# Simulation and Optimization of Utility Tunnels Construction

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***Abstract*— The utility tunnels are major features in several projects on different scales ranges from different sizes of campuses like university and hospital campuses to large scale utility tunnels used in mega residential projects and airports. They are usually the housing space for different utilities required for the projects that are on multi-building scale. The simulation of the construction of utility tunneling hasn't received enough attention in research while tunneling in general has been studied significantly. The scheduling and planning of utility tunnels as an example of linear projects are facing big challenges of optimizing the project duration, work balance and utilization of the available resources. Linear Projects consist of several similar elements with repeated activities from one element to the other. This paper will propose a discrete event simulation model to plan the construction sequence of utility tunnels with optimum duration and resources. It also represents a case study as an example for a utility tunnel construction in Egypt.**

***Index Terms*— utility, tunnels, simulation, modeling, construction, scheduling, planning, management**

## I. Introduction

The definition of the term "Tunneling" is used to define activities related to the underground excavation operations aiming to achieve certain functions based on different types of such operations [1]. Service tunnel or a "Utility tunnel" is an underground tunnel smaller in width and elevation from the Normal Vehicles Crossing Tunnels with the functions of water distribution, sustainability of the environment, limiting the urban expansion, distribution of sewerage systems, increasing green spaces, reducing energy use and reducing emissions and noise levels productions. All these functions are associated with many challenges with the most significant challenge of Space Requirement which is why the use of underground Utility tunnel is an alternative way to solve the problems of urban utility placement since it saves a lot of upper surface space for better use. Utility tunnels have lots of features in comparison to the normal systems used, some examples of these features are the Capability of Locating, Maintaining and Repairing utility systems rapidly, the Capability of avoiding the disruption of the environment of the upper surface and protecting the community from emergencies regarding the infrastructure systems as much as possible (Ex. Outrages), the reduction of the future Maintenance and repairing Costs since the permeant Easy accessibility that the service tunnels can provide, the Easily Cooperation between the systems provided since they are all exposed and accessible in one place Cooperation between the systems provided since they are all exposed and accessible in one place (No Need for digging and Excavation on the long term) and finally Service tunnels can help terminate the need for Manholes in roads [2].

Service Tunnels can have many possible sizes based on the required function, it can be large enough to fit the Utility Systems required or it can be very large to accommodate Humans or even utility transfer Vehicles [3]. The methods of construction of the utility tunnels can be divided into two methods which are Precast Concrete (Prefabricated Concrete) where large ready blocks are prepared, poured off-site and transferred to the site location to be connected together, the advantages of this method is reduction of the amount of reinforcement used in the concrete and the reduction of the cracks and repair of the concrete. The Building scale samples of this method are railway tunnels, water transport tunnel, gas pipeline tunnels and service tunnels [4]. but this method disadvantages are the difficult transportation method of the prefabricated items, the uneconomic suitability of the use of this method in small projects, the need for the availability of a complete well-defined scope of work and large capital cost [5]. for the previous reasons the Cast on site concrete (On-situ Concrete) is used in common projects which also have a very wide scale ranges from small linear projects due to its acceptable cost to very large linear projects due to its high load capacity relative to its cost.

The Utility tunnels are an example of Linear Projects which are projects that consists of several similar elements where the activities included in each element are repeated from one element to the other. This repetition can be either due to the uniform repetition of activities through the project (for example multiple similar houses and high-rise buildings consists of typical floors) or due to geometrical layout of the project (for example highway and Utility tunnels) [6].

Scheduling and resourcing of such linear projects represent a major challenge during the planning phase because the schedules of such project needs to guarantee the optimum smooth flow of resources while obeying the structure elements' dependency, achieving the minimum

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planned duration to complete the project, accounting for all the possible interruptions and risks that might face the project and determine the optimum number of resources required which gives the maximum utilization of such resources [7]. In order to achieve such requirements, an optimization process needs to be prepared that reflects all the feasible alternatives and reach a final optimum decision.

## II. Method

### A. *Planning of Linear Projects "Utility Tunnels"*

The traditional way for the optimization process of resources and duration is using the Microsoft Excel spreadsheets with defining the logical difference between continuous repeated activities then representing the process and results on the Line of Balance (LOB) graph. This method could reserve the resources allocation and the logical dependencies between the construction elements, determining the start and finish time for each activity but without the discussion of the optimization of the work balance [6]. The Line of Balance is a Resource driven technique which means that the resources are the governing factor forming the Line of Balance to reach a full utilization of these resources in linear projects. However, several characteristics of the Line of Balance don't match those of linear projects schedules models [8]. The Genetic Algorithms optimization models are widely used in Linear repetitive projects with the objective of minimizing the project duration, Cost or both in a Multi Objective optimization model which has shown promising results [9].

### B. *Discrete Event Simulation*

The Discrete Event Simulation technique is defined as a way of modeling the operations of a system as a discrete (Independent) sequence of events happening over a certain period. Each event happens at a certain instant in time and marks a variation of state in the system. Between each consecutive event, no change in the system is assumed in order to reach leaping criteria of the simulation from one event to the next one [10]. Different from the commonly used scheduling tools, the discrete event simulation can be used for the planning of linear projects while taking into consideration the effect of variability in the construction process; well consider the effect of changes in the durations of activities along the project construction chain which can lead to optimization of the project total duration and better allocation of the available resources [11]. Also, the discrete event simulation can count for the dynamic nature of the construction project's activities durations and resources; which correct the assumption of fixed durations and available resources for a project along the total project duration in order to reflect the real nature of the construction projects [12].

## III. The Proposed Model

The aim of this model is to find a new approach to manage and plan the liner projects. this new approach is prepared using discrete event simulation as a tool to plan the construction time schedule, number of resources, compare different numbers of resources or any other results that could affect the construction management of the linear projects. Accordingly, this model is developed as a conceptual model depending on the Quantity Surveying data from the Building Information Model (BIM) of the project or these data can be prepared manually by surveying on a Microsoft Excel spreadsheet. These data are prepared, integrated in the Discrete Event Simulation as the inputs to the model, then the model examine the dependency relations between the different elements of the projects which means in order to start working in a certain construction element (for example the Reinforced Concrete foundation) what needs to be prepared or finished before the start of this successor task (for example the Plain Concrete foundation and the insulation). The model also examines the resources available for each construction process and assign each required resource to the activities then consider when to release such resource from the assigned activity to start work on the next task. Finally, the results are computed from the model in the form of how many resources are needed for each construction process and for the overall project, the percentages of utilization of each resources and how many parts the project should be divided into in order for the best use of the available resources and space (Work Balance) as Illustrated in Fig. 1.

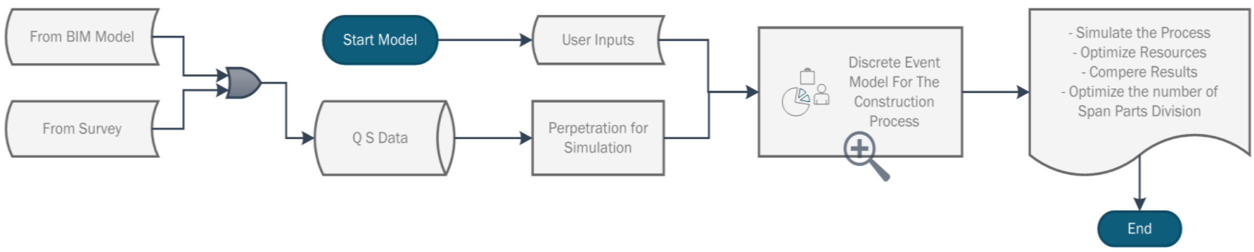


Figure 1. The main logic behind the discrete event simulation conducted

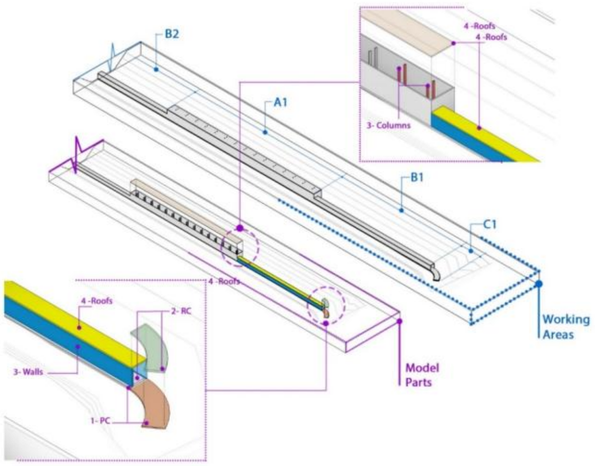


Figure 2. The sequential construction elements of the utility tunnels

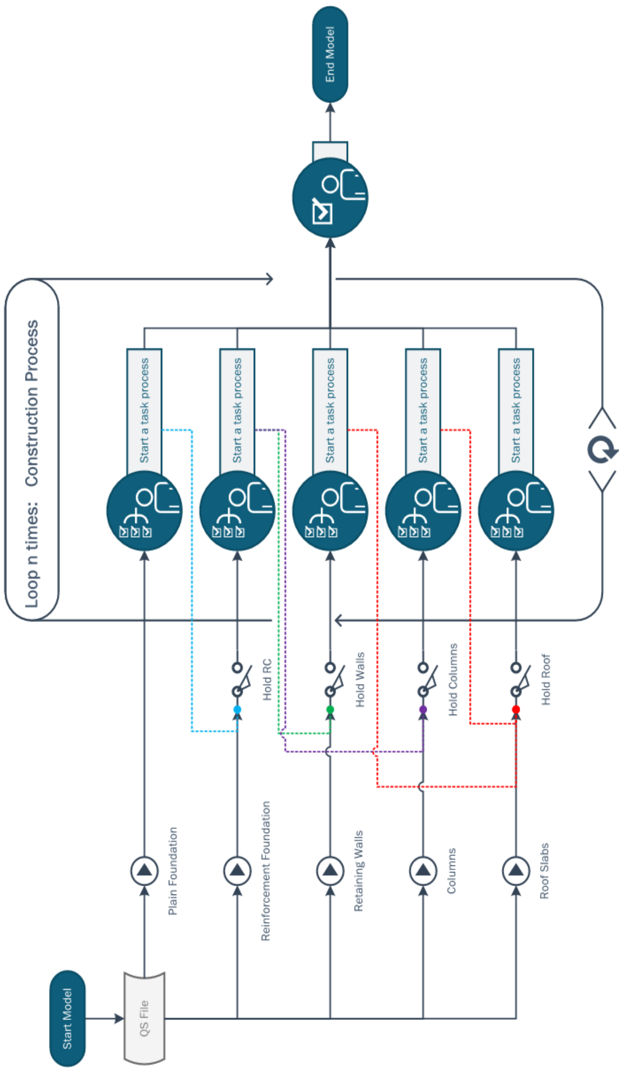


Figure 3. Graphical representation of the Five Stages of the model logic

The Components of Cast on site Utility Tunnels can by classified either with respect to the general layout where the utility tunnels first consists of an Entrance and an Exit; they can be Ramps so that the Utility transfer Vehicles can walk on, second comes the Channels of the Tunnel which are typically a rectangular section; Most of the Cables and lines run through these Channels, third is the Stations of the Tunnels which are bigger than the Channels in width and Elevations and may have an extra floor; these Stations are used to accommodate Equipment and machines of the Tunnel if needed, forth is Control Rooms where the Electrical control panels of the tunnel are connected in certain places, finally, there may be some Command Towers to monitor the tunnel. The development of this model is based on the Sequential process of the Construction Elements where the utility tunnels consist of: Plain Concrete Foundation then the Reinforcement Concrete Foundation which carry the Retaining Concrete walls that are capable of tolerating the lateral load from the backfilling around the tunnel, the Concrete Columns that exist in the stations part of the tunnel to accommodate for the extra elevations required and finally the roof slabs as illustrated in Fig. 2.

The final model developed for the discrete event Simulation logic can be broken down into Five stages which are described as the following. First, the Model Inputs which are the Quantity Surveying data table that can be prepared on a Microsoft Excel Spreadsheet or by using a Building Information Model Software (BIM) for more accurate and detailed data. Second, the Construction Elements that describes the components, dependencies between them based on the data from the Quantity Surveying and the Construction rates defined by the user. Third, the Hold factor that controls the flow of elements in order to maintain the dependency relations, in other words, each element wouldn't start unless the required number of elements holding it has finished. Fourth, the construction process or the delay duration for each element for example the duration of fixing the steel reinforcement or for pouring the concrete, these delays depends directly on the quantities from the spreadsheet and on the resources available. Fifth, the deliverables of the model in term of the optimum number of division parts (Work Balance) and the optimum number of resources required for best utilization of such resources. All the Five Stages are illustrated in Fig. 3.

## *A. The Model Development*

For the proposed model in this paper Anylogic software was used as a discrete event simulation software. The quantity surveying data was extracted from the Autodesk Revit software to the excel sheet then to the model itself on Anylogic. Any logic software was able to provide a very similar simulation to the real-life construction project since it depends on nodes that can be used as a delay node (each construction process) and between these delays are lines describing the conditions and the relations between these delays. The concept of describing each delay as a separate node is very suitable for the discrete event simulation logic. The first construction element of the detailed model is the plain concrete element which is required for the start of the second construction element which is the reinforced concrete. The start of a certain length of the reinforced concrete foundation depends on the finish of a certain length of the plain concrete foundation, this number of lengths is the required optimization result (work balance) which can lead to the best utilization criteria for resources. The same concept is applied to the third element which is the concrete walls then the columns and finally the roofs. This condition that describes the start point of each element is controlled by the hold nodes which needs the queueing or the waiting nodes for the elements, these holding nodes were coded effectively to simulate these start points of different parts. There are seize and release nodes responsible for the assignment of the required resources for each construction process or delay. Finally comes the sink nodes that defines the finishing points of the elements and that the successor construction element process can start like the case of plain and reinforced concrete foundation. This sequence appears in Fig. 4.

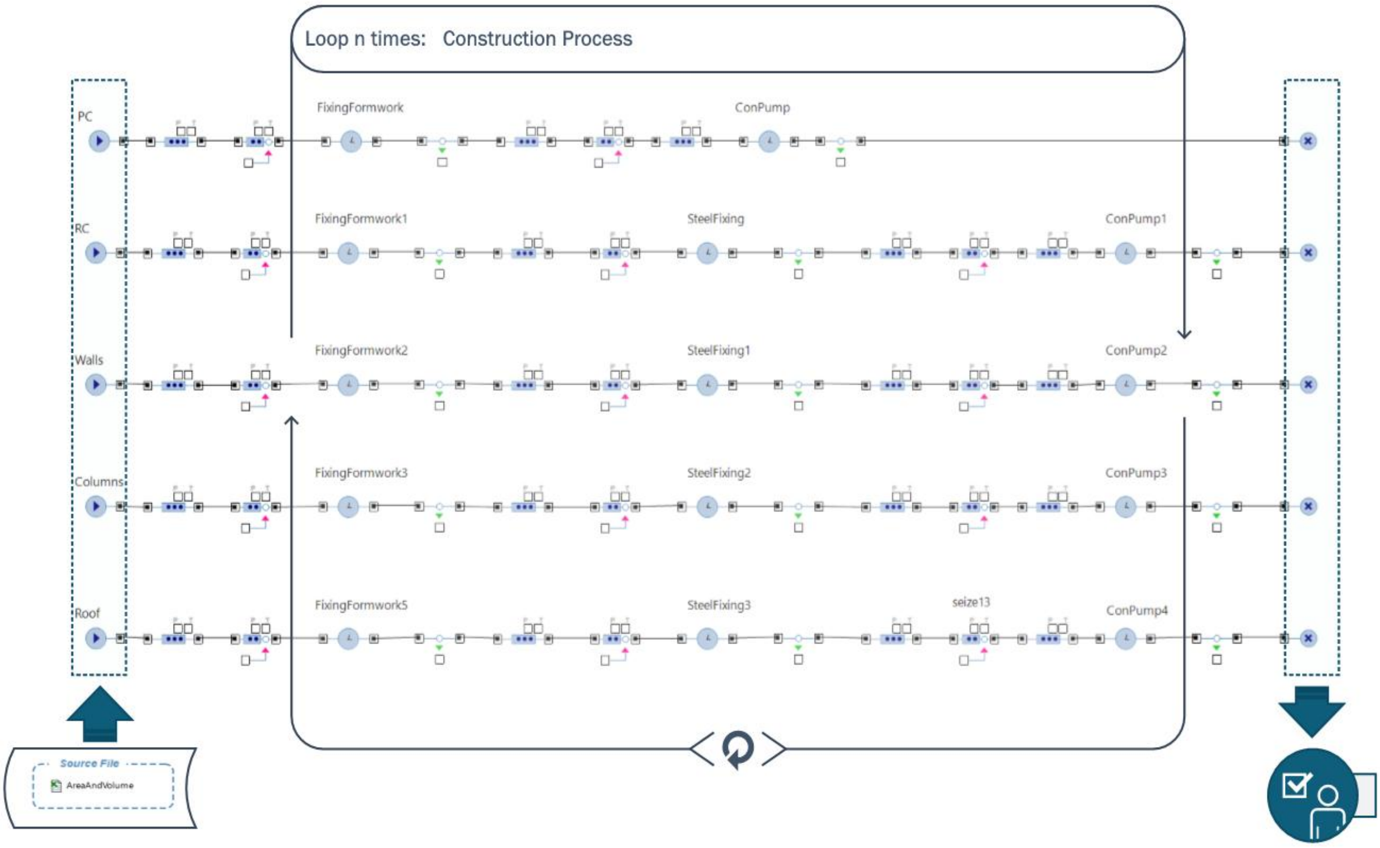


Figure 4. Resources and model development

### B. *The Model Parameters*

The main parameters of the model can be divided into User Inputs which can be the delay rates for each process, then the Resources which can be the amount of formwork and the number of pumps needed and finally the Crews required that can be the number of Carpenters and Steel Fixers.

Figure 5. Utility tunnel construction "New capital of Egypt"

## IV. Case Study

The Proposed Case study is the Construction of a Utility tunnel in Egypt as shown in Fig. 5. This project was done in the New Capital of Egypt by Orascom Construction Industry as the main Contractor in the International Shooting Club Project. The Tunnel is divided into 23 Zones of 10 Stations, 10 Channels and 2 ramps as shown in Fig. 5. The Overall length of the tunnel is 720 m with average of 30 m for each zone.

The Scheduling and resourcing of such project was done based only on duration that the tunnel should be finished in without consideration of the available resources and without doing any work balance for such project which means that the work progress will depend only on the accessibility of zone and resources that can be provided. The Schedule of the Project is done on Primavera P6 Software where the tunnel is divided into 5 Phases (4 Phases of 4 Zones and 1 Phase of 3 Zones). This approach led to a huge loss in resources and time. The proposed model is used as an efficient alternative way to that approach to come up with the optimum work balance and required resources. The quantity surveying data were extracted from the BIM model which was prepared on the Autodesk Revit then represented on a Microsoft Excel spreadsheet in a way to serve the model requirement from the elements order. The User can enter the Number of parts for the division of the tunnel manually as well as the number of resources and crews as initial values for the model to get the results of the model run which are the utilization percentage and Overall Duration. The main part of the model is its Functions and Parameters which controls the retrieving process of data from the Excel Spreadsheets, the dependency relations between the model elements which is described by the Hold Nodes, calculating the overall duration of the project, Assigning the required resources at the right time to the construction process and computing the utilization rates of these resources for the purpose of optimization. All this process is illustrated in Fig. 6.

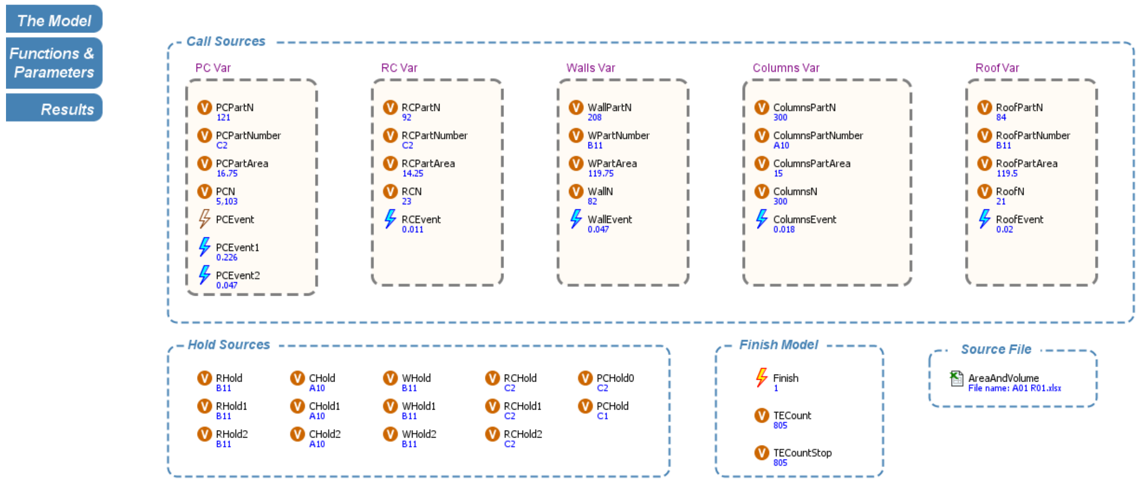


Figure 6. Illustration of the model functions and parameters

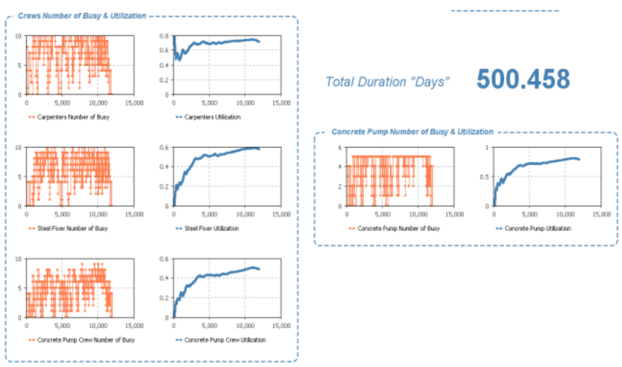


Figure 7. Utilization results of crews and overall duration

## A. Running the Model

The First Level of the Model is Normally Running the model after Entering the Data to the model, the simulation runs for all the project's elements retrieving each element one after the other till the end of the elements then the simulation stops. The Results of running the model are the utilization percentage and number of each Formwork type and each Crew type and finally the Overall duration as presented in Fig. 7. These results are based on the input parameters previously entered.

## B. Comparing Results

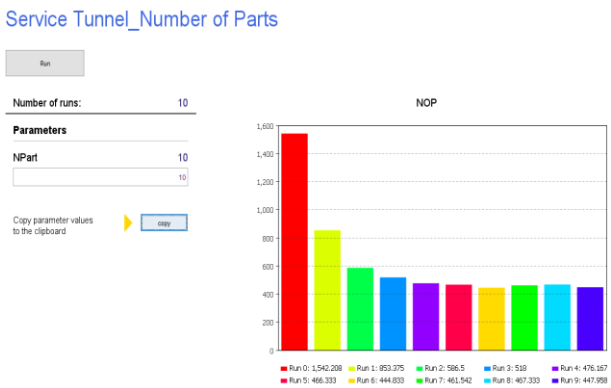


Figure 8. Comparing the number of parts results

The Second Level of the model is Comparing the results system where the user fixes all the variable and increment one required variable by a certain amount for several runs in order to compute its effect on the overall duration. By this concept, Increasing the number of parts (Span Division) while fixing the variables of the resources available will decrease the overall duration of the project to a certain limit until the number of parts will not be the governing factor of the flow of activities but the amount of available resources will be the governing factor as shown in Fig. 8. The same concept can oppositely be applied by Fixing the variable of the Number of Parts and Incrementing the Available Number of Crews Available to see its effect on the overall duration until it stops being the governing factor of the activities flow. The Same can be Done for the Number of Formworks Variable. This level of the model can provide the user with an accurate estimate of the required resources and work balance as a base for the construction process with the study of each parameter effect on the overall duration of the project.

### *C. Model Optimization*

The third and highest level of the model is the Optimization process; the optimization of each of the previous resources can be done by Optimizing the Number of Span Parts first then using the results in the Optimization of the number of Crews available and using the results of both to Optimize the number of Formworks available then Considering all this as a first iteration then repeating the Iterations again by using the results to get the Optimum number of Span parts again for a certain number for iterations while considering that increasing the number of iteration will provide a more accurate results of the model. Fig. 9 illustrates Optimization of the number of Span Parts by running the Optimization Model while fixing all other factors (Work Balance).

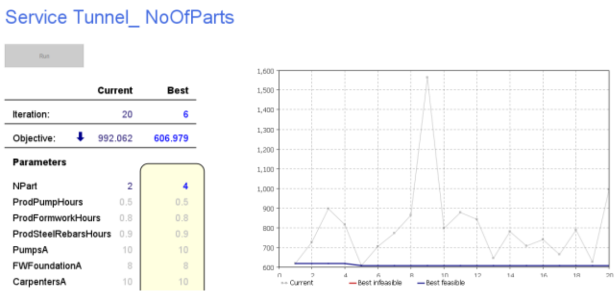


Figure 9. Optimization work balance by fixing other factors

## V. Conclusion

The Scheduling and Planning of the linear projects are considered of big construction challenges due to the need for the optimum resourcing and transacting from one element to the next while obeying the structure elements' dependency on each other and the need for minimizing the overall duration for such projects. Such challenges can be solved by using the discrete event simulation as an approach for providing the optimum work balance and best utilization of resources which will all lead to minimizing the duration of the project. The proposed model can be used for determining the duration of a certain amount of resources, comparing results of different resources situation to compute the effect of each resource on the overall duration and for Optimization of the number of resources, work balance and overall Duration. In Addition, this model can be used to get a detailed time schedule for the activities of a construction processes. Also, this model represents a good representation of the element's dependency relations.

## VI. Recommendation

The use of the simulation models has a lot of valuable incomes in the decision support systems, utilization of resources and leveling and optimization of the project duration. The simulation models are easy to use systems as they are computational based systems that can be developed without difficult mathematical approach and can be modified to suite different situation that can be faced. Also, the automation of such systems can guarantee a faster result when required. That is why this paper recommend more work in the development process of such simulation models especially those related to the construction process.

## Conflict of Interest

The authors declare no conflict of interest with the work done for this paper.

## Author Contributions

Mohamed Sherif and Abdelhamid Abdullah conducted the research; Both analyzed the data and developed the model; Mohamed Sherif had the idea, collected the data and wrote the paper; Dr. Khaled Nassar was the main advisor and contributed to the model and research methodology; all authors had approved the final version.

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