

## An Automated Input Data Management Approach for Discrete Event Simulation Application in Slip-form Operations

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### ABSTRACT

Slipforming operation's linearity is a source of planning complications, and operation is usually subjected to bottlenecks at any point, so careful planning is required in order to achieve success. On the other hand, Discrete-event simulation concepts can be applied to simulate and analyze construction operations and to efficiently support construction scheduling. Nevertheless, preparation of input data for construction simulation is very challenging, time consuming and human prone-error source. Therefore, to enhance the benefits of using DES in construction scheduling, this study proposes an integrated module to establish a framework for automating the generation of time schedules and decision support for Slipform construction projects, particularly through the project feasibility study phase by using data exchange between project data stored in an Intermediate database, DES and Scheduling software. Using the stored information, proposed system creates construction tasks attribute [e.g. activities durations, material quantities and resources amount], then DES uses all the given information to create a proposal for the construction schedule automatically. This research is considered a demonstration of a flexible Slipform project modeling, rapid scenario-based planning and schedule generation approach that may be of interest to both practitioners and researchers.

**Keywords** – Automation, Slip forming, Modeling, planning, Data exchange, Scheduling generation, EZstrobe

### I. INTRODUCTION

Modeling and simulation of construction process supports construction planning and can help in reducing the risks concerning budget, time and quality on a construction project [1]. Construction projects are usually delivered in an uncertain environment in which project resources and activities interact with each other in a complex manner [2]. Due to vertical Slipforming process's linear nature, it is considered a complicated process where it depends on efficient management of numerous parameters, moreover by considering the variability that always exists in construction operations, Slipform operations requires careful and thorough planning where Structure cross section; jacking rate; and concrete layer thickness can affect the Slipforming rate therefore project duration and so can the, pouring method, the site location, equipment location, and many other factors. Therefore, scheduling by coordinating the aforementioned parameters, resources of workers, machines and materials in a time-efficient way is required in order to realize the construction project within the anticipated time and budgeted costs. Traditionally and even today scheduling is still mostly specified and accomplished manually using Gantt chart techniques and the critical path method [CPM] which can be an extensive and very time

consuming process. Although these two concepts are utilized by a number of commercial software solutions in the field of construction planning and scheduling, software is unable to assess schedule correctness, especially of process duration for a given amount of available resources, as well as its inability to optimize the schedule according to total costs or total duration work against the application of these methods within more complex scheduling tasks. In addition to the previous, generation of construction schedules are currently manually accomplished, resulting in an extensive and time consuming process that is insufficiently supported between software applications.

On the other hand, simulation of construction processes has proven to be a suitable approach for detailed investigation of construction schedules, moreover simulation has the ability to incorporate uncertainty, has been used as an effective approach to better capture the complicated interactions and uncertainties found in construction operations [4]. While the benefits of using DES as a decision support tool have been recognized, it has not been widely adopted by the construction industry [5]. One of the reasons for this lack of implementation is the amount of manual work needed to specify and maintain the interdependencies between activities and resources in the construction supply chain [6],

[7]. Therefore, in this paper we consider scheduling within the context of discrete event simulation [DES] with an end goal of generating a construction schedule through automatic data extraction from a DES results file, focusing on automating physical model input.

## II. BACKGROUND

### 2.1 DES in construction

Discrete Event Simulation, referred to as simulation has proved to be an effective tool for complex processes analysis [8] besides being a well-established approach for analyzing, scheduling, and improving construction processes in the AEC arena. [9]. The methodology of discrete-event simulation, which concerns “the modeling of a system as it evolves over time by a representation in which the state variables change only at a countable number of points in time” [10] provides a promising alternative solution to construction planning by predicting the future state of a real construction system following the creation of a computer model of the real system based on real life statistics and operations. An event in the context of discrete-event simulation can be defined as an instant of time at which a significant state change occurs in the system [11]. One of the major aims that operations simulation is used in the construction industry is that DES assists in reducing resource idling time, improving resources utilization, site productivity and identifying logistics bottlenecks for storages and transportation [2]. Since the 1960s, it has been recognized that discrete-event simulation [DES] provides a powerful tool to model and evaluate construction processes, including the overall project duration as well as the utilization of resources. (12) Method is the earliest known method for construction simulation. Developed systems are designed for both simple [e.g., CYCLONE] and very advanced [e.g., STROBOSCOPE] modeling tasks but do not satisfy the need for a very easy to learn and simple tool capable of modeling moderately complex problems with little effort. Nevertheless, while considering the benefits of DES in construction, a major problem that remains valid and restricts the wide utilization of DES is module input data. Input data management within simulation projects often becomes a major challenge. In order to overcome this obstacle and benefit from the power of simulation modeling, Input data management of simulation models have to be simplified to encounter various scenarios and changes in the construction project. [13] Identified four methodologies of input data management as shown in Fig.1: [a] Manual data collection and processing. [b] Manual data collection and processing. [c] Automated connection between data sources and simulation model using an intermediary database and [d] direct link between the CBS and the

simulation model. Since their study, published in 2002, there have been advances in the input data management process itself as well as in support systems such as data collection systems, databases, and simulation software. [14]. Consequently this paper has adapted the third methodology “Intermediate Database” utilizing the MS Access program as an external data storage unit for project conditions material quantities that is considered the simulation model’s main input data.

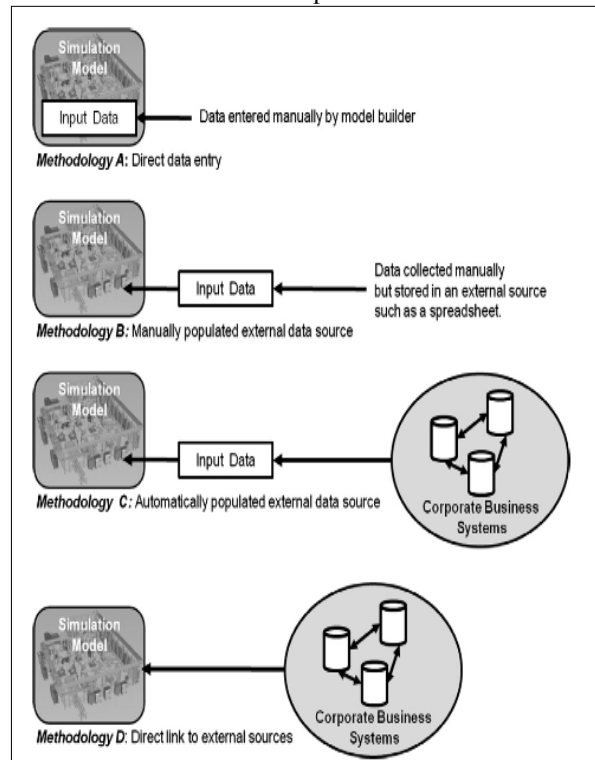


Fig.1 DES Alternative IDMs

### 2.2 Slipforming Principles

Slip-forming is a method of erecting silos by sliding up the whole form using an automated jacking device embedded in concrete and pouring concrete continuously, once concrete has developed early strength enabling it to stand by itself after placing. The essential elements of a Slipforming assembly are two parallel wall panels [about 1.2 m tall] supported by steel frames and horizontal yokes connected to hydraulic jacks as shown in Fig.2. After Slipform is completely assembled on a concrete base, the forms are filled slowly with concrete. When the concrete in the bottom of the forms has gained sufficient rigidity, the upward movement of the forms is started and continued at a speed that is controlled by the rate at which the concrete sets. Many challenges face slip-form usage in the construction industry. The rate of movement of the forms is controlled and matches the initial setting of concrete so that the forms leave the

concrete after it is strong enough to retain its shape while supporting its own weight. The forms move upward by mean of jacks climbing on smooth steel rods embedded in the hardened concrete and anchored at the concrete foundation base. These jacks may be hydraulic, electric, or pneumatic and operate at speeds up to 24 in. /h [609.6 mm/h]. Lifting rates may vary from 2 or 3 in. per hr to in excess of 12 in. per hr, depending on the temperature and other properties of the concrete as shown in Fig.2. The jacks for lifting of the form are installed on the horizontal crossbeam between the yokes. When the Slipform is lifted, all the jacks are activated at the same time. Hydraulic driven jack is the most common type of jack used. The Slipform panel will normally have an inclination in the vertical plane in order to make the panel self-clearing in relation to the concrete wall. The steel reinforcement, inserts and box outs are placed inside the wall panels as they are continuously being lifted by the jacks and as the concrete are placed in layers of uniform thickness. Slipform continuous work needs high-level management of resources and convenient work environment. In addition, weather conditions and labor union restrictions might add to these challenges. It requires many accompanied equipment that have to work continuously parallel to the slip-forms. In addition, any changes in the operational information during construction cost a lot of time and money [15] the main key to a successful operation is the ability to synchronize and control the concrete setting time. A decision as to the economy of Slipforming a structure should be based on the cost savings that may accrue as a result of a decrease in construction time and easier construction of other elements of the structure

### III. RESEARCH METHODOLOGY

#### 3.1 Overview

This paper presents a Discrete event simulation-based scheduling approach as a practical solution for automatic schedule generation for Slipform construction projects by integrating the schedule generation process with a discrete event simulation process in order to enhance both capabilities of the utilized tools. Moreover, this research presents an integrated methodology for estimating and prediction of construction productivity and time generated by Slipform system using EZstrobe software. To facilitate the generation of the input data required for the discrete event-based simulation, this paper introduces an Input Data Methodology [IDM] for simulation; this paper introduces a methodology which is based on extracting the simulation input data from an intermediate database acting as a source of input data. In this research, a Discrete Event Simulation [DES] and Scheduling Software framework is proposed to enable the

implementation and integration of DES in the planning and follow-up of construction activities Fig.3 illustrates the overall workflow.

The framework consists of the following concepts: (1) Estimating quantities of material and geometric data to the indeterminate database external database; (2) Inserting project conditions and activity constraints in Database (3) Maintain database for final simulation input data methodology; (4) Developing an intelligent simulation model that reads data directly from database as export results and lastly (5) generating a CPM schedule in MS project through data from DES. These concepts are explained in detail in the following subsections.

#### 3.2 Collect Project Conditions Stage

First step in the system is gathering and collecting project data, where project data is categorized into two groups [1] Quantification of Materials and Resources quantities, and [2] Inserting activities Data. First, Material quantities is calculated and estimated using traditional quantity surveying method by creating a project WBS for all activities and work packages, this step ends in product data shown as quantity per work package. Second, activities data is inserted in order to generate a valid and realistic schedule. Project constraints such as required activities, tasks durations, duration distribution and interdependencies between activities must be inserted through the system by the user.

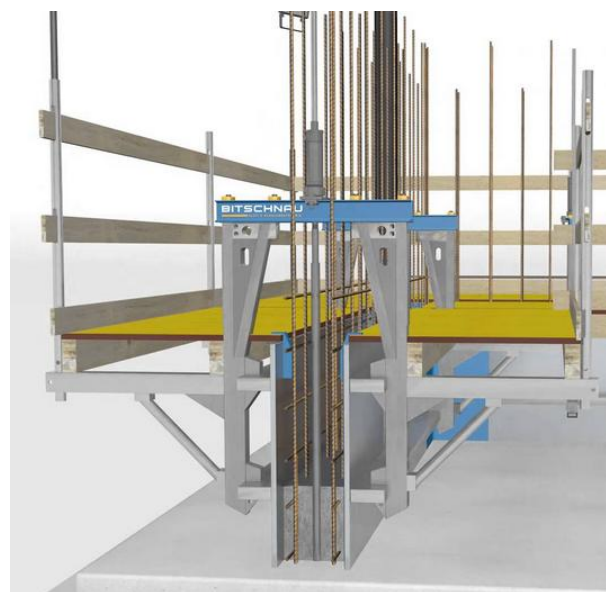


Fig.2 Slip form System Component

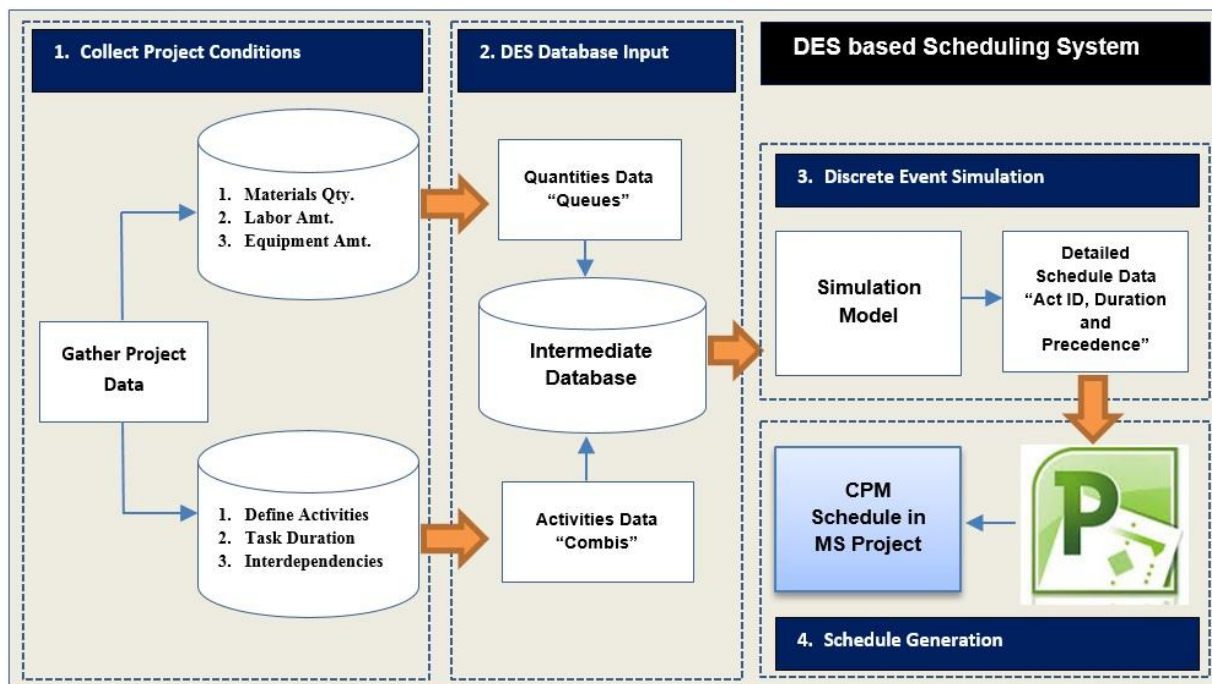


Fig.3 Proposed DES Integrated System Framework

### 3.3 Database Input Data Stage

After project conditions are completely gathered and organized and all project objects quantities [foundations, walls, etc.] are exported to MS Access, the IDM method is considered ready to pass the information from database to the simulation model. The simulation model is generated using EZstrobe simulation software. Data from database is transferred to the simulation Visio objects through an add-in in the Visio named “Database wizard”. Process of transferring is based upon mapping method, where Database wizard assigns each Visio object to its related database element for both Combis and Queues. Fig.4 presents a screen shot of MS Access data stored and ready to be mapped to DES model for Activities durations and Resources Data

ID	Name	Optimistic	Most Likely	Pessimistic	Duration (PERT)	Act Type
1	LoadTruck	8	8.8	9	8.7	Combi
2	HeulTruck	10	10.5	11	10.5	Normal
3	DumpTruck	0.75	1	1.25	1	Normal
4	ReturnTruck	7	8	9	8	Normal
5	LayoutLevel	60	90	120	90	Combi
6	CompactsSurface	60	90	120	90	Combi
7	PCFoundPour	3	4	5	4	Combi
8	WtConchHard	1440	1520	1600	1520	Combi
9	FoundRebarWrk	100	110	120	110	Combi
10	FoundFormWork	65	70	75	70	Combi
11	RCFoundPour	3	4	5	4	Combi
12	StarFormAss	1400	1500	1600	1500	Combi
13	RaiseForms	1400	1500	1600	1500	Combi
14	ConnectJacks	1400	1500	1600	1500	Combi
15	InstallPanels	1400	1500	1600	1500	Combi
16	HydJacksInstall	1400	1500	1600	1500	Combi
17	InstallPlatform	1400	1500	1600	1500	Combi
18	JackForm	10	10	10	10	Combi
19	PlaceConcrete	8.125	9.75	10.25	9.5625	Combi
20	WallRebar	7	8	9	8	Combi
21	RaiseSttoDeck	5	6	7	6	Combi

Fig.4. Database Screen shot of Activities Data

### 3.4 Discrete Event Simulation Stage

EZstrobe discrete event simulation software has been applied through the proposed system in order to conduct the site-level simulation of construction operations Fig.5 shows a screen shot of mapping Combi activities from database to Visio by defining both Name and Duration and mapping it to the Visio Object Further details of the operations simulation that is applied in this work is presented in Section 4.

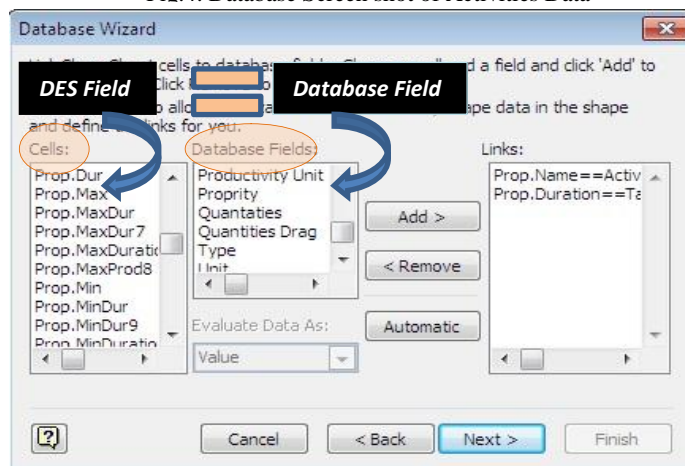


Fig.5. Mapping Database Data to DES Model

### 3.5 Schedule Generation Stage

Second, activities data is inserted in order to generate a valid and realistic schedule. Project constraints such as required activities, tasks durations, duration distribution and interdependencies between activities must be inserted through the system by the user. Fig.6 presents the generation of schedule activities approach where; step [1] results are produced after

DES run; step [2] results are transferred from result template format [.sto] to a manageable format [.txt] and; step [3] activities durations and sequence are connected to the pre-organized schedule in excel file. MS project has the capability to generate schedules by mapping relevant data from excel file with a definite order to facilitate the schedule generation.

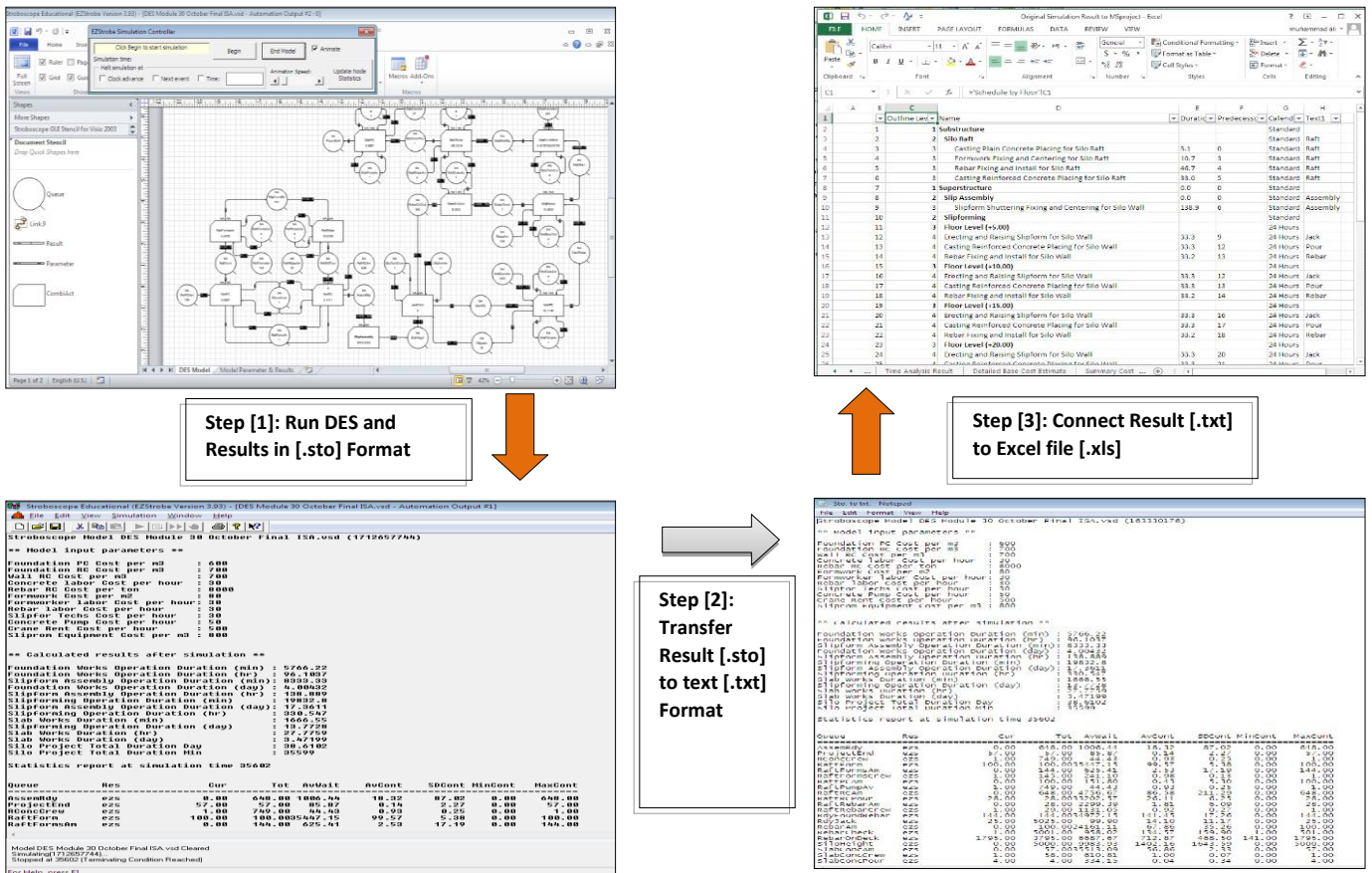


Fig.6. Schedule generation from DES Cycle

## IV. PRELIMINARY PROTOTYPE

As for a case study, the preliminary prototype of the proposed integrated framework has been implemented and developed by using EZstrobe as the DES tool, and MS project as the construction planning software. Furtherer, to illustrate the framework model capabilities a Slipform case of study was chosen to apply the proposed software to a silo project located in Bandar Abbas, Iran for the Hormozghan cement factory project. This building built with Slipform concrete and has a height of 50 m and average productivity of 0.15 m/hr. and a total Slipforming duration of 14 days. The following subsections present the evaluation results of this case study. Prototype Model is based upon four stages of construction processes encountering Silo earthwork,

Foundation work, Slipform Assembly and Slipforming works where each process covers the related activities.

### 4.1 Database Input Data Generating

Project conditions are inserted in the intermediate database where the data stored in the database can be retrieved by the Simulation model using the Open Database Center “ODBC” connection.

#### First; Material and Resources Quantities

Silo material quantities are estimated using traditional Quantity survey where QS estimates quantities from project drawings and provides the relevant parameters needed to perform the quantity takeoffs of the weight [in tons] of steel, the area [m

of the forms, and the volume [m<sup>3</sup>] of concrete for each construction element. After material quantification the calculated material quantities of each building element are inserted to an MS Access files. Table. 1 and 2 presents a quantity table that summarizes the quantities of materials and resources that will be needed for the tasks in the project.

Second: Activity Durations

In order to create the durations input data, each project activity is assigned to duration with a certain distribution. Activities durations is shown in Table 3 where it presents the category of activity, activity name, type of duration and assigned duration. It is noted that due to the uncertainties in the industry both uniform and triangular distributions owns the majority of duration types as illustrated in the aforementioned table.

**4.2 EZstrobe Simulation Model Development**

By working with the practitioners and experts for this case project, an EZstrobe network for a full Slipform project, has been created and developed. This network indicates the construction tasks, the logical links between tasks, and the resources required for the project. Specifically, the following sub models are encountered through building the simulation model the four models are connected through a fusion Queue for ease of studying each sub model. In addition, crews formulation for concrete pouring, steel rebar and formwork crews are involved. The methodology dramatically facilitates the generation of input data for a simulation. The following section illustrates the DES model phases.

Silo Earth works Phase Model

Silo Earth works Model describes Earth works for the Slipform project, where it encounters the excavation works, hauling excavated soil to dumps and dumping, moreover the sub model shows compacting works for the excavated area. Silo earth work Sub model process is furtherer illustrated in Fig.7; durations for activities in phase model are shown in Table 3.

Foundations Works Model

Foundations Works Model describes typical foundation works for the Slipform project, where it encounters the plain concrete pouring under foundations, steel and rebars works for foundations, form work and Reinforced concrete pouring for foundations. Foundations Work Sub model process is furtherer illustrated in Fig.8, durations for activities in phase model are shown in Table 3.

Slipform Assembly Works Model

Slipform Assembly Works Model describes the Slipform assembly process, where it encounters raising the jacks and connecting it using horizontal straps, installing panels, installing hydraulic jacks and platforms. Slipform assembly Sub model process is furtherer illustrated in Fig.9, durations for activities in phase model are shown in Table 3.

Slip forming Works Model

Slip forming Works Model describes the Slip forming operation sequence for Silo construction, the sub model encounters jacking forms based on jacking rates and layer thickness and concrete setting time, moreover concrete placement, rebar work and raising rebar to working decks. Slip forming Sub model process is furtherer illustrated in Fig.10; durations for activities in sub model are shown in Table 3.

Table 1 .Silo project material quantities

ID	Phase	Resource	Resource Description	Unit	Amount
1	Earthworks	Soil	Amount of Excavated Soil	m <sup>3</sup>	555
		Soil	Amount of Compacted Soil	m <sup>2</sup>	340
2	Foundation Works	Plain	Foundation PC Beneath Raft	m <sup>3</sup>	45
		Reinforced	Foundation RC Raft	m <sup>3</sup>	340
		Steel	Raft Rebar Amount	ton	50
		Formwork	Raft Formwork Amount	m <sup>2</sup>	60
3	Assembly Works	Slipform	Yokes Set for Slip Assembly	Set	1
		Slipform	Straps Set for Slip Assembly	Set	1
		Slipform	Panels Set for Slip Assembly	Set	1
		Slipform	Platforms Set for Slip Assembly	Set	1
4	Slipforming Works	Reinforced	Slipform Continuous Concrete	m <sup>3</sup>	1300
		Steel	Slipform Continuous Steel Crew	ton	100

Table 2 .Project resources amounts for IDM

ID	Phase	Resource	Resource Description	Unit	Amount
1	Earthworks	Equipment	Number of Excavators for	No.	1
		Equipment	Number of Trucks for Hauling	No.	1
		Equipment	Number of Compactors for	No.	1
2	Foundation Works	Labor	Foundation Formwork Crew	Crew No.	1
		Labor	Foundation Steel Rebar Crew	Crew No.	1
		Labor	Foundation Concrete Placing Crew	Crew No.	1
3	Assembly Works	Equipment	Number of Foundation Concrete	No.	1
		Labor	Slipform Techs Crew Number	Crew No.	1
		Equipment	Hydraulic Jacks Set Number	No.	1
4	Slipforming Works	Labor	Slipform Continuous Concrete	Crew No.	1
		Labor	Slipform Continuous Steel Crew	Crew No.	1
		Labor	Slipform Finishing Surface Crew	Crew No.	1
		Equipment	Slipform Crane Available	No.	1

Table 3 .Project activities durations for IDM

ID	Phase	Activity Name in DES	Activity Type	Duration Type	Duration [min]	MS Project Calendar Type
1	Earth Work	LoadTruck	Combi	Triangular	[8,8,9]	Standard
		HaulTruck	Normal	Triangular	[10,10.5,11]	Standard
		DumpTruck	Normal	Deterministic	1	Standard
		ReturnTruck	Normal	Triangular	[7,8.5,9]	Standard
		SitePrep	Combi	Triangular	[60,90,120]	Standard
		SurfaceFinis	Combi	Triangular	[60,90,120]	Standard
		PCFoundPou	Combi	Triangular	[3,4,5]	Standard
2	Foundation Work	WtConcHard	Combi	Deterministic	1600	Standard
		FoundRebar	Combi	Triangular	[100,110,120]	Standard
		FoundForm	Combi	Triangular	[65,70,75]	Standard
		RCFoundPou	Combi	Triangular	[3,4,5]	Standard
		StartFormAs	Combi	Triangular	[1400,1500,160]	Standard
		RaiseForms	Combi	Triangular	[1400,1500,160]	Standard
		ConnectJack	Combi	Triangular	[1400,1500,160]	Standard
3	Slipform Assembly Work	InstallPanels	Combi	Triangular	[1400,1500,160]	Standard
		HydJacksInst	Combi	Triangular	[1400,1500,160]	Standard
		Install	Combi	Triangular	[1400,1500,160]	Standard
		JackForm	Combi	Deterministic	10	24 Hours
4	Slip forming Model	PlaceConcret	Combi	Triangular	[8.5,9.5,10.5]	24 Hours
		RebarandEm	Combi	Triangular	[7,8,9]	24 Hours
		RaiseSttoDec	Combi	Triangular	[5,6,7]	24 Hours





### 4.3 Simulation Results

After inputting simulation modeling data, the simulation model runs and generates a result output. The results define both Queues and Combi characteristics. For scheduling purposes the concern will be on the Combi characteristics [activities] only, where activities durations are finally defined. Results are produced after simulation in EZstrobe extension [.sto] therefore to be able to generate the schedule the results must be transferred to an [.xls] format. Consequently the results are saved first as text file [.txt] and after that the required data for scheduling which is the durations of Combi activities are automatically linked to an excel file to automate the operation later and ease of information transfer. Fig.18 illustrates graphically the first data transport route from the simulation model to an applicable readable format in excel for scheduling purposes. The driving results in this case of study are both the Slipforming duration operation and the Total silo construction project. In this case study, EZstrobe took approximately 42.67 s to run 1000 simulation replications. After simulation results are presented in [.sto] file user stores the simulation results in .txt format, which allows the system to read and extract the results. For instance, minimum duration, average duration, and maximum total duration of this Slipform project construction project are 48.8, 53.6, and 57.6 days, respectively, while Slipforming duration for this case study was 12.6, 13.8 And 14.2 Days as minimum duration, average duration, and maximum durations.

In addition to the previous, this research discusses the main factors that should be carefully taken into consideration when planning a Slipform project as schedule can be directly affected by these factors as shown in next section.

### 4.4 Schedule Generation

Within various simulation runs, the same activities, constraints and material are used. For each simulation run, the work step schedule and the workload of employees was recorded and evaluated afterwards. However, this approach generates a multitude of practical schedules that can be analyzed and visualized to identify good solutions manually. Planners can select the best solution according to the objectives of their particular project. The selected schedule can subsequently be imported into standard scheduling systems for further modifications and evaluations. Therefore, after simulation results are generated the user can save these results in a .txt format then link required schedule parameters to an excel file that is in turn mapped to the MS project software as shown in steps 1 to 3 in Fig.11. Then, the user must operate MS Project to map this Excel file and set a starting calendar date for the construction project to generate a network [or bar

chart] schedule. Notably, at this moment, name, duration, and the predecessors of each work task in the Excel file are retrieved automatically by MS Project mapping feature as illustrated earlier. Fig. 11 presents the generated schedule as viewed in MS Project. The proposed system exports activity list of data to the format of a Microsoft Project file. Each activity lists the activity name, description, duration in days [assuming 40-hour workweek] for standard calendar and [assuming 168-hour workweek] for 24 hour calendar, start date, end date and predecessors. By exporting the output in Microsoft Project format, all of the functions of this popular and powerful scheduling tool may easily be applied to the generated preliminary schedule.

## V. MODEL VALIDATION AND VERIFICATION

In this research the case of study data was collected from Hormozghan Cement Project which had more than twenty towers and silos that were constructed using Slipforming technique considering jacking Rates and productivity in meter per hour. [T. Zayed et al, 2008] Average Maximum capable jacking rate was 30 cm/hr; average productivity was 15 cm/hr in which concrete pouring used crane and bucket. The project total Slipform duration was 14 days. This study showed that after utilizing the model in prediction of Slipform operation duration and silo construction project duration the developed model shows robust results with 97.9 % validation. Meanwhile it can be used to predict productivity properly for the presented scenario combinations.

A verification step was held on to ensure the automatic data exchange between database module and discrete event simulation module process. Specifically, the verification was conducted to make sure that the durations and quantities data automatically extracted from database did not lose/skip any data or material properties. Moreover verification was conducted to ensure that simulation model result matches the generated schedule total duration for various strategies implemented. On the other hand, the research considered only the basic building components such as foundations, rebar and formwork to propose a systematic approach in the substructure works, while for the Slipform operation the building components were considered sufficient to compare with the status of the actual case of study. Therefore, the comparison between the result in the case study and real construction project results was not made due to the fact that our demonstration did not include all the building components that a real project would do. However, we intend to include more building components in the future research and verify the results in a more realistic way.

**Step 1: Convert Simulation Results from [.sto] to [.txt]**

```
Stroboscope Model Full Model 24 Nov.vsd (1691640320)

** Calculated results after simulation **

Operation Total Dur Hr : 646.657
Earth work Duration Day : 2.71958
Foundation work Duration Day: 16.1597
Assembly work Duration Day : 18.75
Slipform work Duration Day : 13.6486
Total Project Duration Day : 51.2779

Statistics report at simulation time 38799.4

Queue Res Cur Tot Awaiting AvCont SDCont MinCont MaxCont
-----
AssemBFinish ezs 0.00 5000.00 9850.01 1269.35 1617.52 0.00 5000.00
CheckRebar ezs 180.00 4980.00 540.07 69.32 92.07 0.00 300.00
CompactAmt ezs 1.00 3.0012873.13 1.00 0.07 0.00 1.00
CompactARamt ezs 0.00 340.00 1170.40 10.26 57.58 0.00 340.00
ConcCrwComm ezs 1.00 1001.00 19.28 0.50 0.50 0.00 1.00
DumpSoil ezs 554.00 555.0038203.56 546.48 52.33 0.00 555.00
END ezs 5000.00 5000.00 9854.49 1269.93 1617.96 0.00 5000.00
ExcavationAmt ezs 0.00 555.00 507.60 7.26 50.97 0.00 555.00
ExcavatorAmt ezs 1.00 38.00 1012.57 0.99 0.09 0.00 1.00
GoundCompact ezs 1.00 1.0037674.00 0.97 0.17 0.00 1.00
HydacksAmt ezs 0.00 1.0016075.40 0.41 0.49 0.00 1.00
RaftConcCrew ezs 1.00 386.00 96.53 0.96 0.20 0.00 1.00
RaftFormAmt ezs 0.00 60.00 8575.40 13.26 24.84 0.00 60.00
RaftFormCrew ezs 1.00 4.00 9647.35 0.99 0.07 0.00 1.00
RaftPCAMt ezs 0.00 45.00 1393.40 1.62 8.28 0.00 45.00
RaftPumpAmt ezs 1.00 386.00 96.53 0.96 0.20 0.00 1.00
RaftRCAMt ezs 0.00 340.00 9393.40 82.31 143.30 0.00 340.00
RaftSteelAMt ezs 0.00 50.00 5700.40 7.35 15.95 0.00 50.00
RaftSteelCrew ezs 1.00 51.00 652.93 0.86 0.35 0.00 1.00
RdyConJacks ezs 0.00 1.00 0.00 0.00 0.00 0.00 1.00
RdyConPour ezs 0.00 5000.00 0.00 0.00 0.00 0.00 5.00
RdyFormwork ezs 50.00 50.0032989.00 42.51 16.10 0.00 50.00
RdyFoundc ezs 60.00 60.0030154.00 46.63 24.91 0.00 60.00
```

**Step 2: Generate Schedule in Excel from Simulation Results**

ID	Outline Level	Name	Duration	Predecessors	Calendar
1	3	Foundation Earthworks			Standard Slipform
2	4	Excavation Soil for Raft	2.1		Standard Slipform
3	4	Leveling Site Layout	1.0	2	Standard Slipform
4	4	Compacting Surface	1.0	3	Standard Slipform
5	3	Foundation Concrete works			Standard Slipform
6	4	Placing Plain Concrete (PC) for Raft	1.0	4	Standard Slipform
7	4	Curing Plain Concrete for Hardening	3.2	6	Standard Slipform
8	4	Rebar work for Raft foundation	4.9	7	Standard Slipform
9	4	Form work for Raft Foundation	1.1	8	Standard Slipform
10	4	Placing Reinforced Concrete (RC) for Raft	1.0	9	Standard Slipform
11	3	Slipform Assembly Works			Standard Slipform
12	4	Install and Erect Slipform System	18.8	10	Standard Slipform
13	3	Slipforming Concrete Walls			Standard Slipform
14	4	Level (+5.00) Erecting and Raising Slipform for Silo Wall	1.37	12	Standard Slipform
15	4	Level (+5.00) Casting Reinforced Concrete Placing for Silo Wall	1.37	1455	Standard Slipform
16	4	Level (+5.00) Rebar Fixing and Install for Silo Wall	1.37	1555	Standard Slipform
17	4	Level (+10.00) Erecting and Raising Slipform for Silo Wall	1.37	14	Standard Slipform
18	4	Level (+10.00) Casting Reinforced Concrete Placing for Silo Wall	1.37	15	Standard Slipform
19	4	Level (+10.00) Rebar Fixing and Install for Silo Wall	1.37	16	Standard Slipform
20	4	Level (+15.00) Erecting and Raising Slipform for Silo Wall	1.37	17	Standard Slipform
21	4	Level (+15.00) Casting Reinforced Concrete Placing for Silo Wall	1.37	18	Standard Slipform
22	4	Level (+15.00) Rebar Fixing and Install for Silo Wall	1.37	19	Standard Slipform
23	4	Level (+20.00) Erecting and Raising Slipform for Silo Wall	1.37	20	Standard Slipform
24	4	Level (+20.00) Casting Reinforced Concrete Placing for Silo Wall	1.37	21	Standard Slipform
25	4	Level (+20.00) Rebar Fixing and Install for Silo Wall	1.37	22	Standard Slipform
26	4	Level (+25.00) Erecting and Raising Slipform for Silo Wall	1.37	23	Standard Slipform
27	4	Level (+25.00) Casting Reinforced Concrete Placing for Silo Wall	1.37	24	Standard Slipform
28	4	Level (+205.00) Rebar Fixing and Install for Silo Wall	1.37	25	Standard Slipform
29	4	Level (+30.00) Erecting and Raising Slipform for Silo Wall	1.37	26	Standard Slipform

**Step 3: Retrieve Schedule data from Excel file by MS project Mapping**

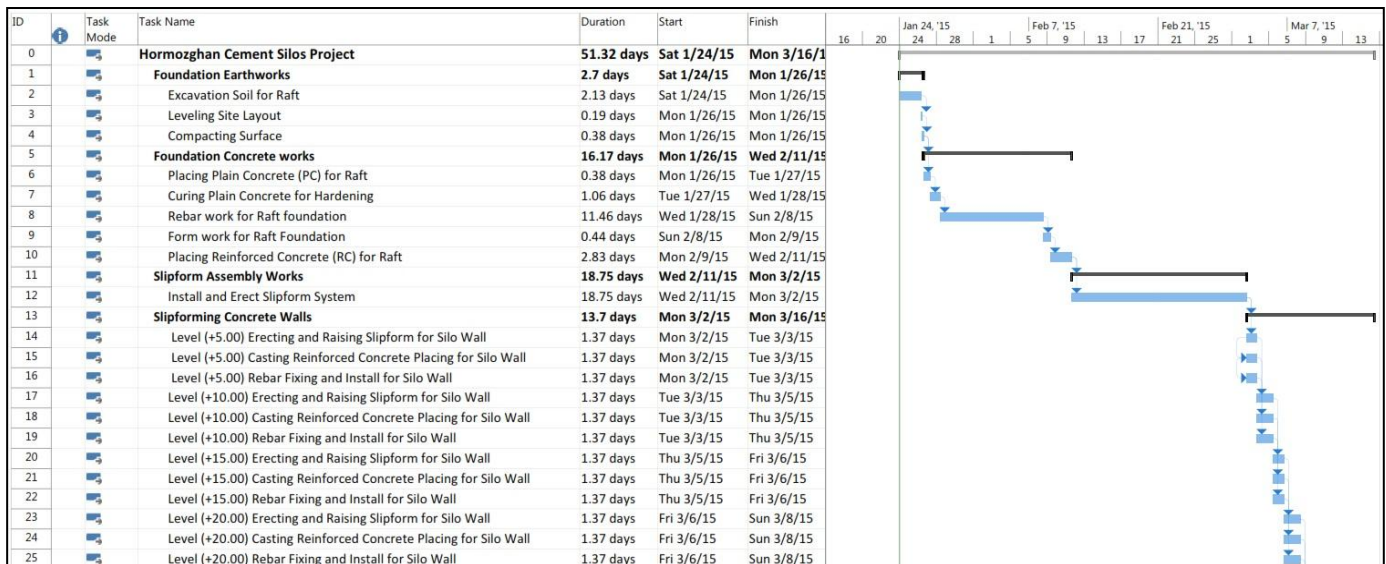


Fig.11. Generating Schedule in MS project from DES Results for Scenario No.13

**VI. CONCLUSIONS**

The scheduling of construction processes for building projects is extremely complex with a multitude of requirements, such as technological dependencies and resource capacities, to be taken into account, together with principal guidelines of project duration and available funds. The constraint-based simulation technique can generate effective schedules virtually automatically, but creating the necessary input data manually is tedious and time consuming.

This paper has introduced a new methodology for creating input data for a discrete-event simulation of construction processes. The methodology, implemented in a software application

is based on an interactive process whereby an intermediate database works provides the simulation model with the process model and a corresponding product model the methodology dramatically facilitates the generation of input data for a constraint-based simulation. Moreover, this paper proposes a framework to be used for automated schedule generation from DES. This system focuses on data exchange using a well-established input data management scheme "Intermediate Database". To test the suggested framework, a prototype has been developed and applies the techniques described in the methodology and through the information gathered, the proposed DES based scheduling approach is used to create construction tasks,

calculate activity durations using PERT technique for duration provided for activities from a database, and apply sequencing rules. Once computed the prototype produces a preliminary schedule.

In the demonstration presented in this paper, the prototype was successfully applied to a DES Slipform construction project consisting of ordinary construction stages and a Slipform operation stage. The project components and stages were modeled with basic DES software "EZstrobe" then results were exported to facilitate construction schedule generation. Applying the prototype system to the produced file, a preliminary schedule was generated and able to be visible in various formats. While the proposed methodology is able to quickly generate construction schedules, there are a few limitations observed. In the paper, a limited number of basic building components such as foundations, rebar works, form work and concrete works were applied in generating the construction schedule in the case study. However, its possible application can be extended to all the building components with further detailing each building component in the process. Another extension of this research could integrate the techniques used here in automatically linking a generated schedule's tasks to a 3D building model using BIM technology for the creation of 4D building simulations.

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