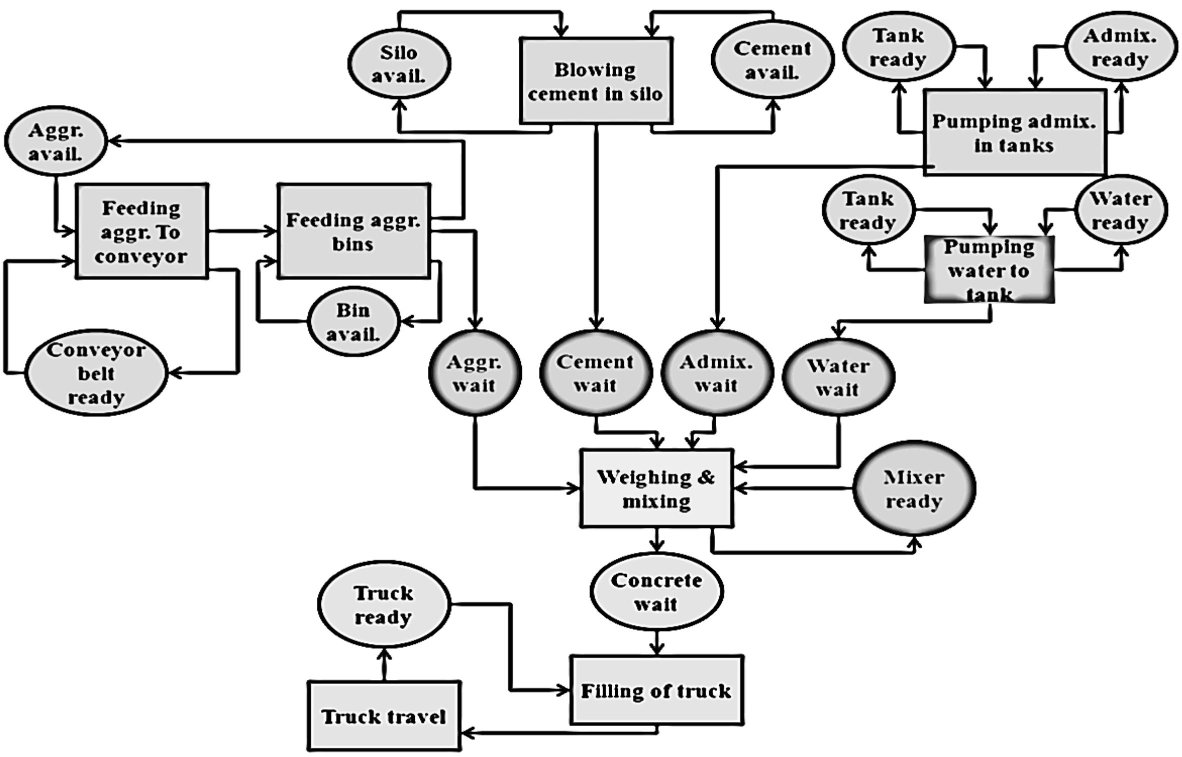

Figure 5. MicroCyclone Model for the Concrete Batch Plant Production

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 show 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), and the output is 0.304 per unit of time. Thus, the stochastic batch plant production (after 30 cycles) is equal to (0.3045*3600) / 20 [m^3/sec] = 54.81 m^3/hr. Now, looking at the different resources (queues) and their respective idleness, Table 4 shows the queues statistics.

Table 4. Cyclone Queues Statistics Information

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

It is observed from Table 4 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 ready mix concrete, only 12% of the time is idle which means the efficiency is about 88%, while the trucks are most of the time idle (87%).

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 5. 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 Table 5, it is observed that changing the number of mixer do not improve the production a lot, since the highest increase is 3% approximately only.

6. 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 concrete batch plant is calculated using two stochastic models: the queuing model and the simulation model. The simulation model resulted in a batch plant productivity of 55 m^3/hr., while the queuing model gave a maximum batch plant production of 23 m^3/hr., almost half. However, due to the important drawbacks of the queuing model, 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.

REFERENCES

[1] Halpin, D.W. (1992). *Planning and analysis of construction operation.* USA: John Wiley & Sons.