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A CASE STUDY IN THE QUANTIFICATION OF A CHANGE IN THE CONDITIONS OF A HIGHWAY CONSTRUCTION OPERATION

Haldun Cor
Julio C. Martinez

Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0105, U.S.A.

ABSTRACT

Changes in the conditions under which construction operations take place disrupt projects and can have severe construction cost impacts that must be quantified. This paper presents a case study in which discrete event simulation was used to quantify the impacts of a change in a highway construction project.

1 INTRODUCTION

Contractors bid jobs based on a site visit and the information given in the contracts and specifications at the time of bidding. They plan tasks and assign resources to each task on the basis of this information. However, as projects progress, the scope of the work may change. These changes may include alterations to the sequence of work, to the design, or to the conditions. Work changes may affect originally planned means and methods. As a consequence, they may impact the quantity and the type of the resources required to perform the work.

There are, however, other factors that affect the number and type of resources that are actually needed for construction. The challenge is to segregate the impacts caused by changes from those due to other reasons. This quantification is necessary to properly compensate contractors for changes not under their control. Traditional techniques employed by the industry to quantify the impacts of the changes (Bramble and Callahan 1987; Wickwire and Smith 1974; Cushman and Carpenter 1990) have limitations that can be overcome using discrete event simulation (AbouRizk and Dozzi 1993; Vanegas and Halpin 1993).

2 IMPACT QUANTIFICATION

The detailed control that is available in simulation modeling allows the technique to replicate operations 1) as they were planned, 2) as they were built, and 3) as they could have been built had certain changes not taken place. It is of interest to quantify the difference between 2 and 3 above because contractors should typically receive compensation for this amount if the changes were not under their control and could not be reasonably forseen.

Common Random Numbers and Trace Driven Simulation (Law & Kelton 1991) can be used to ensure faithful modeling of all three operations. Proper validation, verification, and visualization of the operations lend credibility and provide an opportunity to prove to other parties that the model reflects reality and thus enable reaching a common ground. The highway construction project analyzed in this paper illustrates these techniques.

3 CASE STUDY

The case study is an earthmoving operation in a highway project in Virginia. The project involved hauling earth over a railroad crossing. The contractor planned the operation based on the information in the contract documents at the time of bidding. The as-planned operation was based on using a temporary crossing over a railroad except during short periods before and after trains pass. The operation took place as-planned during the early stages of the project. Due to a communication failure, however, in one instance the flag person failed to close the gate while a train was approaching. A truck then crossed the rails and was almost hit by the approaching train. Fortunately, there was no accident. However, after this event took place, the as-planned operation was no longer allowed by the Railway Administration. The contractor was allowed only limited access through the temporary crossing. The temporary crossing had to be closed almost half hour before and after a train passed. The contractor was directed to use a route in the vicinity of the project with certain stipulated conditions when the temporary crossing was closed. The stipulated conditions were that trucks had priority over the existing traffic at all times except just after a train passed. In addition, during the morning and evening rush hours the trucks were not allowed to use the alternative haul road (this condition was later removed due to the heavy impact on the operation).

This change in the operation had considerable impacts. The study used the historical data kept on site for the train arrivals, down time of the equipment, daily working time, and cut and fill station numbers. The objective was to find the net impact of the change on the performance of the operation. Animations of the two simulation models were used to display how the change affected the operation and, consequentially, the performance.

3.1 As-Planned Operation Model

The as-planned operation is the operation based on the information given in the contract at the time of bidding. This is important because it represents how the baseline understanding affected the means and methods for the particular operation. Any substantial deviation from these conditions may constitute a change in the contract.

In this case, the as-planned operation was the hauling of the material from the cut area over the temporary crossing to the fill area. A simulation model was built to show how the basic understanding of the contractor affected his choice of means and methods.

3.2 As-Built Operation Model

The as-planned operation took place for a while until the "near accident" situation. After the event, the contractor experienced substantial delays at the temporary crossing because of the over-conservative operational policy enforced by the Railway Administration. Sometimes trucks were kept at the temporary crossing just because a train was reported to arrive 30 to 50 minutes later. In order to eliminate these delays, the contractor was directed to an alternative haul road. In this case when the temporary crossing was closed the trucks were directed to the alternative haul road via wireless communication.

The alternative road had some disadvantages as far as the production of the operation was concerned. Obviously, it was longer than the previous haul road. In addition, it was constrained at some narrow portions that only allowed the passage of trucks in a single simultaneous direction. Further, it had an interference with the traffic on Route 122. Trucks had priority over traffic at all times except just after a train passed.

The as-built model is a trace-driven simulation model (Law and Kelton 1991). That is, certain activities perform the operation exactly as they happened on site. The factual data is prepared as input to the model. The model traces these input data and performs the required tasks based on the traced information. By doing so, it is possible to create an environment with the desired level of history. The model uses the following factual data from the project records:

1. Train arrival times,
2. Truck downtimes,
3. The times that the temporary crossing was available,
4. Daily working hours, and
5. Daily cut and fill locations.

Although the model was a fairly good replication of how the operation took place, there were many realities that were not modeled because their impact on all models was the same. These included weather conditions and changes in the physical conditions of the haul roads.

3.3 As-Adjusted Model

The as-adjusted model was developed according to the baseline understanding. It includes the disruption caused by the contractor as well as the observed performance but leaves out the conditions changed by the third party. For example, the downtime of the trucks was a disruption caused by the contractor and was thus included in the model. However, the trucks do not use the haul road over Route 122 in this model. They use only the haul road over the temporary crossing with one minute and half minute waiting times before and after a train passes, respectively.

3.4 Analysis of the Models

The difference between the as-built and as-adjusted models is the net impact of the change, which in this case was measured by the difference in the daily number of loads. This can be seen for a particular month of the operation in Figure 1.

3.5 Animation

It is essential to prove that the model works correctly and that it mimics the operation and the changes that took place on site. The models used for the analysis were animated in order to achieve this. In addition to showing the operations in a very realistic manner, they display the loader and truck utilization (statistics), and productivity and number of loads (performance measures). These values are constantly updated so that observers can see how they change. Train numbers and arrival times are also displayed because 1) they give the viewer a sense of reality because train times and arrival times are factual data from the project records, 2) trains are one of the key issues in the model, and 3) train arrival times are the basic criterion for routing truck traffic.

The animations for the models used in this case study are available from the web in a interactive multimedia presentation at the following URL:

http://strobos.ce.vt.edu/Demos/monfiles.exe

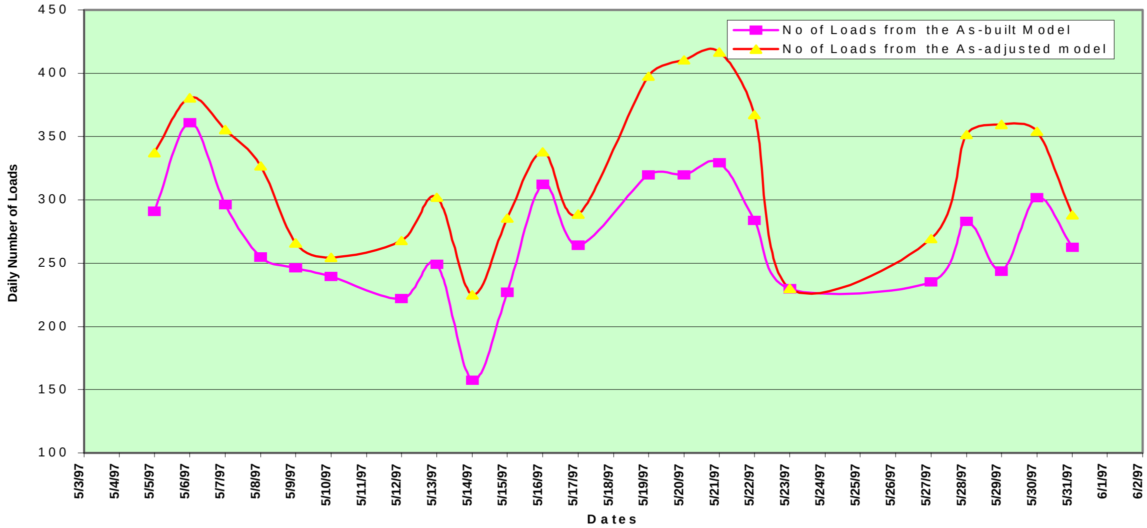

Figure 1: Comparison of the As-built and As-adjusted Models

3.6 Tools

The models used in the analysis were developed using STROBOSCOPE (Martinez 1996), a general-purpose simulation system well suited to the modeling of complex construction operations. The animations were created using PROOF Animation (Wolverine Software Corp. 1992).

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AUTHOR BIOGRAPHIES

HALDUN COR is currently a doctoral student in the Via Dept. of Civil Eng. at Virginia Tech. He received his MS in Civil Engineering from the Via Dept. of Civil Eng. at Virginia Tech in 1998 and B.S. in Civil Eng. from the Civil Eng. Dept. at Orta Dogu Teknik Universitesi (Ankara, Turkey) in 1992. His research interests include discrete event simulation, management information systems, scheduling and claim analysis, and applications of finance in construction.

JULIO C. MARTINEZ is an Asst. Prof. in the Via Dept. of Civil Eng. at Virginia Tech. He received his Ph.D. in Civil Eng. at the U. of Michigan in 1996; an M.S.E. in Const. Eng. and Mngmnt. from the U. of Michigan in 1993; an M.S. in Civil Eng. from the U. of Nebraska in 1987; and a Civil Eng. degree from Univ. Catolica Madre y Maestra (Santiago, Dominican Rep.) in 1986. He designed and implemented the STROBOSCOPE simulation language as part of his Ph.D. dissertation research. In addition to discrete event simulation, his research interests include construction process modeling, decision support systems for construction, scheduling of complex and risky projects, and construction management information systems.