Modeling and Simulation of Construction Operations to Optimize Resource Utilization

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Abstract: Tight budgets and limited resources in construction projects have forced many construction firms to downsize and re-engineer their operations in a way that improves productivity and cost effectiveness. Re-engineering, however, requires thorough analysis of project-specific operations and resource use. In an effort to improve productivity and optimize resource use, this study investigates the use of a simplified approach to model and simulate concrete placing operations of construction projects. This approach offers the diversity and flexibility required for construction models and generates practical models without prior knowledge of simulation terminology. Models were developed for some real-world concrete placing operations and simulation was conducted to come up with the best resource combinations that optimize productivity and, accordingly, minimize the cost of these operations. These models can be used as examples to develop models for other construction operations. The potential of using this approach for resource optimization of large infrastructure networks was then investigated and, finally, possible future extensions were discussed.

Keywords: Construction Operations, Process Modeling, Resource Utilization, Simulation.

I. Introduction and Background

Time, money, and resource constraints, coupled with the high market competition have forced many construction firms to focus more closely on their operations. Typically, these operational aspects are the responsibility of the project manager who assigns available resources to the different activities in a construction project so as to speed site operations and lower the associated expenses. Exploring the various options requires the development of descriptive, analytical, and decision-making models, which accurately represent and simulate these processes. This allows thorough experimentation with different alternatives under different conditions. It has been proven that simulation can be an effective tool for improving the performance of a construction process. As reported by Zaneldin, 2008 [1], several successful applications have been reported in the literature including tunneling, earthmoving and heavy construction, bridge construction, pipeline construction, aggregate production and site dewatering, and concrete batch plant production [2,3,4]. The difficulties associated with modelling construction operations, however, have been widely experienced in the construction industry [1].

Developing construction simulation models has been a complex, time consuming, and costly task [5,6]. The complexities involved in constructing a model and the resulting time requirements have, contributed to the limited use of simulation in the construction industry [1]. In addition, developing a simulation model typically requires the user to be familiar with specific terminology and the modeling schematics of particular software and the ability to write proprietary computer code. This may not be suitable for many practitioners who are otherwise familiar with the details needed for accurate simulation. These problems have also contributed to the limited success of simulation in construction.

Several researchers have employed different ways to simplify the modeling process and to make it more attractive to practitioners. These include efforts to use simulation in areas like project management, decision making, and cost estimation. Chou, 2011 [7], for example, introduced streamlining Monte Carlo simulation procedures in historical construction projects as case study data to create an early-stage cost distribution for budget allocation. Another example is the work of Yaghootkar and Gil, 2012 [8]. The study uses a longitudinal, experiential simulation of a multi-project organization in which a resource capturing practice is used to implement a schedule-driven project management policy. Pendharkar, 2014 [9] presented a decision-making framework for justifying a portfolio of projects that allows managers to consider multiple multi-stage portfolio selection procedure. Ishii et al., 2014 [10] presented a simulation model that describes relations among the volume of man-hours for cost estimation, accepted orders, revenues, and profits in construction projects. Recently, researchers and practitioners have used modelling and simulation for systems analysis and decision making. The power of modelling and simulation is the ability to represent a real system and to study the impact of changes without actually altering the physical system. It provides insight into operational processes and can be used for what-if analysis and optimization. It is used in a wide range of areas including construction, commerce, manufacturing and logistics. Some available simulation software packages offer object-oriented visual modelling systems where models are easily built and visualizes. These systems typically run on a desktop computer and provide a user-friendly modelling interface that can be used with minimal knowledge of programming. Despite the benefits offered by the simulation and visualization of construction processes, this has yet to be adopted on a large scale in the industry [11]. This is because current modelling and simulation tools have some limitations, especially when large-scale systems, such construction operations, are being modelled. More research is, therefore, needed to make simulation an easy-to-use tool for practitioners, no substantial advancement has been reported.

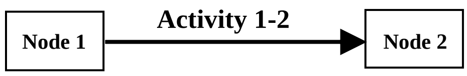
This research uses a simplified and efficient object-oriented approach proposed by Zaneldin, 2008 [1] for modeling and simulation of concrete-placing construction operations that is easy to use and does not require prior knowledge of simulation theory. The approach encompasses an activity-on-arrow representation and powerful process analysis. The basic arrow and node objects allow for diverse modeling capabilities. Some real-world example applications are presented to demonstrate the validity of the approach to simulate construction operations, including concrete placing activities. The possibility of using the proposed approach to model large-size projects is investigated to illustrate its use for conducting modeling and simulation of real-world complex construction operations and demonstrate its capabilities in utilizing available resources in the best manner that improves productivity and reduces costs. Future improvements of the proposed approach is then discussed. The outcome of this study is expected to help construction firms simulate site operations, optimize resources and, accordingly, minimize their projects' costs to become highly competitive, nationally and regionally, within the open market economics and tight budgets.

II. Development of Simulation Models

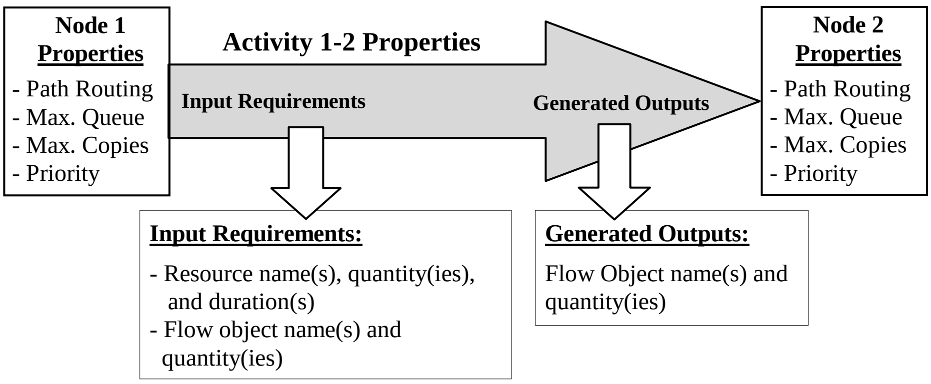
In this research, an object-oriented approach is utilized to simplify modeling and simulation of construction operations. It simplifies modeling by using the familiar activity-on-arrow (AOA) representation of any process, similar to the one used for traditional CPM analysis. The approach also simplifies the simulation process by hiding all queuing and simulation theories to enable the user to focus solely on the logical flow of resources and physical quantities within the process being modeled. The modeling process, as such, becomes intuitive and legible, in addition to being easily performed by a larger base of practitioners. The basic modeling objects are described in the following subsection.

A. Basic Modeling Objects

In the proposed approach, the building blocks of a simulation model are two types of drawing objects: arrows and nodes. Using instances of these objects, it is possible to draw a network diagram of any cyclic process (e.g., an earth moving operation). Using an activity-on-arrow representation, the arrow objects are the activities within the process while the node objects are the control points in the process (Figure 1a). The activities consume resources such as labor, equipment, time, and cost. The control nodes, on the other hand, define the flow mechanism to the various branches in the process. The essential challenge in this approach is to set generic properties to the arrow and node objects that allow us to monitor the movement/consumption of resources and the flow of physical quantities produced by the resources. The main properties of an activity (Figure 1b) define its input requirements and the outputs to be generated at the end of its activation. The input requirements of an activity include: (1) resources and durations; and (2) countable objects (Figure 1b). Resources (e.g. loader, truck or construction crew) and their durations are needed to define the cost and time associated with the activity when it is activated. Countable objects, on the other hand, are utilized to simulate any physical quantities that flow through the process (e.g., cubic meters of moved earth, number of piles driven, etc). They are user-defined objects that flow throughout the model from one activity to the other and they maintain the process logic by being specified as generated outputs of predecessors and as input requirements to successors. The generated outputs of an activity include any countable objects that are generated at its end node, which become inputs to succeeding activities (Figure 1).



(a) Nodes and Activities



(b) Properties of Nodes and Activities

Figure 1: Basic Modeling Objects.

The main properties of a node object are designed to control how the succeeding activities are activated during a simulation run. This includes:

- Path routing to control the manner by which alternative branches are activated. In Figure 2a, Node 5 is set with (Path routing = "Probability") so that trucks can have a 5% chance of breakdown;
- Maximum queue size: the maximum number of objects permitted to queue before an activity (e.g., the maximum number of trucks that can park at node 5 of Figure 2a);
- Maximum copies: the maximum number of objects to proceed simultaneously from a node (e.g., the maximum number of trucks that can simultaneously proceed from node 5 in Figure 2a); and
- Node priority: the priority of assigning resources to succeeding activities.

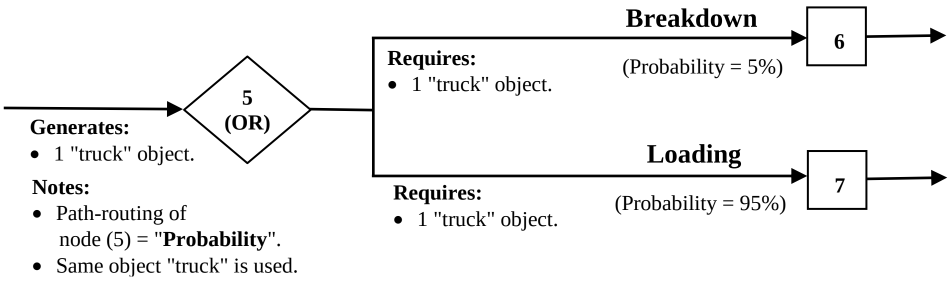
III. Simulation Mechanism and Strategies

Performing a simulation using the proposed approach is simple and does not require prior knowledge of simulation theories. Once a network of a construction process is drawn, the user defines a list of available resources and their hourly rates. Next, the user sets the properties of the nodes and activities, including the resources and their durations, and the objects needed and generated for each activity. The simulation process, in essence, is to monitor the movement of resources and countable objects through the model and later analyze the total objects received at specific nodes and the amount of active and idle times. To model the cyclic nature of a process, the user sets the rate at which new countable objects are generated at the starting node of the model. This is, for example, to model the arrival of a new truck every three minutes (or according to a known distribution) or new concrete batches to be poured. Accordingly, the simulation can be run for a user-specified period of time, starting from the first node and its initial countable object(s). These objects, in addition to existing resources, meet the input requirements of the first activity and accordingly it fires (starts). At the end of its firing, it generates the countable object(s) required for its successor(s). The successor activity(ies) are then fired and the simulation process continues in the same manner, with resources and objects moving according to the logic of the model. When an activity is fired, its start node counts the number of received objects. Also, its end node counts the number of generated objects.

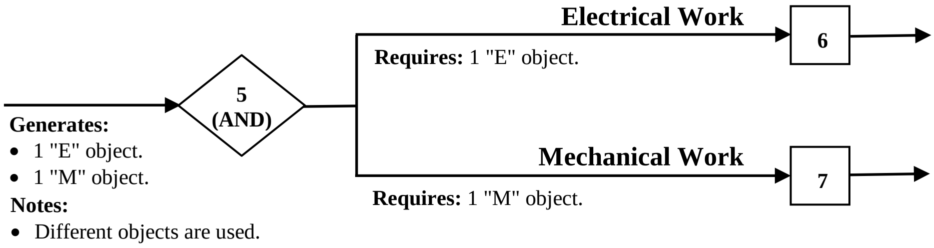
While it is possible to implement this approach using a variety of means, one elegant implementation has been performed using a customizable tool for flowcharting and general-purpose simulation. The tool, however, uses a proprietary terminology (activities are called work-paths and nodes are called activities) and, due to its general nature, it does not provide the diversity needed for developing realistic construction models (flowing objects for conditional branching not included). The basic objects of the software are therefore adapted to satisfy the requirements of real-life construction models. Since construction operations exhibit complex environments with multiple resources and changing situations, three improvements to the basic objects have been performed: (1) simple branching objects; (2) conditional branching objects; and (3) advanced process control strategies. Incorporating these improvements or any other implementation media provides powerful, yet easy-to-use, building blocks for simulation models that suit the construction domain. With relatively little effort, construction managers can simulate their operations before actual construction, and can perform what-if analysis to optimize these operations.

A. Node Branching

To model a process, node branching in the form of (OR) and (AND) is needed. An (OR) node is often used to model the branching among mutually exclusive activities by specifying the probability of each activity being fired, as shown in Figure 2(a) where one "truck" object is generated from the activity prior to the (OR) connection. The same "truck" object is also set as input requirement to each of the two activities (5-6) and (5-7). During a simulation run, a "truck" object that is received at node (5) will be routed to either activity, according to the set probability. For example, if 100 objects pass through this node, about 95 objects will go to activity (5-7) and only 5 will go to activity (5-6), considering the given probabilities in Figure 2(a). An (AND) connection is needed to model the firing of two parallel paths simultaneously as shown in Figure 2(b). As such, a node object had to be designed for it. For the example in Figure 2(b), parallel firing of activities (5-6) and (5-7) is needed to enable the simultaneous execution of the electrical and mechanical work. The activity prior to the (AND) node is set to generate two different countable objects "E" (required by activity 5-6) and "M" (required by activity 5-7). During a simulation run, the object requirements of activities (5-6) and (5-7) will be available at node (5) and the activities will be fired simultaneously if their required resources are also available.



(a) (OR) Connection



(b) (AND) Connection.

Figure 2: Node Branching.

B. Conditional Branching

Building upon the simple (OR) and (AND) branching nodes, it is possible to setup realistic model components that cover situations involving conditional branching. Branching can be conditional upon the accumulation of a predetermined number of countable objects (e.g., 20 "pile-driven" objects) so that the successor activity (e.g., report to the client) can be started. On the other hand, an activity can be conditional upon availability of resources (e.g., availability of aggregates). An (AND-IF) node is utilized when an activity can fire parallel to another if a predetermined number of objects are available. For example, this node can model part of a pile driving operation in which piles are to be filled with concrete once they are driven. Upon driving 20 piles, for example, a progress report is to be sent to the client while continuing with the concreting operation. Similar to a basic (AND) node, the pile driving operation may generates two different countable objects: one "Pile-ready" and one "Pile-driven". The first object "Pile-ready" is required by the "concreting" successor activity. Also, 20 of the second object "Pile-driven" are required so that the other "report-to-client" successor activity can start in parallel with the "concreting" activity. The start node of both activities counts the number of objects received and, therefore, postpones the firing of the "concreting" activity until twenty "Pile-driven" objects are received then the "report-to-client" activity starts. The (OR-IF) connection is used when only one activity can be fired, conditional upon the availability of countable objects. If this condition is met, only one of the branching activities is fired while all others are deprived from firing. Another (OR-IF) connection is used when processing is conditional upon availability of resources. It models a situation where concrete aggregate, for example, will be bought from quarry 1 if available, otherwise, aggregate will be bought from quarry 2 or quarry 3 with 70% and 30% probabilities, respectively'.

C. Controlling the Assignment of Resources

The user can set the rate by which new objects enter the simulation. This is, for example, to model the arrival of new trucks to be loaded. In large models, therefore, the new objects make some activities at the beginning of the network to be ready for firing while existing objects that are ahead in the model make other activities to be ready for firing. In the event that more than one ready-to-fire activity require the same limited resource, a conflict arises and a decision is required on the activity that gets the resource first. The use of node priority (rather than activity priority) in this situation is important to control the assignment of resources in the model. This is also important as it provides alternative strategies for modeling construction operations. The user may, for example, choose to finish existing jobs before starting new ones. This can be modeled by assigning higher priorities to later nodes in the model. Changing this option and re-conducting the simulation provides the project manager with when-if assessment of changing his operational strategy.

IV. Resource Optimization of Construction Operations: Application Examples

Two application examples were analyzed in this study to illustrate the use of the approach for construction modeling and simulation, validate its results, and demonstrate its capabilities. The first example demonstrates the simplicity and modeling ease of the proposed approach and the second illustrates its efficiency and practicality in modeling complex real-world construction operations.

A. Example 1: A Simple Concrete-Placing Operation

This concrete-placing operation was originally introduced and modeled by Paulson et al., 1987 [12] using INSIGHT, an advanced variation of the CYCLONE system. The process involved placing a number of concrete columns, 2 yd3 each, for a new structure. One crane-bucket combination with a capacity of 1 yd3 and a flexible 'elephant-trunk' was assumed for concrete placement. Concrete was delivered by four trucks, each with a capacity of 8 yd3. Because of site constraints, however, only one truck could be moved into the delivery position at a time. One crew of construction workers was also utilized for placing concrete. If a truck and the crane-bucket are both available, then the crane can load the 1-yd3 bucket and hoist it to column placement location. The construction crew then uses the bucket to place concrete into a column. The crane and bucket then return for another load. After two buckets are placed, the column is complete and the crew can move to the next column. After the movement of the crew, placement in the new column can begin. It is assumed also that after a truck is emptied, the truck departs and a new truck can enter into the delivery stall.

The proposed approach was effectively applied to develop a simulation model for this operation. The model is represented by four nodes and six arrows (Figure 3) as opposed to 13 nodes and 18 arrows used to model the same example using INSIGHT. The input requirements of all activities including resources, durations, and objects are presented in Table 1, along with generated outputs. In Figure 3, node (2) is a basic node that receives one countable object "cubic yard" from activity 1-2 (start). The successor activity 2-3 (load and hoist 1 cubic yard) requires the availability of one "cubic yard" object and two resources (truck and crane-bucket), and generates two objects "cubic yard" and "truck counter". The following node (3) is an (AND-IF) node that receives the two objects "cubic-yard" and "truck-counter".

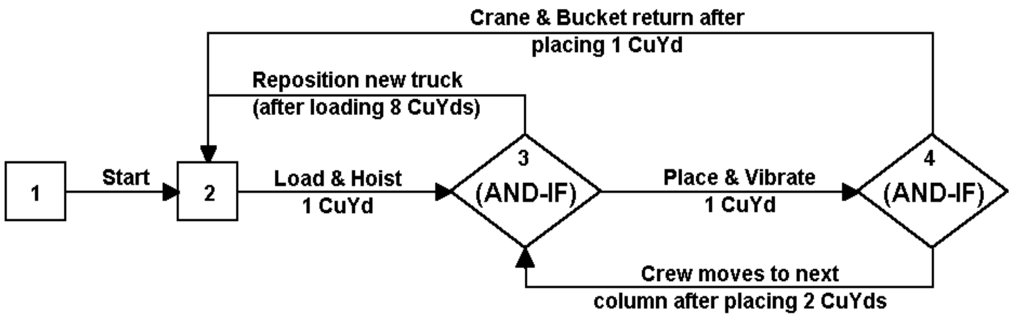


Figure 3: AOA Model of a Simple Concrete-Placing Operation.

The first object "cubic-yard" is used to represent the loading of 1 yd3 required for activity 3-4 (place and vibrate), and also to count cubic yard production. The second object "truck-counter" represents 1/8 of a full truckload and thus 8 of these objects need to be processed before activity 3-2 (reposition new truck) can be started. Similarly, node (4) is an (AND-IF) node that receives two objects "cubic-yard" and "column-counter" that are generated by activity 3-4 (place and vibrate). The first object "cubic yard" is required for activity 4-2 (return crane and bucket) while two of the second object "column-counter" are required for activity 4-3 (crew moves to next column). The cyclic nature of the concrete placing operation is controlled by the number of objects generated at the start node. Since the operation is essentially a sequential one, only one object "cubic-yard" is allowed to enter the simulation through the start node and then rotated over and over through the simulation, following the process network. Using this strategy, the nodes and activities of the model were configured using the data of Table 1. It is noted that all nodes were set with copies = 1, meaning that no activity is allowed to have multiple simultaneous firing (e.g., concreting is done for one column at a time). Once the network was drawn, model setup involves first defining the various resources in the resource spreadsheet. The user, then, needs to specify the type and properties of each node and activity and the simulation process can be started. The software provides the user with the option to step through the simulation one-step at a time or to completely run the simulation for a certain period of simulation time (e.g., 1 day). When the first option is used, the software highlights the activated nodes and activities with a different color and provides details on the movement of objects and resources. Following this process, the user is able to audit-trail the simulation and identify any necessary corrections to the model.

Table 1: Nodes and Activities of Example 1.

Node No. (1)	Activity (arrow) (2)	Input Requirements: Resource Type (3)	Input Requirements: Resource Duration (4)	Input Requirements: Countable Object (5)	Generated Outputs (Countable Object) (6)
1	1-2 Start	---------	--------	--------	- Only 1 cubic-yard at start of simulation.
2	2-3 Loading & Hoisting	- Truck - Crane-Bucket	Normal (1.0, 0.2)* Normal (1.0, 0.2)	- cubic-yard	- cubic-yard - truck-counter
3 (AND-IF)	3-4 Placing & Vibrating Concrete	- Crane-Bucket - Work Crew	Normal (2.0, 0.4) Normal (2.0, 0.4)	- cubic-yard	- cubic-yard - column-counter
	3-2 Reposition New Truck	- Truck	0.01 minute	- 8 truck-counter	---------
4 (AND-IF)	4-2 Crane-Bucket Return	- Crane-Bucket	Normal (0.5, 0.1)	- cubic-yard	- cubic-yard
	4-3 Crew Moves to Next Column	- Work Crew	Normal (3.0, 0.4)	- 2 column-counter	--------

***** Normal Distribution with mean = 1.0 minutes and standard deviation = 0.2 minutes.

Notes: Resources are: 4 Trucks (8 cu yd capacity each), 1 Crane-Bucket combination, and 1 Work Crew

The example was run to simulate a full day (8-Hours) of operation. After the simulation was completed, several statistics data became available, which depict the analysis of the cost, time, and resource utilization. Among the useful outputs are activities' total effort, total cost, active time, idle time, interrupted time, maximum queue, average wait, and maximum wait. In terms of simulation results, the total number of activations made by node 4 in activity 4-3 (51 times of crew movements to a new column) and activity 4-2 (103 times of crane and bucket return after placing 1 yd3). These results provide an hourly production of 6.4 units. As such, the results indicate that the proposed approach is capable of generating useful results in addition to its added advantage of simplicity and ease of use. The approach provides a model representation for this example (Figure 3) that is simple and easy to model. The developed model includes only 4 nodes and 6 arrows as opposed to 13 nodes and 18 arrows used in the INSIGHT model. As such, the application of the proposed approach significantly contributes to simplifying and reducing the complexity of modeling.

B. Example 2: A Real-Life Complex Construction Operation

An operation of substructure activities of a large-size real-world construction project was analyzed to illustrate the use of the proposed approach for conducting modeling and simulation of complex construction operations and demonstrate its capabilities in utilizing available resources in the best manner that improves productivity and reduces operational costs. The data needed for modeling and simulating the operation was first collected. This includes a complete list of all activities, activities bar chart, early start, early finish, late start, late finish, and total float times of activities, durations of activities, number of resources (manpower and equipment) required for each activity, and the complete cost data of all resources (i.e., resources direct cost per hour). A CPM network was then drawn for the operation and critical path(s) were identified to find the critical duration required to finish the operation. Lengths of other non-critical paths for the operation were also calculated to be considered during the process of crashing the durations of activities. A model was developed for the substructure activities. The model represents the main activities such as excavation and compaction, blinding concrete, footing formwork and reinforcement, footing concreting, column neck formwork and reinforcement, column neck concreting, waterproofing, backfilling, compaction, and leveling (Figure 4).

In this research only a single project was modeled. Since the operation is sequential, only one flow-object is allowed to enter the simulation through the start node, thus allowing the processing of one project only. Using this strategy, the nodes and activities of the model were configured using data similar to those used for the previous two examples. Properties of the nodes and activities of the models were configured as per the actual requirements of the operation and were changed according to the various experiments conducted. Also, input and output requirements of flow-objects were set to allow continuity of each operation. Following the configuration of the properties of nodes and activities, activities are assigned resources and their corresponding durations. As a general rule in modeling the operations, the daily working hours for each resource was set to 8 hours per day. Workers are paid 1.5 the normal rate if they work overtime (i.e., if they work more than the normal 8 hours/day). In general, activities were assigned appropriate resources and durations. The "Excavation" activity (activity 2-3 in Figure 4) of the substructure operation, for example, requires 3 operators, 1 excavator and jack hammer, 1 shovel, and 1 truck, all for a period of 4 days (32 hours). Once the model of the process is drawn, available resources and their hourly rates are input. Table 2 shows the types and minimum number of resources needed to complete the operation in its 90 days critical path duration.

Table 2: The Original Resource Combination for Example 2.

Resource	Steel cutting machine	Crane & bucket	Excavator & jack hammer	Shovel	Vibrator	Steel bending machine	Compactor	Truck	Operator	Carpenter	Foreman	Steel fixer	Labor	Concrete mixer	Concrete pump	Wood cutting machine	Air compressor
Quantity	2	2	2	2	2	2	2	2	4	6	2	6	6	2	2	4	2

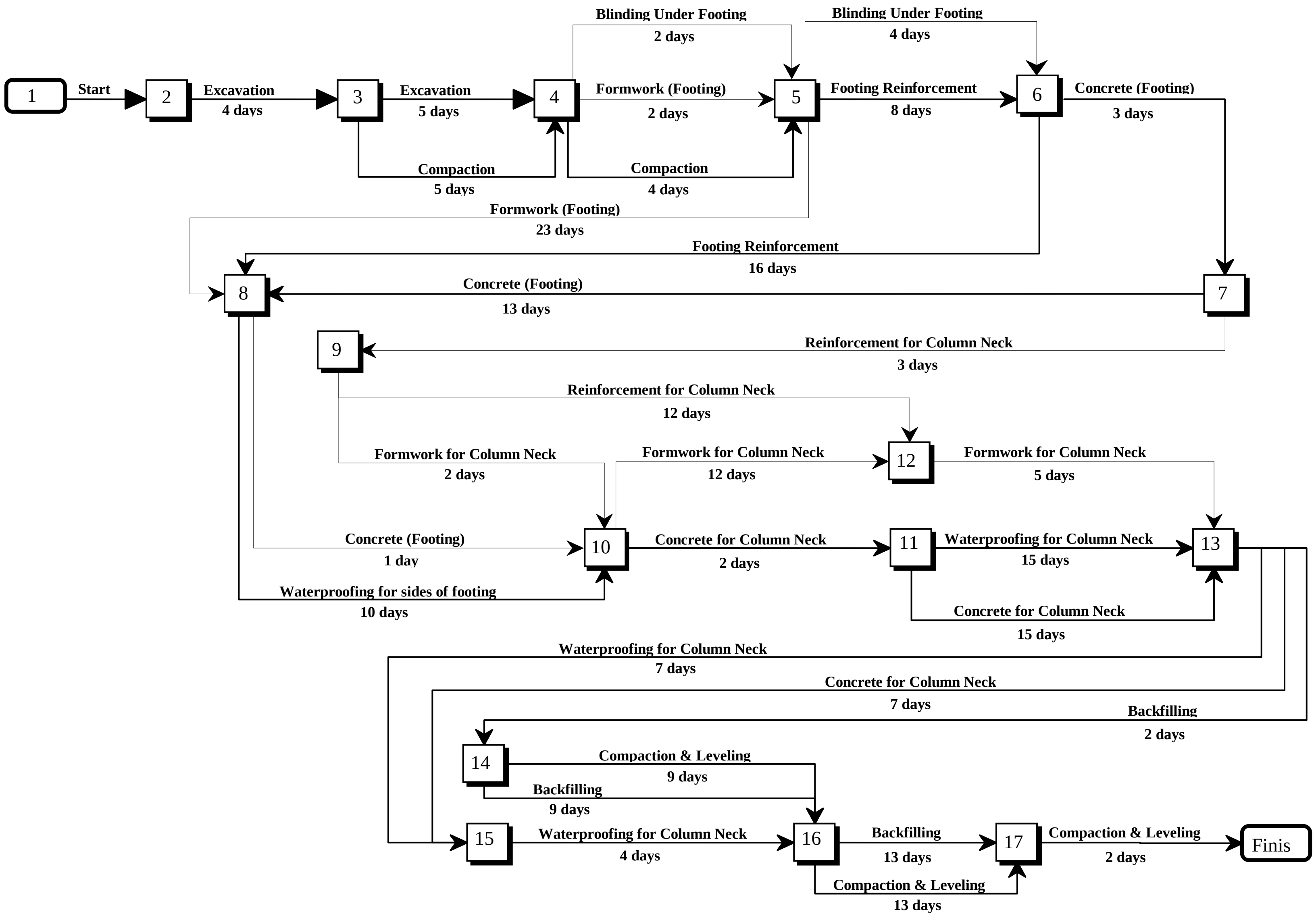


Figure 4: The Model of Example 2 Showing Substructure Activities.

The objective of reducing the project's total cost can be achieved by reducing the number of resources, which may result in increasing the completion time of the project. Three alternative resource combinations were investigated by reducing key resources. These resources are identified by checking the effect of changing each resource on the time needed to complete the operation. This sensitivity analysis was carried out by changing the available number of each of the resources and then checking the effect of this change on the completion time and cost. It was found that the main resources that affect the completion time are: operators, carpenters, foremen, steel fixers, and wood cutting machines. The simulation was run assuming normal work hours per day (i.e., 8 hours per day) and the simulation results of the different resource combinations are shown in Figure 5. These costs are only the direct costs of resources. Due to difficulties associated with obtaining the indirect cost data for the project under consideration, these costs are not considered in this study. Comparing the results of the different resource combinations shown in Figure 5, it was observed that resource combination 3 resulted least cost (486,272 Dirhams) with a completion time of 96 days while combination 2 resulted in the best completion time (95 days) with a corresponding cost of 498,272 Dirhams. Comparing the results with those using the resource combination of the original CPM (with a critical duration of 90 days), it can be noted that, although the completion time is increased by 5 and 6 days in resource combinations 2 and 3, respectively, the cost dropped dramatically by 91,552 Dirhams, respectively. It is worthwhile mentioning that these amounts of savings resulted from one operation only and can be multiples of these numbers considering the activities of the whole project. Therefore, these combinations can be quite attractive to both the contractor and the client and may result in considering them seriously.

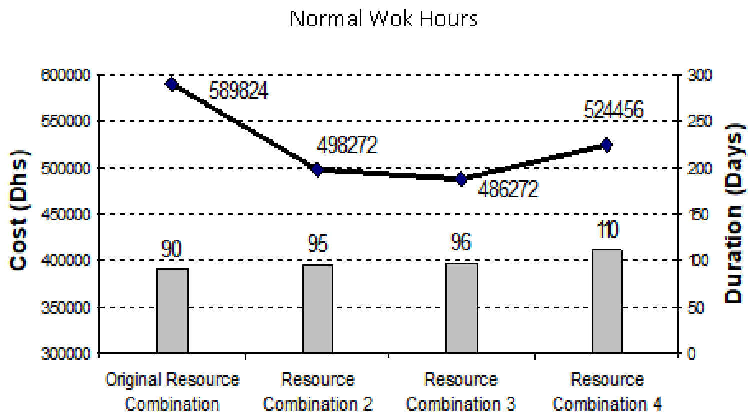


Figure 5: Completion Times and Costs for Different Resource Combinations.

If the objective is to reduce the project's duration, the contractor may choose a strategy that will achieve this objective. One very popular option is to work overtime. The question here is how many overtime hours the contractor needs to work to meet a certain deadline duration. Using the developed models, three overtime options were considered in this study, in addition to the eight normal working hours per day. The contractor may choose to work: 1) one extra hour/day; 2) three extra hours/day; or 3) five extra hours/day. It is assumed that the productivity of crews using options 1, 2, and 3 during overtime hours will drop to 90%, 80%, and 70%, respectively. Working overtime will result in a shorter completion time; however, it will also result in increasing the overall cost of the operation. Figure 6 shows the completion times and costs for the normal work-hours option in addition to the suggested three overtime options. As shown in the figure, working five extra hours resulted in decreasing the duration by 25 days while increasing the operation direct cost by only 55,490 Dirhams. This represents a decrease of 28% of the overall operation duration and an increase of 2,220 Dirhams/day in the direct cost.

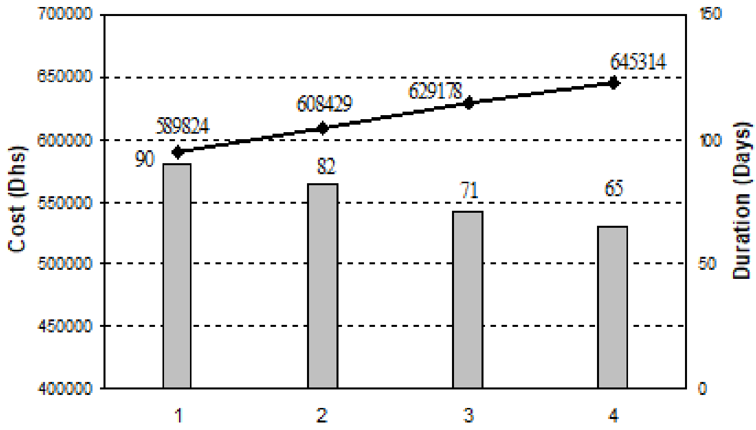


Figure 6: Comparison Among the Different Overtime Options.

V. Resource Optimization of Large Infrastructure Networks

The main advantages of the proposed approach are its simplicity, ease of use, and practicality, which have been illustrated in the above examples. The activity-on-arrow representation is clear and could reduce the number of nodes and arrows needed to model the construction process. The reduced complexity should prove useful in modeling real-life complex construction processes of, particularly large-scale infrastructure networks for roads, water, sewer, and transmission lines, among others. The network representation will be clear and easily configurable by practitioners who need not be familiar with simulation theory. To this end, the use of the presented approach has succeeded in re-engineering the modeling and simulation mechanisms. In terms of modeling, the user needs no more effort than what he/she spent in drawing an AOA network of a process. In terms of simulation, the user focuses on the logical flow of quantities and resources, considering the practical conditions that affect that flow. All other issues related to how simulation is run or how reports are generated are conveniently hidden.

While the proposed approach being potentially usable to model infrastructure networks in terms of presentation and ease of use, its practical application to the infrastructure field mandates a number of future extensions and improvements, including:

- Time-cost tradeoff (TCT) analysis by including the indirect cost of construction operations and crashing the project using different alternative construction methods;
- Modeling and simulation of linear and repetitive projects;
- Using the Genetic Algorithms technique as a non-traditional tool for large-scale optimization. Accordingly, various simulation experiments can be conducted to determine the optimum resources that produce maximum productivity. Also, maintenance activities can be assigned optimum order of operation in order to meet specific budgetary constraints;
- Integration with a GIS system to enable the modeling of large-scale networks;
- Integration with project management software for scheduling and project control; and
- Automate the method of changing the number of available resources in the resources sheet. This will simplify the process of reaching at the optimum resource combination.

VI. Summary and Concluding Remarks

It is well established in the literature that computer simulation tools are useful for analyzing construction operations. In an attempt to spur a wide use of such tools within the industry, this research presented a simple and powerful modeling approach for use in construction. Using the modeling components described in this research, realistic models can be constructed with relative ease and in a legible format. The elegant object-oriented nature of this approach makes it convenient for users who are not familiar with simulation theories and helps them focus more on the accurate mapping of their process rather than on programming and syntax issues. Two example applications were presented to demonstrate the applicability of this approach in construction and to show its applicability to model and simulate complex real-life construction operations. A simulation model for a construction operation of a large-size real-world project was developed and several experiments on the model were conducted using different resource combinations to arrive at the best combination that improves productivity and reduces the cost of the operation. Simulation results indicated that experimenting with different resource combinations may result in direct cost savings and attractive reduction in the completion durations of construction operations. The proposed approach and the developed models can be very useful tools to owners and contractors and can be used as templates for construction firms to better utilize their resources and minimize the cost of their site operations. The advantages of the proposed approach were discussed and can give insight into the features that need to be incorporated in a construction-specific tool. The ultimate goal is to reduce the barriers between simulation and the construction industry and make the process of building simulation models easier and cost-effective.

REFERENCES

[1] E. Zaneldin, "Resource optimization of construction operations using AOA-based simulation," International Journal of Simulation Modeling, vol. 7, no. 3, pp. 146-157, 2008.
[2] E. M. Rojas, and A. Mukherjee, "Multi-agent framework for general-purpose situational simulations in the construction management domain," Journal of Computing in Civil Engineering, vol. 20, no. 3, pp. 165-176, 2006.
[3] S. Lee, S. Han, and F. Peña-Mora, "Hybrid system dynamics and discrete event simulation for construction management," Proceeding of the 2007 ASCE International Workshop on Computing in Civil Engineering, Pittsburgh, PA, USA, 2007.
[4] C. Schexnayder, K. Knutson, and J. Fente, "Describing a beta probability distribution function for construction simulation," Journal of Construction Engineering and Management, vol. 131, no. 2, pp. 221-229, 2005.
[5] H. Zhang, C. M. Tam, and H. Li, "Activity object-oriented simulation strategy for modeling construction operations," Journal of Computing in Civil Engineering, vol. 19, no. 3, pp. 313-322, 2005.
[6] Y. Mohamed, and S. M. AbouRizk, "Framework for Building Intelligent Simulation Models of Construction Operations," Journal of Computing in Civil Engineering, vol. 19, no. 3, pp. 277-291, 2005.
[7] J-S. Chou, "Cost simulation in an item-based project involving construction engineering and management," International Journal of Project Management, vol. 29, no. 6, pp. 706-717, 2011.
[8] K. Yaghootkar, and N. Gil, "The effects of schedule-driven project management in multi-project environments," International Journal of Project Management, vol. 30, no. 1, pp. 127-140, 2012.
[9] P. C. Pendharkar, "A decision-making framework for justifying a portfolio of IT projects," International Journal of Project Management, vol. 32, no. 4, pp. 625-639, 2014.
[10] N. Ishii, Y. Takano, and M. Muraki, "An order acceptance strategy under limited engineering man-hours for cost estimation in Engineering–Procurement–Construction projects," International Journal of Project Management, vol. 32, no. 3, pp. 519-528, 2014.
[11] J. Louis, P. Dunston, and J. Martinez, "Simulating and visualizing construction operations using robot simulators and discrete event simulation," Proceedings of Computing in Civil and Building Engineering, 2014, pp. 355-363.
[12] B. Paulson, W. Chan, and C. Koo, "Construction operations simulation by microcomputer. Journal of Construction Engineering and Management, vol. 113, no. 2, pp. 302-314, 1987.