Alexandria Engineering Journal (2015) 54, 533–540

HOSTED BY ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Analysis of earth-moving systems using discrete-event simulation

K.M. Shawki *, K. Kilani, M.A. Gomaa

College of Engineering and Technology, AASTMT, Alexandria, Egypt

Received 30 September 2014; revised 17 March 2015; accepted 31 March 2015
Available online 18 May 2015

KEYWORDS

Discrete;
Earthwork;
Arena;
Simulation

Abstract Discrete-event simulation has been widely used technique in analyzing construction operations for the past three decades due to its great effect on optimizing cost and productivity. In this paper we will present Arena as a tool for simulating earthwork operations, the advantage of Arena is its easiness and flexibility in simulating most kinds of models in different areas of construction. A case study will be presented, a model will be built and results obtained to reveal the mentioned objectives.

1. Introduction and background

Earthwork operations are one of the most important construction operations needed to be analyzed. Earthwork operations are performed in a highly uncertain environment. These operations include excavation, transportation and placement or disposal of materials. They typically include repetitive work cycles, expensive fleets and large volumes of work. Whereas the planning of these projects can be improved significantly using discrete-event simulation, most projects are still planned using traditional tools. The probable nature of earthwork operations makes it difficult to plan. On site, there will be many decisions that will be taken according to evolving status. A truck, for instance, will be routed to an alternative loading area if the loading unit is under maintenance or trucks are waiting in queue. Each strategy taken in designing the operation will have a direct impact on productivity and cost Han [1], Panas and Pantouvakis [2]. So the importance of using simulation as a tool for accurate planning and estimation of earthwork operations is revealed. Efforts in using simulation in construction industry started with introducing CYCLONE. Martinez et al. [3–5] extended these implementations to object-oriented simulation environments (COOPS, CIPROS, and STROBOSCOPE, respectively). STROBOSCOPE covered limitations found in its predecessors Martinez [4]. For example, Earthmover was introduced by Martinez [5]. It is composed of integrating STROBOSCOPE with Visio, VBA (visual basic for applications) and Excel. A model was introduced by Moselhi and Marzouk [6,7]. Despite these efforts, construction simulation remains at the academic level due to the complexity of simulation methodologies and complexity of the construction process itself AbouRizk and Hajjar [8]. This survey helps fill the gap by introducing a flexible tool for simulating construction operations.

* Corresponding author.

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.03.034
1110-0168 © 2015 Production and hosting by Elsevier B.V. on behalf of Faculty of Engineering, Alexandria University.

2. Simulation fundamentals

In order to have a clear understanding of simulation and simulation tools used academically or commercially and using the appropriate tool for a particular problem, a summary of some definitions will be presented. *Simulation* is the imitation of the operation of the real-world process or system over time. The behavior of the system as it evolves over time is studied by developing a simulation model. Simulation models can be classified as either *mathematical* or *physical*. A mathematical model uses symbolic notations and mathematical equations to represent a system – e.g. mathematical models are queuing theory, linear programming and Monte Carlo simulation.

Simulation using a computer language is a particular type of mathematical modeling where a special-purpose computer language is used to model a dynamic system. Physical simulation is the modeling of physical aspects of a system – e.g. a simulator for modeling robotic earth-moving tasks. A static simulation model represents a system at a particular point in time. D*ynamic* models represent systems as they change over time. D*eterministic* model is a model which contains no random variables. S*tochastic* model is a model which contains one or more random variables as input. D*iscrete* model is a model where the state variables change only at a discrete set of points in time and a *continuous* model is a model where state variables change continuously over time. Fig. 1 depicts these classifications.

Now it is clear the advantage of Arena is simulating most kinds of models. It is capable of modeling deterministic, stochastic, discrete and continuous systems in different areas of construction (not only earthwork operations as in the case of special-purpose simulators).

Banks [9] gave several rules for determining when simulation is not appropriate. Simulation should not be used in the following cases:

1. When the problem can be solved either by common sense or analytically.
2. If it is easier to use direct experiment.
3. If costs exceed savings.
4. If resources or time is not available.
5. If data are not available.
6. If the personnel needed to validate and verify the model is not available.
7. If the system behavior is too complex or difficult to be defined.

3. Using Arena

The advantages of Arena from other simulation tools (ex. STROBOSCOPE) Martinez [10] are the easy of data entry and flowcharting methodology for modeling. While others are code-based and require programming skills which need high certain level of training. Arena input interface is shown in Fig. 2. Arena contains three important built-in applications, Input Analyzer, Process Analyzer and Output Analyzer. Input Analyzer is used to test for the input data to fit to the appropriate probability distribution. Process Analyzer is used as a what-if analyzer for different sceneries. Output analyzer is used to analyze output data. Animation is the only tool to have a clear understanding of the system (as in a traffic problem, illustrated in the following case study).

4. Case study

This case study is based upon the example presented by Martinez [5]. He developed Earthmover – i.e. a special-purpose simulator for earthwork operations. The example involves hauling 1,200,000 m^3 of material uphill. The material must be moved in at most 75 working days with up to two eight- hours shift per day. This means that production should be at least 1000 m^3/day. The contractor has two excavators for use in this operation: a Hitachi EX 1100 and an Ekerman EC450. Both excavators must be used because the type of material and load area configuration limit the production of the larger excavator (the EX1100) to 767 m^3/h (6.5 m^3 per 0.43 min pass) and the production of the smaller excavator (EC450) to 515 m^3/h (2.75 m^3 per 0.32 min pass). Both excavators are positioned in two separate loading areas. Fig. 3 shows Earthmover interface with main layout. The big curve segment allows traffic in only one direction. This creates a logistic problem that significantly affects the operation and needs to be investigated. Table 1 shows details of haul segments. A fleet of Volvo A30C6 trucks will be used. The number of trucks is to be determined.

4.1. Operating strategy

This problem will require different operating strategies related to the establishment of traffic direction on the big curve and to the routing of empty trucks toward the two loading areas. The first strategy needed to be tested (simulated) is the direction of traffic in the narrow segment (big curve). This strategy

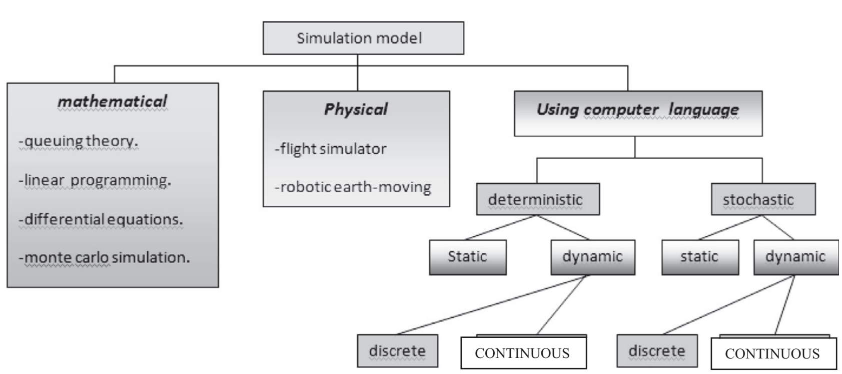

Figure 1 Simulation model classification.