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Concurrent Control on Resource Planning and Revenue/Expenditure Estimation in Large-Scale Shell Material Embankment Projects Management Using Discrete-Event Simulation

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KEYWORDS

Resource planning,
Revenue/ expenditures estimation,
Shell material embankment,
Concurrent control.

ABSTRACT

Resource planning in large-scale construction projects is a complicated management issue requiring mechanisms to facilitate decision-making for managers. In the present study, a computer-aided simulation model is developed based on concurrent control of resources and revenue/expenditure. The proposed method responds to the demand of resource management and scheduling in shell material embankment activities regarding large-scale dam projects of Iran. The model develops a methodology for concurrent management of resources and revenue/expenditure estimation of dam's projects. This real-time control allows managers to simulate several scenarios and adopt the capability of complicated working policies. The main contribution of the proposed model is to employ simulation optimization for analyzing various scenarios of revenue/expenditure in large-scale resource planning projects. Results' validation shows that the proposed model will assist project managers as a decision support tool in cost-efficient executive policymaking on resource configuration. Also, analytical investigations of trend curves indicate the fluctuations of cost/benefit behavior within the study period.

1. Introduction

Resource planning has been an important and complicated issue in construction projects during years and in the coming years. Increasing the number of involved resources in construction project hales an increase in form of an inevitable eventually of intersecting work tasks. It also disrupts the process of construction site operations, the cost of execution, and delay in the termination of the projects. According to the central role of experience and knowledge in the management of construction projects, the existence of a method, which works with professional knowledge, seems to be of utmost importance for project managers, especially in terms of resources and equipment [1,37]. Modeling and simulating of construction projects is nowadays extending rapidly in the field of construction

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research and is known to be a useful tool for examining and evaluating [2]. The role of simulation in construction engineering was presented by working on construction projects and engineering using simulation [2]. Marwa M. Hassan et al. studied concrete-paving operations using simulation [13]. One of the important areas of simulation is earthmoving projects. A framework was presented for optimizing earthmoving operations using computer simulation and genetic algorithms [7]. An Object-Oriented simulation model was studied to provide contractors with a vehicle to estimate the time and cost of project. This paper focuses on the simulation process using discrete-event and simulation. A computer-aided discrete-event simulation was used to estimate the emission of equipment in earthmoving operations [12]. A simulation methodology presented in the evaluation of GPS-based systems' performance has several benefits for earthmoving operations, using web CYCLONE [10]. Since the tasks relevant to earthmoving operations in construction projects, such as dams, road works, and drainage, need several numbers of machines in various types, they are not excluded from the formerly discussed assumptions. One of operations is embankment activities that specialize most of the large-scale dam's projects in earthmoving operations.

In construction projects, time and costs are two essential areas that stand out with respect to control [14,41]. Project cost control is about assuring that work elements within a project accomplish their respective budget [15]. In construction projects, which normally involve a significant amount of cost investment, it is important to control cost in the interest of both the contractor and client [16]. Construction projects include many works, but excavation is one of the most crucial steps in construction projects. The major cost of construction projects concerns excavation. A method has been presented to use in the design of support for underground excavations in rock masses [17,18,19]. The aim of this paper is to decrease total costs of Haraz dam as a large-scale construction project, which is located in Iran, Mazandaran province, Haraz road, and 20 km in southern of Amol city.

In the present study, a computer-aided simulation model has been presented based on discrete-event logic for management, concurrent control, and resource scheduling of embankment activities in dam's projects. Managers and projects' decision-makers ought to be aware of the risks of decisions ahead, such as increasing or decreasing the number of machines, mines selections, route transportations, and administrative and financial policies. Project managers are able to change the input variables during conducting a simulation model; concurrently, they should be aware of the effects of these changes based on simultaneous control. The main contribution of the proposed model is to employ simulation optimization for analyzing various scenarios of cost/benefit in large-scale resource planning projects.

In the next section, a literature review on construction projects with different perspectives is given. Then, a conceptual model that explicitly shows the entities and their features is presented in Section 3. After that, key performance indicators and models logics, which run concurrently, are explained in Section 4. In Section 5, systems models are compared with the real system to distinguish the varieties. In the last section, we conclude the paper to imply the use of computer-aided discrete-event simulation and concurrent control in construction projects.

2. Literature Review

Research has been done on dam's construction projects modeling within different venues such as executive activities planning, optimization, resource allocation, and processes simulation [33]. Because of the nature of the studies within this area and the capabilities of simulation in probabilistic models, the approaches of these studies led to the use of the afore-mentioned approach. In this direction, a discrete-event simulation model was presented to determine the excavation fleet, embankment, and Haul distance [8]. In addition, Fu's research was carried out on the same subject using simulation-based optimization approach [9]. He mentioned the capabilities of simulation in the efficiency estimation considering machines and calculating the cost of operations to use these two indices for earthmoving operations optimization.

Table 1 shows the list of studies which investigated dam's projects control using simulation and costs of construction projects in the last decade.

Tab. 1. The main issues on dam's projects control using simulation approach

Researcher	Year	Consideration
Marzouk & Moslehi [25]	2003	A simulation engine for earthmoving operations to automated systems for selecting a near-optimum fleet configuration
Esther Duflo, Rohini Pande [22]	2005	Productivity and distributional effects of large dams of public infrastructure investment in developing countries
Oliviera & Faria [27]	2006	Numerical simulation of failure scenarios of concrete dams reproduced experimentally on reduced scale models
Seungwoo Han et al. [28]	2006	Estimating the productivity improvement from GPS implementation in earthmoving operations using construction simulation
Michailidis & Mattas [26]	2007	Showing how to calculate the option values of selected options that may be available to managers of irrigation dam investments
Mathew P.McCarthy [30],	2007	A review of the different types of decision support system and their application to water resource management
H.Zhang [29]	2008	A framework of optimizing earthmoving operations using computer simulation and genetic algorithm
Marta Pla et al. [23]	2009	Paying special attention to soil dynamics and the interaction models regarding an excavator's achitecture
PH.Brown et al. [24]	2009	A new tool for evaluating the relative costs and benefits of dam construction based on the multi-objective planning technique
Chang Bum et al. [31]	2009	Presenting an emission model that integrates with discrete-event simulation (DES) for more accurate emission estimates
Rohaninejad & Zarghami [34]	2012	Combining Monte Carlo simulation and finite-difference methods for effective simulation of dam behavior
F.Vahdatikhaki et al. [7]	2013	An overarching tracking-technology-independent framework based on the integration of new tracking technologies with simulation model
Yuxi Liu et al. [21]	2013	Study on a real-time construction quality monitoring method for storehouse surfaces of roller-compacted concrete dams
Atif Ansar et al. [20]	2014	Estimating the cost of building the large dams to find out if it is economical to build more dams
Öncü Hazır [32]	2015	Project monitoring and control with analytical models and decision support tools
Zhou et al. [36]	2016	Numerical simulation of soft longitudinal joints in concrete-faced rockfill dam
Makui et al. [40]	2016	Fuzzy group decision-making for project management considering the static complexity of construction
Cheng et al. [35]	2017	Numerical simulation of reservoir slope deformation during impounding of high-arch dams

A simulation-based approach to real-time data is prior to conducting any simulation by derived statistical data [21,39]. The reason for this superiority is the realistic estimation of the status of system, which increases the accuracy of the resulted prediction models. Consequently, the main core is made up of real-time data. A framework of a real-time simulation for earthmoving construction projects is presented based on tracking the location of executive elements, such as dumps and excavators.

Resource planning in large-scale construction projects has been a complicated management issue requiring mechanisms to facilitate decision-making for managers [3,38]. Computer-aided real-time simulation can be considered as an instrument by which a user can change data manually during the implementation of the model. Moreover, the user can be informed about the effect of changing without needing the connections between simulation model and real system. In fact, the superiority of this simulation using off-line simulation is the possibility of changing the amount of data and modeling variables during the implementation of simulations on the part of project managers. These models have high capabilities in analyzing different situations and "*what-if analysis*". It is necessary to create user interfaces that have the ability of changing variables during model simulation for project managers, considering the nature of these models. For this purpose, the model that is presented in this paper consists of computer-aided software models to simulate the process of shell material embankment in large-scale dam projects.

3. Conceptual Model

The conceptual model is made based on a logical platform where entities require to create a simulated model. Entities of conceptual model in a simulation study are system's entities with their features, system activities and events, and state variables, as shown in Table 2.

Tab. 2. Entities, Attributes, Activities

Type of Entities	Entities	Attributes	Activities
Active Entities	Transportation Machines (TM)	Speed, Capacity, Number, Price of unit Cost	Loading, Transporting, Airdrop
	Loading Machines (LM)	Type of Loading, Number, Price of unit Cost	Lade, Extracting Materials from Mine
	Embankment Machines (EM)	Type of Embankment, Number, Price of unit Cost	Distribute, Clearing, Threshing, Water Spray
Passive Entities	Transportation System (TS)	Transportation Distance	-
	Embankment Area (EA)	Capacity of Embankment Area	-
	Loading Area (mines) (LA)	Capacity of Loading Area	-

Table 3 shows the events and state variables of the conceptual model.

Tab. 3. Events and state variables

Events	State variables
End of Layer Airdrop (ELA)	Whole Amount of Embankment
End of Layers Embankment (ELE)	Amount of Each Layer Airdrop
Beginning of embankment Operation (BEO)	The Coefficient of Efficiency Machines
Creating Traffic in Loading Area or Embankment Area (CTILA)	Income, Cost and Embankment Operation Profit

Figure 1 shows the overview of the logic model as a flowchart. It should be noted that this model is designed based on process-oriented approach. Any movable entity does the same processes during their movements and interactions with different resources in each process. Movable entities of this model are the dumps and their tracks, forming the logic model.

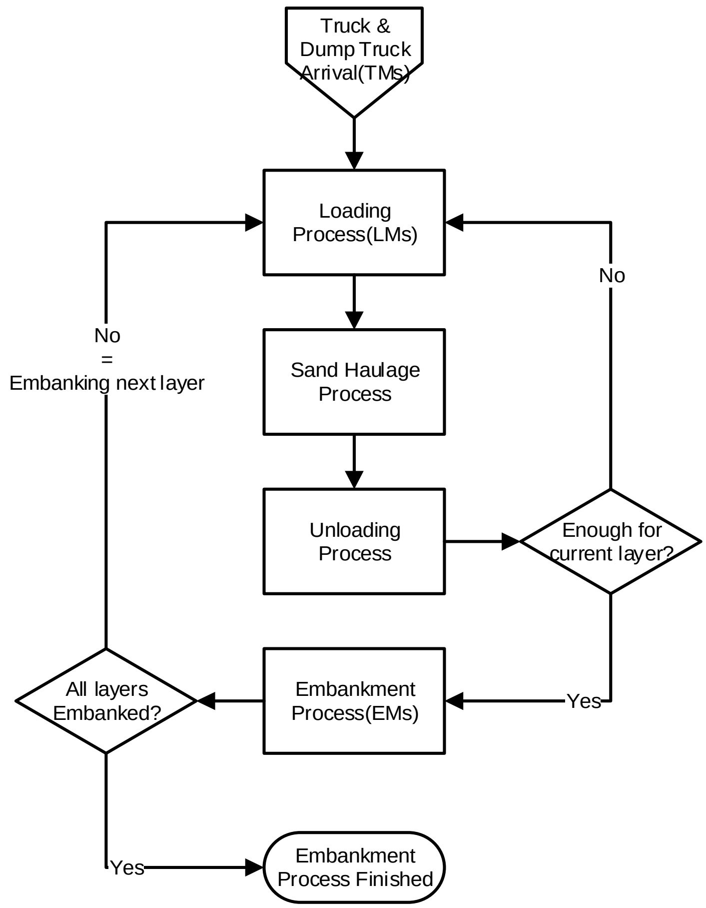

Fig. 1. Embankment operation flowchart in simulation model

At first, transporting machines (TMs) enter LA. Then, LMs that extracts materials from mines do the loading process. When loading process is finished, TMs start Sand Haulage process to arrive at EA. In the EA, the TMs start unloading process. Then, if unloading is not enough for current layer, TMs go for loading process again. However, if it is enough for current layer, the embankment process will be started. In this operation, embankment machines (EMs) act and do the distribution, clearing, threshing, and water spray operations. Therefore, if not all layers are embanked, the loading process will start again; however, if all layers are embanked, embankment process will finish, and when there are many TMs in LA or EA, the traffic has been created.

4. Analytical Model

Shell material embankment is developed based on the real-time simulation approach changing the input variables for the user during the procedure of simulation. This ability allows users to combine two or many scenarios. Therefore, the user is able to make new scenarios during running simulation model. Consequently, if it is possible, better responses than the current responses of optimization models can be achieved.

4-1. Model capabilities

The simulation model has some abilities that are considered as follows:

1) The possibility of entry and changing the number, moving speed, and the capacity of EM during running simulation model sources:
    - Loading (forklifts, excavator)
    - Clearing, threshing, and water spray (bulldozers, graders, roller smooth, water tankers)
    - Transporting (dumps and damp tracks)
2) The simulation model can receive technical specification, the section regarding embankment (whole amount of embankment and the average amount of each layer) and it can run simulation based on these specifications.
3) It can receive loading front's data (mine) and embankment such as the maximum capacity of mine for forklifts and excavator's activities and placement of dumps and damp tracks for loading and maximum capacity of embankment section for dumps and damp tracks for airdropping materials.
4) This model can estimate cost and income based on cost-income unit of shell material embankment operations and price of each unit, cost of machines, coefficient of manpower cost, materials, and coefficient of overhead cost. It should be noted that, in this model, the costs of manpower and materials are considered as a proportion of the machine's cost. The model receives them as one of the inputs from users before running the simulation.
5) By creating a control panel, the performance indicators systems volume can be shown during the procedure of simulation. This panel shows the system state variables such as dumps delay, number of busy dumps in mines and embankment sections, the percentage of embankment operation progresses in each layer, layer No., amount of embankment made, and the rate of available machines' productivity in mines.
6) Analyzing the output of variable trends, such as time of embankment, income, cost, profit, the coefficient of efficiency, etc., to change the number of machines in each of simulation times.

4-2. Mathematical basis

This section describes the mathematical basis of the simulation model. The equations applied to the logics are vital to model's function. Model and its logics, such as loading and embankment logics as well as the logic for controlling variables, are based on certain equations and inequalities that play their role as constraints and decision points in many parts of the model. In the simulation model, many entity holders (known as 'Hold' modules in Arena) are used to check certain conditions that are key points to verify this model and guarantee the model's validity. Cost and revenue estimation are mentioned in this section, too. In order to cover all mathematical equations, they are categorized into three groups: cost and revenue functions, constraints and conditions, updating variables, and process times calculations. The most important equations of these groups are as follows.

4-2-1. Constraints and conditions

Constraints and conditions are mainly defined for model's loading area and embankment area to meet the feasibility of operations. For loading area, if we consider V_{TM} as the volume of a transporting machine (TM), or in other words, the needed space or capacity for a TM, MC_L as loading area's max capacity, and UC_L as the used capacity of loading area, this inequality checks if there is enough space in loading area for the current vehicle:

$$MC_L - UC_L \geq V_{TM}$$

In the model, when this inequality holds, waiting vehicles start moving to be filled with materials by loading facilities. Each vehicle follows the same rule when it is supposed to enter embankment process and unload materials:

$$MC_E - UC_E \geq V_{TM}$$

where MC_E is the max capacity of embankment area, and UC_E is the used capacity of loading area. There should be a condition that determines when the embankment machines have to start embankment processes. When $\overline{V_S}$ is the average volume needed to be dumped for embanking one shell, and V_{CS} is the total material dumped for the current shell, the following inequality is the condition that makes EMs start embankment operations in case of being true.

$$V_{CS} * 0.85 \geq \overline{V_S}$$

The coefficient for V_{CS} is considered in order to take the empty spaces between materials into account. Thus, when dumped materials are compacted by roller machines, the volume of the embanked shell will approximately meet $\overline{V_S}$.

When a TM reaches loading area and both types of loading machines including excavators and loaders are busy at the same time, the model must select which type of loading machine (LM) has to be employed to load materials into the TM. In this occasion, the model will have to select the LM type with less queue length. When the following inequality becomes true, the model sends the TM to be filled by a loader. NQ_{Lo} and NQ_{Ex} are the numbers of queue for loaders and excavators, respectively.

$$NQ_{Lo} \leq NQ_{Ex}$$

4.2.2. Updating variables and process times estimation

When a TM enters loading area, used capacity (UC_L) should be updated. In order to update this variable, TM's volume (V_{TM}) must be added to UC_L:

$$UC_L = UC_L + V_{TM}$$

The same formula is applied to update used capacity of embankment area (UC_E):

$$UC_E = UC_E + V_{TM}$$

The used capacity variables can be updated in the same way when a TM leaves an area:

$$UC_L = UC_L - V_{TM}$$

When a TM leaves loading area, and:

$$UC_E = UC_E - V_{TM}$$

When a TM leaves embankment area.

Machines norms are used to calculate process times of the model. The norm of a machine is the amount of time each machine requires to perform a unit of certain project activity. Thus, to calculate the time of the whole process, the norm has to be multiplied by the amount of activity. For example, if a loader takes 2 minutes to load 1 cubic meter of material, it will take 2*8=16 minutes to fill a truck with 8 cubic meters of capacity. Herein, in this example, there is 8 numbers of activities. Therefore, if N_{Lo} is the norm of loaders and C_{TM} is the capacity of a TM, D_L or duration of loading process will be calculated with the following formula:

$$D_L = N_{Lo} * C_{TM}$$

if the loading vehicle is excavator:

$$D_L = N_{Ex} * C_{TM}$$

While N_{Ex} is the norm of excavators.

It is assumed in the model that no more than one LM can load materials into a truck. However, for embankment facilities, as they can work in a group, the formula for calculating process times changes. The change contains dividing the formula of process time for an activity by the number of machines doing that activity. For example, if a roller spreads 1 cubic meter of material in 5 seconds, 2 rollers can spread 1000 cubic meters of material in (1000*5)/2=2500 seconds. Based on this calculation, the formulas for calculating the duration of spreading, leveling, compacting, and sprinkling processes are as follows:

Norm of dozer (N_{Do})
Volume of current shell (V_{CS})
Number of dozer machines (Q_{Do})
Duration of material spreading process (D_{Sp})

$$D_{Sp} = \frac{N_{Do} * V_{CS}}{Q_{Do}}$$

Norm of dozer (N_{Gr})
Number of dozer machines (Q_{Gr})
Duration of material spreading process (D_{Le})

$$D_{Le} = \frac{N_{Gr} * V_{CS}}{Q_{Gr}}$$

Norm of dozer (N_{Ro})
Number of dozer machines (Q_{Ro})
Duration of material spreading process (D_{Co})

$$D_{Co} = \frac{N_{Ro} * V_{CS}}{Q_{Ro}}$$

Norm of dozer (N_{Sp})
Number of dozer machines (Q_{Sp})
Duration of material spreading process (D_{Sp})

$$D_{Sp} = \frac{N_{Sp} * V_{CS}}{Q_{Sp}}$$

4-2-3. Cost and revenue functions

The costs of project include the cost of machinery (CM), human resources and material cost (HRMC), and overhead cost (OC). In this project, the cost of machinery includes TMs, LMs, and EMs costs. Therefore, the inputs are Loader cost (LC), Excavator cost (EC), Dozer cost (DC), Grader cost (GC), Roller cost (RC), Sprinkler cost (SC), Truck cost (TC), and Dump Truck cost (DTC).

Each machine has a specific unit cost and number. Thus, to estimate the cost of each one, the unit cost should be multiplied by the number of machines. Coefficient of HR and material cost = α and coefficient of overhead cost = β:

Tab. 4. Key performance indicators

Type of machine	Unit cost	Number of machines
Leader	M_1	Q_1
Excavator	M_2	Q_2
Dozer	M_3	Q_3
Grader	M_4	Q_4
Roller	M_5	Q_5
Sprinkler	M_6	Q_6
Truck	M_7	Q_7
Dump Truck	M_8	Q_8

$$CM = \sum_{i=1}^{8} M_i \times Q_i$$

$$HRMC = \alpha \times CM$$

$$OC = \beta \times CM$$

$$Total\ Cost\ [C\ (q)] = CM + HRMC + OC$$

For estimating revenue in this project using Revenue Function, embankment unit price that is a number with million Rials/m^3 has been multiplied by numbers of units.

*Revenue= number of units*Embankment unit price*

$$R\ (q) = q \times D$$

The amount that a producer receives from the sale of q units = R (q)

D is the Embankment unit price per item

Profit Function – *P (q):*

The formula of profit is:

$$Profit = Revenue - Cost$$

$$P\ (q) = R\ (q) - C\ (q)$$

4-3. Computer-aided concurrent logic model

For simulating shell embankment operations in large-scale dam's projects, this model consists of three logics as shown in Figures 2,3, and 4: Main logic, embankment logic, and control logic. The embankment and control logics are sub-layers of the main logic. These three logics are implemented concurrently and contact each other in real-time mode. The embankment is part of the whole work. The main logic consists of four stages where threshing is one of them. Before threshing, the embankment process must be finished. In all of the times, it has been tried to estimate the time and costs of machinery. Therefore, we have to control the quantity all the time.

- Main Logic: this logic consists of the loading process and transporting shell materials from loading area (mine) to airdrop area (a section where the embankment is done).

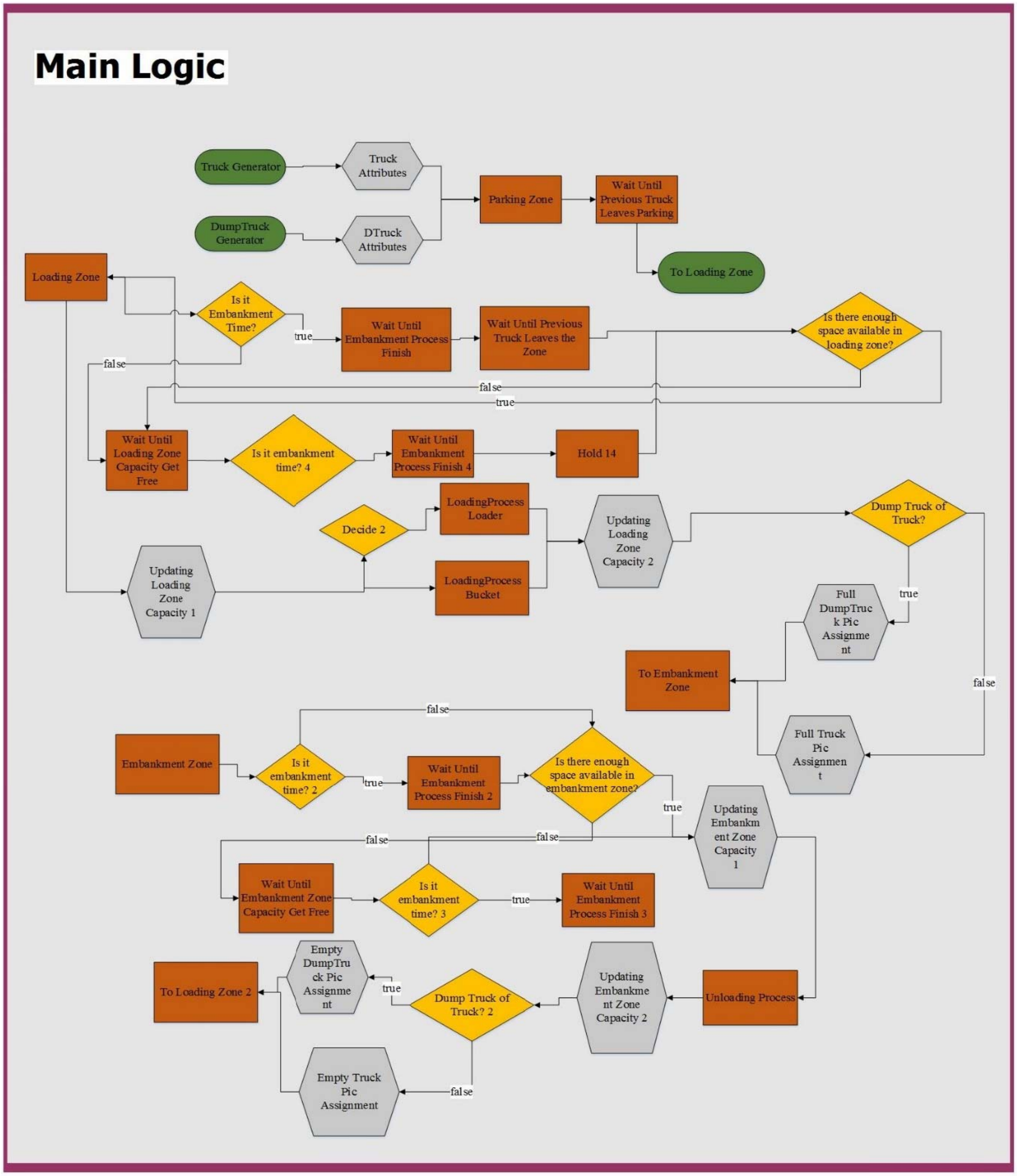

Fig. 2. Simulation main logic

- Embankment Logic: this logic is created for simulating the process of the embankment; that consists of 4 stages which are spreading by bulldozers, clearing by graders, threshing by roller smooth, and water spray by water tankers.

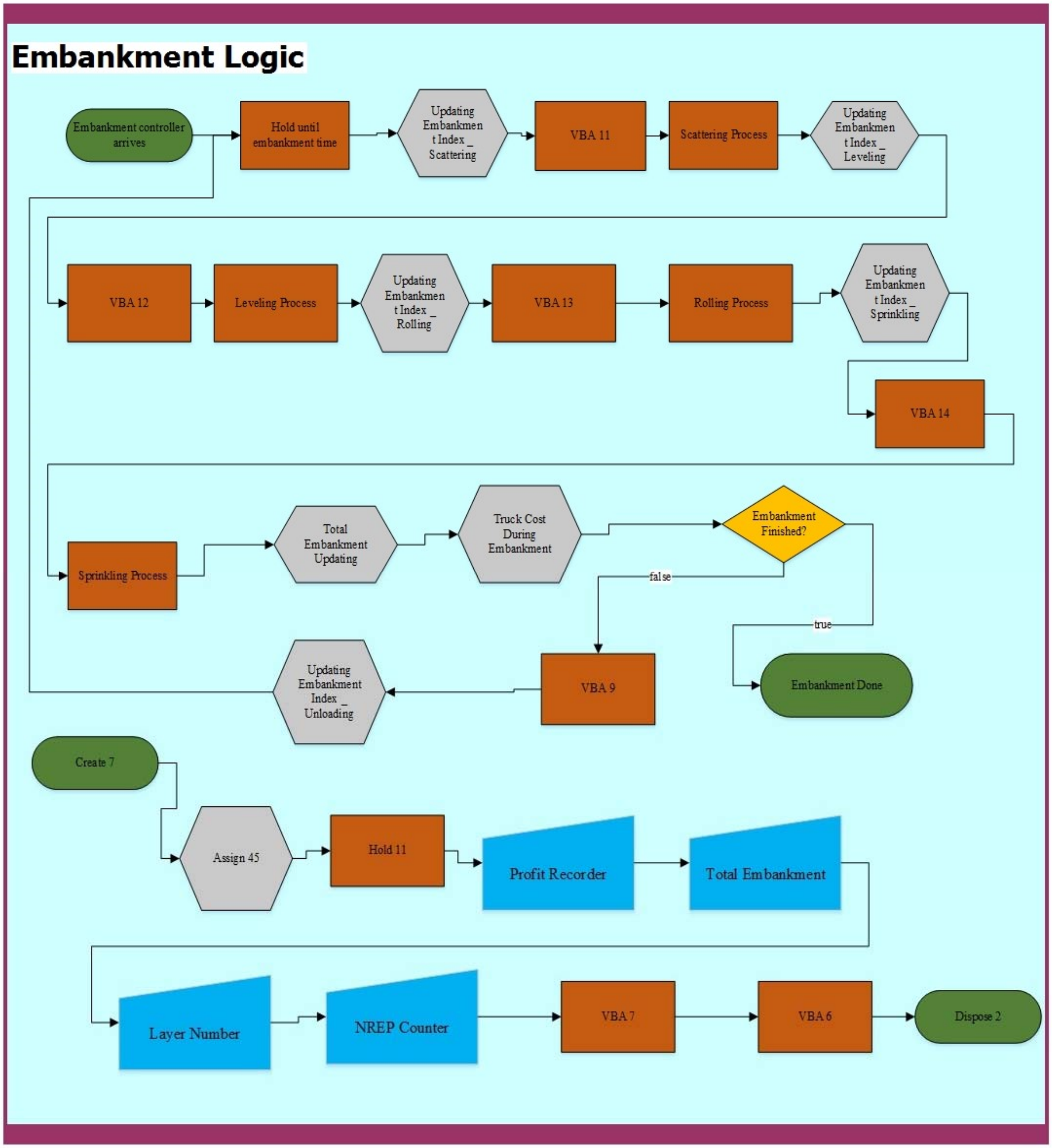

Fig. 3. Shell embankment logic

- Control Logic: this logic controls the quantity of control variables and model input variables at different times of simulation concurrently. The ability to change which is made by users during the simulation is supported by this logic. The VBA (visual basic for application) programming that blocks the control loop is used in this logic. The quantity of control variables and input variables are updated with intervals of an hour simulation. The user will be able to make timescales shorter or longer if needed.

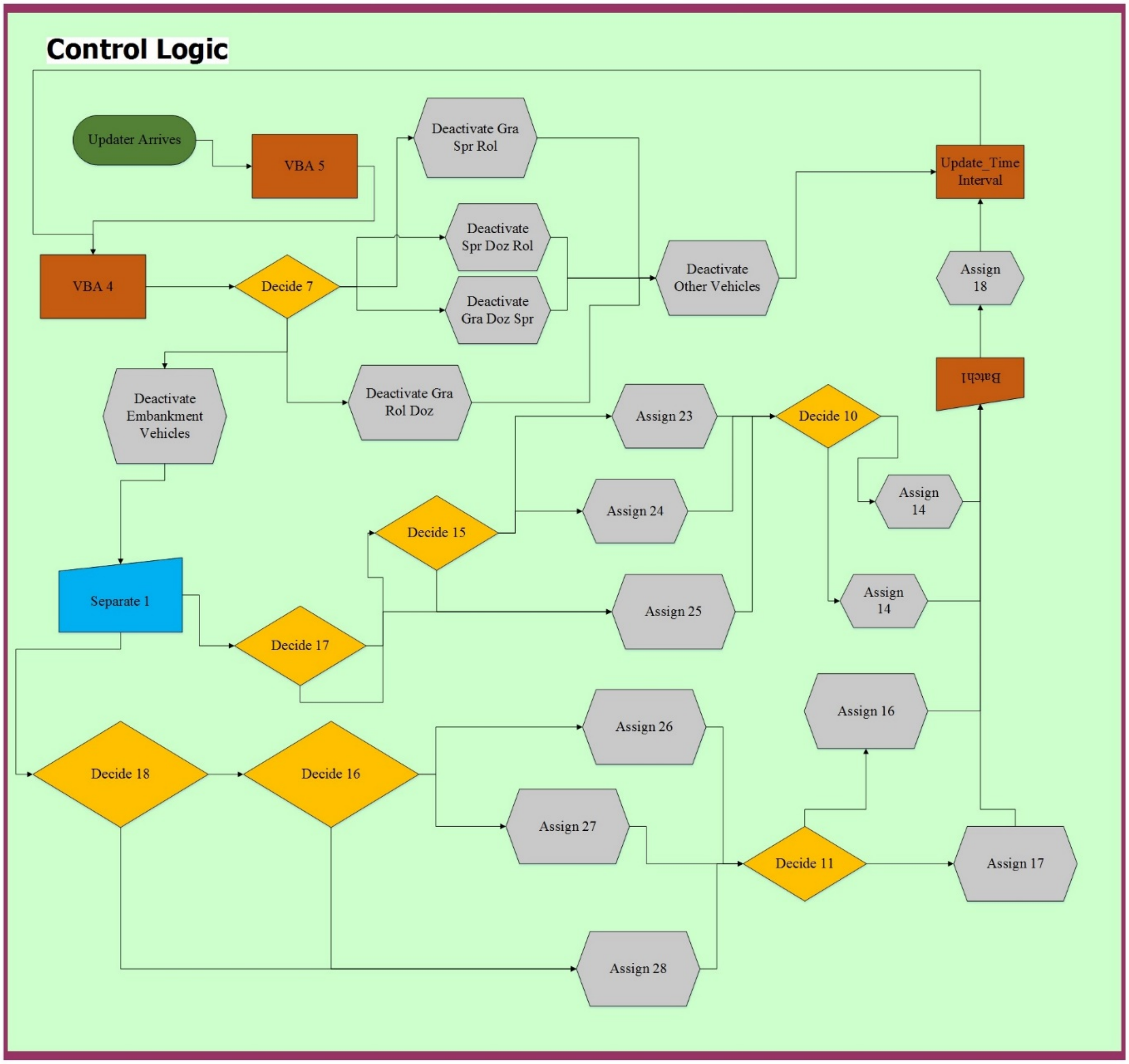

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Fig. 4. Control logic

4-4. Control Panel

In this model, the control panel as a user interface helps managers and project's decision-makers to benefit from the results without needing professional knowledge simulation and access to resource and model logic. This capability makes this model a program for project managers. Figure 5 shows a user panel of shell materials embankment simulation model.

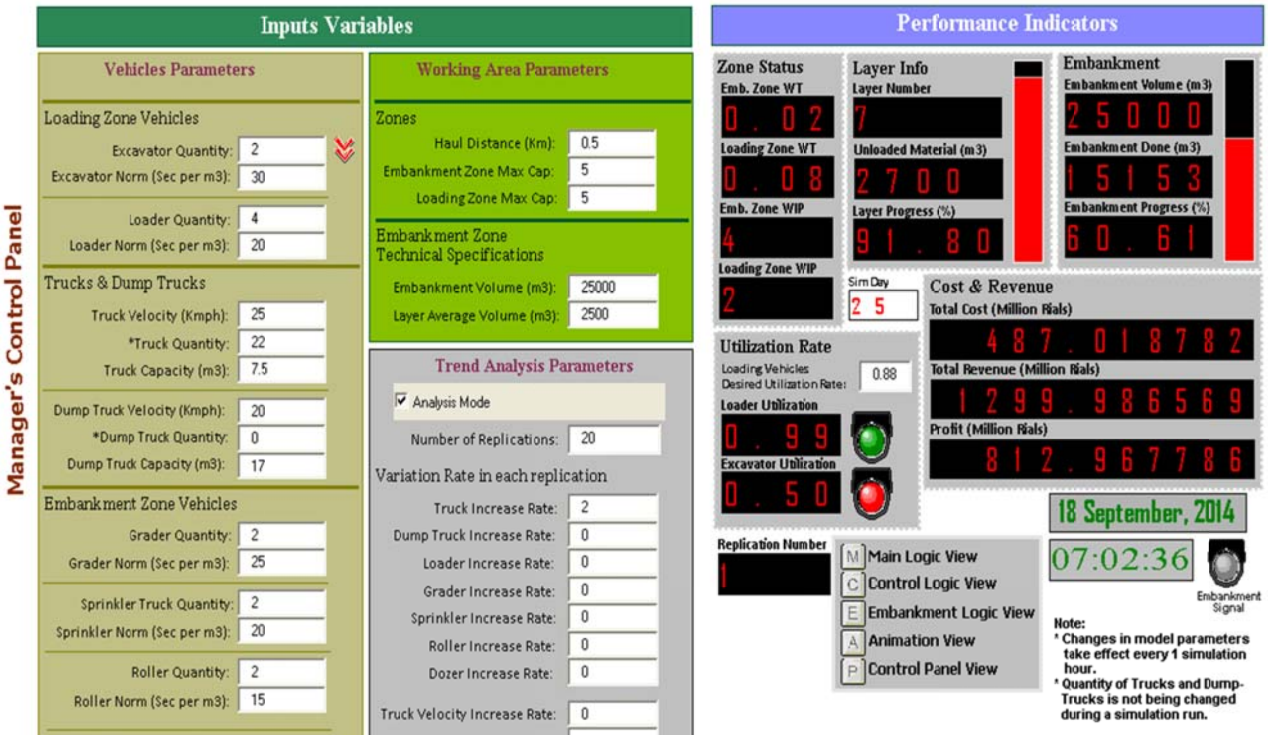

Fig. 5. Control panel of shell embankment execution operations

Input variables of the model are taken from Table 5. A part of control panel input variables that analyzes the trends and makes it possible to monitor the trend of performance indicators in order to change the input variables of the system of users is shown in Figure 5. Before simulation, the costs of project were over 500 million. Key performance indicators, which are shown in Table 4, have been controlled concurrently. By increasing the number of trucks and dump trucks from 10 to 25, the embankment volume decreased from 14763 m^3 to 8254 m^3. Haul distance also decreased from 796 m to 768 m. Thus, system and model cycle time decreased. Consequently, revenue increased, so the profit became 812 million. Performance indicators include profit, productivity rates of forklifts, excavators in mines, and the average delay time of dumps and damp tracks in mine and embankment area.

Tab. 5. Control panel input variables

Category	Name of variable	Unit
Loadings	Number of Excavator	Machine
	Type of Excavator	Second per Cubic Meter
	Number of Forklifts	Machine
	Type of Forklift	Kilometer per Hour
Transporters (Dumps and Damp Tracks)	Number of Dumps	Machine
	Speed of Dump	Kilometer per Hour
	Capacity of Dump	Cubic Meter
	Number of Damp tracks	Machine
	Speed of Damp Track	Kilometer per Hour
	Capacity of Damp Tracks	Cubic Meter
Clearing Machines,	Number of Graders	Machine

Threshing and Water Spray	Type of Graders	Second per Cubic Meter
	Number of Water Tankers	Machine
	Type of Water Tankers	Second per Cubic Meter
	Number of Roller Smooth	Machine
	Type of Roller Smooth	Second per Cubic Meter
	Number of Bulldozer	Machine
	Type of Bulldozer	Second per Cubic Meter
Technical Specifications	Total Amount of Embankment	Cubic Meter
	Average Amount of each Layer	Cubic Meter
Area Specifications	Transportation Distance	Kilometer
	Capacity of Loading Area	Machine
	Capacity of Embankment Area	Machine

This model also can estimate cost and income. Values that are needed for estimating income (price of the unit cost of shell embankment operation in large-scale dam's projects) and estimating the expenditures, such as the cost of machines, manpower, materials, and the overhead cost, will ask the user after the command executed by the user and before running the model (Figure 6). Manpower and materials costs are included as a proportion of the total cost of machines, and overhead costs are included as a proportion of total operation expenses.

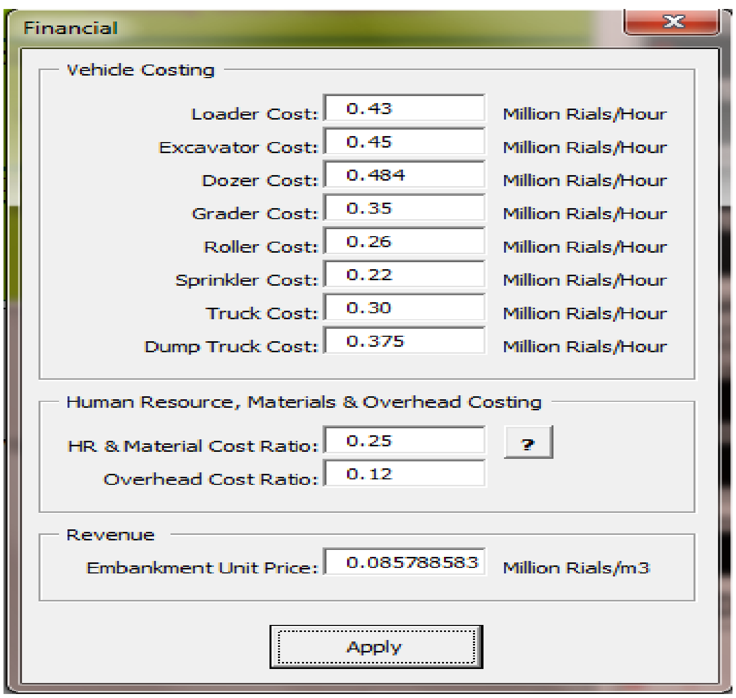

Fig. 6. Parameters of estimating income and cost amount

This model can display the process of embankment transporting by dumps, traffic in mines, and embankment section in a simple animation model, as shown in Figure 7.

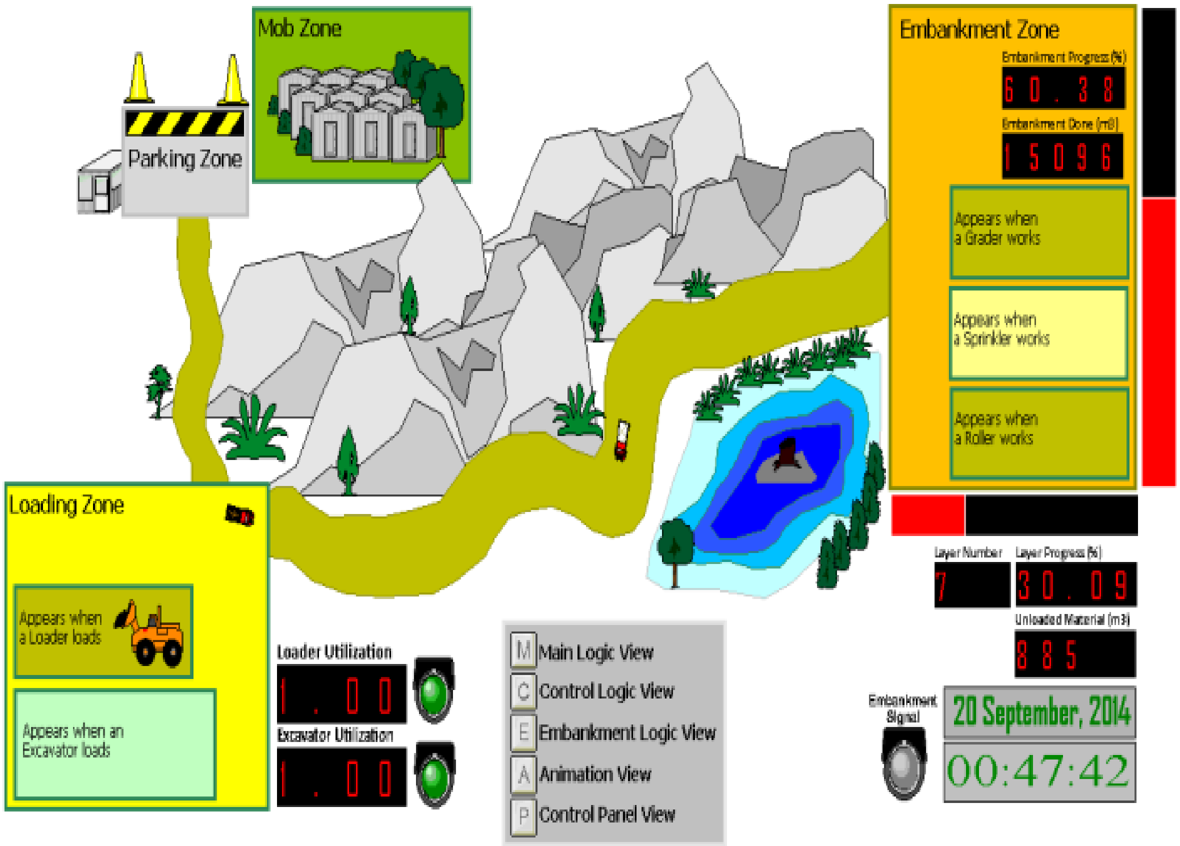

Fig. 7. Shell embankment simulation model

5. Model Validation

Validation of this model is done in two steps. In the first step, the ostensible validity of the model, and in the second step, the validation of model is evaluated in terms of input-output transformation.

5-1. ostensible validations

In ostensible validation, the expected and obvious behaviors are the touchstones of assessing the validity of each model. Accordingly, the reaction to the logic model should not be irrational against any changes. Changing specifications, such as the time of embankment, changes the amount of profit and the number of dumps from 10 to 30; machines examined with primary conditions are represented in Table 6.

Tab. 6. Primary conditions of model for the ostensible validation

Name of variables	Number
Number of excavators	2 (machine)
Number of forklifts	4 (machine)
Number of dumps	10 (machine)
Number of damp track	0 (machine)
Number of graders	2 (machine)
Number of water tankers	2 (machine)
Number of rollers smooth	2 (machine)
Number of bulldozers	2 (machine)
Transportation distance	0.5 (km)
Total amount of embankment	25000 (m^3)
Average embankment amount of each layer	2500 (m^3)

In each iteration of simulation, a dump is added to the model, so the simulation is repeated 21 times. The result of this comparison is shown in Figures 8 and 9.

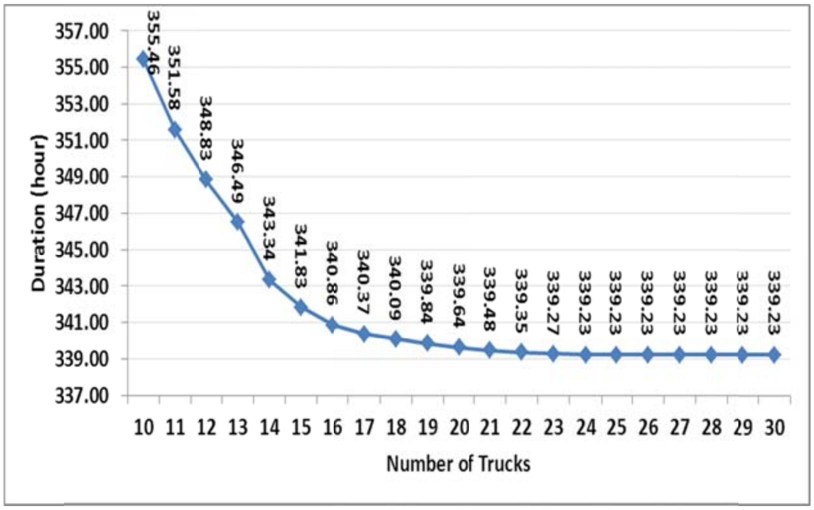

Fig. 8. The embankment to increase the dump

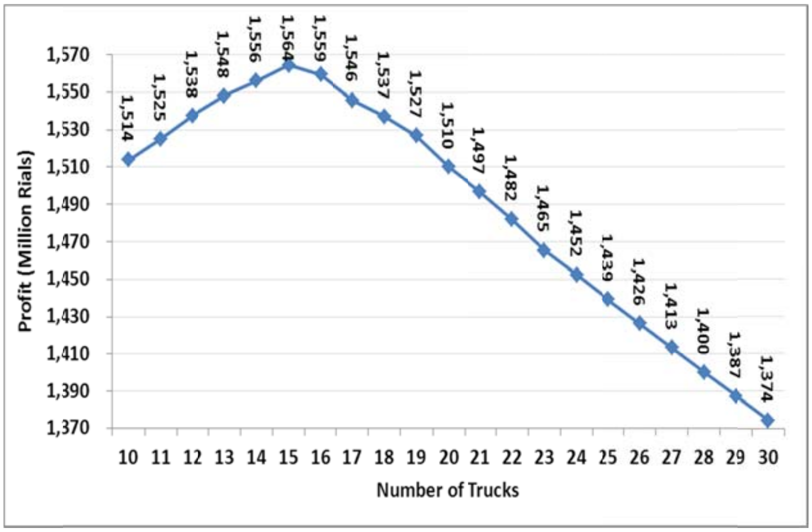

Fig. 9. The process of change profit to increase the dump

According to Figure 8, time of embankment operations of 25000 m^3 of shell materials with average amount of 2500 m^3 of embankment for each layer is reduced, when the number of dumps increased; this is a natural process, as expected. This chart also shows that the shorter time of operation after 24 dumps has stopped, and this point includes the lack of capacity of the mentioned systems. Therefore, increasing the number of dumps to more than 24 has not affected the embankment operations and time, and it only increased the operation's cost. Figure 9 shows that 15 dumps are optimal for this operations under the conditions visible in Table 6. If the number of dumps increases from 15 to 24 machines, each dump has a part in revenue, yet the cost imposed on model would be higher. Consequently, operations profit is reduced. If the number of dump is more than 24 units, because of complete system capacity, extra dump will be idle and inefficient. Therefore, it not only has a role in revenue, but also will only impose financial burden on operations.

5-2. Validation by input-output transformation

A module of embankment operations process, which is done in the real system, is chosen as a criterion. Consequently, the evaluation of the models empowers it to create similar outputs with the outputs of the real system by entering input variables of this module in the simulation model. 20 cases of embankment activities carried out in the study with the number of machines and embankment amounts are selected for comparison. The duration of completing 20 cases of shell embankment activities in Haraz dam site has been compared and contrasted with that in the propsoed model. The result of this comparison is shown in Table 7. According to the definitive model, a simulation is run for each item only once. After the test, the results of paired comparison in α=5% between the outputs of the model and real system are provided in Table 8 and Figure 10.

Tab. 7. Outputs of the system and model

Cases	Loader Qty	Excavator Qty	Truck Qty	Embankment Volume (m^3)	Layer Average Volume (m^3)	Haul Distance (m)	System Cycle Time (Days)	Model Cycle Time (Days)
1	1	1	23	14763	1136	796	33.50	33.85
2	3	2	18	14778	739	1223	31.00	30.59
3	3	3	25	12264	681	531	25.00	25.25
4	2	1	11	18042	1002	937	39.00	38.78
5	1	1	15	8105	623	878	20.50	20.25
6	3	1	16	9207	921	1026	19.50	19.25
7	1	3	10	17167	1321	1174	27.00	26.85
8	3	2	15	9682	605	793	31.00	31.42
9	3	3	20	14796	1480	556	35.00	34.65
10	3	3	15	14757	1135	1731	31.00	31.48
11	2	3	25	13775	1060	1418	28.50	28.44
12	1	3	25	11079	923	1642	24.00	23.60
13	1	3	16	18098	1392	1974	39.00	38.72
14	3	3	17	15242	802	1830	32.00	32.42
15	2	3	10	14796	779	515	30.00	30.08
16	3	1	14	10764	979	662	23.00	22.53
17	2	2	12	12644	843	539	18.50	18.57
18	1	2	18	15790	831	684	38.00	37.52
19	2	1	15	10638	818	1788	22.50	22.88
20	2	1	17	8254	486	768	18.00	17.91

In Table 7, the simulation of 20 cases with inputs of the real system is shown. The model's cycle time has been estimated so as to be compared with the system's cycle times. Therefore, to decide whether the model is valid or not is done based on the differences. As shown, there are no massive differences between them. So, it can be understood that the model is valid, but it has to be compared with statistics so that it could have a scientific form. The paired comparison test is used to test the validation.

6. Discussion

In Table 8, using T-paired to compare system's cycle time and model's cycle time with α=0.05 and if P-value is greater than null hypothesis, the following holds.

$$\begin{cases} H_0: There\ is\ no\ significant\ difference\ between\ the\ outputs\ of\ simulation\ model\ and\ real\ system \\ H_1: There\ is\ significant\ difference\ between\ the\ outputs\ of\ simulation\ model\ and\ real\ system \end{cases}$$

Therefore, the model is valid through estimating Mean, Standard deviation (Stdev), and Standard error (SE) for the Mean at the level of 95% confidence interval for the mean difference of the obtained P-value. Therefore, it can be easily understood if the null hypothesis is rejected or not.

Tab. 8. Results of paired comparison test

T-Paired for System Cycle Time (Days) - Model Cycle Time (Days), α=0. 05				
	N	Mean	StDev	SE Mean
System Cycle Time	20	28.3	6.75	1.51
Model Cycle Time	20	28.25	6.75	1.51
Difference	20	0.0484	0.3289	0.0736
95% CI for mean difference: (-0.1055, 0.2023)				
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.66, P-Value = 0.518				

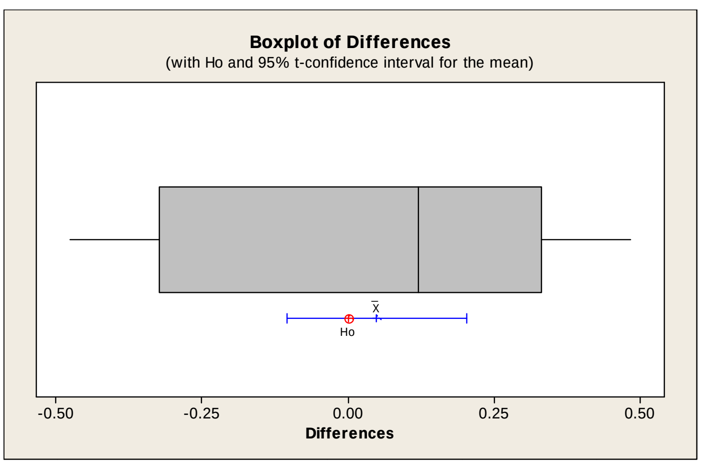

Fig. 10. Box plot of result of paired comparison test

Based on the results, P-Value>α, there is no reason for rejecting the null hypothesis. Therefore, there is no significant difference between the outputs of simulation model and the real system; therefore, the model is valid in terms of input-output transformation. For managers, it is very helpful to obtain information about fluctuations of cost/benefit on resources of a project. The current project management software products cannot handle the case, and the necessity is handled through the proposed simulation-based method. Furthermore, the discrete-event simulation methods primarily used in previous studies have a limitation to modeling a whole construction process of the project. This study presents a practical framework to conceptualize the primary components and flows of large-scale construction projects and their interrelationship resulting from shared resources to control revenue/expenditure.

7. Conclusion

This study presents a model of computer-aided simulation for large-scale shell embankment operations. Computer-aided simulation, as a decision support tools, facilitates project's resource management for managers. Previously, costs and revenues, number of vehicles, embankment volume and other parameters were calculated separately. Most of the calculations were manually done. In this paper, revenue/expenditure, embankment volume and a number of vehicles are controlled concurrently using the computer-aided simulation. The simulation model of this study runs several scenarios created prior to the implementation of the model for making a decision according to the results. It also allows a user to create combination scenarios (possibility to react to output variables behavior and change input variables during execution model) to examine and adopt different policies for operations management. This study shows capabilities of a simulation model for large-scale shell embankment operations presented in the form of a decision support system. Results' validation has shown that using this model in real projects as a decision support tools will assist project managers in making correct decisions.

The possibility of extending this model can open a way to other researchers to use the approach of this study. They can choose different types of earthmoving operations because of capabilities of the model presented in this paper. The realization of this idea requires a mechanism. This mechanism allows users or managers to add and subtract without requiring any access to the resources and logic of software. The main limitation of the proposed model is the data collection from different projects' site, which was very time-consuming due to lack of integrated centralized database. The model could not be used for representing the complex behaviors of resources sharing in large-scale construction projects. The model is not also tailored to the problems encountered in large-scale construction projects; many of its elements are superfluous (e.g., explicit resources, queues, even entities), and others are heavily modified (e.g., events of construction occurrences rather than sites where the system variables change).

With extending this model, a specification that is more technical can be received from embankment section; and also it can be assigned through the theoretical thickness of each layer on the map. These extensions make closer the conditions of question to the conditions of the real system. The scope of using this model in the field of development projects management can be expanded by adding the probability of failure for machines, the possibility of cost breakdown of manpower, materials, overhead cost, and also the processing time and movement speed of dumps and damp tracks.

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