Simulation of Concrete Paving Operations on Interstate-74

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Abstract: The objective of this paper was to study and optimize the concrete paving operations taking place in the reconstruction project of Interstate-74 using computer simulation. To achieve this objective, field data were collected during construction, and were then used to determine adequate probabilistic density functions for the activities' duration and to test a developed simulation model. Upon testing, the developed model was used to study the impacts of resources on the flow of operations and on the cost effectiveness of the construction process. In general, application of simulation methods to concrete paving operations was successful and its accuracy was acceptable as compared to field measurements. Based on the results of a sensitivity analysis of the critical resources, multiple factors were considered in the decision-making process to ensure that all aspects of the operation are evaluated. This includes total operation time, productivity, costs of the operation, average truck delay, and idle times for the paver and the spreader. For the conditions pertinent to this construction site, ten trucks, one paver and one spreader, and three finishing and plastic-covering crews are recommended. Using this set of resources would result in a prompt and effective execution of the operation. Practical implementation and limitations of the developed model in similar construction operations is discussed.

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Introduction

Continuously reinforced concrete pavement (CRCP) is a rigid pavement structure that is constructed with no preventative measures for transverse expansion or contraction joints. This type of design is currently favored for use in high-priority routes due to its stability, durability, and low maintenance requirements, thus reducing user delays caused by frequent maintenance and rehabilitation activities (Kim et al. 2000). Despite these advantages, adequate construction practices are critical to ensure proper installation and performance of CRCP and the swift completion of the operations. Effective and quick construction operations offer many advantages to the public and to the state agencies including reduction of traffic delays and safe operating conditions at the site for the road users and workers.

Analysis and design of construction operations related to the placement of CRCP is usually conducted by the contractor intuitively. In this process, appropriate crew sizes and equipment, operating logic, and the most suitable construction methods are selected based on experience. Despite its simplicity, such empirical practices do not guarantee that concrete is placed in the most effective and cost-efficient way. In addition, with the expanding variety of construction techniques and the increasing need to optimize equipment and personnel, the process of selection and planning could be challenging due to the unique work environment in each construction project.

Several methodologies have been developed to predict the outcomes and performance associated with a set of construction operation parameters. Experimentation and mathematical modeling (e.g., queuing systems) were first introduced but the associated cost and the level of complexity prevented widespread use of these techniques. In addition, interaction and complex logics associated with construction operations cannot be effectively modeled using these techniques (Zayed and Halpin 2001). Computer simulation is another methodology that offers many advantages as compared to experimental and mathematical modeling because of its flexibility, realistic nature, and marginal cost. Application of simulation to construction operations has many advantages including estimation of possible delays, productivity determination and improvement, resource management and optimization, system stochastic response to unforeseen conditions, and ability to respond to random and dynamic features in the operation of the system (Halpin 2003).

The benefits provided by the use of simulation have been documented through monitored attempts in the construction industry. A contractor has reported productivity improvements due to the use of simulation ranging from 30 to 300% (Halpin and Martinez 1999). A saving of $2,000 was achieved in 1999 for every hour of simulation analysis used; reflecting a cost saving of $10 million in 30 construction projects (Shi 2001).

The objective of this paper is to study and optimize the placement of a CRCP paving operation in the reconstruction of Interstate-74 using computer simulation. To achieve this objective, field data were collected during construction, and were then used to determine adequate probabilistic density functions for the activity's duration and to test a developed simulation model. Upon testing, the developed model was used to study the impacts of the resources on the flow of operations and on the cost effectiveness of the construction process.

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Background

Construction operations often involve critical decision-making processes. Simulation models contain and produce data that provide information that assists in this process. This approach offers a fast and inexpensive means of studying the performance of the operation and the response of the system to change resources and equipment allocations. Computer simulation is the process of dynamically exercising a model to evaluate the effects of selected inputs on output measures of performance (Shi 2001). The benefits achieved by using computer simulation to model construction operations are due to the complex interaction among various units at the jobsite. Simulation techniques can be used to model heavy construction activities such as sewer line construction, matching casting process, and other typical repetitive processes. Most of the operations that form these processes are complex in nature and the output from one operation usually acts as the input to another operation. The most suitable approach to model construction operation is discrete-event simulation.

Discrete-event simulation allows the dynamic modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time (Law and Kelton 2000). These points in time are measured when the event occurs (e.g., loading of a truck, spreading of concrete, finishing of the placed material, etc.). At each occurrence, the state of the system and its measures of performance are updated to account for the fact that an event has occurred. Most construction activities can be efficiently modeled using discrete-event simulation since events only occur at specific points in time.

Discrete-event simulations can be theoretically performed by hand calculations. However, due to the large amount of data that are stored and analyzed during a discrete-event simulation, a wide array of computer simulation systems have been developed and designed to specifically model construction operations. One of the first simulation software tools specifically designed to model construction operations is the Cyclic Operations Network (CYCLONE), which was later improved to meet specific construction simulation needs by introducing MICRO-CYCLONE (Halpin 1973, 1990). Since the development of CYCLONE in the 1970s, many simulation tools were introduced including activity based construction (ABC), which focuses on a single element, the construction activity, to model construction processes (Shi 1999). SIMPHONY was also introduced as an integrated environment for building special purpose simulation (SPS) tools for modeling construction operation (Hajjar and AbouRizk 1999). SIMPHONY provides various features that enable to evaluate different characteristics of the developed model such as simulation behaviors, graphical representation, statistics, and animation.

In this study, the advanced simulation software products STROBOSCOPE and EZStrobe were employed. These software tools were selected given their simplicity, flexibility, and capability to model moderately complex logics such as the ones encountered in this study. These advantages make these software products attractive for possible implementation by the construction industry. A brief description of these software products is provided in the following section.

STROBOSCOPE and EZStrobe

The state and resource based simulation of construction processes (STROBOSCOPE) software product is an advanced simulation tool that can dynamically determine the state of the simulation and the characteristics of the resources involved in an operation (Martinez 1996). This software product was specifically designed to simulate construction operations and makes use of concepts found in structured query language (SQL) to select resources for operations and aggregate their properties.

Table 1. Modeling Elements in EZStrobe

Elements (1)	Function (2)	Parameter (3)	Description (4)
Queue	Holds idle resource until used	Queue name Number of Resources	Queue 10
Combi	Constrained activity that can starts whenever required resources are available	Combi name Probability distribution density function	Combi Normal [15, 0.75]
Normal	An activity that is not constrained and that can start whenever a preceding activity is complete	Normal name Probability distribution density function	Normal Uniform [10, 15]
Fork	A probabilistic element to randomly select the path to follow	---	
Link	Connects different activities and queues	Condition necessary for the successor activity to start. Number of resources to be consumed.	>0, 1

To present the use of STROBOSCOPE in a simple graphical format, EZStrobe was developed (Martinez 2001). EZStrobe is based on activity cycle diagrams (ACDs) and employs a three-phase activity-scanning pattern. It is therefore capable of modeling moderately complex systems without having to write advanced computer code, as it is required with the use of STROBOSCOPE. Concurrently, EZStrobe is still based on the STROBOSCOPE solution but may not uniquely identify resources and cannot incorporate extremely complex logic. Both EZStrobe and STROBOSCOPE were used in this study to simulate a wide array of input-output relationships for the concrete paving operation considered.

EZStrobe makes use of simple modeling elements to represent the sequence of activities and their interactions. The main components of EZStrobe, (Table 1), are the Queue, Combi, Normal, Fork, and Link elements. A Queue element holds idle resources that are waiting to be used. The number of resources held at a specific simulation time is shown below the queue name. A Combi element represents a constrained activity that can start whenever the resources that are available in the Queues that precede it are sufficient to support the task. To determine the duration of an activity, a probability distribution is used and is shown below the name of the Combi. A Normal element is an activity that is not constrained and that can start whenever an instance of any preceding activity ends. A Fork is a probabilistic routing element. A Link connects a Queue to a Combi element. A draw Link shows two pieces of information separated by a comma. The first part is the condition necessary for the successor Combi to

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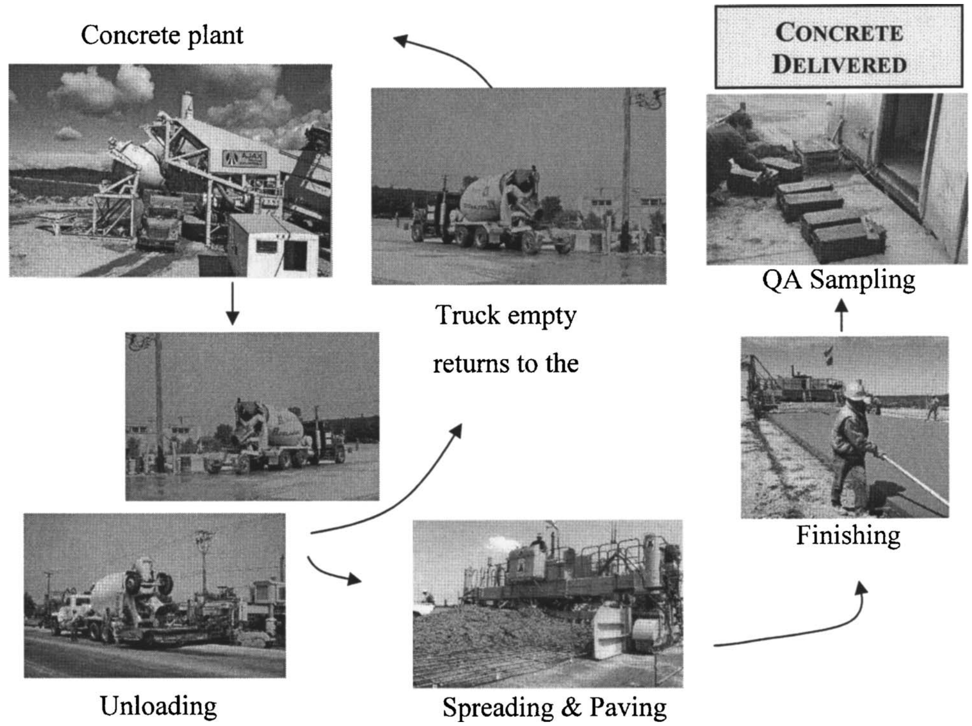

Fig. 1. Simple representation of concrete paving operation

start. The second part is the number of resources that the Combi will consume from the predecessor Queue in the event that the Combi takes place.

Project Description

The Interstate-74 (I-74) reconstruction plan is the largest road construction project in the history of Southern Illinois. I-74 is the main interstate serving the city of Peoria, East Peoria, and the tri-county area. This critical highway was designed and built in 1959 according to the traffic and freight volume relevant to that era. At that time, more than 12 million vehicles traveled on I-74/year (that number has more than doubled). While this highway system has performed satisfactorily in the past, it was evident that this pavement was now failing more rapidly. In order to address the increasing traffic volume and to improve safety of the road users, an upgrade of I-74 began in 2002. At a cost of nearly $460 million over 5 years, reconstruction of I-74 included repaving of 11 mi of roadway, replacement of 32 bridges, and construction of two tunnels. The project also includes the reconstruction of all interchanges through Peoria and East Peoria. Additionally, reconstruction of I-74 will incorporate 162 light towers for safer driving conditions with upgrades to the landscaping and ornamentation.

Description of Concrete Paving Operation

The concrete paving operation considered in this study consisted of the placement of a 290-mm-thick CRCP layer on I-74 over a total pavement width of 7.2 m (two lanes). CRCP is widely used in Illinois urban areas as it only requires little maintenance and does not necessitate the use of transverse joints. The concrete layer was to be placed on a high-quality smooth bituminous asphalt mixture (BAM) base. The developed model did not consider the process of installing the forms or the steel reinforcement but only focused on activities taking place on the day of paving.

The paving operations were modeled starting from the loading of the trucks with concrete at the plant (ACPA 2000). At the construction site, the paver is driven to the start location of the paving operation. Upon arrival of the concrete mixer trucks at the site, an inspector promptly checks the mixture delivered. The haul truck is then driven so that the back aligns with the front of the spreader. The truck dumps the concrete into the spreader and may then return to the plant for a new load of concrete. At this point, material quality is assured through sampling and testing. Sampling was conducted once every 91 m, and did not interfere with the paving process. After spreading, the dumped concrete is moved by the paver, which distributes the mixture uniformly across the width of the pavement at the desired thickness. After spreading and paving of the material, the finishing crew starts its operation. Fig. 1 presents a simple representation of the concrete paving operation.

Model Development

The developed model simulated the previously described concrete paving operation. The activities and cycles taking place in this model are as follows (Fig. 2):

1. A concrete truck is loaded at the plant, and then travels to the site in which it waits in queue (conctrucksite) until the spreader is available. At that time, the truck backs up until it aligns with the spreader (truckbackspread). A laborer (laborguide) guides the backing process. The truck then dumps the concrete mixture into the spreader (truckdumpconc) until it is completely empty and then travels back to the plant for reloading (truckplantback);

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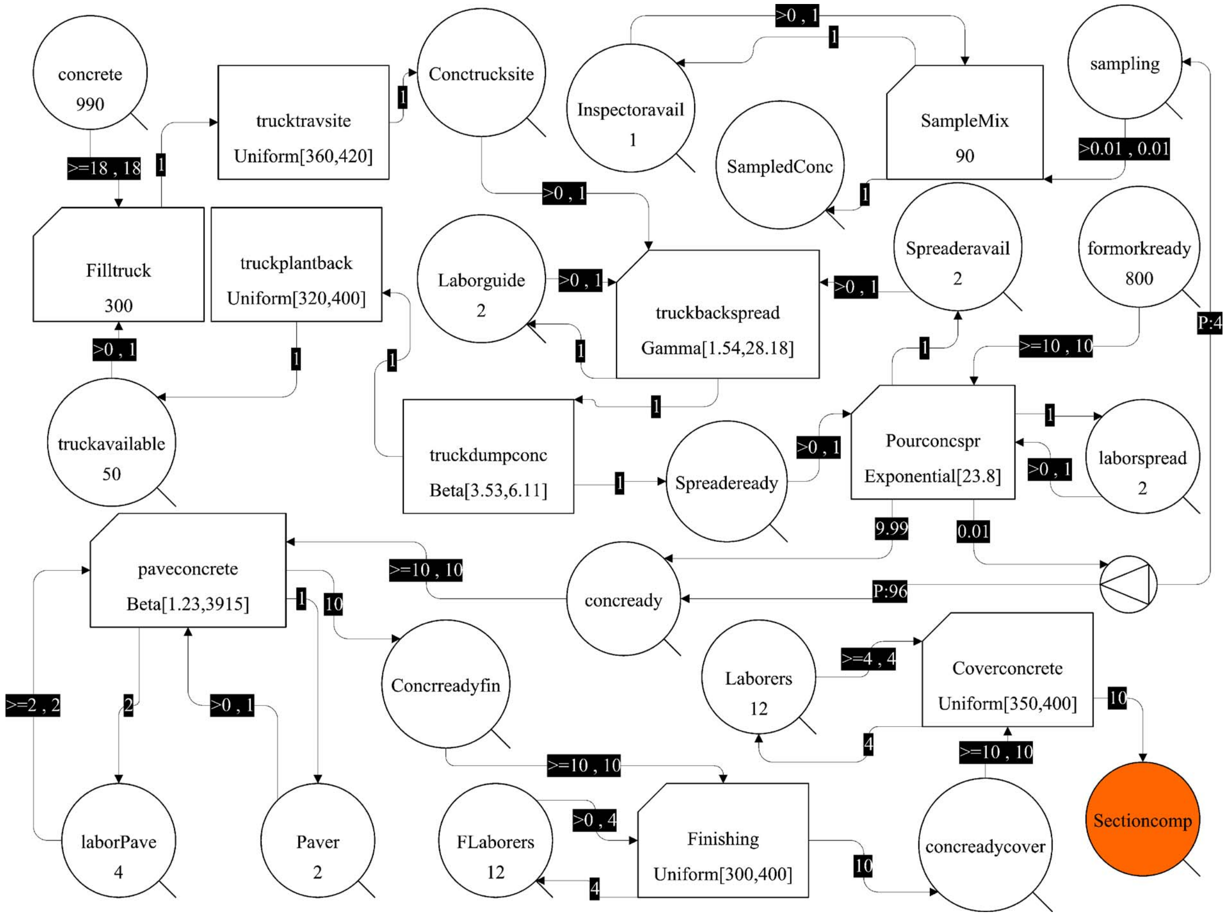

Fig. 2. Activity cycle diagram for concrete paving operation in I-74

2. A Fork element is used to simulate the sampling process. It was noticed in the field that the concrete is being sampled every 91 m. This is modeled by assigning a probability of 96:4 for the Fork element. In that case, the program will randomly determine whether the mixture is sampled or not. If the mixture is inspected, the Combi element (SampleMix) is used;
3. The spreader distributes the concrete evenly in front of the paver (pourconcspr) and the paving process may then start. During this operation, it is critical that the paver does not remain idle to ensure that the mixture is continuously placed. Concurrently, it is essential that the waiting time for the trucks is not so excessive that the concrete mixture begins to set before completion of the operation;
4. Once the paver has placed the concrete, finishing can start (Finishing). This Combi activity necessitates that a finishing crew is available in its queue (FLaborers);
5. Once the concrete is finished, it is covered with plastic sheets (Coverconcrete). Warmer than usual temperatures during installation necessitated the plastic covering to avoid excessive evaporation of water, which may result in poor quality of the installed concrete. This Combi activity necessitates that a covering crew is available in its queue (Laborers); and
6. For this particular model, the total concrete quantity installed during a 6.25-h work period was 538 yards^3. The Queue element (concrete) controls the termination of the model as it initially starts with the total quantity of installed concrete. Once there is no more concrete to fill the trucks, this Queue is empty and the model stops.

Data Collection and Fitting of Activities Duration

To ensure that the model is an accurate simulation of the system response, it is necessary to represent each source of randomness in the model by an adequate probability distribution density function. The rationale behind using a probability distribution function rather than the data values themselves in the simulation is that the collected observations are usually limited and do not offer enough flexibility in the analysis.

Field data were collected during construction for each activity considered in the simulation model. In the data collection process, activities were observed at the site and the time required to complete each process was recorded. To assess the source of randomness in each activity, a sufficient number of data points were collected for each construction process. The number of observations collected during installation ranged from 25 to 53 data points depending on the frequency of occurrence on site.

Activity duration for each Combi and Normal element was fitted to a selected probability distribution based on the analysis of the collected field data. An illustrative example is presented in the following section for the activity duration of the Combi element (truckdumpconc). The activity duration for this element was

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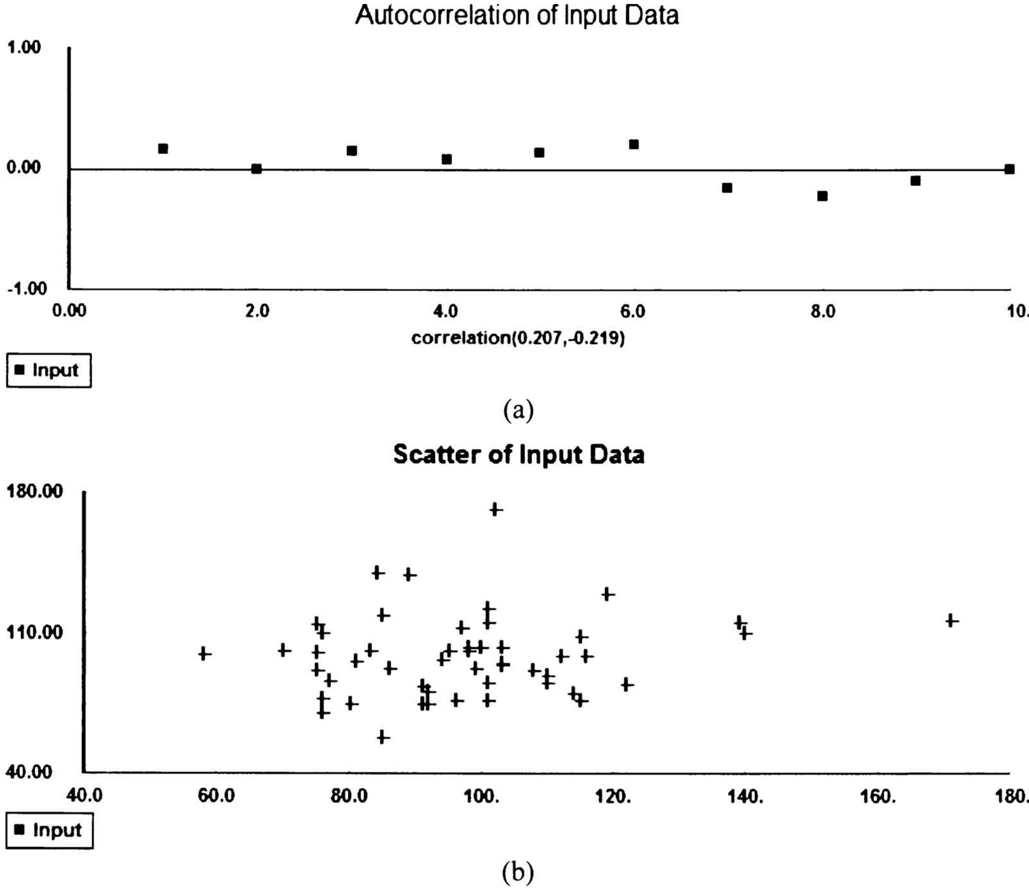

Fig. 3. Assessment of sample independence using: (a) correlation plot; (b) scatter diagram

fitted to the beta probability density distribution (Law and Kelton 2000)

$$F(x)=\begin{cases}\dfrac{x^{\alpha_1-1}(1-x)^{\alpha_2-1}}{B(\alpha_1,\alpha_2)} & 0<x<1\\ 0 & \text{otherwise}\end{cases} \tag{1}$$

where $B(\alpha_1,\alpha_2)$=beta function defined as follows

$$B(\alpha_1,\alpha_2)=\int_0^1 t^{\alpha_1-1}(1-t)^{\alpha_2-1}dt \tag{2}$$

where α_1, α_2=shape parameters greater than zero. The process of selecting the most suitable probability distribution function is usually an involved one, but can be facilitated by the use of a statistical software product such as STATFIT, as it was the case in this study. This process is divided into four major steps:

1. Assess sample independence. Fitting of a probability distribution function to the collected data is only valid if the observations are independent;
2. Select possible distribution functions based on summary statistics;
3. Estimate the parameters for each candidate distribution function; and
4. Determine the accuracy of the selected distribution functions in predicting the model response and select the most precise one.

For the concrete dumping process (truckdumpconc), 51 observation points were collected for the duration of the activity. Sample independence was first assessed through sample correlation and scatter diagram (Step 1—Fig. 3). As shown in Fig. 3(a), the maximum correlation was 0.207 and the minimum correlation was −0.219. Sample correlation can vary between −1 and 1. Theoretically, entirely independent samples will have a correlation of zero. However, this is not achievable even with totally independent observations. If the sample correlation is significantly large, there is strong evidence of dependency. In the case of observations' dependency, the scatter diagram will also show a trend along a line. As shown in Fig. 3(b), the observations are well scattered depicting the independency of the observations in this case.

Using STATFIT, 25 continuous distribution functions were tested against the collected data, and the most promising ones were selected (Step 2). The selection process was based on quantile summaries and box plots (Fig. 4). The quantile summary is a synopsis of the data that are used to determine whether the underlying probability density function and the measurements agree in terms of skewness. The box plots shown in Fig. 4 allow graphically representing the quantile summaries (i.e., minimum, maximum, mean, median) for the measured data and fitted probability density function. In the box plot, 50% of the observations fall within the horizontal boundaries of the box. As shown in this figure, the agreement between the measured and predicted box plots is acceptable, indicating the suitability of the considered probability density function in representing the behavior of field measurements.

Accuracy of the selected distribution function, which in this case was the beta distribution, was then determined (Step 4). Fig. 5(a) presents a comparison between the measured data and the

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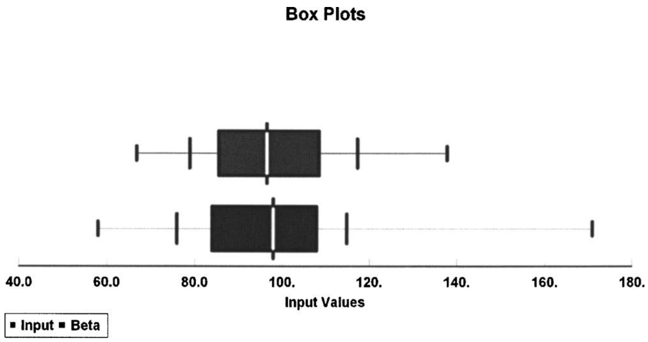

Fig. 4. Comparison between quantile summaries and box plots for measured data and fitted beta distribution

fitted beta distribution function. The residual plot for the beta distribution function is also shown in Fig. 5(b). The goodness-of-fit test, the chi-square test, and the Kolmogorov–Smirnov test were also used at a significance level of 0.005 to validate the assumed distribution functions. In the case of the concrete dumping process, none of these tests rejected the hypothesis that the collected data may be fitted to a beta probability distribution function.

Model Testing

Prior to evaluating the effects of resources and the construction environment on the effectiveness of the concrete paving operation, the model was tested. In general, a single run of the model is not sufficient to produce adequate outputs. For a terminating simulation such as the one considered in this study, the number of simulation runs to produce the desired level of accuracy can be estimated as follows (Law and Kelton 2000)

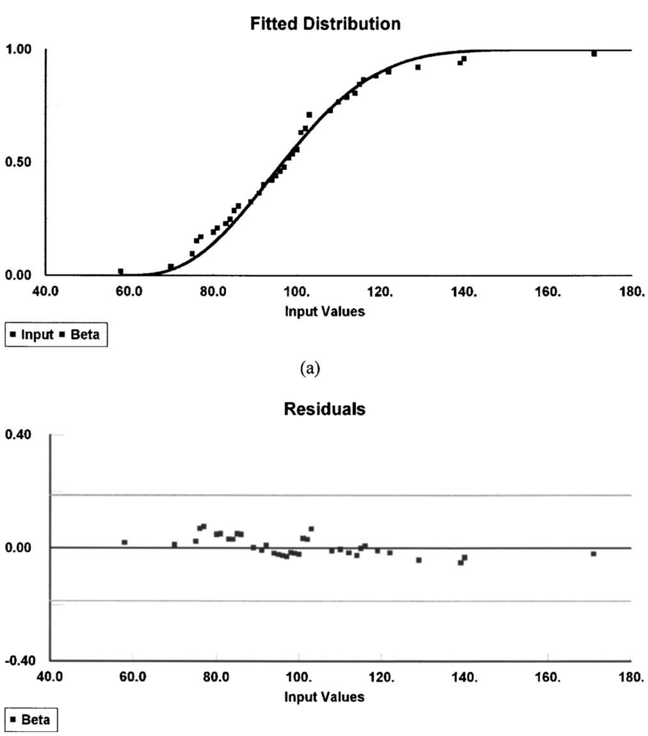

Fig. 5. Statistical measures of fitting process for concrete dumping process. (a) comparison between measured and fitted durations; (b) residual plot for beta probability distribution function

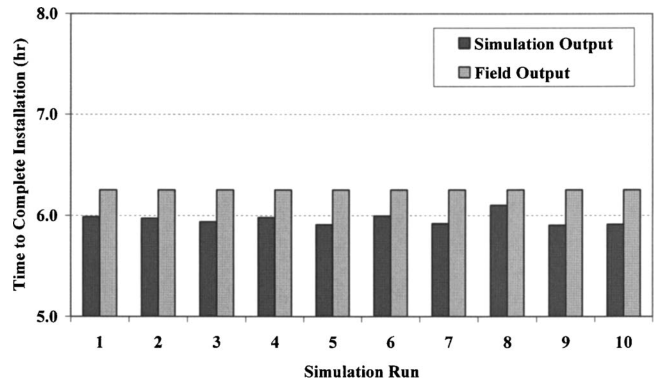

Fig. 6. Comparison of simulation outputs to field measurement

$$n_a^*(\beta) = \min\left\{ i \geq n; t_{i-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{i}} \leq \beta \right\} \tag{3}$$

where n_a^*=number of simulation runs to achieve the desired level of accuracy β (assumed 2 min); $S^2(n)$=variance estimate of an initial number of runs n; i=iterative value of n_a^*; α=desired level of confidence; and t=t distribution for the standard normal distribution. n_a^* was estimated to achieve a level of accuracy β of 2 min in the total time to complete paving 538 yd^3 of concrete as was the field case. The variance estimate was determined for an initial number of runs n of five replicates. Then, at a level of confidence of 95%, Eq. (3) indicated that the required number of simulation runs to achieve the desired level of accuracy is seven replicates or greater (ten simulation runs were used in this analysis). In the field, it took the contractor exactly 6.25 h to complete installation of 538 yd^3 of concrete. Fig. 6 compares the results of the ten simulation runs to the actual field output. The average of the ten simulation runs was 5.96 h, indicating that the percentage error in the simulation prediction was 4.6%, which was considered acceptable.

Simulation Analysis

As previously mentioned, the main advantage of construction simulation is to allow decision makers to experience the response of the system to different configurations. This section presents the results of a sensitivity analysis conducted to estimate the effects of the resources on the cost of the operation and the productivity at the site. The resources considered in this analysis are presented in Table 2 along with the cost per hour.

Table 2. Resource Costs and Variation Ranges

Resource	Cost/h (including laborers) ($)	Resource variation
Trucks	75.00	5–30
Paver	263.00	1–2
Spreader	111.00	1–2
Finishing crews (4)	140.00	1–3
Plastic covering crews (2)	60.00	1–3

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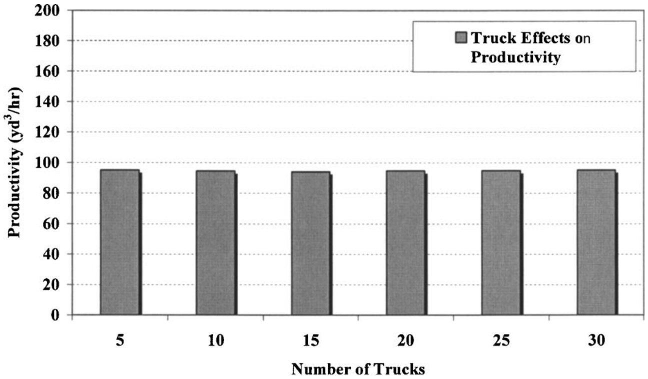

Fig. 7. Variation of productivity with truck overall cost

Number of Haul Trucks

Productivity of the construction operation is defined as the output of the system per unit of time. Therefore, the productivity in yd^3/h (assuming a concrete density of $150\ lb/ft^3$) and overall cost of trucks were calculated as follows:

$$\text{productivity } (yd^3/h) = \frac{990 \text{ t}}{\text{total operation time}} \times 0.5443 \quad (4)$$

$$\text{cost of trucks} = \text{number of trucks} \times \text{total operation time} \times \text{cost/h} \quad (5)$$

The variation of the productivity with the overall number of trucks is presented in Fig. 7. This analysis assumed the use of one paver, one spreader, one finishing crew, and one plastic covering crew. It appears from the results shown in Fig. 7 that a truck fleet consisting of five trucks or greater provides a comparable system of productivity. Therefore, increasing the number of trucks only resulted in increasing the cost of the operation without any return on the productivity of the system. It is worth noting that despite the availability of trucks at the site ready to be serviced, they will have to wait in queue until a spreader is available. This explains why the increase in the number of trucks and availability of concrete materials at the site does not affect the system overall productivity.

Table 3 shows the impact of the number of trucks on the time the spreader and paver are idle waiting for additional concrete to be delivered and the time the trucks wait in queue before service. As shown by these results, the number of trucks had little or no effect on the paver and spreader idle times. As expected, increasing the number of trucks also increased the trucks average waiting time before service. It should be noted, however, that the spreader and paver idle times are probably lower than what is predicted from the simulation since at the beginning of the day, the paver and spreader will remain idle until the first truck arrives at the site.

From these results and to balance the aforementioned factors, it appears that a total number of trucks between five and ten would be acceptable. Under these conditions, the truck average waiting time would be approximately 1 min but the spreader and paver idle times will be too high. However, other resources can be used to reduce these idle times as presented in the following sections.

Table 3. Effects of Number of Trucks on Waiting Time before Service and on Paver and Spreader Idle Time

Number of trucks	Trucks waiting time (min)	Paver idle time (min)	Spreader idle time (min)
5	0.41	6.43	5.31
10	1.55	6.48	5.26
15	2.58	6.45	5.38
20	7.54	6.47	5.12
25	13.21	6.47	5.17
30	15.42	6.44	5.19

Table 4. Comparison of Performance Measures in Case of Using One or Two Pavers

Number of spreaders/pavers	Total operation time (h)	Average truck waiting time (min)	Average idle time for paver (min)	Paver/spreader cost ($)
1/1	5.94	1.55	6.48	2,226
2/2	5.94	0.60	12.72	4,450

Number of Pavers and Spreaders

It is a common practice to use only one paver unless site or contract conditions dictate the use of more. Table 4 compares the performance measures for cases of using one or two pavers/spreaders at the site. As recommended by the results of the previous analysis, ten trucks were assumed in this simulation. As shown in Table 4, using two pavers did not decrease the total operation time, and significantly increased the paver and spreader idle times. In addition, the cost associated with these two pieces of equipment almost doubled.

To further evaluate the effects of the number of spreaders and pavers on the operation effectiveness, the use of this equipment was varied concurrently with the number of finishing and plastic-covering crews. Results are presented in Table 5. As shown by these results, the use of a single paver/spreader along with three finishing and plastic-covering crews results in the best productivity and cost combination. In addition, using this resource combination reduces the spreader and paver idle times to 1.2 and 2.5 min, respectively.

Number of Finishing and Plastic-Covering Crews

Analysis was also conducted to evaluate the effect of the number of crews on the effectiveness of the paving operation. Results are presented in Table 6 for a number of crews varying from one to three. The cost presented in this table is the cost associated with the selected number of crews. This analysis assumed the use of a single spreader/paver and ten haul trucks. Based on these results,

Table 5. Comparison of Productivity and Cost of Different Combinations of Pavers/Spreaders and Crews' Sizes

Pavers/spreaders	1/1		2/2	
crews	Productivity	Cost	Productivity	Cost
1/1	91	3,779	91	6,001
2/2	172	2,815	171	4,006
3/3	240	2,601	244	3,387

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Table 6. Comparison of Performance Measures in Case of Using Different Numbers of Crews

	Finishing crews					
	1/1		2/2		3/3	
PC crews	Productivity	Cost	Productivity	Cost	Productivity	Cost
1	91	1,188	97	1,445	97	1,794
2	91	2,017	172	1,255	180	1,380
3	91	2,848	172	1,695	240	1,347

one should notice that the optimum number of finishing and plastic-covering crews is three of each. In addition, the maximum achievable productivity was 240 yd^3/h.

Practical Implementation of Proposed Model

The proposed simulation model has been tested in one project and has been used in this study to optimize resources and productivity during the course of the ongoing construction activities on Interstate-74. The methodology presented has great potential to optimize resources and production rates in similar concrete paving operations. Moreover, benefits of simulation would be maximized if it were used during the planning phase, as it will affect equipment orders and material shipments. Two possible methods can be used in the implementation of the model presented in practical applications. First, managers may be provided guidance in the use of the simulation model through short courses. This is the preferred approach since it provides personnel with flexibility in addressing project-specific conditions and limitations. If this approach is not feasible and in the case of repetitive processes such as the one considered in this study, production charts may be developed to easily determine the optimum resources given specific time constraints and quantity.

Model Limitations

The simulation model developed is based on certain conditions to which the model use should be limited. First, the results of the optimization process are site dependent and vary depending on the equipment used and the work environment at the construction site. If equipment with varying capacities and productivities is used (e.g., trucks with different capacities), the model developed should be modified to allow for this logic. In some instances, design of construction operations may be different than the one encountered in this study. In these cases, the model developed should be modified. It is also worth noting that the simulation model was tested on only one project and additional validation is recommended.

Conclusions

The objective of this paper was to study and optimize the concrete paving operations taking place in the reconstruction project of Interstate-74 using simulation. In general, application of simulation methods to concrete paving operations was successful and its accuracy was acceptable as compared to field measurements. Based on the results of a sensitivity analysis of the critical resources, multiple factors were identified in the decision-making process to ensure that all aspects of the operation are considered. This includes total operation time, productivity, costs of the operation, average truck delay, and idle times for the paver and the spreader. For the conditions pertinent to this construction site, ten trucks, one paver and one spreader, and three finishing and plastic-covering crews are recommended. Using this set of resources would result in a prompt and effective execution of the operation. Predictive capability of the simulation model developed on other construction projects is underway.

The process presented in this study demonstrates the application of simulation to civil engineering operations such as concrete paving. This approach can be successfully applied to many repetitive processes widely encountered in civil engineering applications. Using simulation methods, decision makers and strategists can evaluate different resource combinations and construction options with a high level of accuracy rather than relying solely on experiences.

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