SIMULATION ANALYSIS TO FORECAST PROGRESS AND OPTIMIZE RESOURCE UTILIZATION FOR MATERIAL TRANSPORTATION ACTIVITIES IN THE CONSTRUCTION PROJECT ON PHU QUY ISLAND

Quang Nam Nguyen[1,*]

[1]*Institute of Techniques for Special Engineering, Le Quy Don Technical University, Hanoi, Vietnam*

Abstract

This article presents the main results of using a simulation tool to predict time and optimize the resource utilization for the transportation of materials processes in the construction project on Phu Quy island. A simulation model, which includes activities of material transfer processes, has been established and developed based on the EZStrobe simulation program. Various simulation scenarios with different resource usage options have been analyzed. The simulation results are also compared and evaluated with real-world project data. It indicates that for both productivity, time and cost, the option of using two 50-ton cranes at the dock, two 25-ton cranes at the storage yard and four trucks will be the best solution. The results of the study demonstrated the effectiveness of the simulation program, which may help managers choose the resource allocation plan and apply necessary changes to obtain the optimum results in terms of production and cost efficiency for the transportion of contruction materials on the island.

***Keywords**: Simulation; EZStrobe; transfer material; schedule and productivity.*

1. Introduction

In construction projects on offshore islands in Vietnam, transporting construction materials to the islands often faces difficulties due to factors such as weather conditions, tides, and location including ship anchorage or restrictions on equipment and transportation distance. In fact, in some projects, planning for material transportation activities on the island has not been focused on or mainly depends on the manager's experience to implement. Therefore, the time it takes to transport materials from ships to the island is often increased. This problem affects the construction schedule of project items, inefficiently utilizes resources, and increases transportation costs. To address the aforementioned problem, this research was conducted with the goal of providing solutions to help managers predict time and choose the best resource allocation plan to effectively manage material transportation activities on the island.

Email: quangnam@lqdtu.edu.vn
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Currently, with the development of computer science, methods utilizing discrete event simulation have been increasingly employed to predict time and analyze productivity within the construction industry. Globally, over the past 20 years, numerous studies have utilized discrete event simulation to analyze various construction activities. Notable examples include earth moving activities [1], bored pile construction activities [2], road construction activities [3, 4]. In Vietnam, the application of discrete event simulation for researching productivity and predicting time in construction activities is relatively new. The number of studies is small, limited, and focuses on specific activities such as tunnel construction activities [5], multi-storey building construction activities [6, 7]. Previous studies have demonstrated the effectiveness of applying discrete event simulation to research and evaluate construction activities, highlighting the need for further development in Vietnam. Especially, for construction projects on offshore islands, where there are many activities involving uncertain factors in terms of schedule and productivity such as material transportation activities.

2. Introduction EZStrobe simulation program

EZStrobe is a discrete-event simulation system uses STROBOSCOPE as a simulation tool. This program serves as a simple but powerful general-purpose simulation system capable of modeling numerous complex construction operations. EZStrobe operates based on extended and annotated Activity Cycle Diagrams (ACD). Program was developed to function within Microsoft Visio. Given an initial graphical network, EZStrobe automatically creates an equivalent model using STROBOSCOPE statements and transfer it to STROBOSCOPE to perform the simulation. This entire process is automated and remains completely invisible to the user. Therefore, learning and utilizing EZStrobe does not require any direct knowledge or utilization of STROBOSCOPE [8].

EZStrobe comprises five essential modeling elements: queue, conditional activity, bound activity, fork, and link (draw link, release link, and branch link). The output results of the EZStrobe simulation are shown through the variables in Table 1.

Table 1. Global Variables (accessible all the time while the simulation is running)

No.	Variable Form	Description
1	SimTime	The current value of the simulation clock
2	Activity.CurInst	The current number of instances of activity
3	Activity.TotInst	The total number of instances of activity that have been created
4	Activity.AveDur	The average value of the duration of the instances of activity
5	Activity.SDDur	The standard deviation of the durations of the instances of activity
6	Activity.MaxDur	The maximum value of the durations of the instances of activity
7	Activity.MinDur	The minimum value of the durations of the instances of activity
8	Activity.AveInter	The average time between successive instance starts of activity
9	Activity.SDInter	The std.dev. of time between successive instance starts of activity

No.	Variable Form	Description
10	Queue.AveWait	The average waiting time for resources that have entered queue
11	Queue.CurCount	The current content of queue
12	Queue.TotCount	The total amount of resource that has entered queue
13	Queue.AveCount	The time-weighted average of the content of queue
14	Queue.SDCount	The time-weighted standard deviation of the content of queue

Readers interested in exploring EZstrobe can easily download the program along with detailed user manuals from Professor Photios G. Ioannou's [9].

In this study, the author used the EZStrobe simulation program to construct and develop a simulation model of the material transport process on the island. Simulation scenarios involving different resource utilization options will be analyzed by the author. The simulation results are compared with data from the actual project to select an effective resource allocation plan and predict the time required to complete the transportation task.

3. Description of the case study

The case study focuses on the transportation process of cement materials on the island for a housing construction project on Phu Quy Island. The cement used in the project is Vissai PCB40 cement produced at the factory, packaged in 1.5-ton Jumbo bags, and then transported to the island via cargo ship. In the project, the total volume of cement materials is 6.450 tons. At the time of the study, the contractor was transferring materials from the Vinacomin Ha Long ship, which carried 2.250 tons of cement with a quantity of 1.500 Jumbo bags. The contractor's plan for organizing the transhipment process is described in Fig. 1. Regarding equipment, a 50-ton crawler crane located at the dock is utilized to hoist materials from the ship's compartment, while two 18-ton trucks are employed for transporting materials. Additionally, at the storage yard 600 meters from the dock, a 25-ton wheeled crane is used to hoist materials onto the truck and put them in position. As for human resources, the arrangement includes four service workers: one crane hook worker inside the ship's compartment, one worker removing the crane hook from the car at the dock, one worker tied crane hooks onto the cars, and one worker removing crane hooks at the storage yard.

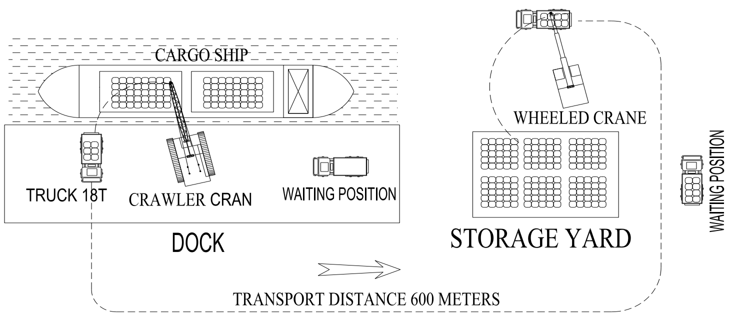

Fig. 1. Plan for organizing the transportation of cement materials on the island.

Based on actual conditions on the island, the wharf only has enough space for one cargo ship at a time. Consequently, when there are many cargo ships, the cargo ships must queue and wait for unloading in sequence, and it takes 3 to 5 days to unload one ship. At the position on the dock, a maximum of two 50-ton crawler cranes can be arranged to hoist materials. For convenience in the process of tying and unhooking the crane, as well as the arrangement of cement bags on the truck, at the dock and at the storage yard, only a maximum of 2 Jumbo cement bags, weighing 3 tons in total, are lifted each time. Each truck can transports a maximum of 10 bags of cement, with a load of 15 tons. The transport distance is 600 meters. The detailed operations of the cement transportation process are shown in Table 2.

Table 2. Description of material transportation process activities

No.	Activity name	Activity description
1	The truck moves into position at the dock	• Drive the truck into the transfer position after an empty position becomes available
2	Cranes hoist materials from the ships	• Turn the crane to bring the crane hook with the ship's cargo compartment • Lower the crane hook and attach the crane hook to the two bags of cement • Raise the crane hook and turn the crane towards the truck
3	Cranes transfer materials into position on trucks	• Adjust the crane hook to position on the truck, lower and remove the crane hook.
4	Transporting materials to the storage yard	• The truck is loaded and moved to the waiting position at the storage yard
5	The truck moves into position at the storage	• Adjust the truck to the unloading position once a space becomes available
6	Cranes transfer materials from trucks	• Turn the crane to bring the crane hook to the truck • Lower the crane hook and attach the crane hook to two bags of cement • Raise the crane hook and rotate the crane to position on the storage yard
7	Cranes arrange materials into position at the storage	• Adjust the crane hook to the position placed on the storage yard, lower and remove the crane hook.
8	The truck returns to the waiting position at the dock	• The truck moves back to the waiting position at the dock to wait for loading
Note: Activities 2 and 3 are repeated continuously until the truck is fully loaded with 10 bags of cement. Operations 6 and 7 repeat continuously until the truck is empty.		

4. Build a model to simulate the material transport process on the island

4.1. Collect input data for simulation

To build a simulation model of the material transportation process, it is necessary to gather input data for the simulation including, which includes: activities, resources required for those activities, activities durations, execution sequence and binding relationships between activities. Based on the activities of the transportation process shown in Table 2, the author conducted actual observations on the construction site to record all relevant input data. The resource variables used in the model are described in Table 3, which shows the variable symbols within the model and their corresponding actual values within the queues.

Table 3. Parameters of resource variables used in the model

No.	Resource	Symbol	Value	Unit	Quantity
1	XCMG crane 50 tons	CC50T	n1	pcs	01
2	Vissai PCB40 cement bag type 1.5 tons each	BaoXM	n2	bag	1500
3	Hyundai 18 tons truck	Xecho	n3	truck	02
4	KATO crane 25 tons	CC25T	n4	pcs	01
5	Workers tie crane hooks onto ships	CN1	-	man	01
6	Workers remove crane hooks from trucks at the dock	CN2	-	man	01
7	Workers tie crane hooks onto trucks at the storage	CN3	-	man	01
8	Workers remove crane hooks at the storage	CN4	-	man	01
9	Location for trucks to load materials at the dock	Vitri1	-	-	01
10	Location for trucks to unload materials at the storage	Vitri2	-	-	01

Before performing the simulation, it is essential to determine an appropriate time distribution for each activity in the material transportation process. Based on time data after multiple observations of the same activity, the author collected a dataset including 50 samples for the duration of each activity. Crystal Ball v11.2 software was employed to identify the time distribution for each activity, and the Kolmogorov-Smirnov test was utilized to assess the distribution of the collected data.

In statistics, the Kolmogorov-Smirnov test (K-S test) serves as a nonparametric method for assessing the equality of variances. This test was used to check whether the distribution of observed data is significantly different from a selected distribution. The Kolmogorov-Smirnov statistic quantifies the maximum distance between the Empirical

Distribution Function (EDF) derived from the sample and the Cumulative Distribution Function (CDF) derived from the reference distribution, as plotted in Fig. 2.

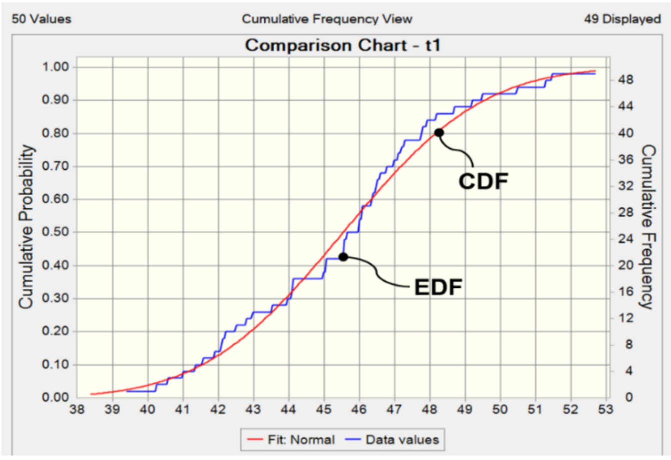

Fig. 2. K-S statistical comparison chart between the cumulative distribution function (CDF) and the empirical distribution function (EDF) of time t1.

The maximum deviation between the experimental distribution function $F_n(x)$ of n observed samples and the cumulative distribution function $F(x)$ of the assumed distribution is determined by the following formula [10]:

$$D_n = max\left|F_n(x) - F(x)\right|$$

The quantity D_n is used to test the hypothesis H_0 regarding the suitability of the distribution function, through comparison with the critical value $D_{n,\alpha}$ obtained from the lookup table in the K-S test [10].

The statistical hypotheses for the K-S test can be stated as follows:

1. Null hypothesis (H_0): the observed data follow a specific probability distribution

2. Alternative hypothesis (H_A): The observed data do not follow a specific probability distribution.

If $D_n \geq D_{n,\alpha}$, then hypothesis H_0 is rejected; conversely $D_n < D_{n,\alpha}$ then hypothesis H_0 is accepted.

The analysis results from Crystal Ball v11.2 software on the appropriate distribution form for each activity's time are shown in Table 4.

Table 4. Fitted assumed distributions

Data Series:	t1	t2	t3	t4	t5	t6	t7	t8
Best Fit:	Normal	Normal	Normal	Triangular	Normal	Normal	Normal	Triangular
K-S	0.0843	0.0550	0.0575	0.0681	0.0657	0.0478	0.0526	0.1177

Based on the table to look up the critical value $D_{n,\alpha}$ in the K-S test available in [10], with a probability of error when rejecting the default hypothesis H_0 $\alpha = 0.05$ and $n = 50$ samples, the value $D_{n,\alpha} = 0.190$.

The results in Table 3 indicate that the K-S statistical values from t1 to t8 are all smaller than the critical value $D_{n,\alpha}$, so the hypothesis H_0 is accepted. This implies that the distributions listed in Table 3 can be used to specify time distributions for activities in a simulation program. The time distribution of material transportation process activities in the simulation is shown in Table 5.

Table 5. Probability distribution of activity durations in the EZStrobe simulation model

No.	Activity name	Activity symbol	Time symbol	Duration (seconds)
1	The truck moves into position at the dock	XevaoVT1	t1	Normal [45.5,3.1]
2	Cranes hoist materials from ships	LayHtuTau	t2	Normal [98.1,3.7]
3	Cranes transfer materials into position on trucks	ChHlenXe	t3	Normal [29.6,2.7]
4	Transporting materials to the storage	VCveKho	t4	Triangular [151.5,163.5,175]
5	The truck moves into position at the storage	XevaoVT2	t5	Normal [39.9,2.5]
6	Cranes transfer materials from trucks	LayHtuXe	t6	Normal [85.9,3.2]
7	Cranes arrange materials into position at the storage	XHvaoVT	t7	Normal [34,3.7]
8	The truck returns to the waiting position at the dock	XeveBenT	t8	Triangular [136.1,154.9,164.6]
Note: The order in the table is the sequence of activities in the simulation model				

4.2. Simulation modeling in EZStrobe

In this study, the author will analyze different simulation scenarios to compare and choose the optimal option for the material transportation process. To develop the simulation, it is essential to initially build a fundamental simulation model according to the actual transportation organization plan at the construction site. Subsequently, the accuracy of the simulation model will be evaluated in comparison to reality. Using the input data shown in Tables 3 and 5, the simulation model according to the actual plan is established on EZStrobe, as shown in Fig. 3.

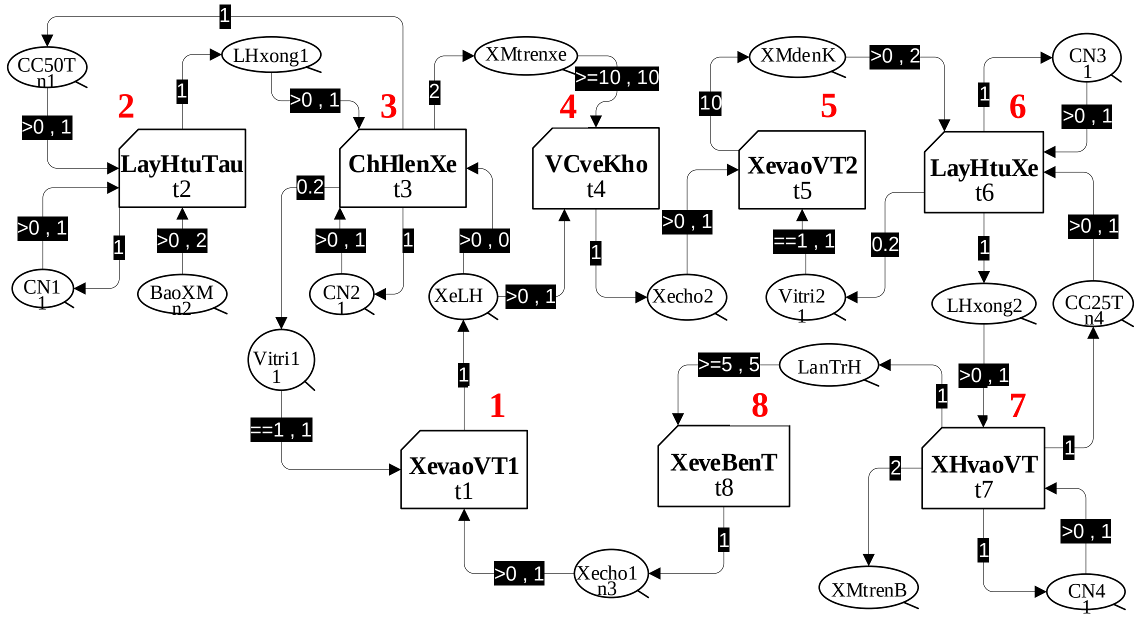

Fig. 3. The simulation model of the material transportation process on the island using a crawler crane at the dock.

4.3. Simulation results and evaluation

In the simulation model, formulas must be built so that the model automatically calculates and outputs the results. The formulated equations within the simulation are as follows:

- Transport time (hours): Time = SimTime/(60*60);

- Transport productivity (bags/hour): Productivity = 1500/Time.

After checking and correcting model errors, the simulation is executed 10.000 times. The simulation results for material conveyance time and productivity are shown in Table 6.

Table 6. The simulation results of material transportation time and productivity

Value	**Average value**	**Difference**	**Max value**	**Min value**
Transport time (hour)	**32.33**	0.034	32.44	32.23
Transport productivity (bags/hour)	**46.39**	0.048	46.54	46.23

The data on time and material transportation productivity of the actual plan were recorded by the author at the site, and shown in Table 7.

Table 7. Data regarding time and productivity of the actual cement transportation process

Date	Transport time			Time (hour)	Quantity (bag)	Productivity (bags/hr)
	Morning	Afternoon	Evening			
15/6/23	6h30-10h37	13h30-17h36	19h05-22h10	11.30	500	44.25
16/6/23	6h35-10h26	13h33-17h22	18h50-21h55	10.75	470	43.72
17/6/23	6h20-10h31	13h25-17h40	19h05-22h17	11.63	530	45.57
Total transport time (hour)				**33.68**		
Average value of productivity (bag/hr)				**44.51**		

* *Discussion:* From result in Table 6 and 7, we see that the material transportation time in the simulation is 32.33 (hours), which is slightly less than the actual transportation time of 33.68 (hours) with a deviation of 4.18%. Similarly, the productivity of the transportation process in the simulation is calculated to be 46.39 (bags/hour), which is 4.22% higher than the actual transport productivity of 44.51 (bags/hour). This result can be explained that during the actual tra02 nsportation process in hot weather conditions during the day, workersmay require breaks. However, in the simulation model, it is difficult to include this condition. Therefore, the time in simulation tends to be shorter than the actual time. With small acceptable deviations, the comparison results show that the simulation model is close to reality. Thus, it can be used to develop and analyze scenarios.

5. Develop simulation models and analyze simulation scenarios

At the dock, the transport plan with 2 crawler cranes will be used by the author for comparison. The transportation organization layout is shown in Fig. 4. From the basic simulation model established in Fig. 3, with the available input data, the author built an additional simulation model for the operation of the second crawler crane at the dock, as illustrated in Fig. 5.

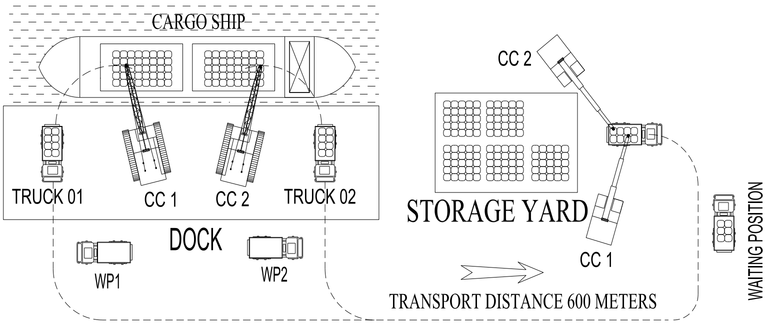

Fig. 4. Plan for organizing material transportation using 2 crawler cranes at the dock.

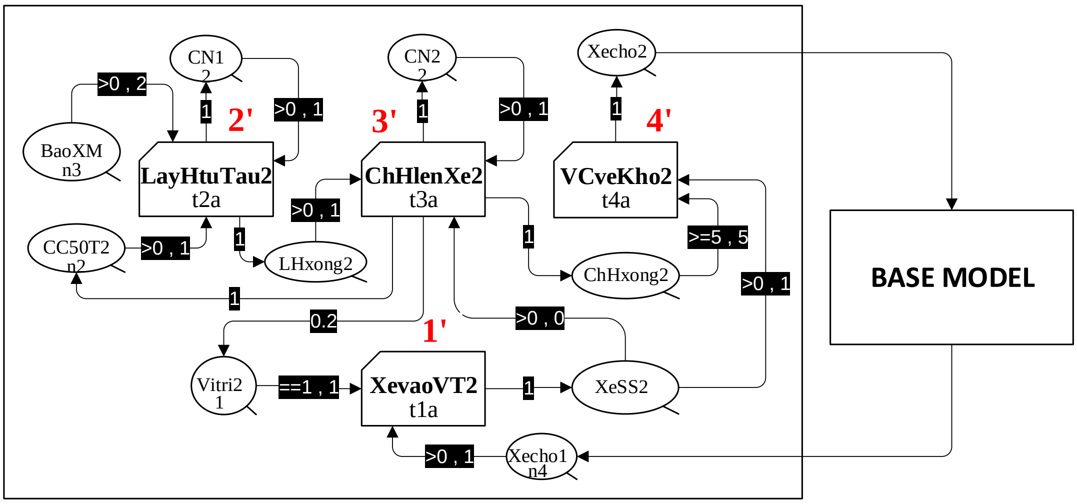

Fig. 5. Simulation model for the operations of the second crawler crane at the dock.

With the developed simulation model, the author analyzed simulation scenarios involving different resource usage strategies for the transportation process. Three comparison criteria were considered: time, productivity and cost. The option with the lowest transportation time, highest productivity and lowest cost would be selected. Actual data on costs for equipment and workers serving the transportation process were collected by the author from construction contractors and are shown in Table 8. These are also cost input data for the simulation model. To make the model closer to reality when analyzing productivity and cost factors, the transport time result from the simulation will be increased by 4.2% and considered as the worker's break time during the day in this case study.

Table 8. Data on the costs for labor and equipment serving the transportation process

Symbol	Cost type	Value (million VND/hour)
G1	Cost for 50-ton crane	2.00
G2	Cost for 25-ton crane	0.75
G3	Cost for trucks	0.30
G4	Costs for workers	0.0625
G5	Costs for drivers	0.0875

The results of time, productivity and cost for transportation are automatically calculated by the simulation program through the following formulas entered into the model:

- Transport time (hour): Time = SimTime*1.042/(60*60);
- Transport productivity (bags/hour): Productivity = 1500/Time;
- Labor costs (million VND): LC = (G4*nL+ G5*nD)*Time;
- Equipment cost (million VND): EC = (G1*nC50+G2*nC25+G3*nTr)*Time;

- Total transportation costs (million VND): Cost = LC + EC;

- Waiting time (hour): Waittime = $\left(\sum Q_L.AveWait + \sum Q_E.AveWait\right)/(60*60)$.

where SimTime is the simulation run time in seconds; nL denotes the number of labor; nD indicates the number of drivers; nC50 represents the number of 50-ton cranes; nC25 is the number of 25-ton cranes; nTr denotes the number of trucks; "Q.AveWait" represents the average wait time value of a resource in the queue to exit the queue and participate in the activity it is associated with.

In this study, waiting times are calculated for queues related to labors (L) and equipment (E), as specifically declared in the simulation model. With 10.000 simulation runs for each scenario, the analysis results are listed in Table 9, and shown as a comparison chart in Fig. 6.

Table 9. Comparison of analysis results between simulation scenarios

Scenarios	Resources used in the model				Time (hour)	Productivity (bag/hour)	Cost (Million VND)	Waiting time (hour)
	Labor	Crane 50 ton	Crane 25 ton	Truck				
Real	4	1	1	2	33.68	44.51	133.06	-
RSim	4	1	1	2	33.69	44.52	133.08	0.72
1	4	1	1	3	28.00	53.57	121.45	0.71
2	4	1	1	4	28.00	53.57	132.30	0.89
3	5	1	2	2	30.74	48.80	149.07	0.71
4	5	1	2	3	27.96	53.65	146.45	0.77
5	5	1	2	4	27.96	53.65	157.27	0.95
6	6	2	1	2	33.49	44.79	206.38	1.34
7	6	2	1	3	26.14	57.38	171.23	1.52
8	6	2	1	4	26.14	57.37	181.37	1.66
9	7	2	2	2	28.19	53.2	199.13	1.59
10	7	2	2	3	18.94	79.16	141.16	1.12
11	**7**	**2**	**2**	**4**	**14.35**	**104.51**	**112.49**	**0.82**
12	7	2	2	5	14.34	104.31	116.05	0.85

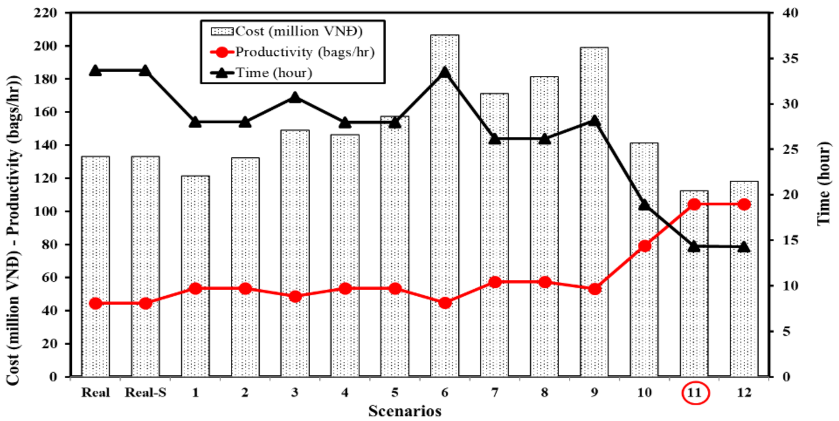

Fig. 6. Comparison chart of simulation results for time, productivity and cost between scenarios.

**Discussion*: From the comparison chart of simulation scenarios in Fig. 6, it is shown that in the case of using 1 crawler crane at the dock in scenarios 1 to 5, the optimal number of trucks required to enhance productivity efficiency and minimize waiting time for both workers and equipment is 3 trucks. When comparing scenarios 1 and 5, it is evident that while using two 25-ton cranes at the storage yard and 4 trucks might lead to a slight increase in productivity, it also incurs higher costs. Therefore, in the case of using 1 crane at the dock to save costs and reduce waiting time, the contractor could enhance efficiency by increasing the number of trucks from 2 to 3 trucks, as in scenario 1, which will achieve better efficiency than the actual case when only 2 trucks are used for material transportation.

In the scenario involving the use of 2 cranes at the dock, it can be seen that, if only increasing the number of trucks from 2 to 4, as depicted in scenarios 6 to 8, it will increase costs while productivity and time insignificant change, the waiting time also increases and will be wasted. When increasing the number of cranes at the storage yard to 2 and increasing the number of trucks, as shown in scenarios 9 to 12, it can be seen that scenario 11, which entails the utilization of two 50-ton cranes at the dock, two 25-ton cranes at the storage yard, 4 trucks for transporting materials, and 7 workers serving is the optimal method for organizing material transportation in this case study. Scenario 11 results in the shortest transportation time of 14.35 hours, the highest material transportation productivity of 104.51 (bags/hour), and the lowest transportation cost of 112.49 million VND. Compared to the actual transport case on the island, time is reduced by 57.4%, productivity is increased by 133.7% and costs are reduced by 15.5%. Through analysis results obtained from simulation, managers gain a deeper understanding of the relationships between resources and can make more decisions regarding appropriate resource utilization options.

6. Conclusion

The study has built a comprehensive simulation model that shows the material transportation process on the island, encompassing all the specific and realistic activities involved. Simulation model were developed to analyze 12 different scenarios. Scenario No. 11 was selected as the best resource utilization arrangement with the utilization of two 50-ton cranes at the dock; two 25-ton cranes at the storage yard and four trucks will achieve the highest productivity, shortest transfer time and lowest cost.

This model serves as a valuable tool for construction contractors, enabling them to swiftly analyze productivity and evaluate various scenarios without wasting unnecessary cost and time expenditures. By utilizing this model, contractors can efficiently assess the most optimal resource utilization options for transporting materials on the island. From there, construction contractors can accurately predict work completion time, save budget and effectively use resources.

This study is a further demonstration of the powerful capabilities of discrete event simulation programs in analyzing and optimizing construction systems. It aids construction contractors and engineers in achieving optimized strategies and decisions in the combined use of construction resources.

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PHÂN TÍCH MÔ PHỎNG ĐỂ DỰ BÁO TIẾN ĐỘ VÀ TỐI ƯU HOÁ VIỆC SỬ DỤNG NGUỒN LỰC CHO HOẠT ĐỘNG CHUYỂN TẢI VẬT LIỆU TRONG DỰ ÁN XÂY DỰNG TRÊN ĐẢO PHÚ QUÝ

Nguyễn Quang Nam[1]

[1]*Viện Kỹ thuật công trình đặc biệt, Trường Đại học Kỹ thuật Lê Quý Đôn, Hà Nội, Việt Nam*

Tóm tắt: Bài báo trình bày những kết quả chính của việc sử dụng công cụ mô phỏng để dự báo thời gian và tối ưu hoá việc sử dụng nguồn lực cho quá trình chuyển tải vật liệu tại đảo trong dự án xây dựng trên đảo Phú Quý. Một mô hình mô phỏng bao gồm các hoạt động của quá trình chuyển tải vật liệu đã được xây dựng và phát triển dựa trên chương trình mô phỏng EZStrobe. Các kịch bản mô phỏng với các phương án sử dụng nguồn lực khác nhau đã được phân tích. Kết quả mô phỏng được so sánh và đánh giá với dữ liệu từ dự án thực tế đã cho thấy. Với cả năng suất, thời gian và chi phí, phương án sử dụng 2 cần cẩu 50 tấn tại bến; 2 cần cẩu 25 tấn tại kho chứa và 4 xe tải vận chuyển sẽ là giải pháp tốt nhất. Kết quả nghiên cứu đã thể hiện tính hiệu quả của chương trình mô phỏng, giúp các nhà quản lý lựa chọn được phương án phân bổ nguồn lực và áp dụng các thay đổi cần thiết để đạt được kết quả tối ưu về năng suất và chi phí cho công tác chuyển tải vật liệu xây dựng tại đảo.

Từ khóa: *Mô phỏng; EZStrobe; chuyển tải vật liệu; tiến độ và năng suất.*

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