SIMULATION OF CONCRETE BATCH PLANT PRODUCTION

By Tarek M. Zayed,1 Student Member, ASCE, and Daniel Halpin,2 Member, ASCE

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 concrete batching operations to analyze alternative solutions and resource management. Data are collected to define activity durations for the plant. A simulation model is constructed for the plant using the MicroCYCLONE 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 determining production time, production cost, and resources for a required distance from the plant. The feasible region chart is used for determining 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.

INTRODUCTION

A model is a representation of a real-world situation and provides a framework within which a given system can be investigated and analyzed. Models contain and reflect data that, when interpreted according to certain rules or conventions, provide information that 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 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, dynamic systems modeling is required. Mathematical models (e.g., queuing systems) can be applied to a limited number of special cases. In construction, output from one operation tends to be the input to the following operation. This leads to 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.

Simulation techniques can be applied to the modeling of concrete batch plant operations to study different combinations of resources. MicroCYCLONE modeling and programming techniques can be used to simulate this process. The elements of MicroCYCLONE, originally developed by Halpin in 1973, are used to model and simulate concrete batch plant operations. The MicroCYCLONE elements used for construction modeling are shown in Fig. 1 (Halpin 1992). MicroCYCLONE is a simple and powerful tool for construction process planning, as demonstrated by many researchers (Liu and Ioannou 1992; McCahill and Bernold 1993; Huang et al. 1994).

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STUDY OBJECTIVES

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. The subobjectives of this study are as follows:

1. Study of each component of the plant-truck-pump cycles.
2. Development of a MicroCYCLONE model for these processes.
3. Data collection for the simulation. A simulation is designed to: calculate the optimum number of trucks corresponding to the various distances; determine the optimum supply areas around the batch plant; and develop decision-making tools for concrete batch plant management. The optimum resource combination that minimizes cost per unit is determined.

MODEL BUILDING

To establish a decision-making framework, a batch-plant transit mix delivery operation, located in the 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 mi (24 km) radius. The production capacity of the plant was rated as approximately 40 cu yd/h (30.4 m³/h).

Fig. 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 conveyor belt 2.

MODEL DESCRIPTION

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

1. Conveyor belt 1 transports the aggregates from the storage area to the storage hopper. It has three different work tasks, namely—waiting for the aggregates, transporting the aggregates, and maintenance.
2. A hopper store the different types of aggregates. It received the aggregates from conveyor belt 1 and stores them for feeding to conveyor belt 2. After feeding conveyor belt 2, it waits for conveyor belt 1 to provide re-supply.
<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination (COMBI) Activity</td>
<td>![Symbol]</td>
<td>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.</td>
</tr>
<tr>
<td>Normal Activity</td>
<td>![Symbol]</td>
<td>This is an activity similar to the COMBI. However, units arriving at this element begin processing immediately and are not delayed.</td>
</tr>
<tr>
<td>Queue Node</td>
<td>![Symbol]</td>
<td>This element precedes all COMI activities and provides a location at which units are delayed pending combination. Delay statistics are measured at this element.</td>
</tr>
<tr>
<td>Function Node</td>
<td>![Symbol]</td>
<td>It is inserted into the model to perform special functions such as counting, consolidation, marking, and statistic collection.</td>
</tr>
<tr>
<td>Accumulator</td>
<td>![Symbol]</td>
<td>It is used to define the number of times of the system cycles.</td>
</tr>
<tr>
<td>Arc</td>
<td>![Symbol]</td>
<td>Indicates the logical structure of the model and direction of entity flow.</td>
</tr>
</tbody>
</table>

**FIG. 1. Basic CYCLONE Modeling Elements**

![Diagram](image)

**FIG. 2. Flow Diagram for Concrete Batch Plant and Transit Mixer Cycles**

3. Conveyor belt 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 belt 2 should be available. After the truck mixer is loaded, it travels to the site where there is a 15% probability main-
tenance will be performed 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 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, which moves it to the placement sites. After this operation, the pump waits for other truck mixers to deliver concrete.

6. Laborers at the placement sites, where the concrete is received from the pump, do the spreading operation. After finishing the spreading operations, labor crews finish the concrete surface.

**DURATION OF SIMULATION ACTIVITIES**

To build a management decision-making tool, 205 data sets were collected for the durations that are 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. This set of data was collected by observing operations over a period of 1 month (7–8 trips per day). Some of the trip data were eliminated, because they were outliers that might bias the analysis.

Loading and unloading times were calculated as beta distributions from the collected data by using a beta curve fitting program. Hauling and returning times were calculated using regression analysis. Two regression models were constructed to calculate the hauling and returning times. The plant manager estimated other times as deterministic or triangular distributions. Others were estimated as beta distributions using the VIBES Program (Abourizk 1991).

The haul time was calculated by conducting a regression analysis relating time and distance for various distances. The statistical analysis that establishes the significance of this model is shown in Appendix I. The regression model is:

\[
\text{Haul time(min)} = 0.0571 + 1.6006 \times \text{distance(mi)}
\]

(1)

The return time was also calculated by regression between return time and distance. The statistical analysis supporting this model is shown in Appendix I. The model is:

\[
\text{Return time(min)} = -0.019 + 1.4003 \times \text{distance(mi)}
\]

(2)

The two regression models that were used in this study had been statistically checked to best fit the data. They were statistically acceptable. At the beginning of the study, two techniques had been used to achieve b = 0 in the model. The first trial used regression models constrained to pass through the origin. The second trial used many data points that are (0,0) in the data set to force the regression line to b = 0. The results of both trials were statistically insignificant and did not achieve the goal of b = 0. Since data collected from the sites exhibited high variability, it was difficult to establish the appropriate percent significance. Therefore, the current models provided the statistical best fit for the observed data. In addition, the study does not take into consideration distances less than 3 mi (4.8 km) or more than 15 mi (24 km). Therefore, these models are valid only for distances between 3 and 15 mi (4.8 and 24 km).

**COST OF CRITICAL MODEL RESOURCES**

Cost estimation for the resources that were critical to the model was used to conduct sensitivity analysis by using dif-
different resource combinations. The costs that are estimated are shown in Table 1.

**SIMULATION MODEL 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 within the ranges shown in Table 1. Simulation features were as follows:

1. Number of combinations is 232.
2. Hauling and returning distance was incremented by 2 mi (3.2 km) starting from 3 mi (4.8 km) to 15 mi (24 km).
3. Using the MicroCYCLONE program, 1,000 cycles were simulated.

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.

**SIMULATION RESULTS ANALYSIS**

As noted earlier, MicroCYCLONE was used to simulate the model with various resource combinations. The resulting solutions were analyzed to eliminate infeasible ones. 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. These results have been used to develop three charts, which are useful to decision makers in developing unit costs for their product (i.e., batched concrete) as follows:

1. The productivity unit cost chart provides an indication of the range of feasible solutions at each distance (e.g., 3–15 mi [4.8–24 km]). It establishes a zone of feasibility.
2. The contour line chart relates cost and distance in terms of a map of the geographical area around the batch plant.
3. Two Time-Cost-Quantity (TCQ) charts relate lowest cost and best solutions to production levels at each distance. They are helpful in comparing lowest-cost solutions with best solutions. The lowest-cost solution may require too much time. The best solution gives the highest productivity for the lowest cost and therefore, optimizes both cost and time.

![Graph showing feasible solutions selection chart](Image)

**FIG. 4. Feasible Solutions Selection Chart**

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Feasible Solutions

The criteria for eliminating infeasible solutions are shown graphically in Fig. 4. The cost and productivity combinations are drawn for different sensitivity analysis results of the simulation model for 5 mi (8 km) 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 meter. 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 (negative cost-productivity slope). For example, point 1 (solution 1) has a lower cost than point 2 (solution 2), where it has the same productivity. 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 cannot 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 Fig. 5.

Productivity Unit Cost Chart

Based on the criteria explained in Fig. 4, the sets of feasible solutions according to their unit cost, productivity and different combination of resources are drawn in Fig. 5. In this figure, the productivity is drawn against the unit cost for each feasible solution. According to productivity, the solutions for distances 3, 5, 7, and 9 mi (4.8, 8, 11.2, and 14.4 km) are close to each other inside the same set of solutions. They are not widely spread. The productivity set of solutions for distances 11, 13, and 15 mi (17.6, 20.8, and 24 km) are widely spread inside each set from approximately an average 20 to 30 units/h. Fig. 5 shows that the feasible solution lower limit represents the changes in distances. In other words, the longer the distance, the lower the productivity. The lower productivity limits change from 29.7 cu yd/h (22.6 m³/h) 19.56 cu yd/h (14.9 m³/h) for 3 mi (4.8 km) and 15 mi (24 km) distances, respectively. This decrease in productivity is logical, given the longer distance of travel. The case is different in the upper limit for the feasible solutions. The upper-limit change in productivity is not clear, the same as it is in the lower limit. This might be because the control element of the productivity is not the trucks but the batch plant itself. Therefore, increasing the number of trucks will not affect the productivity for different miles, because they are not the critical element in the process. Fig. 5 is only an indicator for the range of feasible solutions at each distance. It is very essential to select the best feasible solution out of this feasible solution range. The best feasible
solution may not be the lowest cost solution, because the productivity of the highest cost solution is approximately 1.5 times that of the lowest cost solution.

The numbers that are between two brackets represent the resource combination. The arrangement of these resources is number (#) of truck mixers, # of pumping spaces, # of conveyor belt 1, and # of conveyor belt 2 from left to right, respectively. For example, if 3 truck mixers, 2 pump spaces, 1 conveyor belt 1, and 2 conveyor belts 2 are used, then, the productivity (unit/h) will be 29.72 for 3 mi (4.8 km) distance. On the other hand, the cost will be $25.24/unit of production. It also indicates the feasible region for each set of solutions according to 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.

Use of Contour Lines Chart

Fig. 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, and 15 mi (4.8, 8, 11.2, 14.4, 17.6, 28.8, and 24 km) 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, 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.

Using 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 mi (20.8 km) from the plant. Fig. 5 indicates that the productivity will be 20.93 units/h 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 belt 1, and 1 conveyor belt 2 (3211). If the client needs higher productivity (more cu yd/h [m³/h]), management can use other resource combinations, such as (5222) to deliver the required concrete. This would increase the cost per cubic yard to $36.00 ($47.4/m³) since the (5222) combination is at the upper limit; it does, however, increase productivity to about 30.25 cu yd/h (23 m³/h) an increase of almost 10 cu yd/h (7.6 m³/h). Therefore, higher production levels can be provided if a premium is paid.

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. Fig. 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. For instance, if 30 cu yd (22.8 m³) are to be delivered to a site 13 mi (20.8 km) away, the delivery time will be 1.43 h. This would support a production level of 30 cu yd/1.43 h (22.8 m³/1.43 h) or 20.97 (say 21) cu yd (15.9 m³/h). The lowest unit cost is $32.49 ($42.75/m³) + overhead + profit per cubic yard (m³). The management will know that it needs 3 truck mixers, 2 pump spaces, 1 conveyor belt 1, and 1 conveyor belt 2 to achieve this quantity at this delivery time.

The Best Set of Solutions

In many circumstances, the best solution may not be the minimum cost solution, because this is a multiobjective problem where productivity and cost both influence the decision. Therefore, a method for deciding the best solution from a productivity-cost point of interest is applied. Fig. 8 shows the best solutions. For instance, again considering the 13 mi (20.8 km) delivery distance, Fig. 8 indicates that the best combination would reduce the time to supply 100 cu yd (7.6 m³) to 3.34 h (versus 5 h for the lowest cost solution). This would require 5 trucks and increase the unit cost to $35.09 ($46.17/m³). However, the contractor will save over 1.5 h due to the higher productivity. A decision index method is used. The 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. The solution optimizes both cost and production. 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 of solutions for each distance.

Example

Based on 5 mi (8 km) distance simulation model results, three candidate combinations are identified in Table 2. The results include the resource combination, unit cost, and productivity. The steps for calculating the decision index are as follows.

1. Divide the unit cost by the productivity 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 other words, the cost per unit of time is better 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 3 indicates the decision index for all the feasible solutions.

<table>
<thead>
<tr>
<th>TABLE 2. Simulation Results Candidates (8.0 km Distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination 1 (1)</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>1—(3212)</td>
</tr>
<tr>
<td>2—(4212)</td>
</tr>
<tr>
<td>3—(5222)</td>
</tr>
</tbody>
</table>
FIG. 6. Contour Lines for Distances, Production Times, and Plant Resources
FIG. 7. Time-Cost-Quantity Chart Based in Lowest Cost Solution

FIG. 8. Time-Cost-Quantity Chart Based on Best Solution
### TABLE 3. Decision Index Calculation for Simulation Model

<table>
<thead>
<tr>
<th>Combination (1)</th>
<th>Cost (dollars/m³) (2)</th>
<th>Production (m³/h) at distances</th>
<th>Decision index (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>3212</td>
<td>33.21</td>
<td>22.59</td>
<td></td>
</tr>
<tr>
<td>3222</td>
<td>34.29</td>
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<td>4212</td>
<td>37.97</td>
<td>23.70</td>
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<td>5212</td>
<td>45.54</td>
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<td>3222</td>
<td>36.20</td>
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<td>4212</td>
<td>38.24</td>
<td>23.54</td>
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<td>5212</td>
<td>39.80</td>
<td>23.61</td>
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<td>44.33</td>
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<td>37.59</td>
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<tr>
<td>5222</td>
<td>42.60</td>
<td>22.66</td>
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</tr>
</tbody>
</table>

Note: Best solutions optimizing both cost and time (index method) are shown in boldface type.

### TABLE 4. Best Solutions for Different Distances

<table>
<thead>
<tr>
<th>Resource combination (1)</th>
<th>Distance in miles (km) (2)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(4212)</td>
<td>5 (8 km)</td>
<td></td>
</tr>
<tr>
<td>(5212)</td>
<td>11 (17.2 km)</td>
<td></td>
</tr>
<tr>
<td>(5212)</td>
<td>13 (20.8 km)</td>
<td></td>
</tr>
<tr>
<td>(5212)</td>
<td>15 (24.0 km)</td>
<td></td>
</tr>
</tbody>
</table>

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

4. If the decision index is below one for more than one solution, select the solution of the lowest index value.

Table 3 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 greater than 1.0, then this solution is not more feasible than the lowest cost solution. According to Table 3, the best solutions for distances 3 and 9 mi (4.8 and 14.4 km) are the lowest cost solutions. At other distances, the best solution is not the lowest cost solution, since by increasing cost slightly, the productivity grows to be on average 1.5 times more than the lowest cost solution. Therefore, this index identifies 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 mi (4.8 and 14.4 km) where the resource combinations are (3212) and (4212), respectively. The best solutions for the other distances are shown in Table 4.

The TCO chart in Fig. 8 shows the best solutions based on the index approach. This helps the contractor and batch-plant manager to evaluate the best overall solution considering time and cost.

### SUMMARY, CONCLUSION, AND FUTURE WORK

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 useful decision-making tools for plant operation. The TCO and contour lines charts are used for establishing 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.

Common practice typically calculates the unit price for the concrete, based only on the mix design. Greater precision can be achieved by considering the haul distance in addition to the mix design when determining unit price. This study introduces the idea of evaluating different distances to reflect the precise unit price. Consequently, the plant manager has the flexibility to determine his concrete unit price based on mix design and different distances. Simulation provides a flexible tool to evaluate these options at a higher level of precision than is presently used.

### APPENDIX I. REGRESSION MODELS ANALYSIS

The haul time was calculated by conducting a regression analysis relating time and distance for various distances: The regression model is:
Haul Time(min) = 0.0571 + 1.6006 * distance(mi)

(Haul Time[min] = 0.0571 + 1.0 * distance[km])

Note: pushing the intercept to be zero resulted in an insignificant model. Statistical Analysis

Test the linear relation

1. F-value = 259.06 with probability p = 0.0001. Then, β1 is acceptable at the 5% level of significance, and there is a linear relation between hauling time and distance.

Relative variation

2. r-square = 0.9511 where, this is an indicator that the reduction in variation is small.

Visual or graphical tests

3. 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.

Adequacy of the model

4. The lack of fit (LOF) test is done for this data, where there are replications in the data. The probability of the LOF-test is p = 0.203, which indicates that the model is adequate for this data.

The return time was also calculated by regression between return time and distance: The model is:

Return time(min) = −0.019 + 1.4003 * distance (mi)

(Return time[mi] = −0.019 + 0.875 * distance [km])

Note: pushing the intercept to be zero resulted in an insignificant model. Statistical Analysis:

Test the linear relation

1. F-value = 178.64 with probability p = 0.0001. Then, β1 is acceptable at 5% level of significance and there is a linear relation between hauling time and distance.

Relative variation

2. r-square = 0.934 where, this is an indicator that the reduction in variation is small.

Visual or graphical tests

3. 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.

Adequacy of the model

4. LOF test is done for this data, where there are replications in the data. The probability of the LOF-test is p = 0.1876, which indicates that the model is adequate for this data.

APPENDIX II. REFERENCES


