

SIMULATION AS A TOOL FOR RESOURCE MANAGEMENT

Tarek M. Zayed
Daniel W. Halpin

Division of Construction Engineering And Management
School of Civil Engineering, Purdue University
West Lafayette, IN 47907-1294, U.S.A.

ABSTRACT

The decision-making process is a very essential part of any construction operation. Simulation can be used as a tool to assist construction managers in making informed decisions. In this paper, simulation is applied to a Concrete Batch Plant to analyze alternative solutions and resource management. Data is collected to define activity durations for the plant. A simulation model is constructed for the plant using the Micro CYCLONE simulation system. Based on sensitivity analysis, management tools are constructed to help the decision-maker. These tools are a Time-Cost-Quantity chart, a feasible region analysis and a contour lines chart. Time-Cost-Quantity and contour lines charts are used for deciding production time, production cost and required resources for a required distance from the plant. The feasible region chart is used for deciding the range of alternative solutions that can be taken to minimize production time and cost of the available plant resources according to the required transportation distance.

1 INTRODUCTION

A model is a representation of a real-world situation and provides a framework within which a given situation can be investigated and analyzed. Models contain and reflect data that, when interpreted according to certain rules or conventions, provide information which supports the decision making process. The precision with which these models reflect the real world varies widely. Abstract or conceptual models depend on a set of modeling and interpretive rules. Scheduling networks and bar charts, for example, have their own individual modeling and interpretive rules. Schematic models are representations that portray a physical situation (e.g. a map) so that a representational modeling or perception of the real world situation is achieved. Construction drawings are an excellent example of a schematic model. Models of various types are at the heart of problem solving.

Due to the complex interaction among units on the construction job site and in the construction environment, mathematical models (e.g. queuing systems) can be applied to only a limited number of special cases. Output from one operation tends to be the input to the following operation in construction. This leads to the development of chains of work tasks as well as situations in which many units are delayed at processors pending arrival of a required resource. Such chained or linked situations are too complex to be modeled using classical queuing models. Simulation techniques offer the only general methodology that affords a means of modeling such situations.

One class of simulation models that has been used to model chains of queues in which units interact is referred to as the "link-node" modeling format (Teicholz, 1963). The link-node method gets its name from the chain like or linked appearance of the graphical representation of the model. Nodes are located at the end of each link and indicate an activity.

Simulation techniques can be applied to the modeling of concrete batch plant operations in order to study different combinations of resources. Micro CYCLONE modeling and programming techniques can be used to simulate this process. The elements of Micro CYCLONE, originally developed by Halpin (1973), are used to model and simulate concrete batch plant operations. The Micro CYCLONE elements used for construction modeling are shown in Figure 1 (Halpin 1992). Micro CYCLONE is a simple and powerful tool for construction process planning, as demonstrated by many researchers.

2 ANALYSIS OF CONCRETE SUPPLY

This paper develops a simulation approach for the study of concrete batch plant operations. The results of the study provide a means of predicting systems production and defining optimum supply areas around a concrete batch plant. The optimum areas support efficient resource allocation with minimum duration and cost for different distances.

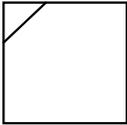
Name	Symbol	Function
Combination (COMBI) Activity		This element is always preceded by Queue Nodes. Before it can commence, units must be available at each of the preceding Queue Nodes. If units are available, they are combined and processed through the activity. If units are available at some but not all of the preceding Queue Nodes, these units are delayed until the condition for combination is met.
Normal Activity		This is an activity similar to the COMBI. However, units arriving at this element begin processing immediately and are not delayed.
Queue Node		This element precedes all COMBI activities and provides a location at which units are delayed pending combination. Delay statistics are measured at this element.
Function Node		It is inserted into the model to perform special functions such as counting, consolidation, marking, and statistic collection.
Accumulator		It is used to define the number of times of the system cycles.
Arc		Indicates the logical structure of the model and direction of entity flow.

Figure 1: Basic CYCLONE Modeling Elements

The sub-objectives of this study are as follows:

- 1- Study of each component of the batch-truck-pump cycles.
- 2- Development of a Micro CYCLONE model for these processes.
- 3- Collection of data about the duration of each activity to estimate both deterministic and random times intrinsic to the model.
- 4- Simulation of the performance and productivity for various numbers of trucks and various distances.
- 5- Calculation of the optimum number of trucks corresponding to the various distances.
- 6- Construction of the contour lines for the optimum travel areas around the batch plant.
- 7- Development of decision-making tools for concrete batch plant management to decide the optimum resource combination with minimum production time and cost.

3 MODELING CONTEXT

In order to address the decision-making environment, a batch plant transit mix delivery operation located in Lafayette, Indiana was studied. The observed facility consisted of storage bins for sand and gravel, a hopper

tower, two belt conveyors, two cement silos, and a discharge unit. This facility serves an area of approximately 15 miles radius. The production capacity of the plant was rated as approximately 40 cy/hr.

Figure 2 shows the flow diagram for the concrete batch plant and the transit mixer cycles. The material is withdrawn from the storage area to fill the batch hopper through conveyor belt 1. There is a scale for measuring the aggregate weight in the hopper tower before discharging to the transit mixer through the conveyor belt 2.

4 MODEL DESCRIPTION

The model developed consists of several cycles for the following resources as indicated in Figure 3:

- (1) Conveyor 1 is used to transport the aggregates from the storage area to the storage hopper. It has three different operations, namely, waiting for the aggregates, transporting the aggregates, and maintenance.
- (2) A hopper is used for storing the different types of aggregates. It receives the aggregates from conveyor 1 and stores them for feeding to conveyor 2. After feeding conveyor 2, it waits for Conveyor 1 to provide re-supply.

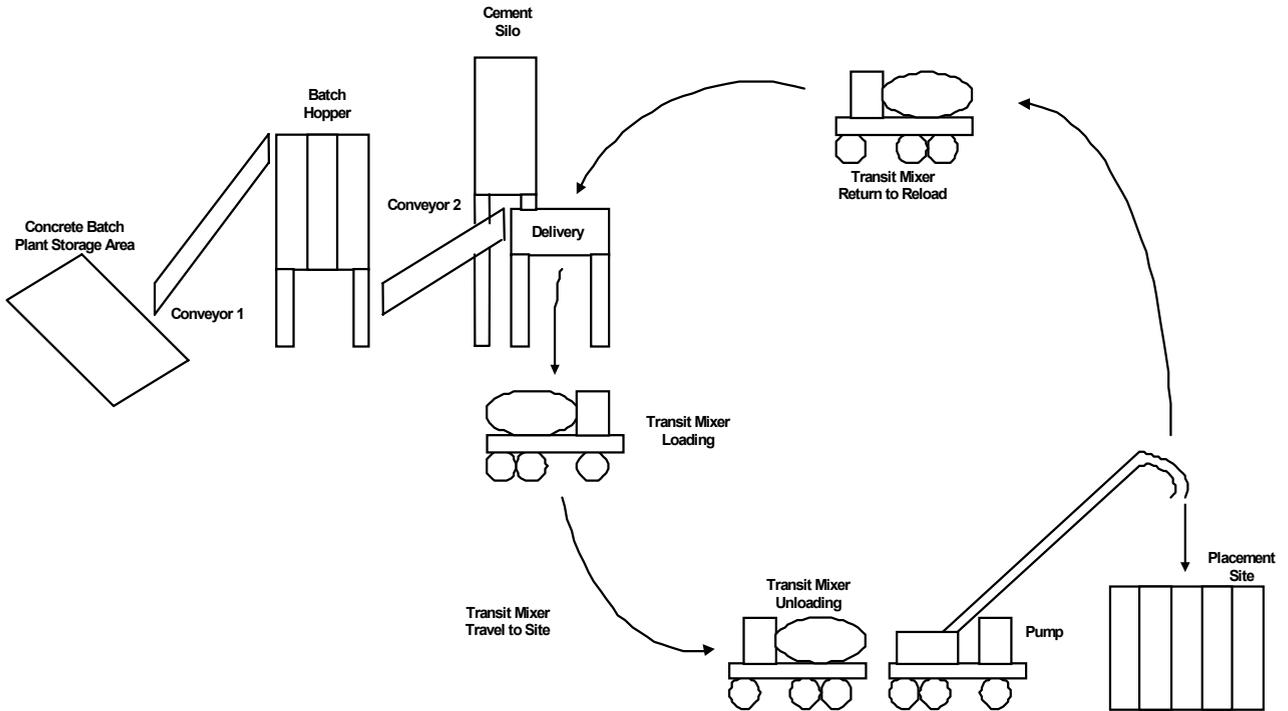


Figure 2: Flow Diagram for the Concrete Batch Plant and the Transit Mixer

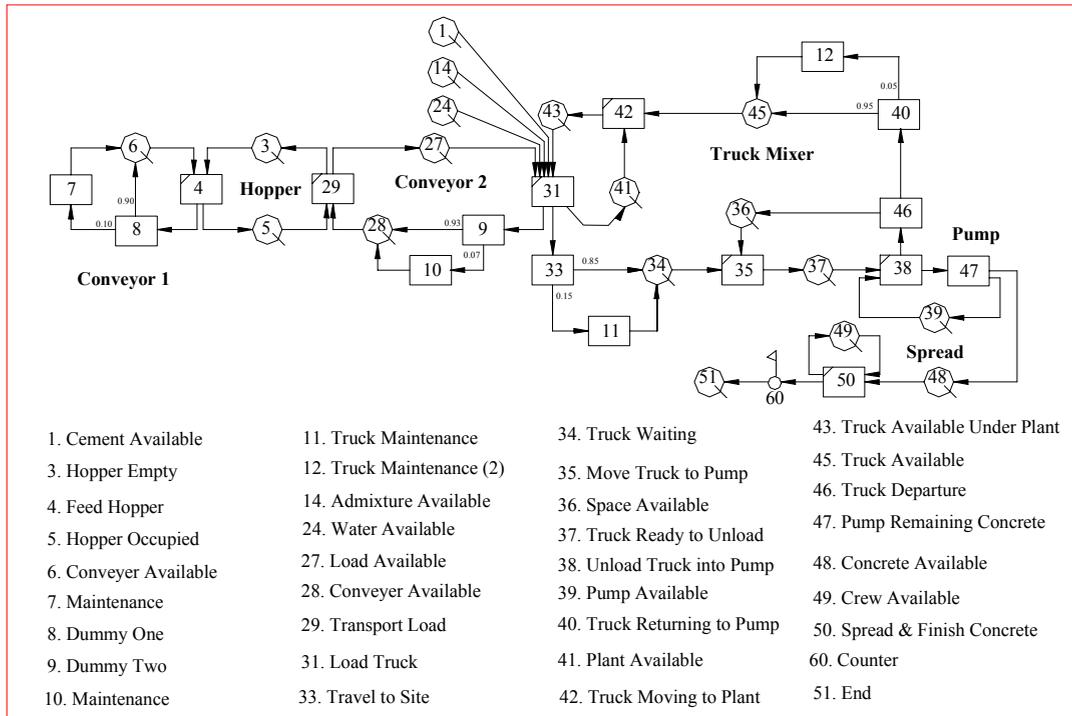


Figure 3: Micro CYCLONE Schematic Model for Concrete Batching Plant

- (3) Conveyor 2 transports the aggregates from the hopper to the truck mixer. It waits for the truck mixer. Following truck loading, maintenance is done 7% of the time. After feeding the truck mixer, it waits for the hopper to be available.
- (4) The truck mixer transports the concrete from the plant to the placement sites. To load the truck mixer, cement, aggregates, water, admixtures, and conveyor 2 should be available. After the truck mixer is loaded, it travels to the site where there is a 15% probability maintenance will be done while waiting for the pump. To deliver the concrete to the pump, a truck mixer and a space should be available beside the pump. After unloading, the truck mixer returns back to the plant. There is a 5% probability that maintenance will be done prior to returning to the plant for reload.
- (5) The pump receives the concrete from the truck and supplies it into the pump pipes to the placement sites. After this operation, the pump waits for other truck mixers to deliver concrete.
- (6) Laborers in the placement sites where the concrete is received from the pump pipes do the spreading operation. After finishing the spreading operations, labor crews finish the concrete surface.
- (7) These tasks are done repetitively.

5 DURATION OF SIMULATION ACTIVITIES

In order to build a management decision making tool, data were collected for the duration that were required for simulating the truck cycle, (i.e. loading, unloading, hauling, returning, and delay times for truck mixer). In addition, transport times for sand and gravel and other concrete ingredients in the batch plant were also required.

- (1) The Haul Time was calculated by conducting a regression analysis relating time and distance for various distances: The regression model is:

$$\text{HaulingTime}(\text{min}) = 0.0571 + 1.6006 * \text{Distance}(\text{miles})$$

(Note: pushing the intercept to be zero resulted in insignificant model.)

Statistical Analysis:

- a- Test the Linear Relation:
F-value = 259.06 with probability $p = 0.0001$. Then, β_1 is O.K. at the 5% level of significance and there is a linear relation between hauling time and distance.
- b- Relative Variation:
r-square = 0.9511 where, this is an indicator that the reduction in variation is small.

- c- Visual or graphical tests:
 - Scatter plot indicates that the straight line is a good fit for the data.
 - Normality assumption for the residual is achieved and approximately good.
 - Constancy assumption for the residual is approximately good.
 - Independence assumption for the residual is approximately good.
- d- Adequacy of the model:
Lack of fit (LOF) test is done for this data where there are replications in this data. The probability of LOF-test is $p = 0.203$ that indicates that the model is adequate for this data.

- (2) The Return Time was also calculated by regression between Return time and distance: The model is:

$$\text{Returning Time}(\text{min}) = -0.019 + 1.4003 * \text{Distance}(\text{miles}).$$

(Note: pushing the intercept to be zero resulted in insignificant model.)

Statistical Analysis:

- a- Test the Linear Relation:
F-value = 178.64 with probability $p = 0.0001$. Then, β_1 is O.K. at 5% level of significance and there is a linear relation between hauling time and distance.
 - b- Relative Variation:
r-square = 0.934 where, this is an indicator that the reduction in variation is small.
 - c- Visual or graphical tests:
 - Scatter plot indicates that the straight line is a good fit for the data.
 - Normality assumption for the residual is achieved and approximately good.
 - Constancy assumption for the residual is approximately good.
 - Independence assumption for the residual is approximately good.
 - d- Adequacy of the model:
Lack of fit (LOF) test is done for this data where there are replications in the data. The probability of LOF-test is $p = 0.1876$ that indicates that the model is adequate for this data.
- (3) Loading and Unloading times are calculated as BETA distributions from collected data by using a Beta curve-fitting program.
 - (4) Other times were estimated as deterministic or triangular distributions by the plant manager.

- (5) Others are estimated as BETA distributions using the VIBES Program (Abourizk, 1991).

6 RESOURCES COST ESTIMATION

Cost estimation for the resources that were critical to the models presented was used to conduct sensitivity analysis by using different resource combinations. The costs that are estimated are as follows.

- Truck cost is estimated as \$150 /hr.*
Conveyor Belt (1) cost is estimated as \$70 /hr.
Conveyor Belt (2) cost is estimated as \$ 40 /hr.
Sand & Gravel Hopper cost is estimated as \$30 /hr.

7 SIMULATION SENSITIVITY ANALYSIS

Sensitivity analysis was done for the model by varying different resources. The selected resources were those that had zero or close to zero percent idleness. This percent means that these resources are critical in a sense that they control the process. Therefore, changing them may affect the production and cost of the operation. The resources were varied in the model as follows:

- # of trucks: 3 - 5
- # of pumping spaces: 1 - 2
- # of conveyor (1): 1 - 2
- # of conveyor (2): 1 - 2
- # of hopper loads: 4 - 5
- # of combination is 232 combination.
- hauling and returning distance was incremented by 2 miles starting from 3 mile to 15 miles.
- 1000 cycles were simulated using the Micro CYCLONE program.

Simulation was done to analyze the batch plant operation by investigating these resource combinations and distances in the model. This analysis is discussed in the following sections.

8 SIMULATION RESULTS ANALYSIS

Micro CYCLONE was used to simulate the model with various resource combinations as noted above. Micro CYCLONE provides a sensitivity analysis report that includes the productivity and unit cost for each resource combination or alternative. This report is done for each distance starting from 3 miles and incremented by two up to 15 miles. This generates 232 alternative solutions. These solutions were analyzed to eliminate infeasible solutions. Sensitivity results were analyzed to eliminate the solutions that have high cost and low productivity. After this screening, the set of solutions that had the same trend in cost and productivity (e.g. low cost and high productivity) was

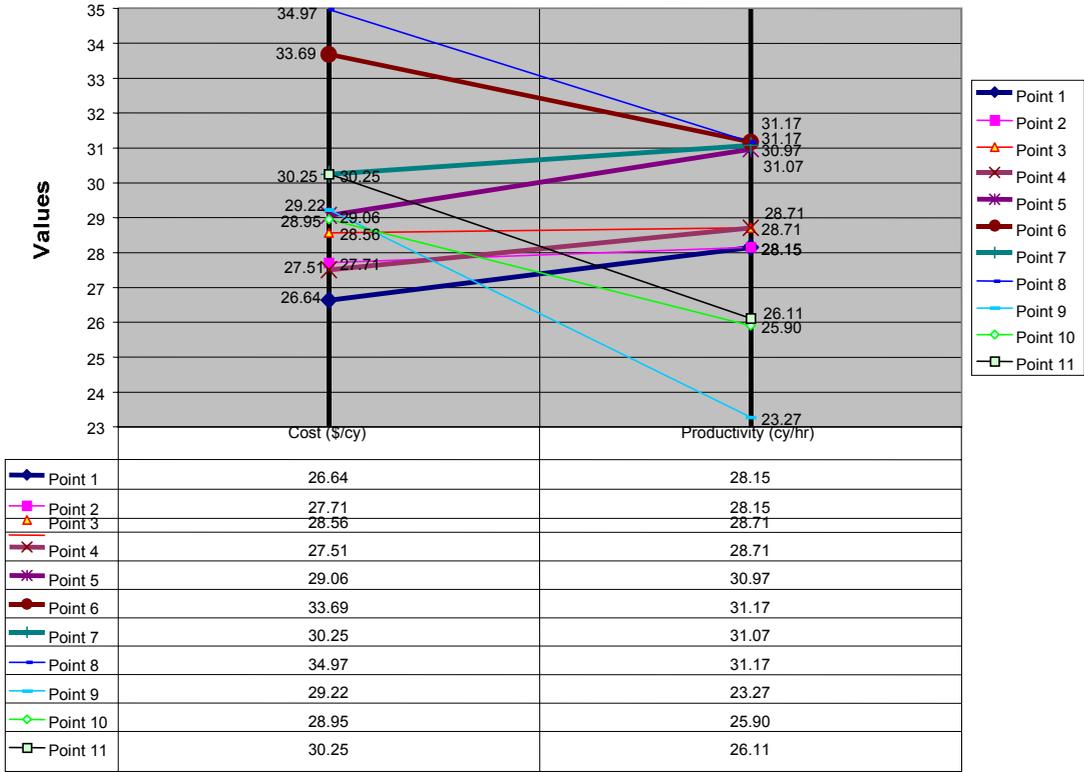
selected as the feasible region of solutions. The same trend means that a solution should have cost and productivity that are more than the previous solution to keep it in the feasible region. Therefore, when a solution combination of cost and productivity is more than that of the previous solution, it can not be eliminated since we do not know if it is feasible or not.

8.1 Selecting Feasible Solutions

The criteria for eliminating infeasible solutions are shown graphically in Figure 4. In this figure, the cost and productivity combinations are drawn for different sensitivity analysis results of the simulation model for 5 miles distance. The points provide examples of the resulting sensitivity analysis solutions. Each solution or point has a value for the productivity and a value for the cost per concrete cubic yard. The bold lines represent the connection between the cost value and the productivity value for the feasible solutions and the thin lines represent the connection between the cost value and the productivity value for the infeasible solutions (e.g. negative cost-productivity slope). For example, point 1 (solution 1) has a lower cost than point 2 (solution 2) where it has a higher productivity than the same point. This means point 1 is more feasible than point 2. This also means that any solution line (with a negative slope) intersecting the solution line representing point 1 could be logically eliminated because it has a higher cost and lower productivity than point 1. Therefore, points 2, 9, 10, and 11 are eliminated because of point 1. Point 8 is eliminated because of point 7 where it has the same productivity and larger in cost. Point 3 is eliminated due to point 4 where they are equal in productivity and point 4 is less in cost. On the other hand, points 1, 4, 5, 6, and 7 could not be eliminated because the solution lines do not intersect. In other words, each solution has a higher cost and a higher productivity than the previous one. Therefore, one point can not eliminate the other. These solutions are feasible and the best solution is one of them. The best solution may not be the lowest cost solution. The same procedure of selecting the feasible solutions is followed for the sensitivity results for all the assigned distances. These sets of solutions corresponding to different distances are indicated in Figure 5.

8.2 The Productivity Unit Cost Chart

Based on the criteria explained in Figure 4, the sets of feasible solutions according to their unit cost, productivity and different combination of resources are drawn in Figure 5. In this figure, the productivity is drawn against the unit cost for each feasible solution. The feasible solutions productivity for each of the distances 3, 5, 7, and 9 miles are close to each other. On the contrary, the feasible solutions productivity for each of the distances 11, 13 and 15 miles



Cost and Productivity

Figure 4: Feasible Solutions Selection Chart

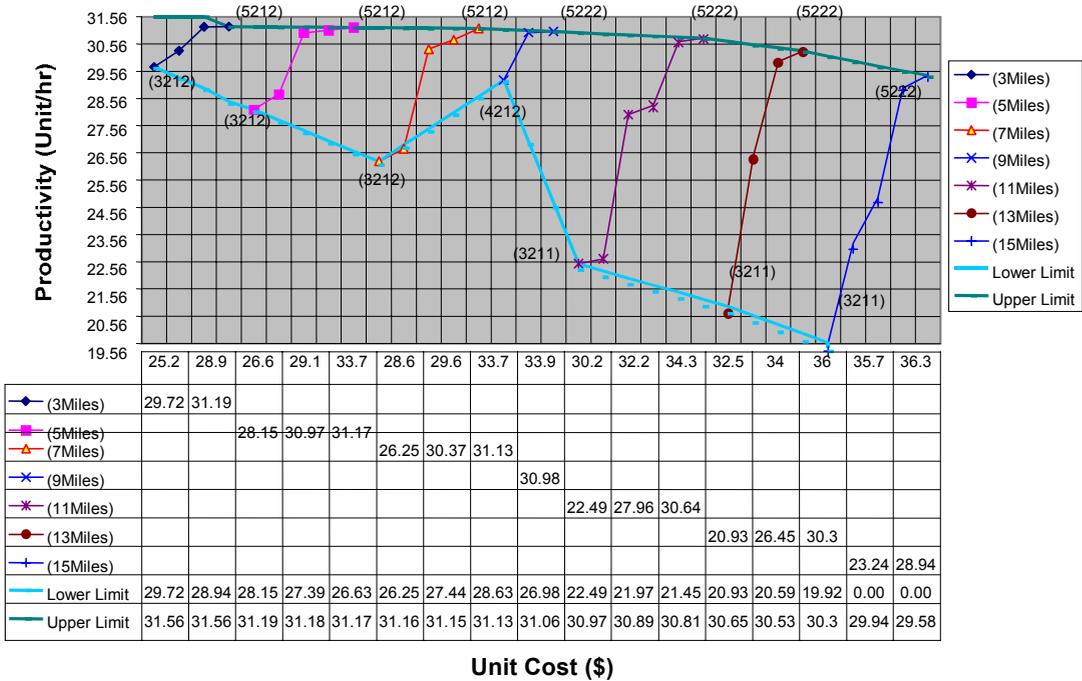


Figure 5: Productivity - Unit Cost Chart

are widely spread from 20 to 30 units/hr on average. However, The best solution may not be the lowest cost solution because the productivity of the highest cost solution is approximately 1.5 that of the lowest cost solution in which the cost is not varied too much.

Figure 5 shows some numbers between brackets that represent the possible resource combinations. The order of these resources is # of truck mixers, # of pumping spaces, # of conveyor 1, and # of conveyor 2 from left to right respectively. For example, if 3 truck mixers, 2 pump spaces, 1 conveyor 1, and 2 conveyor 2 are used, then, the productivity (unit/hr) will be 29.72 for 3 miles distance. On the other hand the cost will be \$25.24 per unit of production. It also shows the feasible region for each set of solutions for different distances. This region is limited by the minimum (lower) and maximum (upper) productivity limits for each set corresponding to various distances. This decision region or zone helps the decision-maker to take his action according to productivity, unit cost, distance and the combination of resources that is required to achieve this productivity and cost.

8.3 Use of Contour Lines Chart

Figure 6 indicates the position of the concrete batch plant under study within the West Lafayette and Lafayette (Indiana) area. The contour lines represent the different distances around the batch plant. They represent the surrounding distances 3, 5, 7, 9, 11, 13, 15 miles from the concrete batch plant within the West Lafayette and Lafayette area. The lowest cost solution is assigned to each contour line to indicate the productivity, unit cost and combination of resources that is feasible for each distance or contour line. Consequently, the plant management is capable of deciding the price and time of providing concrete for these various distances if they have any order within these regions. On the other hand, plant management could decide the optimum set of resources that could produce the required amount of concrete within these borders.

8.4 Using the Charts

Consider a case in which a client at the intersection of state road 26 and state road 52 requests an amount of concrete. Management must decide the cost, the time, and the resources needed to deliver the required amount of concrete. Based on the contour lines chart, this client will be 13 miles from the plant. Figure 4 indicates that the productivity will be 20.93 units/hr where the unit cost will be \$32.49/unit. It also indicates that the optimum resources required will be 3 truck mixers, 2 pump spaces, 1 conveyor 1, and 1 conveyor 2 (3211). Based on Figure 5, the management can use other resource combinations, such as (5222)

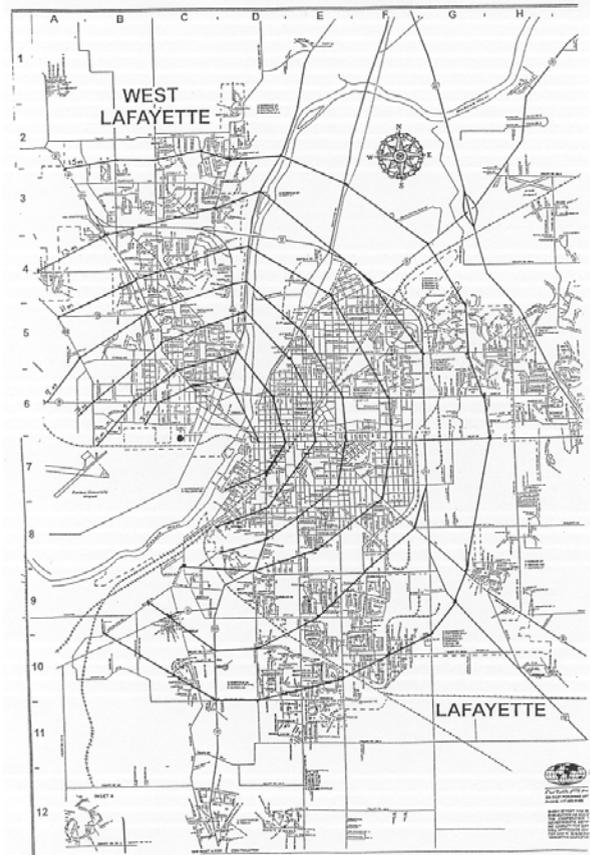


Figure 6: Contour Lines for Distances, Production Times and Resources

to deliver the required concrete but this depends on the client time limits and the availability of the resources. The feasible region for the decision making process indicates that management can use other resource combinations.

Based on the lowest cost solution (resource combination), a set of curves is constructed to measure the time and cost for various concrete quantities to different distances. Figure 7 indicates this set of curves. In this figure, with a known concrete quantity, the duration of concrete delivery can be determined. In addition, the unit cost and the total cost based on different resource combinations for various distances can be determined. Suppose that the concrete batch plant management has a client who is 13 miles from the plant and requests 100 cy of concrete. Based on the chart in Figure 6, the management can inform him that the delivery time will be in approximately 5 hours and cost \$32.49 + overhead + profit per cubic yard. The management will know that it needs 3 truck mixers, 2 pump spaces, 1 conveyor 1, and 1 conveyor 2 to achieve this quantity at this delivery time.

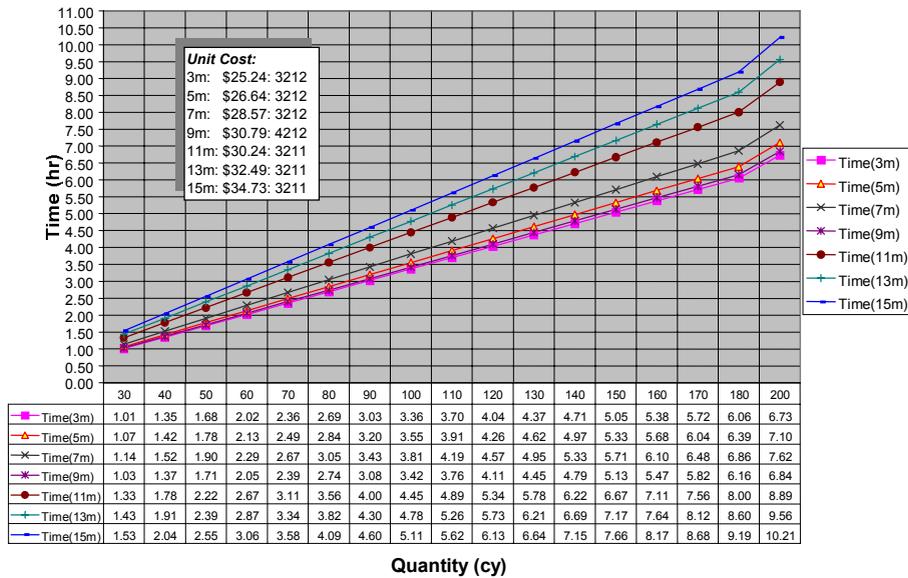


Figure 7: Time-Cost-Quantity Chart

8.5 The Best Set of Solutions

In many circumstances, the best solution may not be the minimum cost solution because this is a multi-objective problem where productivity and cost both influence the decision. Therefore, a method for deciding the best solution from a productivity-cost point of view is applied. A decision index method is used. This decision index allows one to distinguish between the different solutions inside the feasible zone for each distance. This method relies on the difference between the unit costs of different solutions and the differences in productivity. In other words, if a solution has a cost difference that is less than the productivity difference referenced to the lowest cost solution, this solution is better than the lowest cost solution and vice versa. Consequently, the best solution may or may not be the lowest solution. The following example explains the procedure of calculating the decision index to select the best solution in the feasible set for each distance.

8.5.1 Example

Based on 5 miles distance simulation model results, three candidate combinations are identified in Table 1.

Table 1: Simulation Results Candidates

Combination	Cost	Productivity	(\$/cy)/(cy/hr)	Index
1- (3212)	\$26.64	28.15	26.64/28.15 =0.9464	1.00
2- (4212)	\$29.06	30.97	29.06/30.97 =0.9383	0.9915 < 1
3- (3222)	\$27.51	28.71	27.51/28.71 =0.9582	1.0125 > 1

The steps for calculating the decision index are as follows:

- 1- Divide the unit cost (\$/cy) by the productivity (cy/hr) for each solution of the feasible region.
- 2- To compare all the feasible solutions to the lowest cost solution, divide the results of step 1 for all other candidate solutions by the result of step 1 for the lowest cost solution.
- 3- The result will be the decision index. The index for the lowest cost solution is 1.0 since the same number is divided by itself. If the index for any solution is less than 1 as in case 2, this means that this solution is better than the lowest cost solution because the distribution of the unit cost over the productivity is less than that of the lowest cost solution. In case 3, the distribution of the unit cost over the productivity is greater than that of the lowest cost solution. Therefore, the solution in case 3 is not better than the lowest cost solution. According to this methodology, all the feasible solutions for each distance are analyzed using the decision index technique. Table 1 indicates the decision index for all the feasible solutions.
- 4- If the decision index is below one for more than one solution, select the solution of the lowest index value.

Table 2 explains this operation for our simulation model where the index for each solution is indicated in front of each case. The lowest cost solution has an index of 1.0. If the solution index is bigger than 1.0, then this solution is not more feasible than the lowest cost solution. According to Table 2, the best solution for distances 3 and 9 miles is the

Table 2: Decision Index Calculation for the Simulation Model

Combination	Cost (\$/cy)	Distances (miles)							Decision Index
		(3Miles)	(5Miles)	(7Miles)	(9Miles)	(11Miles)	(13Miles)	(15Miles)	
3212	25.24	29.72							1.0000
3222	26.06	30.31							1.0124
4212	28.86	31.19							1.0762
5212	34.61	31.2							1.1989
3212	26.64		28.15						1.0000
3222	27.51		28.71						1.0125
4212	29.06		30.97						0.9915
4222	30.25		31.07						1.0288
5212	33.69		31.17						1.1421
3212	28.57			26.25					1.0000
3222	29.58			26.71					1.0175
4212	29.63			30.37					0.8964
4222	30.61			30.71					0.9158
5212	33.73			31.13					0.9955
4212	30.79				29.23				1.0000
5212	33.89				30.98				1.0385
5222	35.14				31.02				1.0754
3211	30.24					22.49			1.0000
3221	31.76					22.67			1.0419
4212	32.19					27.96			0.8562
4222	33.2					28.31			0.8722
5212	34.27					30.64			0.8318
5222	35.42					30.77			0.8561
3211	32.49						20.93		1.0000
4212	34.03						26.45		0.8288
5212	35.09						29.92		0.7555
5222	35.97						30.3		0.7647
3211	34.73							19.58	1.0000
4211	35.71							23.24	0.8663
4212	36.14							24.91	0.8179
5212	36.28							28.94	0.7068
5222	37.08							29.4	0.7111

lowest cost solution. It is different for the other distances since by increasing a cost slightly, the productivity grows to be on average 1.5 more than the lowest cost solution. Therefore, this index is recommended for selection of the best solution among the feasible solutions or feasible region. Based on this index, the best solution is the lowest cost solution for 3 and 9 miles where the resource combinations are (3212) and (4212) respectively. The best solutions for the other distances are shown in Table 3.

Table 3: The Best Solutions for Different Distances

Resource Combination	Miles
(4212) *	5
(4212) *	7
(5212) *	11
(5212) *	13
(5212) *	15

*Where: the combination (4212) means: 4 truck mixers, 2 pumping spaces, 1 conveyor #1, and 2 conveyor #2 respectively.

Based on the best solutions that are selected from Table 1, the Time-Cost-Quantity chart is reconstructed for the simulation model as indicated in Figure 8. This figure

is a powerful tool for batch plant management, it supports rapid decision making regarding concrete delivery time, concrete prices and plant resource combinations.

9 SUMMARY AND CONCLUSION

In conclusion, this paper has discussed the role of simulation as a tool for decision-making and resource management. The concrete batch plant example is presented as a case study to demonstrate how simulation can be of benefit.

Simulation sensitivity analysis is used to generate some useful decision-making tools for plant operation. These tools are a Time-Cost-Quantity chart, a feasible region for decision-making processes and a contour lines chart. The Time-Cost-Quantity and contour lines charts are used for deciding production time, production cost and required resources for a required distance from the plant. The Feasible region chart is used for deciding the range of alternative solutions available to minimize production time and cost of the available plant resources according to the required transport distance.

Consequently, simulation sensitivity analysis can be used as a very powerful tool for decision-makers and

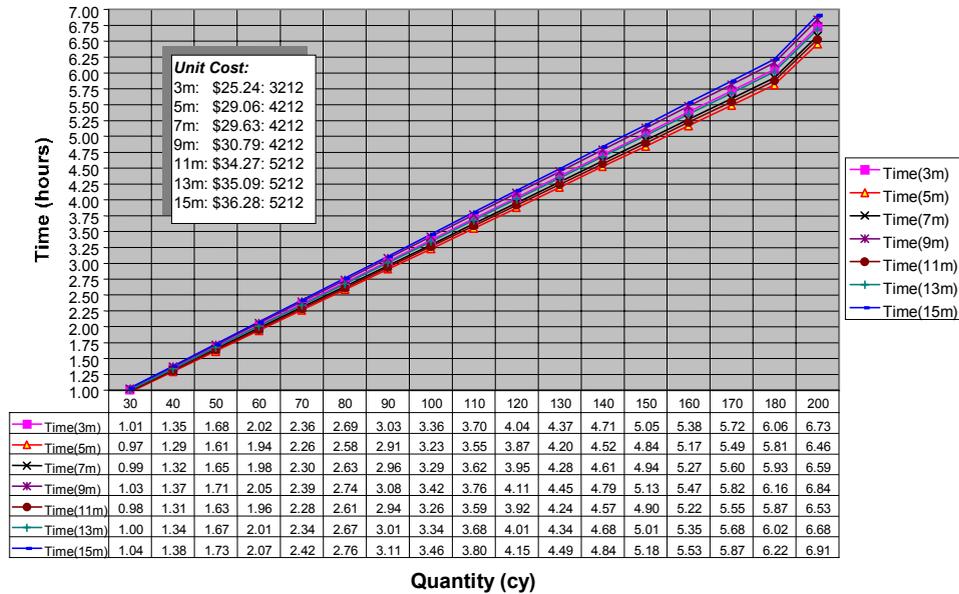


Figure 8: Time-Cost-Quantity Chart Based on Best Solution

resource management not only for concrete batch plants but for any construction operation as well.

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AUTHOR BIOGRAPHIES

TAREK M. ZAYED is an Assistant Lecturer in Construction Engineering department at Zagazig University, Zagazig, EGYPT. He received his B.S. and M.S. degrees in Construction Engineering and Management from Zagazig University, EGYPT in 1988 and 1992 respectively. He has been working toward his Ph.D. in Construction Engineering and Management in the school of Civil Engineering at Purdue University, West Lafayette, Indiana since 1997. His M.S. thesis was in studying the production efficiency of concrete batch plants. His Ph.D. thesis is in the area of applying artificial intelligence techniques to the construction productivity especially concrete bored piles. His email address is <zayed@ecn.purdue.edu>.

DANIEL W. HALPIN is Professor and Head of the Division of Construction Engineering and Management at Purdue University in West Lafayette, Indiana. He received a B.S. degree from the U.S. Military Academy at West Point in 1961. He received M.S. and Ph.D. degrees in Civil Engineering from the University of Illinois in Champaign in 1969 and 1973 respectively. He was on the faculty at Georgia Tech (1973-1985), and held the A. J. Clark Chair Professor Position at the University of Maryland (1985-1987). He developed the CYCLONE methodology for construction simulation. He has received many awards, including the Huber and Peurifoy Awards, for his contributions to computer applications in civil and construction engineering. His email address is <halpin@ecn.purdue.edu>.