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MODELING EXCAVATION OPERATION IN BUILDING PROJECTS - A SIMULATION APPROACH*

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ABSTRACT

Pile foundations, loading area layout, excavation depth, haul distance, operator skills, and other factors, complicate the estimation of the production rates and unit cost of excavation operation. Simulation can be used as a tool to assist construction engineers in analyzing and designing construction operations. The objective of this paper is to develop a simulation model for the excavation operation in building construction to provide planner and estimators with a powerful tool for predicting the production rates and unit cost. Moreover, this model facilitates the investigation of resources' combination effect on this operation. For this purpose, the model was developed using realistic activities durations. Therefore, full-time observations were conducted to collect these data from several building projects constructed in the city of Alexandria (Egypt). Based on the results, the impact of resources' combination and variation of these resources on the production rates and unit costs are discussed. In conclusion, the results indicate that the benefits of simulation would be maximized if it were used during the planning phase, as it will affect the selection of the suitable combination of equipment.

KEY WORDS**:** Simulation, Excavation operation, Production rates, Unit cost.

OPERATION D'EXCAVATION MODELISATION EN PROJETS DE CONSTRUCTION - UNE APPROCHE DE SIMULATION

RÉSUMÉ

Fondations sur pieux, mise en espace de chargement, la profondeur de l'excavation, distance de transport, les compétences des opérateurs, et d'autres facteurs, compliquent l'estimation des taux de production et le coût unitaire de fonctionnement d'excavation. La simulation peut être utilisé comme un outil pour aider les ingénieurs en construction dans l'analyse et la conception des opérations de construction. L'objectif de cet article est de développer un modèle de simulation pour l'opération d'excavation dans la construction de fournir planificateur et estimateurs avec un outil puissant pour prédire les taux de production et le coût unitaire. En outre, ce modèle facilite l'enquête de l'effet combiné des ressources des sur cette opération. A cet effet, le modèle a été développé en utilisant réalistes des durées d'activités. Par conséquent, à temps plein des observations ont été menées pour recueillir ces données à partir de plusieurs projets de construction construits dans la ville d'Alexandrie (Egypte). Basé sur les résultats, l'impact de la combinaison des ressources et de la variation des de ces ressources sur les taux de production et les coûts unitaires sont discutés. En conclusion, les résultats indiquent que les avantages de la simulation serait maximisé si elle était utilisée pendant la phase de planification, car elle aura une incidence sur le choix de la combinaison appropriée de l'équipement.

MOTS CLÉS: Simulation, opération d'excavation, les taux de production, le coût unitaire.

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1. INTRODUCTION

Construction projects involve five main stages: feasibility, design, tendering, construction, and commissioning. These stages are not equally important, and carelessness during any stage can cause budget overruns and work delays. If the routine-planned procedures can be simulated using reliable data, construction costs and time can be reasonably estimated (Chou[4] (2011)).

For better understanding of the performance of the construction operation, project planners can use computer simulation to predict the performance of the construction operation in terms of process flows and resources utilization (Cheng and Feng[2] (2003)).

Discrete-event simulation has been used to assist construction engineers in analyzing and designing construction operation. One of the advantages to utilize simulation in designing construction processes is that planners may examine various schemes of the simulation model to better understand how resources influence the overall performance of a construction system so as to select a better resource assignment (Cheng et al.[3] (2006)).

Construction simulation is a tool that can be used by a construction company for a number of purposes, such as productivity measurement, risk analysis, resource planning, design and analysis of construction methods, and site planning (Sawhney and AbouRizek.[14] (1996)).

In the construction field, there is several custom developed simulation packages specially designed for applications in construction projects. Halpin[5] (1977) developed CYCLic Operation NEtwork (CYCLONE) methodology for the simulation modelling of construction process. Based on CYCLONE, different simulation implementations have been developed which include INSIGHT (Paulson[12] (1978)), RESQUE (Chang and Borcherding[1] (1986)), UM-CYCLONE (Ioannou[9] (1989)), Micro - CYCLONE (Halpin and Rigges[6] (1992)), Dynamic Interface for Simulation of Construction Operation (DISCO) (Huang et al.[8] (1994)). Oloufa[11] (1993) proposed an object-oriented approach for simulating construction operation. Tommelein et al.[17] (1994) developed an object-oriented system (CIPROS) that models construction processes by matching resource properties to those of design components. Sawhney and AbouRizek[14] (1996) developed a hierarchical simulation modelling (HSM) for planning construction projects. Shi and AbouRizk[15] (1997) developed a resource-based modelling for construction simulation, which defines the operating processes into atomic models. Zaneldin and Hegazy[18] (1998) presented a flowchart-based approach for the modelling and simulation of construction operation. This approach uses simulation software, Process Charter that does not require prior knowledge of any simulation terminology, theoretical background, or any programming language. Martinez and Ioannou[10] (1999) developed a general purpose simulation programming language (STROBOSCOPE).

Excavation operation in building construction is one of the construction operations that must be simulated because of the variability of excavation operation activities time and the resources combination of this operation. To improve the production rate of this operation, project managers and engineers first need to understand the behaviour of the interactions of these activities and resources.

The objective of this paper is to develop a simulation model for excavation operation in building construction projects. It can provide the planner and estimators with a powerful tool for predicting the production rates and investigate the effects of the resources used in this operation. For this reason, Process Charter is used to simulate the excavation operation. This software is a simple and powerful tool for construction process planning, as demonstrated by many researchers (Zaneldin and Hegazy[18] (1998)), Hegazy and Kassab[7] (2003)).

The main advantage of this software is its simple flow chart based modelling capabilities in addition to its object-oriented simulation engine. The simulation engine of the software is flexible and allows the user to adapt its basic modelling elements. Another advantage of the software is that it applies simulation to traditional activity-on-arrow (AOA) networks used for scheduling projects. Arrow and node objects of various types are designed to allow simple or conditional branching during simulation (Process Charter, User's Guide[13] ((2000)).

2. DATA COLLECTION

There is no realistic data available to develop the simulation model for the excavation operation whether the pile foundations exist or not in building projects. For this reason, full-time observations of several construction sites were done by the researcher over a period of twelve months in the city of Alexandria (Egypt). In the data collection process, activities were observed on site. Moreover, the production rates, resources and the time required to complete each activity was recorded. For this purpose, a data collection form was designed to collect the realistic data (loading time, travel time, dumping time, return time and breakdown time of the equipments). For more information, the reader is referred to Thabet[16] (2011).

3. MODEL BUILDING

In order to develop the skeletal framework of the excavation operation in building construction it is necessary to identify the major resources involved (i.e., trucks, excavator, and soil) and establish the basic structure of the operation by integrated the resource paths and cycles. Construction operation can be considered and defined in term of specific collections of work tasks (Halpin and Riggs[6] (1992)).

The excavation operation can be represented schematically as shown in the Fig. (1) and consist of four basic tasks:

(1) Excavation and loading.

(2) Travel-loaded (from the excavation area to the dumping area).

(3) Dumping.

(4) Travel-empty (returning from the dumping area to the excavation area).

The simulation model is designed to determine the production rates and unit cost of the excavation operation. In this study, the production rates will be defined as the total amount of material handled by the excavator to the truck, the truck once loaded, haul to the dump area, dump the load and return to the queue in a unit time such as a minute or an hour.

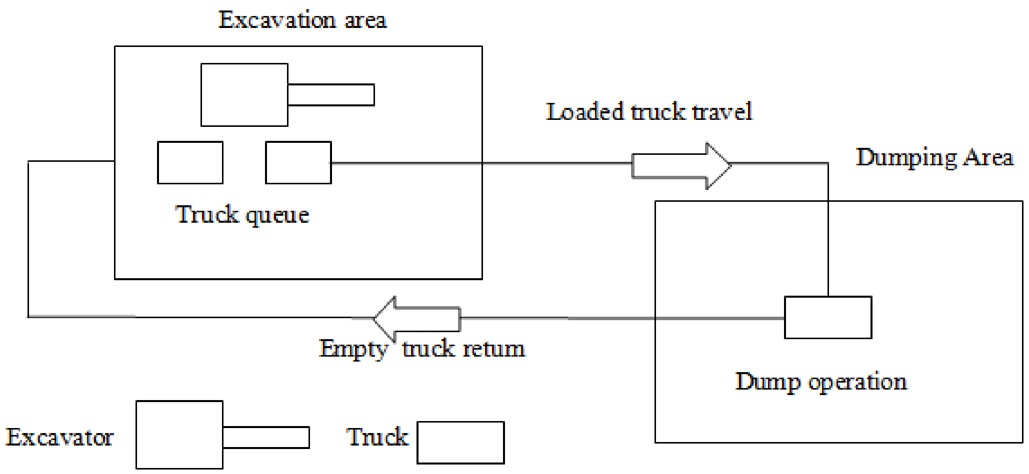

Fig. 1. Schematic outline of excavation operation

4. MODEL DESCRIPTION AND DESIGN

The simulation of construction operations can be used as an experimental ground during planning and this allows an early identification of problem areas. Simulation thus helps the planner and estimators to reduce the effort required for planning excavation operation as well as to improve the accuracy of production rates and cost estimation.

In this study, several Process Charter models have been developed to evaluate and demonstrate the effects of resources (i.e., number of truck, capacity of truck and bucket capacity of excavator) on excavation operation.

Table 1: Resources specifications and cost rate

Resources	Capacity	Cost/ hour (including laborers) (L.E)
Trucks 1	8 m^3	75
Truck 2	10 m^3	90
Excavator	0.75 m^3	137.5

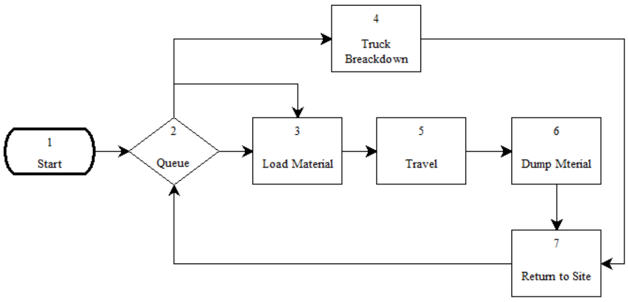

Fig. 2. Simulation model of excavation operation (case 1)

5. CASE STUDIES

5.1 Case Study 1

This section presents the development of four simulation models of excavation operation in building construction with existence of the pile foundation. The first model shows the designed simulation model for excavation operation. The operation involved loading excavated material (sandy clay) using two types of trucks and one excavator. The resources considered in these models are presented in Table (1). The distance between the loading area and dumping area is 4.5 km. For practicality, truck breakdown probabilities were used to model the real situation. The work is carried out in one 8-h shift per day.

Using Process Charter, process modelling is conducted in four steps starting with flowchart drawing as shown in Fig (2). In this step, the model represented by seven nodes (activities) and eight arrows (work paths). The second step is to define available resources (truck and excavator) and specify their working hours and hourly rates as shown in Fig (3).

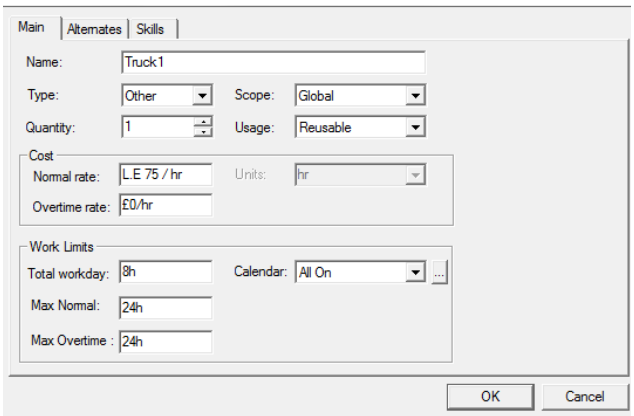

Fig. 3. Define resources of excavation operation

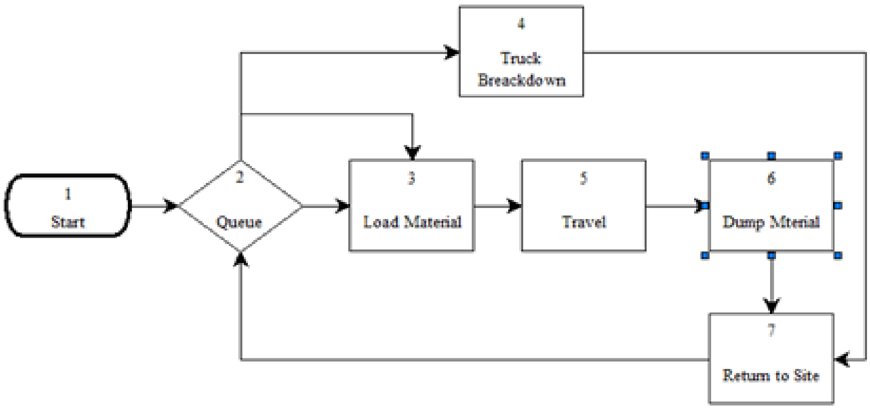

Fig.4. Simulation result- number of trucks (activity 6)

These resources can then be assigned in the third step to the appropriate work-paths (arrows) in the flowchart along with necessary flow-objects (trucks). Finally, the process simulation can be executed in the fourth step for a specific time period. As a result of the simulation model, the total activation of dumping activity (activity 6) was found to be 45 and 22 for truck (1) and truck (2) respectively as shown in Fig. (4). Therefore, the production rates and unit cost of the excavation operation can be calculated by using the following equations:

Production rate (m^3/day) = number of trucks departure dumping area*capacity of truck ... **(1)**

Unit Cost (L.E/m^3) = [(number of truck * total operation time * cost/hour) + (number of excavator * total operation time * cost/hour)] / production rate. ……………..................... **(2)**

Using the same steps, the other three models were developed for testing the effects of equipments combination on the production rates, unit cost and waiting time of truck and excavator. The variation of the production rates, unit cost and waiting time of trucks and excavator are presented in Table (2). As shown by these results, the number and capacity of the trucks affect the production rates, unit cost and waiting time of truck and excavator. In addition, as expected inaccurate identification of the trucks' number cause decrease in the production rates and increase in the waiting time of truck and excavator. Moreover, based on these results, model (4) produced a maximum production rate and a minimum unit cost with 644 m^3/day and 8.79 L.E / m^3 respectively. In comparison to the other three models, this model also produced a minimum waiting time cost of trucks and excavator with 245.42 L.E / day.

Table 2: Results of case 1

Model	No. of Truck		Production Rates (m^3/day)	Unit Cost (L.E./m^3)	Truck Waiting Time(min.)	Cost of Truck Waiting Time (L.E/day)	Excavator Waiting Time(min.)	Cost of Excavator Waiting Time (L.E/day)
	Truck ($8m^3$)	Truck ($10m^3$)						
1	3	2	482	9.00	107	141.25	80	183.33
2	3	3	568	8.91	119	116.25	55	126
3	4	2	554	8.92	137	171.25	62	142
4	4	3	644	8.79	156	195	22	50.42

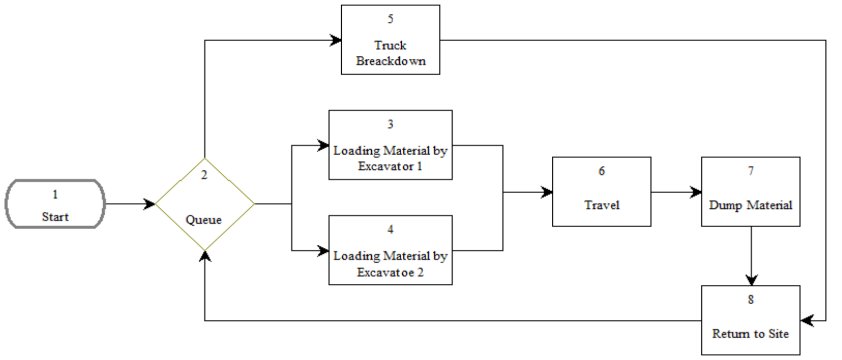

Fig. 5. Simulation model of excavation operation (case 2)

5.2 Case Study 2

As shown in Fig. (5), this case study presents the development of four simulation models of excavation operation in building projects without existence of the pile foundation. The operation involved loading excavated material (sand) using two types of truck and two excavators. The resources specifications and cost rate of these resources are presented in Table (1). The distance between the loading area and dumping area is 4.5 km. For practicality, truck breakdown probabilities were used to model the real situation. The work is carried out in one 8-h shift per day. The results of these models are presented in Table (3). As shown by these results, the number of trucks and excavator affect the production rates, unit cost and waiting time of trucks and excavator. In addition, as expected inaccurate identification of the trucks' number cause decrease in the production rates and increase in the waiting time of truck and excavator. Moreover, based on these results the model (4) produced a maximum production rate and a minimum unit cost with 1316 m^3/day and 8.69 L.E / m^3 respectively. In comparison to the other three models, this model also produced a minimum waiting time cost of trucks and excavator with 411.54 L.E / day. However, the maximum production rate and the minimum unit cost produced by model (4) in this case study are even better than the maximum production rate and the minimum unit cost produced by the best model in case study (1).

Table 3: Results of case 2

Model	No. of Truck		Production Rates (m^3/day)	Unit Cost (L.E./m^3)	Truck Waiting Time(min.)	Cost of Truck Waiting Time (L.E/day)	Excavators Waiting Time(min.)	Cost of Excavators Waiting Time (L.E/day)
	Truck ($8m^3$)	Truck ($10m^3$)						
1	5	4	912	8.86	122	164	134	307.1
2	6	5	1078	8.72	133	175.25	118	270.42
3	7	6	1276	8.92	141	191.75	106	242.92
4	7	7	1316	8.69	148	203	91	208.54

Table 4: Resources specifications and cost rate

Resources	Capacity	Cost/ hour (including laborers) (L.E)
Trucks (1)	8 m^3	75
Truck (2)	10 m^3	90
Excavator	1m^3	150

5.3 Case Study 3

This case study presents the development of four simulation models of excavation operation in building projects without existence of the pile foundation. These models have the same process structure were defined in case study (1) and presented in Fig. (2). The operation involved loading excavated material (sand) using two types of truck and one excavator. The resources considered in these models are presented in Table (4). The distance between the loading area and dumping area is 5 km. The work is carried out in one 8-h shift per day. The results of these models are presented in Table (5). As shown by these results, the number of trucks affects the production rates, unit cost and waiting time of trucks and excavator. In addition, as expected inaccurate identification of the trucks' number cause decrease in the production rates and increase in the waiting time of truck and excavator. Moreover, based on these results the model (4) produced a maximum production rate and a minimum unit cost with 904 m^3/day and 7.83 L.E / m^3 respectively. In comparison to the other three models, this model also produced a minimum waiting time cost of trucks and excavator with 215 L.E / day.

Table 5: Results of case 3

Model	No. of Truck		Production Rates (m^3/day)	Unit Cost (L.E./m^3)	Truck Waiting Time(min.)	Cost of Truck Waiting Time (L.E/day)	Excavator Waiting Time(min.)	Cost of Excavator Waiting Time (L.E/day)
	Truck (8m^3)	Truck (10m^3)						
1	3	4	704	8.35	95	118.75	80	200
2	4	4	776	8.35	110	137.5	47	117.5
3	5	3	808	7.88	102	127.5	65	162.5
4	5	4	904	7.83	120	150	26	65

5.4 Case Study 4

This case study presents the development of four simulation models of excavation operation in building projects without existence of the pile foundation. These models have the same process structure were defined in case study (2) and presented in Fig. (5). The operation involved loading excavated material (sand) using two types of truck and two excavator. The resources specifications and cost rate of these resources

are presented in Table (4). The results of these models are presented in Table (6). As shown by these results, the number of trucks and excavator affect the production rates, unit cost and waiting time of trucks and excavator. In addition, as expected inaccurate identification of the trucks' number cause decrease in the production rates and increase in the waiting time of truck and excavator. Moreover, based on these results the model (4)

Table 6: Results of case 4

Model	No. of Truck		Production Rates (m^3/day)	Unit Cost (L.E./m^3)	Truck Waiting Time(min.)	Cost of Truck Waiting Time (L.E/day)	Excavator Waiting Time(min.)	Cost of Excavator Waiting Time (L.E/day)
	Truck ($8m^3$)	Truck ($10m^3$)						
1	7	7	1434	8.12	110	149.75	101	252.5
2	8	7	1508	8.11	121	164	87	217.5
3	8	8	1618	8	132	177.5	79	197.5
4	9	8	1738	7.80	143	189.5	64	160

produced a maximum production rate and a minimum unit cost with 1738 m^3/day and 7.80 L.E / m^3 respectively. In comparison to the other three models, this model also produced a minimum waiting time cost of trucks and excavator with 349.5 L.E / day. However, the maximum production rate and the minimum unit cost produced by model (4) in this case study are even better than the maximum production rate and the minimum unit cost produced by the best model in case study (3).

6. CONCLUSION

Construction site operations are very complex, and they involve complicated relationships among numerous activities and factors. The objective of this paper was to develop a simulation model for excavation operation whether the pile foundations exist or not in building construction. It can provide the planners and estimators with a powerful tool for predicting the production rates and help them to understand the behaviour of the interactions of these tasks and factors effect this operation. Based on the results, planners and estimators not only able to predict the production rates but also they can identify the affect of the resources' variation on the production rates, unit cost and waiting time of trucks and excavator. In addition, the maximum production rate and the minimum unit cost produced by the best models (model 4) in case studies (2) and (4) are better than the maximum production rate and the minimum unit cost produced by the best models in case studies (1) and (3). Due to the variation in resources used in the excavation operation the planners and estimators need to develop many models to achieve the suitable combination of resources that improve the production rate and minimize the unit cost. Therefore, the combination between simulation and optimization is essential requirement to find the appropriate combination resources that minimize the unit cost of the excavation operation. In that regard, genetic algorithms are recommended for improving production rate and saving time and cost.

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