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SIMULATION-BASED CONSTRUCTABILITY ANALYSIS OF AN RCC DAM

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Abstract: Designing and planning construction operations is a challenging part of construction due to their highly complex dynamic nature. Simulation is a powerful approach, which has the ability to quantitatively, logically, and visually represent the construction process, its resources, and surrounding environment. Therefore it can improve the design and plan of construction operations. This paper presents a simulation-based approach to model a major milestone of construction process of a roller compacted concrete (RCC) dam. Several what-if construction scenarios have been modeled for the milestone, based on different combinations of the resources. A time-cost trade-off analysis has been used to select the optimum construction scenario for the milestone. The results of the study demonstrate the capabilities of the simulation based approach in designing and planning of RCC dam construction projects, based on a time-cost-tradeoff framework.

1. Introduction

Construction simulation, a fast-growing field, is the science of developing and experimenting with computer-based representations of construction systems to understand their underlying behavior (S Abourizk et al. 2011). This branch of operations research applications in construction management has experienced significant academic growth over the past two decades (Simaan Abourizk 2010).
The prevailing approach for simulating construction operations has traditionally been discrete event process interaction simulation, wherein a simulationist creates a model of a construction operation using specific modeling components (S Abourizk et al. 2011).
Construction researchers spent considerable effort since the 1970s to develop simple-to-use simulation tools so that they can be adopted by the industry (Simaan Abourizk 2010). CYCLONE (Halpin 1977; Morley, Lu, and Abourizk 2014), STROBOSCOPE (Martinez and Ioannou 1996), Simphony (D. Hajjar and AbouRizk 1999), Simphony.Net (Dany Hajjar and Abourizk 2002) and VitaScope (Kamat and Martinez 2003), are some of the simulation tools which have been developed in the last decades. The more recent modeling systems, such as Simphony.Net or STROBOSCOPE, provid many features for modeling flexibility including, for example, the possibility of the user writing their own programming code to manipulate the model and its components for more accurate modeling (S Abourizk et al. 2011).
Construction simulation can be used by a construction company for a number of tasks such as productivity measurement, risk analysis, resource planning, design and analysis of construction methods, and site planning (Sawhney, Abourizk, and Halpin 1998). Designing and planning construction operations is a challenging part of construction due to their highly complex dynamic nature. Simulation is a powerful approach, which has the ability to quantitatively, logically, and visually represent the construction process, its resources, and surrounding environment. Therefore it can improve the design and plan of construction operations (S Abourizk et al. 2011). Many researchers have implemented simulation approach in designing and planning construction operations. To name a few ones, Shi and Abourizk (1998) developed a

continuous model and a combined event-process discrete model by employing the Slam II general purpose simulation language for simulating pipeline construction projects. Ruwanpura et al. (2001) proposed a special purpose simulation tool for actual tunnel construction operations. Chung, Mohamed, and Abourizk (2006) applied Bayesian techniques into simulation model of the north Edmonton sanitary trunk tunnel project. Mohamed, Borrego, and Francisco (2007) presented a simulation-based approach for scheduling pipe-spool module assembly, which incorporates physical and logical constraints. Wang and Abourizk (2009) developed a special modeling system tailored for building large-scale simulation models for industrial construction. Taghaddos, Hermann, et al. (2012) proposed a simulation-based multi-agent approach for scheduling modular construction. Taghaddos, Abourizk, et al. (2012) presented a simulation-based auction protocol to solve resource scheduling problems in large-scale construction projects. Al-bataineh, Abourizk, and Parkis (2013) proposed an integrated simulation-based solution for tunnel planning and decision support by using modular development and a high level architecture (HLA)-inspired communications framework. Shahin et al. (2014) proposed a framework for simulating and planning tunneling construction activities executed under severe cold weather conditions.

This paper presents a simulation-based approach for designing and planning a major milestone of construction process of a roller compacted concrete (RCC) dam. Several alternative construction scenarios have been modeled for the milestone, based on different combinations of the resources. The proposed approach gives the managers a vision about the total time and cost of the project based on the different what-if scenarios. A time-cost trade-off analysis has been used to select the optimum construction scenario for the milestone.

2. Koukoutamba RCC Dam

The koukoutamba project is construction of an RCC dam in Guinea-Bissau. Construction process of the project has been started on January 2017. The construction process of the koukoutamba dam has been divided into 6 stages based on weather being in the wet or dry year season. As shown in Figure 1, the construction process during the first year wet season, can be broken down into five major milestones including cofferdam bed excavation, cofferdam embankment, left-wall bed excavation, left-wall bed stabilization and dam left-wall concreting. Each of the milestones contains some activities. In this study the process of concreting the left-wall has been modeled in simphony.Net environment, as a visual discrete event simulation package specialized for construction systems (Alvanchi et al. 2012). The following section describes the construction method in details.

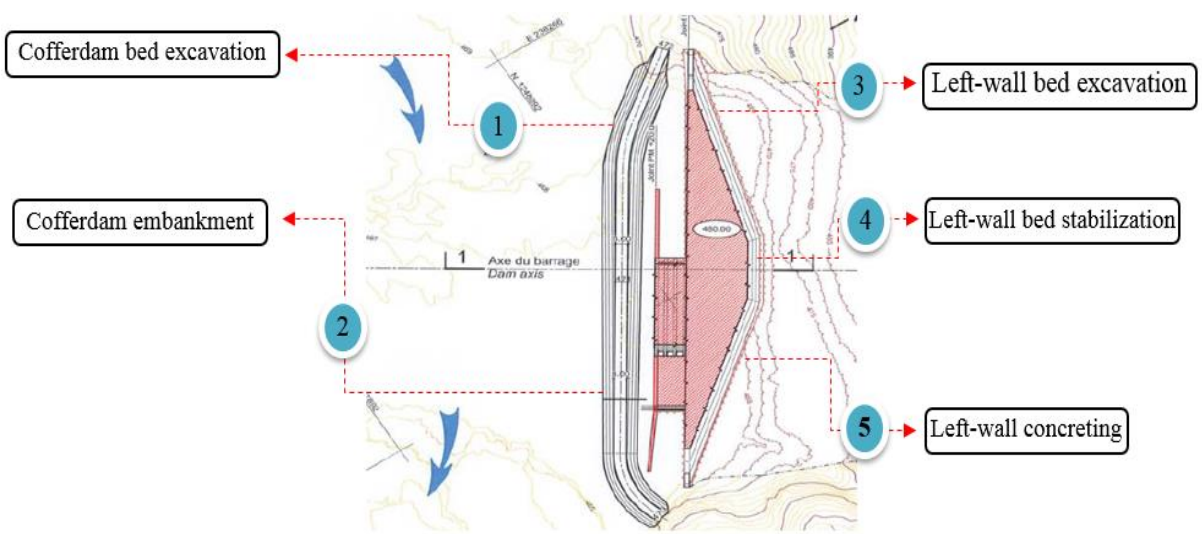

Figure 1: Dam construction process during the first year wet season

3. Description of Dam Left-wall Concreting Method

The process of concreting the dam left-wall can be started after stabilizing its bed. The roller compacted concrete (RCC), is poured and compacted in 49 discrete layers with 30 centimeters height. The construction process starts by transferring roller compacted concrete (RCC) from batching plants to the construction site. The distance of the batching plants form the construction site is considered to be 2kms. Some trucks are loaded in the batching plants to transfer the required concrete to the construction site. After being loaded, the trucks travel to the dam site. When the trucks arrive the dam site, they dump the concrete and return back to the batching plants. Each time a truck dump a specific volume of the concrete, a bulldozer grade the RCC and then some rollers start compacting it. The compression coefficient of the RCC concrete is considered to be 0.8. A three day curing time is considered after execution of each 10 layers of RCC concrete. The process continues until the end of the left-wall bed construction

4. Simulating Dam Left-wall Concreting Process

Figure 2. Shows the developed simulation model in Symphony.net, which simulates the required activities for concreting the left-wall. Table 1 shows the duration and required resources for the activities of concreting the left-wall. The duration of the activities have been calculated based on the assumptions in the construction methods, the traveling distances of the equipment, the traveling speed of the equipment, and also some experts' opinions. The travel performance of the equipment has been also used to calculate the duration of the activities. Table 2 shows rental and mobilization cost of the equipment, which are assumed to be used in concreting the left-wall.

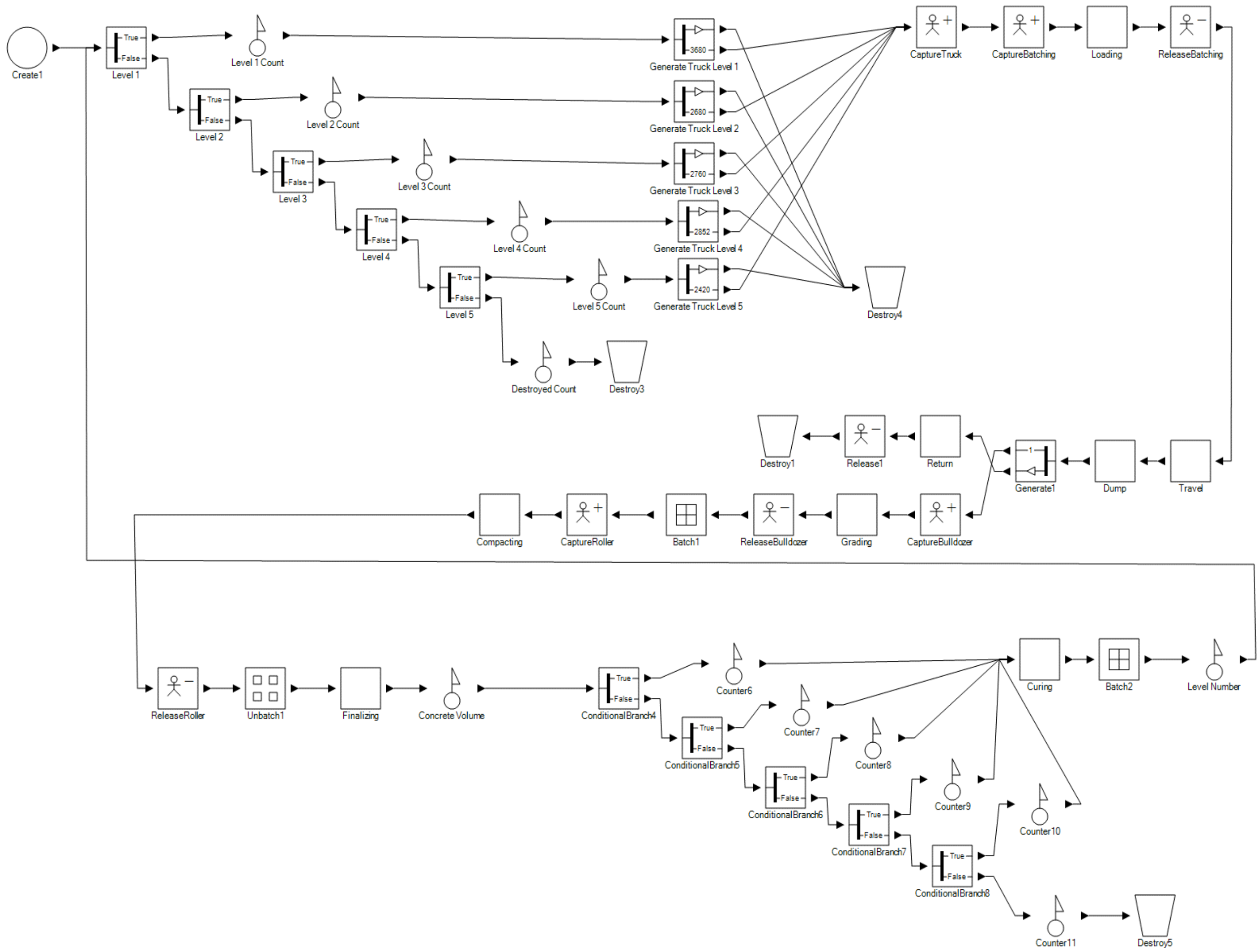

Figure 2: Developed Simphony.Net model for concreting dam left-wall

Table1: Duration and required resources/conditions for the activities of concreting the left-wall

Activity	Duration (minutes)	Required resources / conditions
Loading	6	Truck, Batching
Traveling	12	Truck
Dumping	3	Truck
Returning	8	Truck
Grading	5	Bulldozer
Rolling	25	Roller
Finalizing	10	-
Curing	2700	Every 10 layers

Table 2: Rental and mobilization cost of equipment

Equipment	Rental Cost ($/hour)	Mobilization Cost ($)
Truck	5140	580
Bulldozer	95	1330
Roller	60	730

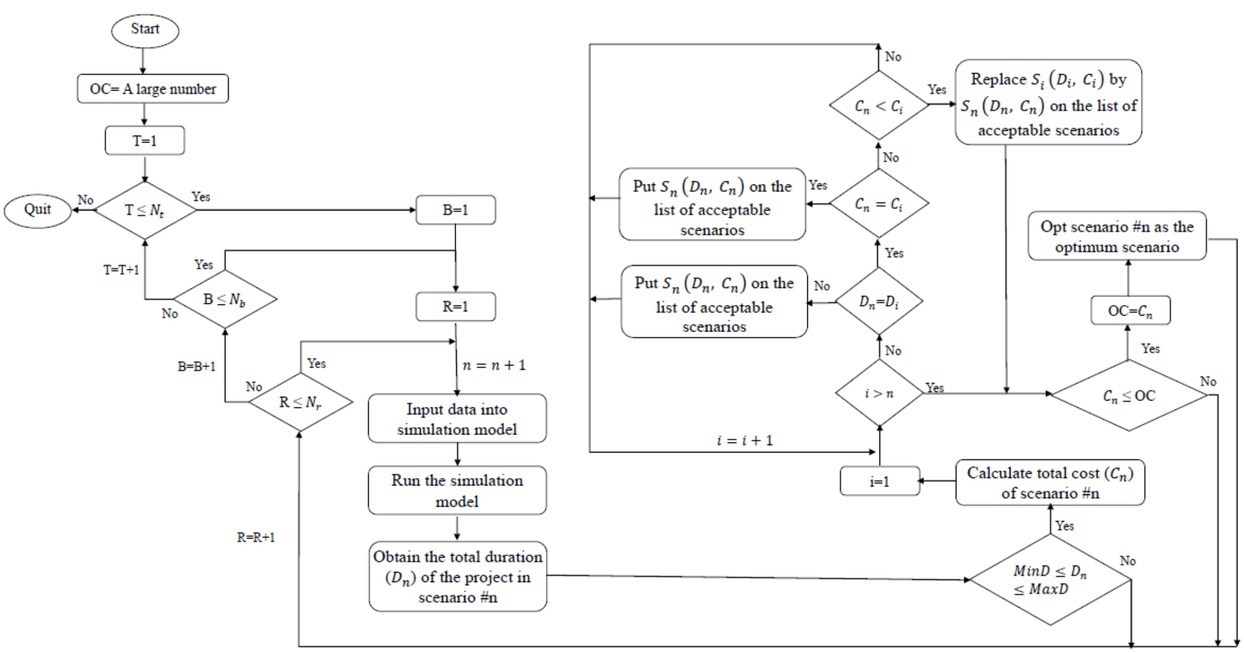

Figure 3: Flowchart for finding optimum scenario of combination of resources in dam left-wall concreting process

5. Scenario Analysis of the Dam Left-wall Concreting Process

By changing the number of the required resources in the developed Simphony.Net model, the total time required for concreting the left-wall changes. Therefore, in order to find the optimum scenario of combining different resources, all possible scenarios should be modeled to find the optimum one, considering the utilization of the resources, the total duration of the milestone, and also the total cost of the milestone. The maximum number of truckS, bulldozers and rollers available at the site are 6, 2, and 6 respectively. Therefore the total number of possible scenarios, which can be modeled is equal to 72. According to the preliminary schedule, the owner of the project expects the contractor to execute left-wall bed concreting in the time interval [110, 180] days.

An algorithm is provided in this paper for optimizing the search for the optimum solution. By this algorithm all the possible scenarios of the combination of the resources are modeled and those scenarios, which satisfy the constraints provided by the owner for completing the milestone are filtered. In the cases that two scenarios with a same duration satisfy the constraints, the scenario with the lower cost is opted to be put on the list of acceptable scenarios. Finally the scenario with the minimum cost among all acceptable scenarios is selected as the optimum one. The flowchart illustrating the process of finding the optimum scenario of the combination of the resources among all possible scenarios, is shown in figure 3. Variables T, B, and R in the flowchart represent the number of the truck(s), bulldozer(s), and roller(s) in each scenario respectively. Variables N_t, N_b and N_r represent the maximum number of the truck(s), bulldozer(s) and roller(s) available at the site respectively. Variable n represents the scenario number, which is modeled. D_n and C_n represent the duration and cost of the scenario #n. MinD and MaxD represent the minimum and maximum acceptable duration of the project according to the owners opinion. The vector $S_n\,(D_n,\,C_n)$ represents the duration and cost the milestone in the scenario #n. Finally OC represents the cost of the milestone in the optimum scenario.

As shown in table 3, among different scenarios, which have been modeled, four scenarios satisfy the time constraints (Scenarios #28, 40, 52 and 54). However, scenario #40 is opted as the optimum one, since it has the minimum total cost. Therefore the optimum number of the truck(s), bulldozer(s) and roller(s) required for concreting the left-wall is 4, 1, and 4 respectively.

Table 3: Acceptable scenarios of modeling the process of concreting the left-wall

	Truck(s) number (T)	Bulldozer(s) number (B)	Roller(s) number (R)	Duration (D) (Minutes)	Duration (D) (Days)	Total cost (C) ($)
Scenario #28	3	1	4	152861	169.9	1358823
Scenario #40	4	1	4	118092	131.3	1327253
Scenario #52	5	1	4	103720	115.3	1409112
Scenario #54	5	1	6	100127	111.3	1375361

Figure 4 shows the utilization rate of the trucks during concreting dam left-wall based on the optimum scenario. As shown in the figure, the mean utilization rate of the trucks is 0.884. Figure 5 shows the utilization rate of the bulldozer. As shown in the figure, the mean utilization rate of the bulldozer is 0.609. Finally, Figure 6 shows the utilization rate of the rollers. As shown in the figure, the mean utilization rate of the rollers is 0.762.

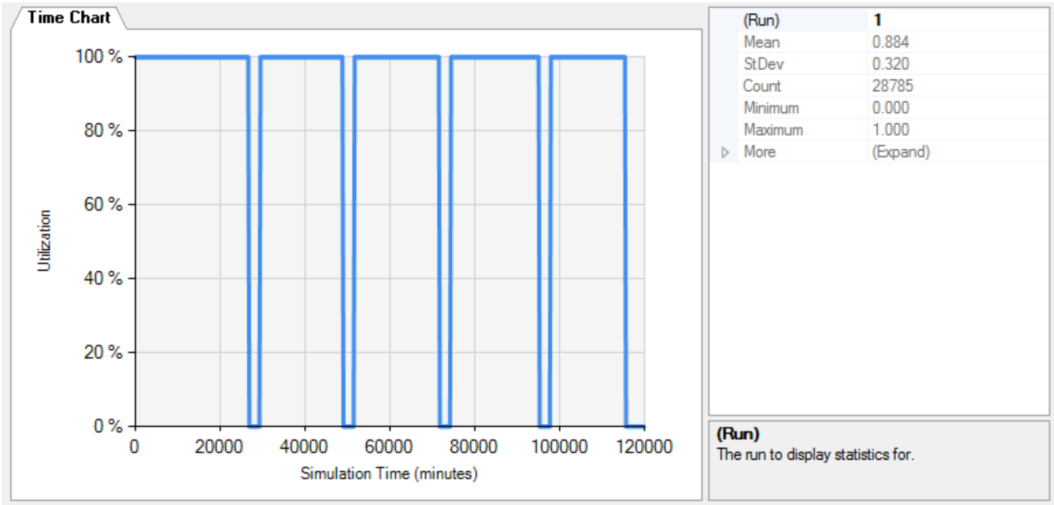

Figure 4: Utilization rate of the trucks during the process of concreting the dam left-wall based on the optimum scenario

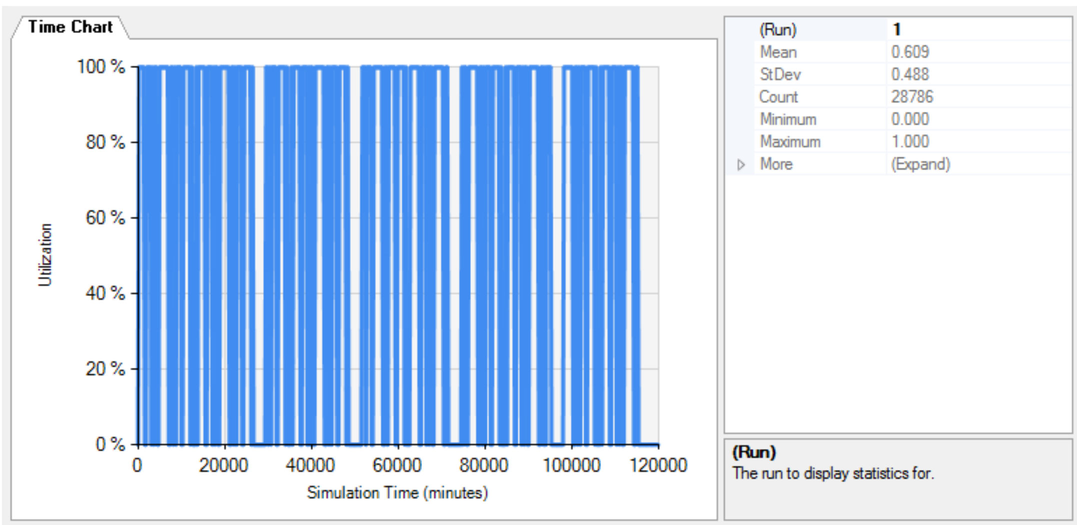

Figure 5: Utilization rate of the bulldozer during the process of concreting the dam left-wall based on the optimum scenario

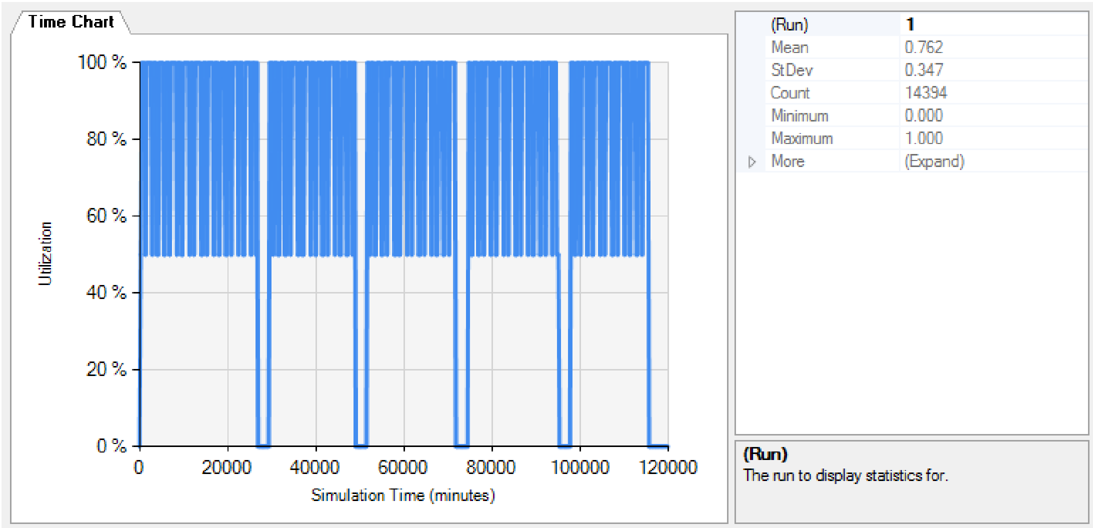

Figure 6: Utilization rate of the rollers during the process of concreting the dam left-wall based on the optimum scenario

Figure 7 shows the rate of concreting the dam left-wall. The volume of RCC, which is compacted in the dam left-wall is estimated based on the simulation time. The horizontal and vertical axes of the figure represents the simulation time and the volume of RCC, which is compacted. As shown in the figure, the total volume of RCC, that should be compacted is 115136. The total duration of concreting the dam left-wall bed has been estimated to be 131.3 days (118092 minutes). As shown in the figure, there are some points, where the production rate has been decreased to zero. These points refers to the curing time of RCC after each 10 layers concreting.

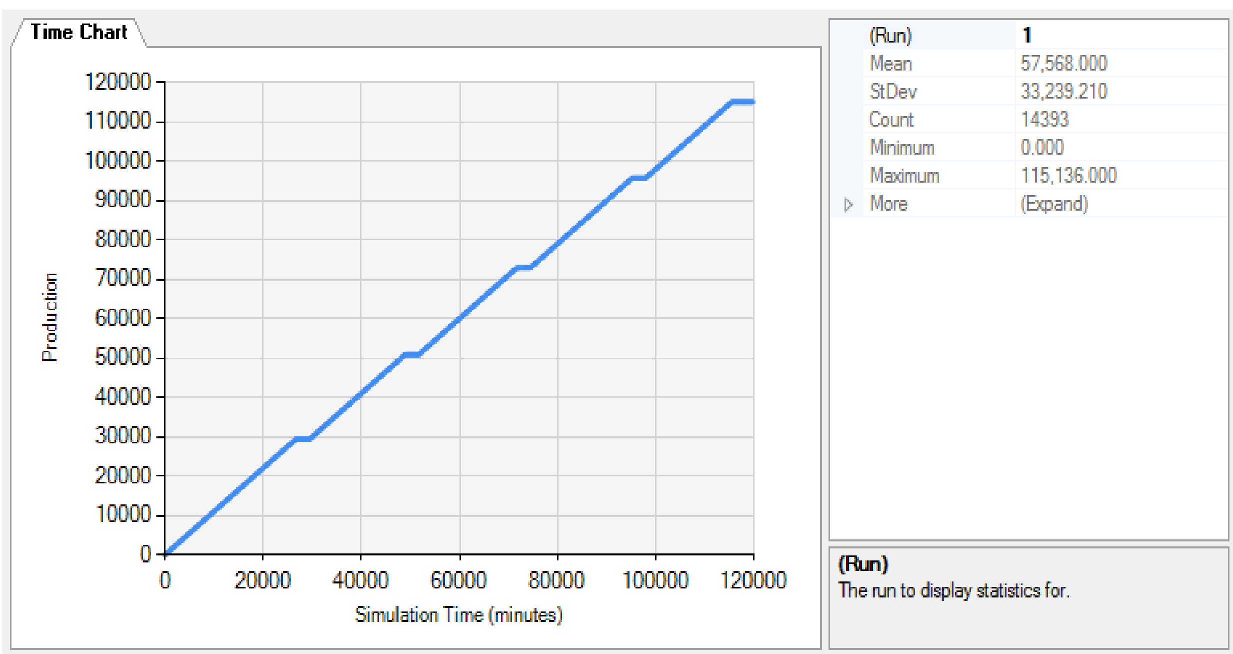

Figure 7: Rate of concreting the dam left-wall

6. Simulation Model Validation

To validate the obtained results of simulating the process of concreting the dam left-wall in Simphony.Net, the process has been also modeled in Arena environment (Rockwell Automation 2000). Figure 8 shows the developed Arene model for concreting the left-wall of the dam. Table 4 compares the results of modeling the process of concreting the left-wall of the dam by Simphony.Net and Arena. As shown in the table, the obtained results of the two simulation environments, have been completely same as each other. Furthermore the results of the study were validated by 5 experts' involved in the project. The results of the study demonstrate the capabilities of the developed approach in designing and planning of RCC dam construction projects. The optimum number of the resources can be fined by considering a time-cost-tradeoff approach. It gives the managers a vision about the total time and cost of the project based on the different what-if scenarios.

Table 4: Comparing results of modeling the process of concreting the left-wall in Simphony.Net and Arena

Obtained results	Arena Environment	Simphony.Net
Total duration (minutes)	118092	118092
Total concrete volume ($\mathbf{m^3}$)	115136	115136
Batching plant utilization	0.73	0.731
Trucks utilization	0.88	0.884
Bulldozer utilization	0.61	0.609
Rollers utilization	0.76	0.762

Conclusions

Designing and planning construction operations is a challenging part of construction due to their highly complex dynamic nature. Construction simulation, a fast-growing field, is the science of developing and experimenting with computer-based representations of construction systems to understand their underlying behavior.(S Abourizk et al. 2011). Simulation is a powerful approach, which has the ability to quantitatively, logically, and visually represent the construction process, its resources, and surrounding environment. Therefore it can improve the design and plan of construction operations (S Abourizk et al. 2011).

This paper presents a simulation-based approach based on Simphony.Net to model a major milestone of construction process of a roller compacted concrete (RCC) dam. Several what-if construction scenarios have been modeled for the milestone, based on different combinations of the resources. A time-cost trade-off analysis has been used to find the optimum construction scenario for the milestone. The proposed approach gives the managers a vision about the total time and cost of the project based on the different alternative scenarios.

To validate the performance of the simulation model developed in Simphony.Net environment, the process has been also modeled in Arena environment. The obtained results of the two simulation environments, have been completely same as each other. Furthermore the experts' involved in the project validated the results of the study.

The results of the study demonstrate the capabilities of the simulation based approach in designing and planning of RCC dam construction projects, based on a time-cost-tradeoff framework.

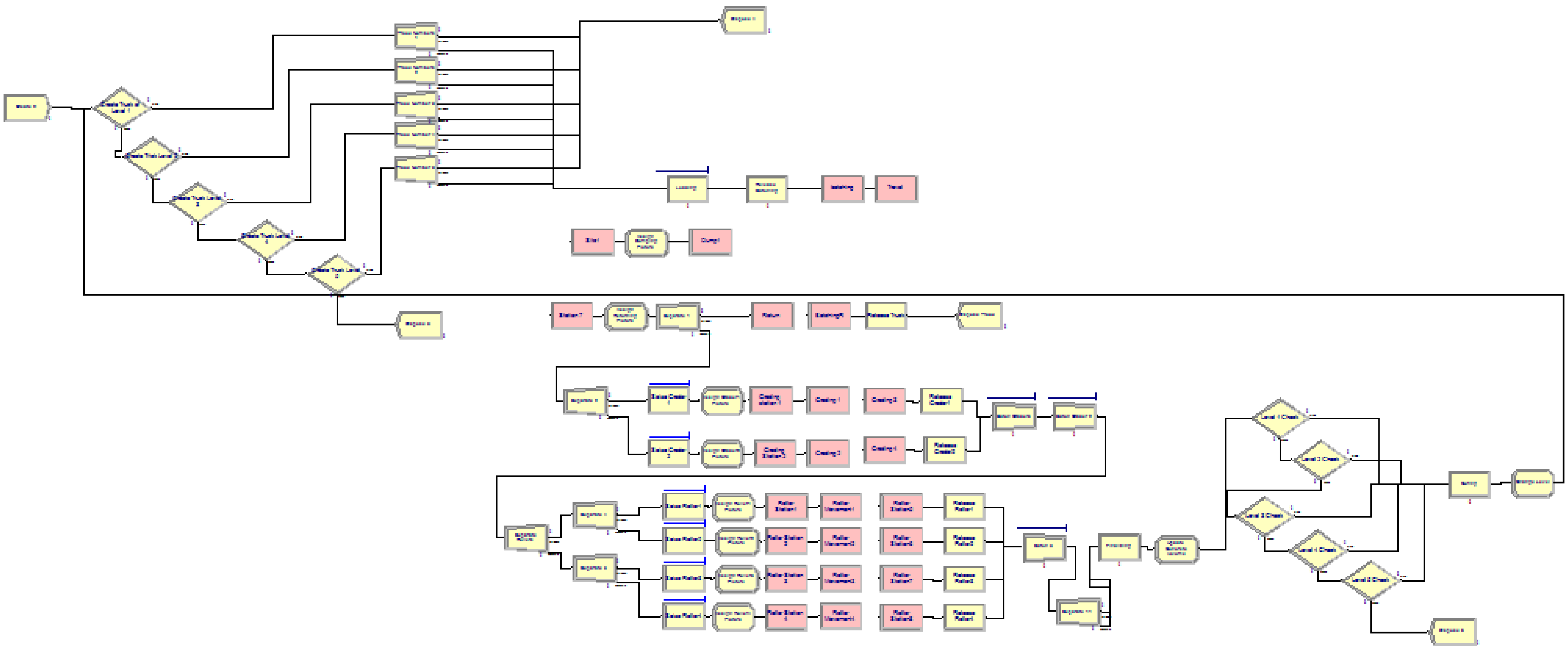

Figure 8: Developed Arena model for concreting dam left-wall

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