Application of Computer Simulation in Resolving Construction Disputes

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Abstract: Mediating construction disputes arising from changed conditions involves reviewing contractor's estimates prior to construction, analyzing the motives for the claim and determining the owner's and designers' responsibilities. This process can be enhanced by using applicable computer-based tools such as simulation. This paper discusses the use of simulation in the mediation process. CYCLONE models are developed to analyze part of a claim between the public owner and a steel contractor. In particular, simulation models are developed to estimate the cost of the operation as envisioned by the contractor at time of bidding and to estimate the cost of the operation after the change. The two models give an accurate picture of the direct costs involved the additional costs incurred due to the added complexity resulting from the change. The paper reviews the complexity claim, discusses the operation that is the subject of the dispute, and presents the CYCLONE models developed to assist in the mediation.

Introduction

Complex projects often lead to contractors underestimating jobs, designers making mistakes or overlooking items and owners faced with tight budgets especially after committing to a competitive low-bid lump-sum contractual arrangement. This frequently leads to disputes commonly ending with expensive mediation, arbitration, or litigation. The parties involved with such disputes are faced with a number of issues including quantifying the values reflective of the anticipated conditions envisioned at time of bidding and the as-built (or to-be-built) conditions. Complexity claims are a common form of such disputes. Complexity claims arise when contractors underestimate projects because of failure to recognize the complexity of the construction operation and thus its true cost.

To analyze and attempt to resolve complexity claims, construction management consultants often use subjective estimation techniques, their intuition, and experience, thereby introducing new information and opinions. A mediator will use legitimate and pertinent evidence in order to satisfactorily resolve the dispute, which can be augmented by the use of the available quantitative tools.

The critical path method and other network models have been successfully used in the past. Spreadsheets and spreadsheet-based estimating techniques are also commonly used. Learning curve models have been applied in tunneling-related disputes. Time motion studies, regression methods, the method productivity delay model (Adrian and Boyer 1976), queuing theory and mathematical modeling can be applied to measure the operation's productivity and relate it to expected (before a change) productivity.

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J. Constr. Eng. Manage., 1993, 119(2): 355-373

System and process simulation can be applied to enhance the analysis process in resolving disputes based on changed conditions. Simulation makes it possible to accurately model a construction operation thus enabling the modeler to estimate, with good degree of accuracy, the system's productivity, its required time and its overall cost. Simulation models can be developed with many degrees of flexibility allowing the modeler to recreate the condition after redesign based on normal (or conventional) practices. This provides a benchmark that can be used to analyze the motives of the contractor for the claim. Simulation can also provide a medium for sensitivity analysis as well as an environment for asking "what-if questions." Simulation languages developed specifically for construction [e.g., CYCLONE (Halpin 1977)] made it relatively easy for consultants to develop and experiment with simulation models. Furthermore, simulation provides a unique medium for modeling the probabilistic nature of construction, the complex nature of dynamic resources and their interactions, and the implications of various management decisions on the outcomes. This gives the mediator (directly or through the use of consultants) an excellent tool that can be used to enhance the dispute resolution process.

This paper discusses how computer simulation in general, and CYCLONE in particular, can be used during the mediation process of a complexity claim. The second author was hired by the Alberta Transportation and Utilities (ATU) and the steel contractor—Northern Steel Inc. (NSI) to mediate a claim arising from added complexity due to changes in the design after contract award on the Peace River Bridge. The writers investigated the use of simulation modeling to quantify the extent of the changes on the cost. The paper is organized as follows: The first section reviews the general nature of the claim providing a background to the mediation. The second section presents a brief description of the construction operation, which is the subject of the claim. The third section discusses the simulation models, their development and the MicroCYCLONE (Halpin 1991) analysis. The fourth section discusses the use of the simulation results in assisting the mediator in arriving at a fair assessment of the claim. Finally, the last section presents the conclusions.

Description of Complexity Claim

Alberta Transportation and Utilities (ATU), Bridge Engineering Branch contracted with Northern Steel Inc. (NSI) of Edmonton, Alberta, to supply and erect the structural steel for a bridge across the Peace River, 18 km northeast of Weberville. This location is approximately 25 km downstream of the town of Peace River and immediately upstream of the Diashowa pulp mill. Contract award date was May 8, 1989. Steel erection was completed in October 1991.

The bridge consists of four lines of I-shaped welded plate girders with a nominal depth of 4.6 m at 3.15-m centers. A schematic representation of the bridge is given in Fig. 1. Overall length of steel works is 674 m made up of seven spans of 82 m (span 1), five spans of 112 m, and one span of 92 m. The initial 60 m of the 82 m end span was splayed 3.48 m to accommodate geometric road design. Bridge piers were skewed at 25° from perpendicular to the bridge axis. At the bid stage the total steel tonnage was estimated at 4,376 t. After award, approximately 98 t of reinforcing was added to the permanent bridge steel for strength and stability requirements during erection of the bridge. NSI originally bid $12,865,734 (Canadian

J. Constr. Eng. Manage., 1993, 119(2): 355-373

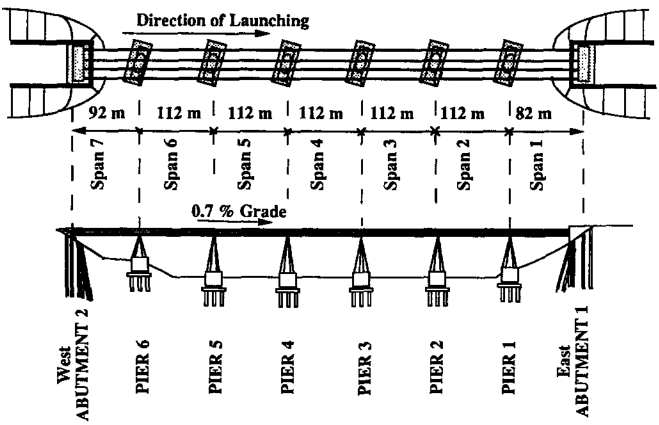

FIG. 1. Schematic of Peace River Bridge

FIG. 2. Bridge during Launching

dollars), excluding any extras; two other contractors submitted bids of $17,066,000 and $17,586,45.

The method of erection was by launching the entire steelworks from the west abutment on a 0.7% grade downward towards the east abutment. The bridge launching is shown in the picture given in Fig. 2. A unique and complex feature was the launching of the splayed end (span 1 as shown in Fig. 1).

The extent of the complexity was not initially apparent to the owner, contractor, and construction engineering consultant. The extent and, therefore, the additional complexity was not apparent before construction progressed. NSI submitted a claim for extra costs due to additional complexity that was not apparent at time of bidding. Special provisions of the specifications read as follows (Buckland and Taylor, unpublished design documents, 1989):

"The girders are designed and detailed assuming erection by launching from the west bank. If the girders are launched the erector shall be

J. Constr. Eng. Manage., 1993, 119(2): 355-373

responsible for launching procedures, launching equipment and all other material required for launching operations."

The bidders were also advised that the method of erection was at the option of the erector and entirely his responsibility. However, prebid consultations with contractors determined the only feasible method was by launching, which was incorporated into the contract documents. During a prebid meeting, ATU discussed a scheme with a curved bottom chord trussed launching nose and one set of rollers per girder west of each bridge bearing. The drawings issued for bidding stated:

"The girders have been detailed to facilitate erection by launching from the west bank with a 20 m long launching nose attached to the end of span 7."

Further drawing notes referred to "details incorporated in girder design for launching, maximum launching roller reactions, maximum girder deflections, and weight of launching nose."

From these clauses NSI concluded that the main bridge material was adequately proportioned for launching and did only enough prebid engineering to size and cost erection equipment. Further, NSI adopted an articulated rocker assembly for landing the launching nose and rolling the girders over the pier tops as shown in Fig. 3. For this initial scheme, the intention was to launch the bridge high and would have required only 300 mm of jacking to lower the bridge into the permanent bearings. After award of the contract, detailed engineering calculations revealed the inadequacy of the preliminary engineering carried out for bidding purposes by both parties. For the limit states approach used, the load factor of 1.2 used for preliminary construction design was increased to 1.4 to provide a level of safety compatible with working stress design methods. Detailed assessment of wind loads and web buckling added to the revisions required for both permanent bridge steel and erection launching equipment. It was also established that the optimum launching height was 800 mm above the final required elevations.

The complexity claim consisted of the following components for the launching scheme.

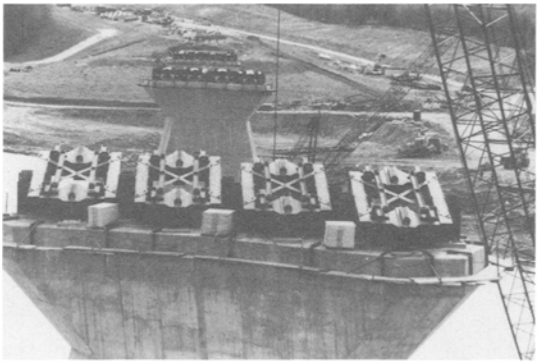

FIG. 3. Rocker-Roller Assemblies on Pier 1

J. Constr. Eng. Manage., 1993, 119(2): 355-373

1. Extra engineering.
2. More costly and complex erection aids, which include the rocker assemblies, jacking equipment, and shim materials.
3. Additional labor for the installation and removal of the more complex erection equipment.
4. Additional complexity of the launching nose.
5. Reinforcing of the permanent bridge steel for strength requirements during launching.
6. Additional labor due to the jacking sequence.

The main focus of this paper is item 6. The claim for this additional labor was $236,000.

In the case that negotiations could not settle a dispute, the contract provided for dispute resolution by mediation, which was not binding. Differences of opinion existed as to how much if any liability is attributable to each party. Also the basic question is not what makes NSI whole vis. a vis. the bridge launching scheme but what, if anything, was required to put NSI back to the situation at the time of bidding. NSI claimed that notes on the drawings and specification clauses were misleading and, as a result, added complexities were experienced beyond those envisaged at the time of bidding. The bid breakdown showed that the variation was largely due to the differences in the estimated erection costs. Notwithstanding the clauses mentioned, the two unsuccessful bidders did include a substantial amount for the reinforcing of the permanent bridge steel, whereas NSI chose a literal interpretation of these clauses. On this basis, ATU agreed to consider the claim for added complexity.

Description of Jacking Operation

The erection scheme consists of launching the entire bridge over rollers located at abutments and piers and in the assembly area (refer to Figs. 2 and 3 for illustration). Sections of the girders are added in an assembly area immediately west of the abutment. For each launch one span is assembled including bracing and catwalks. Across the end of the assembled girder, a deep horizontal jacking girder is attached and cables are fastened to the outboard ends of the jacking girder. A jacking arrangement pulls these cables moving the bridge forward in increments equal to the jack stroke. A launching nose is attached to the lead end of the girders. This nose is much lighter than the girders and is shaped such that it lands on pier rollers when the maximum permissible deflection (approximately 3 m) of the cantilevered bridge girders is reached as shown in Fig. 4. The length and shape of the nose is selected to land and provide support within load limits of the girders. Upon landing of the launching nose on the rocker assembly at the forward pier the reaction created provides restoring moments and shears that must increase sufficiently rapidly in order to overcome the effects on the girders of continuing movement due to the launching operation.

In order to limit the size and length of the launching nose and to accommodate the height of the launching rocker/roller equipment, the bridge is launched high. This height above the permanent bridge bearing is established considering the optimum launching nose length and weight, dimensional width clearances at the pier tops, and the deflection (approximately 3 m) of the cantilevered lead end of the bridge. Jacking is therefore required to lower the bridge onto the permanent bridge bearing.

J. Constr. Eng. Manage., 1993, 119(2): 355-373

FIG. 4. Launching Nose Landing on Pier 4

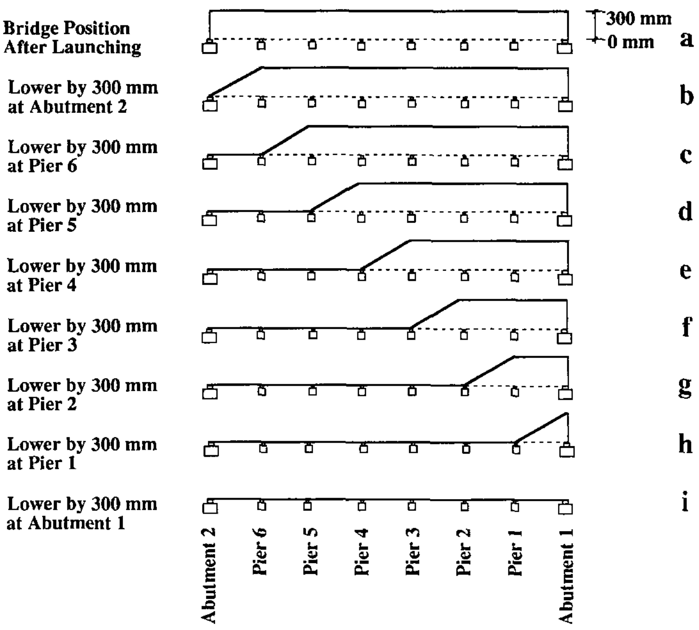

FIG. 5. Schematic of Jacking Sequence for Estimated Operation

The jacking operation, which constitutes only part of the complexity claim is the main subject of this paper. At time of bidding the contractor established that the additional height of 300 mm would accommodate the jacking arrangement and the roller/rocker assembly required for launching. Consequently, NSI estimated that it will take approximately 1,417 man-hours to complete the jacking sequence lowering the bridge by 300 mm as illustrated in the schematic representation given in Fig. 5.

Lowering 300-mm Process

For the CYCLONE model, the sequence was assumed to begin at abutment 2 and then progress in order to pier 6 to abutment 1 (refer to Fig. 1 for bridge layout).

Prior to the lowering process, the rocker/roller assembly is removed. Jacks at position "A" shown in Fig. 6 are pressurized to lift the assembly and free the articulation pins. Shim stack "B" is placed on the permanent bridge bearings. Jacks are pressurized and the load is transferred from the transitional rollers on the roller/rocker assembly to the central shim stack "B." The rocker roller assembly is removed. Shims and inverted jacks are positioned at location as shown in Fig. 7.

The lowering is accomplished by an alternative sequence of pressurizing and extending the jacks (thereby removing the load on shim stack "B") and removing 40-mm shims from shim stack "B." The inverted jacks are then depressurized (transferring the load to shim stack "B") and shims removed from shim stack "C." Jacks are pressurized extending the jack and applying load to shim stack "C." The cycle is repeated to completion of the lowering process. Shims at the abutment are removed in 80-mm increments (2 × 40-mm shims) thus requiring four repetitive cycles of the tasks given in Table 1 to lower the bridge to its final elevation. This process is carried by the main crew on the bridge. Normally eight to ten men are used in such an

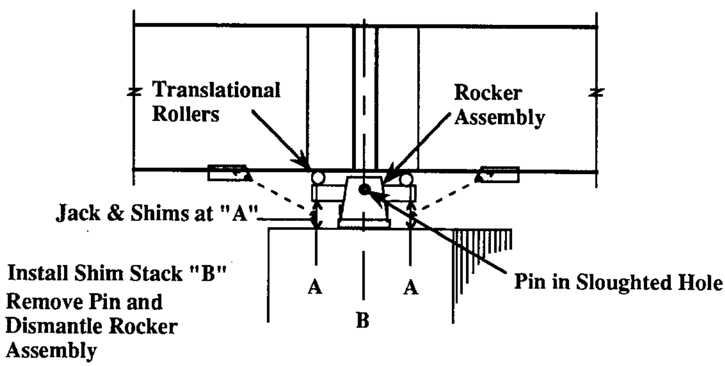

FIG. 6. Schematic Rocker Assembly Removal, Jack Pressurization, and Shim Placement

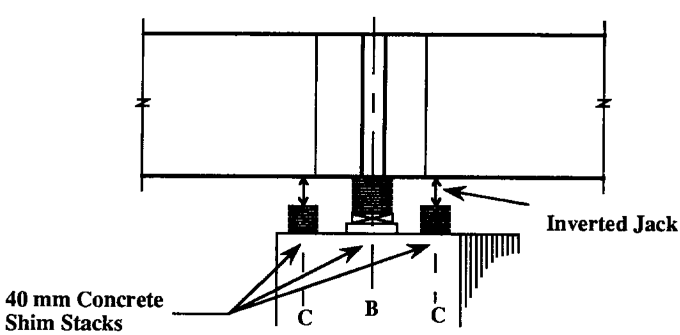

FIG. 7. Schematic Shims and Inverted Jacks Positioning

J. Constr. Eng. Manage., 1993, 119(2): 355-373

TABLE 1. Tasks Involved in Jacking Process at Abutment or Pier

Task no. (1)	Task description (2)
1	Extend jacks 80-mm transferring bridge load to shim stack "C."
2	Slacken clamping rods on shim stack "B."
3	Remove 40-mm shims from shim stack "B."
4	Retract jacks to lower bridge—40 mm (maximum capacity allowed).
5	Remove 40-mm shims from shim stack "B."
6	Retract jacks to lower bridge and transfer load to shim stack.
7	Remove 80-mm shims from shim stack "C".

operation. In addition, the work on the bridge proceeds in the linear fashion represented in Fig. 5. Work is restricted to one pier at a time. Upon completing the lowering of 300 mm, the bearing base plates and anchor bolts are aligned and grouted. The jacks are then removed and the abutment cleaned off. The latter process is carried by another small crew of two men while work is proceeding elsewhere on the bridge.

The work on the piers is repetitive, particularily if the lowering is in the 300-mm range. When the elevation is higher, intermediate alignment is necessary, thus requiring more construction resources and time. The lowering process on a typical pier involves installation of the jacks under the roller frames. Jacks beneath the four girders are piped together to ensure equalized force distribution on all elements. The jacking alternates between two shim stacks with each constructed 40-mm-thick shims, which are removed in pairs requiring a total of four cycles to complete the lowering process for final elevation. When the five cycles are completed the bearings are grouted, equipment removed, and pads grouted. Abutment 1 follows the same procedure as abutment 2 with minor modification to allow for final location of the bridge.

A combination of factors required the bridge to be launched higher than the 300 mm assumed level at time of bidding. These factors included strength and buckling limitation of permanent bridge material and dimensional clearances required at the piers. The bridge was launched 800 mm high at each pier.

Lowering 800-mm Process

The 800-mm height dictated a more complex construction procedure including larger erection aids and an alternating two phased lowering at each pier and abutment. The arrangement of the erection aids and jacking details, for each line of girders, consisted of a rocker beam assembly which carried two sets of rollers used for translation of the bridge, three stacks of shims and two jacks. The bridge was lowered at each pier or abutment limiting the differential between any two points to 400 mm. This necessitated use of the sequence illustrated in Fig. 8. The bridge after launching would be 400 mm high at abutment 2 and 800 mm at all piers and abutment 1, as shown in Fig. 8(*a*). The jacking commences at pier 6 where the bridge is lowered to a 400-mm level following the sequence of tasks given in Table 1. The bridge would be at the level shown in Fig. 8(*b*). The crew moves to abutment 2 and lowers the bridge to its zero-level shown in Fig. 8(*c*) according to the sequence of tasks given in Table 1. The work proceeds to pier 5 where the bridge is lowered from 800 mm to 400 mm yielding the elevation shown in Fig. 8(*d*). The sequence of tasks is similar to pier 6. The

J. Constr. Eng. Manage., 1993, 119(2): 355-373

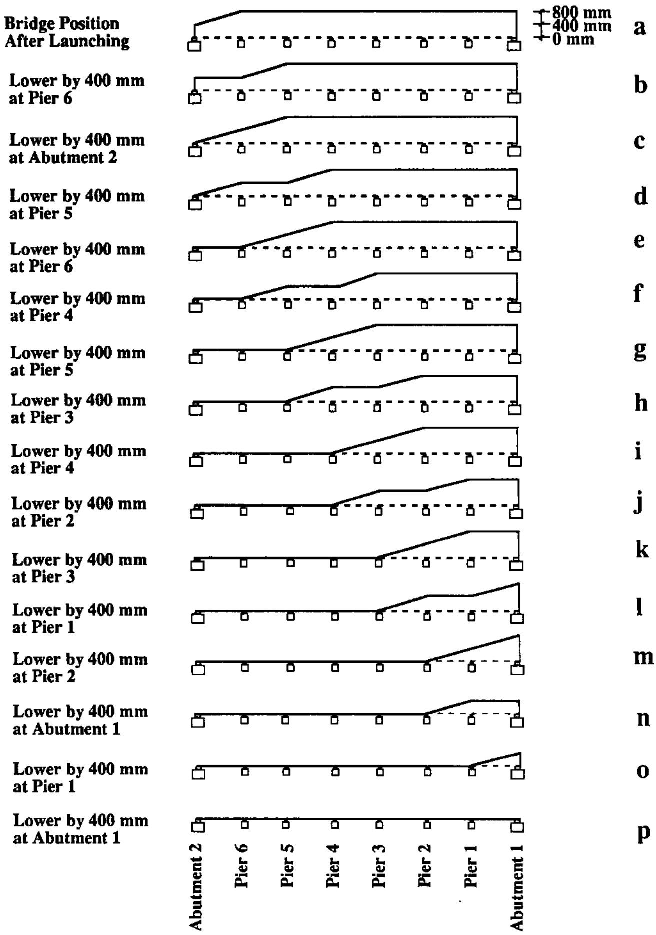

FIG. 8. Schematic Jacking for Actual Operation

work then follows this alternating sequence passing through the elevations shown in Fig. 8(*d*) (pier 5), through Fig. 8(*p*) (abutment 1). The only exception to this sequence is at Piers 2 and 1 where the lowering from 400 to 0 mm passes through a two-step alternating sequence from 400 to 300 then to 0 mm. This is required to suit material stress limitations of the main girders.

During the lowering, the jacks at location C (as shown in Fig. 7) are extended releasing the load off the shim stack B. Two 40-mm shims are then removed from the shim stack B while the load is being carried on shim stack "C." Bridge is lowered and the load is transferred to shim stack "B" and 80-mm shims are removed from the shim stack "B." The sequence is repeated until 400 mm of shim are removed. This requires five repetitive cycles. The jacking cycle is carried by the same crew and work proceeds linearly along the pier. Upon completion of the five cycles, the bearings are grouted and cured for 48 hours. Grouting is carried by another small crew

J. Constr. Eng. Manage., 1993, 119(2): 355-373

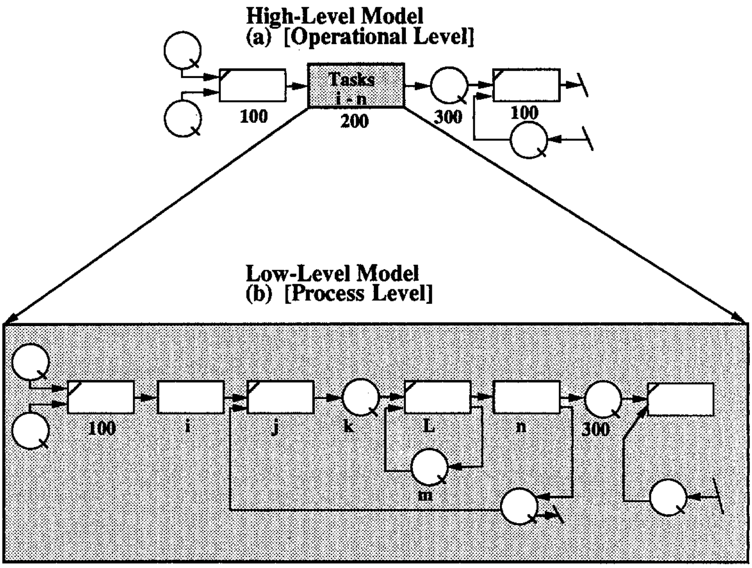

FIG. 9. Conceptual Breakdown Structuring for CYCLONE Modeling

while the main crew moves to another pier. The exact sequence of construction tasks is given in CYCLONE format in the following sections.

CYCLONE Model Development and Simulation

Two CYCLONE models were constructed to validate the modeling strategy followed for the anticipated situation, and to provide a measure (based on the normal construction practices) of expected productivity. This eliminates the need to rely solely on contractor's estimates in the mediation as these tend to be biased.

It was decided that two models would be required. The first provides an estimate of the required man-hours to complete the actual operation and the second provides an estimate of the man-hours that would have been required to complete the operation as envisioned at time of bidding. The models reflect the spirit of the construction procedure laid out in the design documents supplied to the contractor and are not biased by the contractor's employed methods or productivity. This would provide the mediator with an unbiased estimate that is not influenced by motives for cost recovery from a low-bid situation by the contractor or unfair underestimation of the complexity involved that was not clearly indicated in the design documents. It was first decided to use SLAMSYSTEM (Pritsker 1985) to make use of its programming capabilities to reduce the number of anticipated nodes in the model (over 300 nodes are required to describe all tasks without any cycling allowed). The SLAM model was successful but difficult to communicate to representatives of the owner and the contractor since it was mainly composed of Fortran code.

CYCLONE model development is extensively documented in the literature [see for example, Halpin and Woodhead (1976), Halpin (1977), and Halpin and Riggs (1991)]. The basic elements of the CYCLONE model are

J. Constr. Eng. Manage., 1993, 119(2): 355-373

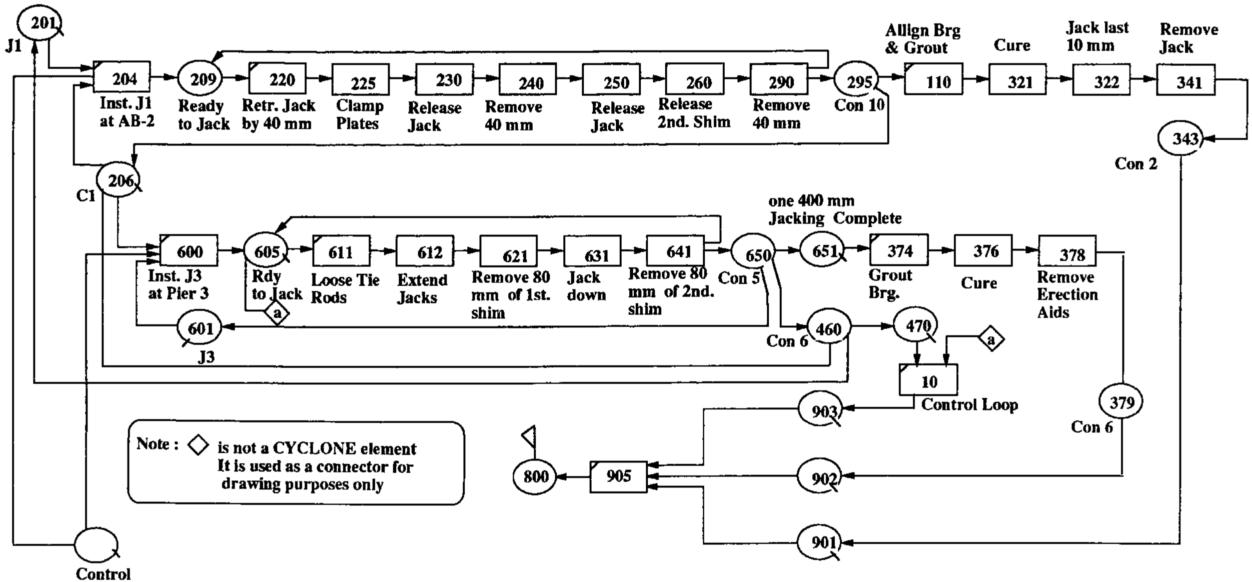

FIG. 10. CYCLONE Model for Jacking of Estimated Operation

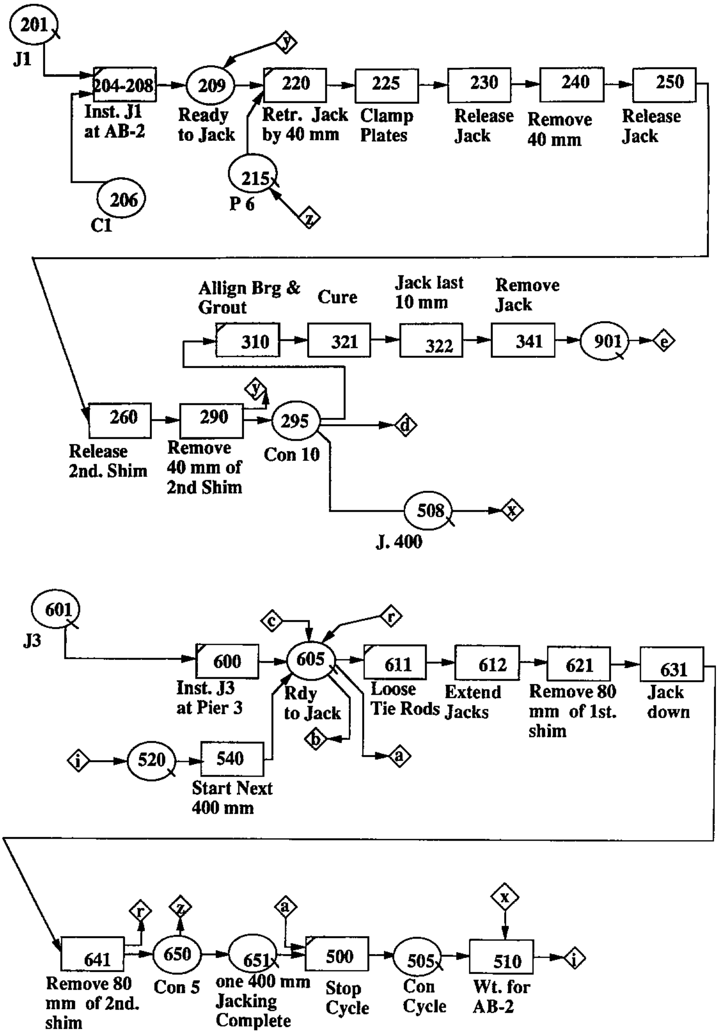

FIG. 11. CYCLONE Model for Actual Jacking Down Operation

a circle that describes a waiting state of a resource and a square that describes the resource's active stage. A model is built by recognizing the main cycles of the various resources in the construction operation and their interactions. The model then reflects the flow of the resource from one node to another.

The CYCLONE model was developed making use of an organized work breakdown structure in the model development and explanation phases. This adheres to the breakdown representation suggested in Halpin and Woodhead (1976) (i.e., a project is made up of individual operations consisting of individual processes, which are made up of individual tasks). A number of processes were defined in the overall jacking operation. For example, tasks as given in Table 1 were at first aggregated into one representation since they occur in series. These tasks were modeled by one

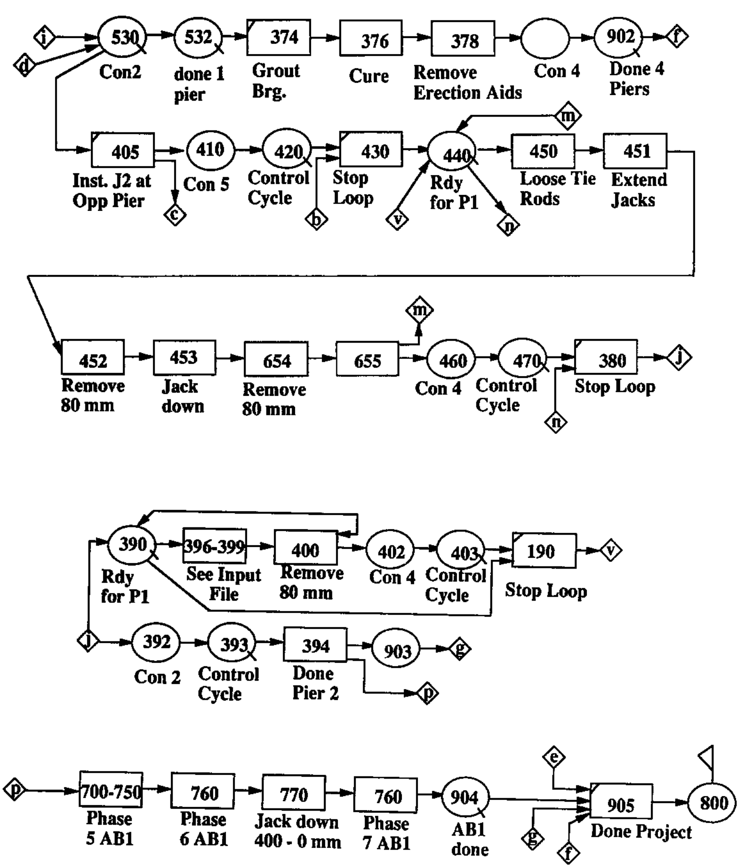

FIG. 11. ***(Continued)***

element (a normal or combination since MicroCYCLONE does not currently support insertion of processes in a model) to create the high-level abstraction model as schematically illustrated in Fig. 9. This facilitates understanding of the overall model and allows the modeller to focus on the underlying topological structure of the operation rather than that of the individual processes. Upon finalization of the high level models, tasks in series, or individual processes, replace the aggregated elements and are directly inserted to the MicroCYCLONE input file without complicating the working graphical models. It was felt that this modeling strategy can be generalized and automated in the future to allow development of project-oriented CYCLONE models as compared to the process-based ones currently in wide use.

The two CYCLONE models were then developed in accordance with the design documents specifying the construction procedure (Buckland and Taylor 1989), the experience with similar projects and actual consultations with the involved parties. In the jacking operation described in the previous section two key resources can be immediately recognized, namely the main crew and the jacks (since they move from one pier to the other). The

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NAME 'JACKING -PEACE RIVER BRIDGE AS ESTIMATED' LENGTH 20000 CYCLE 1
NETWORK INPUT
1 QUE 'ALLOW ONLY 8 STARTS ONE FOR EACH PIER/AB'
10 COMBI 'CONTROL' SET 1 PRE 410 605 FOL 903
50 NORMAL 'BUILD SHIM A' SET 60 FOL 56
56 NORMAL 'ISRT RDS' SET 61 FOL 57
57 NORMAL 'BUILD B' SET 62 FOL 58
58 NORMAL 'RLS ROCKING ROLLERS' SET 63 FOL 59
59 NORMAL 'RMV ASSEMBLY' SET 64 FOL 60
60 NORMAL 'RMV X-BEAMS' SET 65 FOL 61
61 NORMAL 'BURN OFF GUIDES' SET 66 FOL 209
110 COMBI 'ALIGN BRG & GROUT' SET 10 PRE 209 296 FOL 321
201 QUE 'J1'
204 COMBI 'INSTALL J1 AT ABUTMENT 2' SET 2 PRE 201 206 FOL 50
206 QUE 'CREW-1'
209 QUE 'READY TO JACK'
220 COMBI 'RETRACT JACKS BY 30 mm -BEAR ON A' SET 3 PRE 209 FOL 225
225 NORMAL 'CLAMP SOLE PLATE' SET 4 FOL 230
230 NORMAL 'RELEASE JACKS' SET 5 FOL 240
240 NORMAL 'REMOVE 30 MM OF SHIM B' SET 6 FOL 250
250 NORMAL 'RELEASE JACKS' SET 7 FOL 260
260 NORMAL 'RELEASE SHIM A' SET 8 FOL 290
290 NORMAL 'REMOVE 40 mm FROM A' SET 9 FOL 295 209
295 FUNCTION CONSOLIDATE 10 '10 CYCLES' FOL 296 206
296 QUE
321 NORMAL 'CURE FOR 48 HOURS' SET 11 FOL 322
322 NORMAL 'JACK LAST 10 mm' SET 12 FOL 341
341 NORMAL 'REMOVE J1 AND GROUT' SET 13  FOL 343
343 FUNCTION CONSOLIDATE 2 'ABUTMENTS' FOL 901
374 COMBI 'GRT BRGS ON PIER' SET 24 PRE 651 FOL 376
376 NORMAL 'CURE 48 HRS & LAST 10mm JACKING' SET 25 FOL 378
378 NORMAL 'REMOVE ERECTION EQPT' SET 26 FOL 379
379 FUNCTION CONSOLIDATE 6 'DONE WITH 4 PIER GROUTING' FOL 902
400 FUNCTION CONSOLIDATE 6 'PIERS' FOL 206 201 410
410 QUE
600 COMBI 'INSTALL JACK AT PIER' SET 14 PRE 601 206 FOL 660
601 QUE 'J3'
605 QUE 'READY TO JACK'
611 COMBI 'LOOSEN RODS HLDG B' SET 15 PRE 605 FOL 612
612 NORMAL 'EXTND JACKS LOADING C' SET 16 FOL 621
621 NORMAL 'RMV 80mm OF SHIM B' SET 17 FOL 631
631 NORMAL 'JACK DWN TO BEAR ON B- RETRACT FROM C' SET 18 FOL 641
641 NORMAL 'REMOVE 80 mm OF SHIM C' SET 19 FOL 650 605
650 FUNCTION CONSOLIDATE 5 '5 80mm SHIMS=400mm' FOL 400 651
651 QUE 'DONE WITH ONE 400 mm JACKING'
660 NORMAL 'INSTL PHASE 3' SET 70 FOL 661
661 NORMAL 'INSTL PHASE 4' SET 71 FOL 662
662 NORMAL 'INSTL PHASE 4.3 ' SET 72 FOL 663
663 NORMAL 'INSTL PHASE 5' SET 73 FOL 605
800 FUNCTION COUNTER QUANT 1 FOL 900
900 QUE
901 QUE
902 QUE
903 QUE
905 COMBI 'DONE PROJECT' SET 51 PRE 903 FOL 800
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FIG. 12. Bridge-Jacking Tasks in CYCLONE Notation as Estimated CYCLONE Model

J. Constr. Eng. Manage., 1993, 119(2): 355-373

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NAME 'JACKING -PEACE RIVER BRIDGE AS REDESIGNED' LENGTH 20000 CYCLE 1
NETWORK INPUT
5 NORMAL 'BUILD SHIM A' SET 60 FOL 6
6 NORMAL 'INSERT 4 RODS' SET 61 FOL 7
7 NORMAL 'BUILD SHIM B' SET 62 FOL 8
8 NOMRAL 'RELEASE ROCKING ROLLERS' SET 63 FOL 9
9 NORMAL 'REMOVE ASSEMBLY' SET 64 FOL 10
10 NORMAL 'REMOVE CROSS BEAMS' SET 65 FOL 11
11 NORMAL 'BURN OFF INNNER GUIDES' SET 66 FOL 209
190 COMBI 'STOP LOOP' SET 1 PRE 390 403 FOL 440
201 QUE 'J1'
204 COMBI 'INSTL PERM BRGS AB2' SET 2 PRE 201 206 FOL 5
206 QUE 'CREW-1'
208 QUE 'CONTROL UNIT FOR AB-2'
209 QUE 'READY TO JACK'
215 QUE 'PIER 6 IS DONE' GEN 10
220 COMBI 'RETRACT JACKS BY 40 mm -BEAR ON A' SET 3 PRE 209 208 215 FOL 225
225 NORMAL 'CLAMP SOLE PLATE' SET 4 FOL 230
230 NORMAL 'RELEASE JACKS' SET 5 FOL 240
240 NORMAL 'REMOVE 40 MM OF SHIM B' SET 6 FOL 250
250 NORMAL 'RELEASE JACKS' SET 7 FOL 260
260 NORMAL 'RELEASE SHIM A' SET 8 FOL 290
290 NORMAL 'REMOVE 40 mm FROM A' SET 9 FOL 295 209
295 FUNCTION CONSOLIDATE 10 '10 CYCLES' FOL 206 310 530 508
310 NORMAL 'ALIGN BRG & GROUT' SET 10 FOL 321
321 NORMAL 'CURE FOR 48 HOURS' SET 11 FOL 322
322 NORMAL 'JACK LAST 10 mm' SET 12 FOL 341
341 NORMAL 'REMOVE J1 AND GROUT' SET 13  FOL 901
374 COMBI 'GRT BRGS ON PIER' SET 24 PRE 532 520 FOL 376
376 NORMAL 'CURE 48 HRS & LAST 10mm JACKING' SET 25 FOL 378
378 NORMAL 'REMOVE ERECTION EQPT' SET 26 FOL 379
379 FUNCTION CONSOLIDATE 4 'DONE WITH 4 PIER GROUTING' FOL 902
380 COMBI 'STOP LOOP AFTER 300mm' SET 34 PRE 440 470 FOL 390 392
390 QUE
392 FUNCTION CONSOLIDATE 2 FOL 393
393 QUE
394 COMBI 'DONE 2 PIERS' SET 36 PRE 393 390 FOL 903 700
396 COMBI 'LOOSEN RODS HLDG B' SET 37 PRE 390 FOL 397
397 NORMAL 'EXTND JACKS LOADING C' SET 38 FOL 398
398 NORMAL 'RMV 80mm OF SHIM B' SET 39 FOL 399
399 NORMAL 'JACK DWN TO BEAR ON B' SET 40 FOL 400
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FIG. 13. Bridge-Jacking Tasks in CYCLONE Notation as Redesigned CYCLONE Model

movements of both resources are, however, synchronized allowing the model to focus on only one combined resource except for flow control purposes. The cycles of the crew were then identified. This was accomplished by developing high-level models, as previously discussed, reflecting the process sequence described in Fig. 5 for the estimated operation and Fig. 8 for the actual operation. The two high-level abstracted models were then enhanced by inserting the required tasks as given in Table 1, for example. The models are given in Figs. 10 and 11 for the estimated and the redesigned actual operations respectively. The individual processes are also highlighted on the same drawing to illustrate the work breakdown strategy employed. It should be noted that the linear nature of the operation and the cyclic nature of the involved processes within the operation facilitated the development of such a concise model for this large construction operation.

After completing the model development phase, durations were estimated

J. Constr. Eng. Manage., 1993, 119(2): 355-373

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400 NORMAL 'REMOVE 80 mm OF SHIM C' SET 41 FOL 390 402
402 FUNCTION CONSOLIDATE 2 FOL 403
403 QUE
405 NORMAL 'INSTL JACK AT OPP. PIER PHASE 2' SET 27 FOL 406
406 NORMAL 'INSTL J PHASE 3' SET 80 FOL 407
407 NORMAL 'INSTL J PHASE 4' SET 81 FOL 408
408 NORMAL 'INSTL J PHASE 5' SET 82 FOL 605 410
410 FUNCTION CONSOLIDATE 4 'PIERS 6-5-4-3 DONE' FOL 420
420 QUE
430 COMBI 'STOP LOOP' SET 28 PRE 420 605 FOL 440
440 QUE 'READY FOR PIERS 1 & 2'
450 COMBI 'LOOSEN RODS HLDG B' SET 29 PRE 440 FOL 451
451 NORMAL 'EXTND JACKS LOADING C' SET 30 FOL 452
452 NORMAL 'RMV 80mm OF SHIM B' SET 31 FOL 453
453 NORMAL 'JACK DWN TO BEAR ON B' SET 32 FOL 454
454 NORMAL 'REMOVE 80 mm OF SHIM C' SET 33 FOL 440 460
460 FUNCTION CONSOLIDATE 4 'lower by 320 mm' FOL 470
470 QUE 'CONTROL'
500 COMBI 'PREVENT FURTHER CYCLING' SET 21 PRE 651 605 FOL 505
505 QUE 'DONE WITH THE PIER'
508 QUE 'DONE WITH AB-1' GENERATE 100
510 COMBI 'WAIT TILL AB-1 IS DONE' SET 22 PRE 508 505 FOL 520 530
520 QUE 'CONTROL UNIT'
530 FUNCTION CONSOLIDATE 2 'DONE WITH ONE PIER' FOL 532 405
532 QUE
540 COMBI 'ALLOW JACKING WITHOUT REINSTALLING JS' SET 23 PRE 520 FOL 605
600 COMBI 'INSTALL JACK AT PIER PHASE 2' SET 14 PRE 601 602 FOL 660
601 QUE 'J3'
602 QUE 'C2'
605 QUE 'READY TO JACK'
611 COMBI 'LOOSEN RODS HLDG B' SET 15 PRE 605 FOL 612
612 NORMAL 'EXTND JACKS LOADING C' SET 16 FOL 621
621 NORMAL 'RMV 80mm OF SHIM B' SET 17 FOL 631
631 NORMAL 'JACK DWN TO BEAR ON B- RETRACT FROM C' SET 18 FOL 641
641 NORMAL 'REMOVE 80 mm OF SHIM C' SET 19 FOL 650 605
650 FUNCTION CONSOLIDATE 5 '5 80mm SHIMS=400mm' FOL 215 651
651 QUE 'DONE WITH ONE 400 mm JACKING'
660 NORMAL 'INSTALL AT PIER PHASE 3' SET 70 FOL 661
661 NORMAL 'INSTALL AT PIER PHASE 4' SET 71 FOL 662
662 NORMAL 'PHASE 4.3  RMV JACKS ETC' SET 72 FOL 663
663 NORMAL 'INSTALL AT PIER PHASE 5' SET 73 FOL 605
700 NORMAL 'INSTALL JACK AT AB-1' SET 42 FOL 750
750 NORMAL 'PHASE 5 OF AB-1' SET 47 FOL 760
760 NORMAL 'PHASE 6 OF AB-1' SET 48 FOL 770
770 NORMAL 'JACK DWN AB-1' SET 49 FOL 780
780 NORMAL 'PHASE 7 OF AB-1' SET 50 FOL 904
800 FUNCTION COUNTER QUANT 1 FOL 900
900 QUE
901 QUE
902 QUE
903 QUE
904 QUE
905 COMBI 'DONE PROJECT' SET 51 PRE 903 904 FOL 800
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FIG. 13. ***(Continued)***

for each of the involved tasks. Three estimates were obtained for each task in the form of pessimistic, optimistic, and most likely values of the duration. The source of the three estimates were the mediator (over 20-years experience in bridge construction), field engineer, contractor estimates, and information available from the owner from past projects. The actual manhours expended by the field crews can be challenged because it can be

TABLE 2. Summary of 20 Runs of Simulation for Each of Two Models

Observation (1)	Time required to complete operation as redesigned (crew-hours) (2)	Time required to complete operation as estimated (crew-hours) (3)
1	296.8	135.2
2	294.0	124.4
3	291.8	130.6
4	294.1	128.5
5	284.1	125.8
6	304.0	137.8
7	302.9	140.9
8	283.9	134.9
9	292.0	135.6
10	283.5	129.4
11	288.5	136.8
12	284.1	128.7
13	307.6	136.9
14	300.0	139.3
15	303.2	132.4
16	294.8	141.6
17	298.3	142.7
18	288.1	133.2
19	299.2	139.6
20	277.8	129.6
[Mean]	[287.3]	[132.4]
[Standard deviation]	[13.44]	[3.96]
[95% confidence interval]	[282.1–292.5]	[130.9–133.9]

argued that the contractor did not perform efficiently or experienced unnecessary lost time. The contractor's original estimates may also be in error. Therefore, it was decided to obtain three time estimates to approximate what the original anticipated time on each task would have been according to normal practices and likewise for what would have been in the actual redesigned work. These estimates were fitted to triangular distributions as the level of information available could not support more flexible distributions like the Beta or Johnson system. Moreover, it was shown that the triangular distribution yields fairly acceptable results when three-time estimates are only available (AbouRizk 1990). The input files for the models shown in Figs. 10 and 11 are given in Figs. 12 and 13, respectively.

The simulation was then carried out using MicroCYCLONE (Halpin 1991). Since the input was probabilistic, twenty runs were then executed resulting in 20 observation for the time required to complete the bridge jacking operation for each of the two situations. The results are summarized in Table 2. The mean value for the redesigned operation was 287.3 crew-hours whereas the mean for the estimated model was 132.4 crew-hours.

A review of the contractor's estimates at bidding time and as redesigned reveals the values shown in Table 3. The estimate reflects a total of 1417 man-hours at $80.6 per man-hour for the operation at time of bidding compared to the 3,675 man-hours at $78.58 per man-hour for the new construction requirements.

J. Constr. Eng. Manage., 1993, 119(2): 355-373

TABLE 3. Contractor's Estimates

Item (1)	As estimated (2)	As redesigned (3)
Labor	1,417 man-hours = $60,096	3,675 man-hours = $143,625
Expenses	$28,020	$36,000
Rental	$26,100	$43,100
Subcontracts	None	$66,000
Total	$114,216	$288,795
Per man-hour	80.6/man-hours	78.58/man-hours

The simulation results can be used at this stage to estimate the reasonable range of cost that should be awarded to the contractor. The range of values given in Table 2 show that it is possible that the work be completed on the redesigned operation in (282.1–292.5) crew-hours. with a crew of 10 men the range will be 2,821–2,925 man-hours. This range is then multiplied by the hourly cost ($78.58) after verifying the cost to attain the total cost of $227,384–$235,767. The original scenario yields a total cost of $102,861–$105,218. The total compensation for extra work would then be the difference of the two ranges, which would result in $124,523–$130,549. The mediator can use these numbers during the mediation. The models should help bring the parties positions closer to each other as they reflect very closely the actual operations as they would have been realized.

The complexity claim has been partially resolved. Other parts of the claims remain to be resolved.

Conclusions

The authors demonstrated that simulation can be successfully applied in mediations involving construction operations. What made this effort successful, however, are the following factors: (1) Using a breakdown structure for the operation to provide an easier communication platform and more accurate modeling; (2) the cyclic nature of the operation itself which made it adaptable to CYCLONE modeling; (3) the extensive knowledge of the mediator with similar operations which was essential for constructing the models; (4) experience with CYCLONE simulation; (5) acceptance of new concepts by the contractor and owner representatives (the fact that the mediation was not binding made the involved parties more receptive to the use of simulation as a technique that could potentially assist in the mediation); and (6) the availability of simple to use simulation methods like CYCLONE.

Simulation provides more tools than used in this application. This enhances the subjective process involved in mediating a dispute. With more facts uncovered and modeled, better and more accurate quantitative techniques, and effective reports and comparisons, there is a higher probability that disputes can be resolved expeditiously.

The experiences acquired during the development of the two models emphasized the importance of hierarchical modeling techniques. The idea was first presented by Halpin and Woodhead (1976), it has not however been automated to facilitate its use. For simulation modeling techniques to be useful at the project level this hierarchical development should be implemented as part of the modeling methodology and the programming implementations.

J. Constr. Eng. Manage., 1993, 119(2): 355-373

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