An Integrated Modelling Framework for Stochastic Simulation of Pipe-Rack Construction

Aly Abdel-Fattah,
PhD Candidate, University of Calgary
Email: abdelfaa@ucalgary.ca
Kamran Hazini,
PhD Candidate, University of Calgary
Email: khazinib@ucalgary.ca
Janaka Ruwanpura,
PhD, PQS, Professor and Canada Research Chair (CRC) in Project Management Systems,
Director, Centre for Project Management Excellence
Email: janaka@ucalgary.ca

Abstract

Pipe-racks are one of the major structures in oil, gas and petrochemical plants supporting pipes and cables that connect different process units to each other. Since the construction of pipe-racks is amongst the critical activities starting early at site, timely completion of their construction is utmost importance. For this reason, accurate and realistic estimation of pipe-rack construction duration plays a critical role in planning of project construction. Authors in this paper are presenting a developed integrated simulation application that interacts with commercially used drafting software (AutoCAD) to simulate pipe-rack construction. The simulation tool imports the design information from AutoCAD drawing by using Visual Basic of Applications (VBA). The application performs the simulation for construction and erection of the pipe-rack using the imported design information and along with other input data and assumptions. The outputs of the model are likely durations of the pipe-rack construction with their respective probability of occurrence. The results can be drawn in a graph that assists project managers and planners in better estimating of pipe-rack construction duration in an uncertain environment. In this paper the developed application is implemented and validated on an under construction oil & gas industry project and results are analyzed in detail.

Keywords: Simulation, Pipe-rack, Construction, CAD, VBA

1. Introduction

The input modeling, model design, and output modeling are critical issues in simulation modeling for any given situation. (AbouRizk & Halpin, 1990) conducted in-depth research on modeling input data for the simulation of construction operations. There are many problems faced by the model designers and users when creating simulation models. When a real system is converted into a simulation model, several logical assumptions are applied to obtain the data to simulate the models. Sometimes these assumptions do not represent the correct nature of the real system (Ruwanpura, Aburizk, Er, & Fernando, 2001). Hence, automatically accessing real and accurate data from a design model to a simulation model is critical to ensure the accuracy of the data for simulation purposes.

Three-dimensional computer-aided design (CAD) systems have not yet been fully used in construction, as their use is mostly restricted to automated drafting rather than taking advantage of its features to create product objects to be used by other construction applications, such as simulation. Part of this is due to the fact that almost all CAD systems are restricted to purely geometric data modeling, with all non-geometric data attached to geometric entities. This makes it difficult to semantically describe dependent relationships (Xu, AbouRizk, & Fraser, 2003). A few attempts have been done in the past to link the CAD systems with simulation. For example, (Moorthy, 1999) established the connection in industrial fields by generating a formatted ASCII flat file (SDX) to describe the manufacturing data and translate it into a simple simulation model format. (Xu & Aburizk, 1999) introduced the integration of CAD systems with simulation for construction projects, which is achieved by exporting the objects' physical attributes, their relationships, and the methods from CAD to a product hierarchy (PH) which has been accessed by the simulation. (AbouRizk & Mather, 2000) used an add-in program for AutoCAD software to extract object information from AutoCAD, which is then translated into the information-simulation format. Further, (Xu, et al., 2003) introduced a CAD integration simulation environment (CAD-ISE) representing an integration between commercially available 3D-CAD software and discrete-event simulation modeling, which drew on the physical features of the facility stored in the CAD drawing to dynamically feed input to a simulation model through object-oriented product components. (Abdel-Fattah & Ruwanpura, 2008) introduced an integrated model using Special Purpose Simulation model linked with Microsoft Access, Visual Basic for Application (VBA) and AutoCAD software to model for pouring the concrete for an upper raft slab - which is the largest in Canada and the third in the world - for "The Bow " project in downtown Calgary. The main concept of the paper is to extend the work of (Abdel-Fattah & Ruwanpura, 2008) to develop a comprehensive modeling framework to assist the capabilities of CAD systems for simulation to extract real and accurate data for simulation purposes and apply it to an industrial construction operation of pipe rack.

2. Pipe-rack Construction

Pipe-racks are essential components of oil, gas and petrochemical plants as they play an important role in the integrity of the whole complex. Having an accurate estimation and correct understanding of pipe-rack construction duration is of utmost importance for the project managers and construction managers since any delay in completion of this important element may jeopardize timely completion of the entire project. By having an accurate estimation of pipe-rack construction duration and knowing the date by which the pipe-rack should be completed and doing a simple back calculation, project managers can easily predict the date when the design drawings and materials are required at site with a high level of confidence.

The main function of pipe-racks is to support the equipment, pipes and cables and connect various process units to move the process and utility liquids or gases for further processing or storage purposes. Sometimes, depending on the design, pipe-racks are also supporting equipment such as air coolers. In many cases, pipe-racks are located centrally in the plant and surrounded by the process units and various equipment. Pipe-racks' sizes vary depending on the number of levels, number of pipes carried over each rack and equipment specifications. In addition to the pipes, instrument and power cables also run on the pipe-rack inside the cable trays to connect the electrical equipment or instrument devices to the related control panels or switchgears.

However, from the construction perspective, pipe-racks are usually amongst the first elements which should be constructed before other construction activities can be started. Since completion of pipe-rack construction is the predecessor to many other tasks such as piping and mechanical installation, pipe-rack construction is mostly on the critical path of the schedule. Although the pipe-racks are the first elements which should be constructed at site, their design cannot be finalized unless the engineering for all the connecting process units reach a certain maturity level that the designers can fix the tie-in locations and loading data on top of the pipe-racks. In some fast-track projects, project managers prefer to finish pipe-racks' design with less mature data and by applying various overdesign factors. This enables them to accelerate material ordering and delivery as well as support early construction activities at site.

In many cases, pipe-racks are a combination of the concrete and steel structure. For this reason, the steel structure supply period also should be considered and added to the chain of activities which makes the task even more critical. The proposed model is aimed at replacing the conventional subjective duration estimation of pipe-rack construction by experts and professionals as supported by their experience or simple calculations of quantity divided by average productivity with no consideration of the risks and uncertainties.

The subject of simulating the complete construction of a pipe rack is rarely addressed. (Dehghan, Khoramshahi, & Ruwanpura, 2009), used Simphony software to simulate only, the phase of installing the steel in the pipe-rack construction process. Other than the model of (Dehghan, et al., 2009), there is no well known theoretical model or application developed to simulate the construction of the pipe-rack in an uncertain and risky environment.

The developed model as illustrated in this paper is capable of simulating the construction time of pipe-rack in a stochastic model and to predict the estimated duration of construction. The flow of data and information in the application is designed and developed in a way that it receives pipe-rack drawings as input, calculates the quantity of the concrete and passes the data to the simulation software from CAD system. Then the stochastic model simulates the construction processes using the inputs and other assumptions and pre-defined parameters in the given number of simulation runs. At the end, model output is the graph with which the project managers can predict the likely duration of construction and probability of each occurrence, enabling them to have clear visibility according to their own confidence level.

3. Model Components

The integrated model is developed using three different software packages that work together for extracting data from AutoCAD and simulating the construction of pipe-rack. The model components are AutoCAD 2007, Microsoft Access and the Simphony.NET simulation platform.

AutoCAD is one of the most admired CAD software in construction industry. AutoCAD 2007 software is chosen to provide the drawing of the pipe-rack. Visual Basic for Application (VBA) is used to transfer the object’s information to Microsoft Access. VBA is an implementation of Microsoft's event-driven programming language Visual Basic 6. VBA is built into most Microsoft Office applications; as well as being at least partially implemented in AutoCAD. One “VBA” file has been developed, for sending the objects’ volume measurements and the number of objects to a Microsoft Access file. Figure# 1 displays the AutoCAD drawing for the foundation while running of the VBA file. A Microsoft Access file is then developed to receive AutoCAD’s data from AutoCAD 2007 and make it available for the Simphony modelling element.

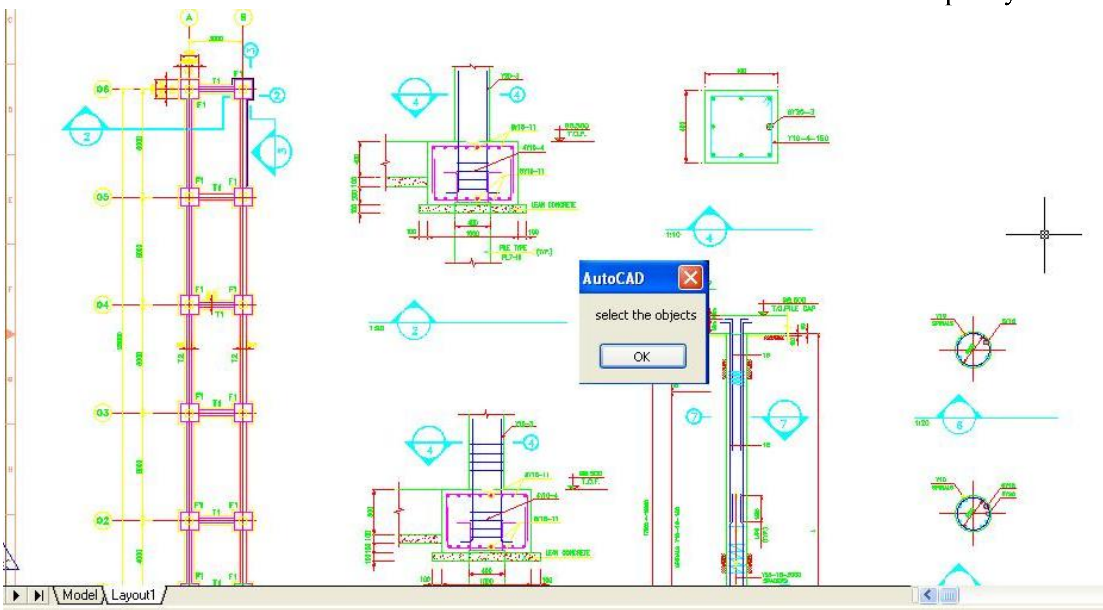

Figure 1: AutoCAD Drawing for Foundation

Simphony is a special purpose simulation (SPS) tool. It was developed with the objective of providing a standard, consistent and intelligent environment for both the development as well as the utilization of construction SPS tools (D Hajjar & AbouRizk, 1999). A simulation template is generated to create simulation model which demonstrates the construction of a pipe-rack. For more information about Simphony, readers may refer to (AbouRizk & Hajar, 1998) and (Dany Hajjar & AbouRizk, 2002). When developing models using Simphony, there are global modeling elements (called Parent in Simphony) and specific modeling elements (called children modeling elements in Simphony). The global modeling element has inputs that can be retreated by any other modeling elements. The same global elements include the statistics and outputs based on the modeling processes of any level. In the children type of modeling elements, the inputs are only specific to the function/process of the modeling element. You may refer to Ruwanpura et al. (2001) for specific details of global and children modeling elements.

The “Pipe-rack SPS Simulation Template” is a discrete-event template in which the state of a model changes only at a specific event (Schriber & Brunner, 2009). Figure# 2 illustrates the structure of the Simphony model. The “Pipe-rack” is the main global modeling element of the model (Figure# 3). Figure# 4 shows the second level of the model which contains three main elements: the Foundation, Concrete Structure and Steel Structure and three other modeling elements to represent project start, curing concrete and project finish. Additionally, it contains the Start, Curing Concrete, and Finish elements. Figure# 5 shows the “S” curve (cumulative density function) for days after 100 runs of the simulation.

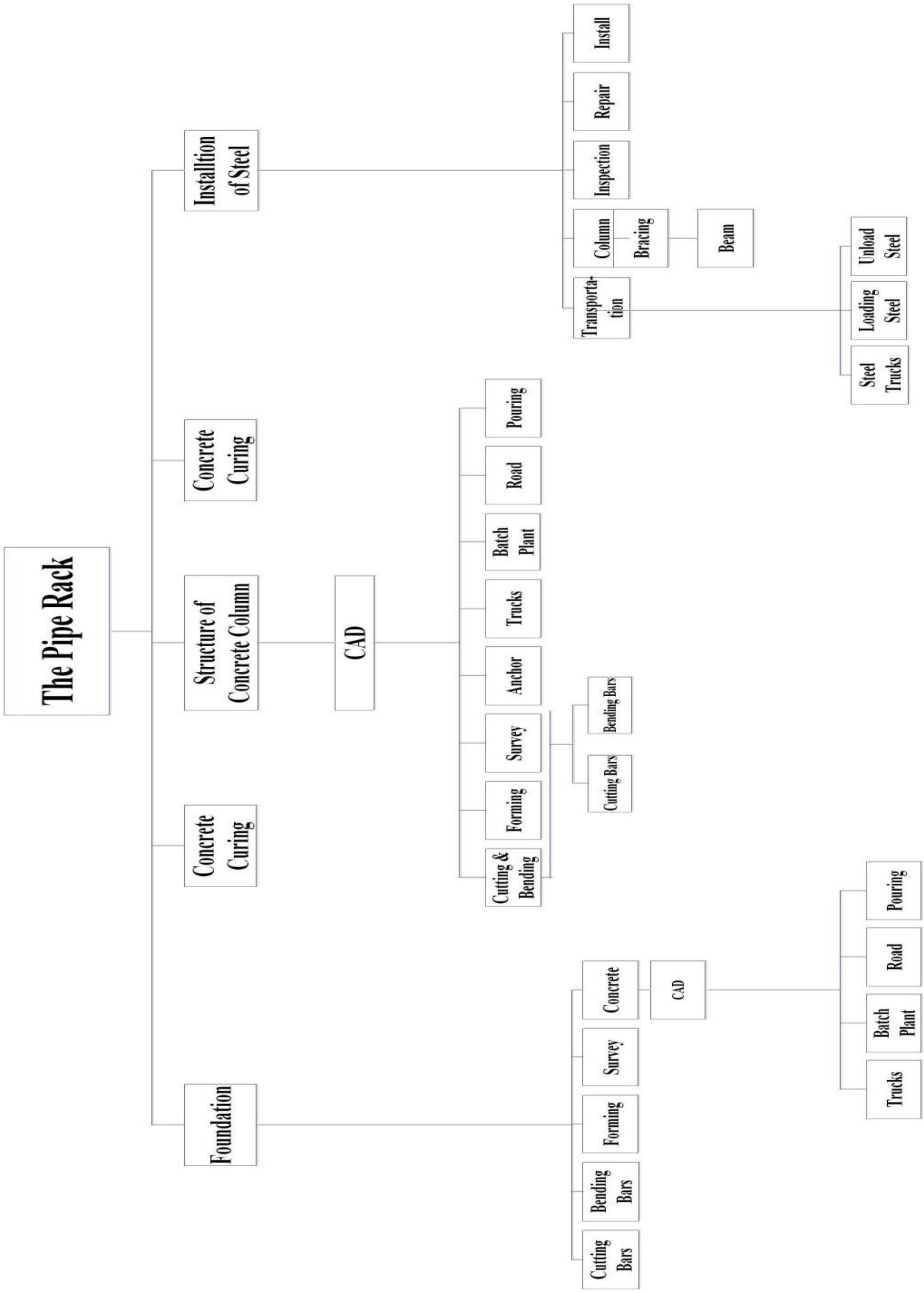

Figure 2: The Components of the Model

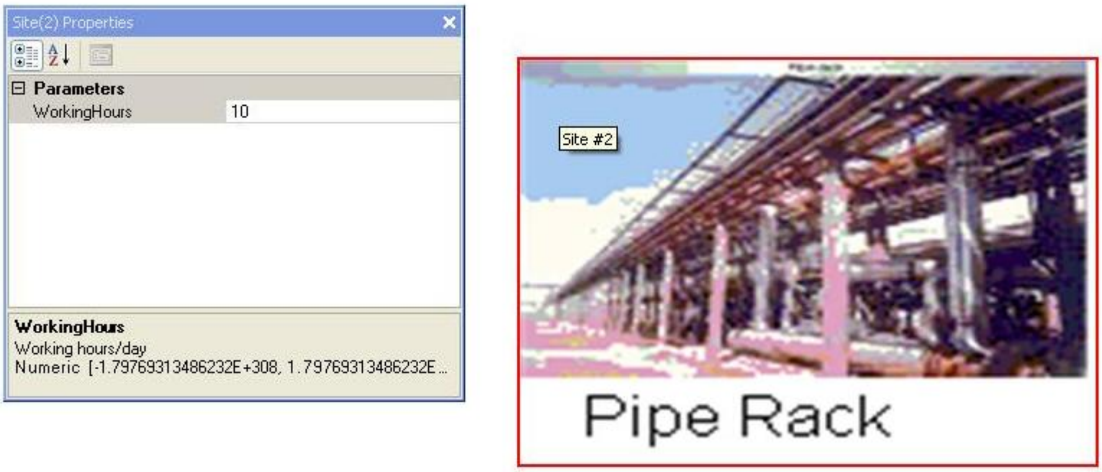

Figure 3: Pipe-Rack element

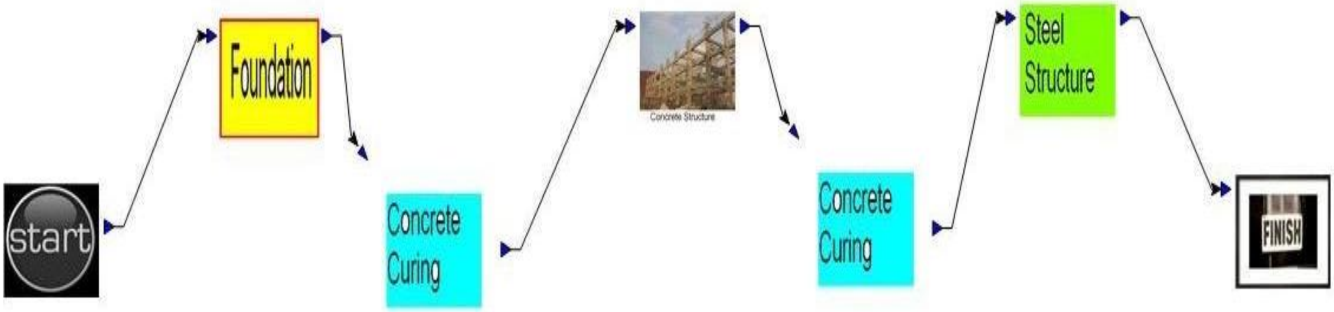

Figure 4: The child elements of Pipe-Rack element

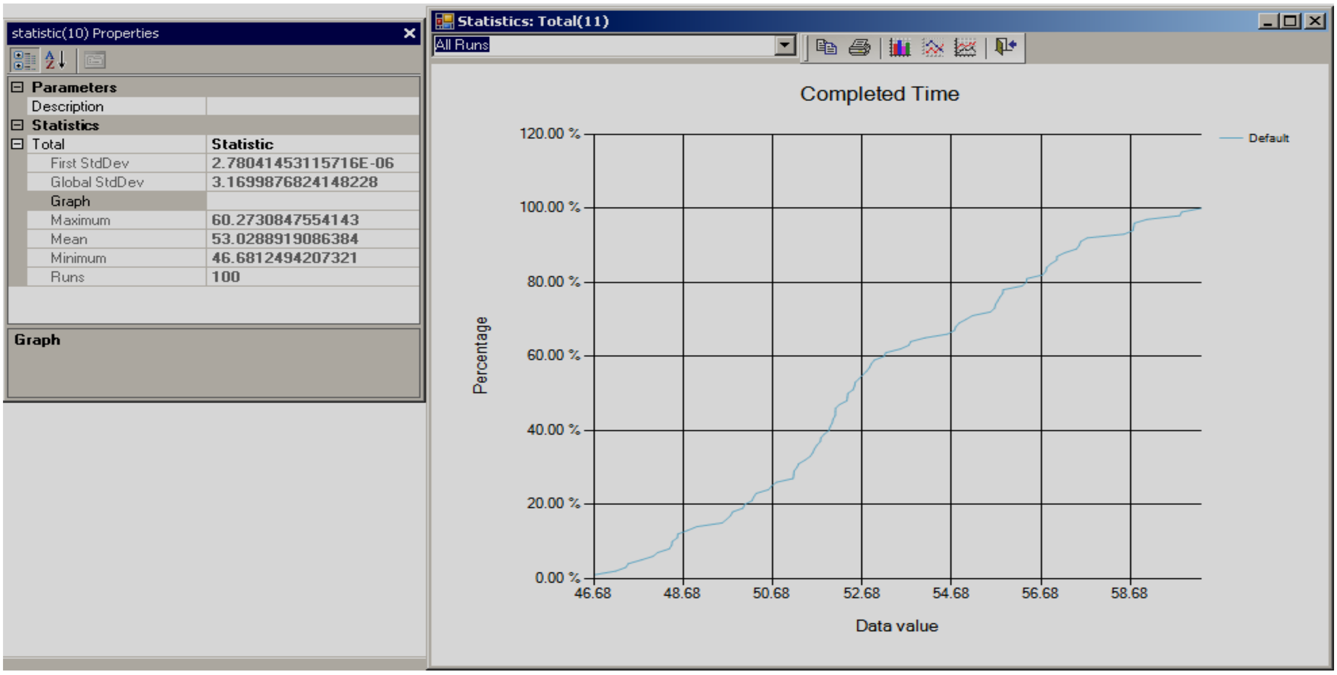

Figure 5: Cumulative Density Function of the Project Duration

4. Application and Validation of the Model

In order to validate the developed model, authors decided to choose an ongoing construction project to implement the model and compare the results with the actual data from construction site.

The selected project was construction of a PVC Petrochemical plant in the Middle East. This petrochemical plant is among the largest PVC production plants in the world which is located south of Iran in Bandar Imam. The selected pipe-rack for validating the model is located on common facilities plant that has the task of producing and distributing the utilities all over the complex to perform the required chemical processes. In addition to this, design and construction of main control building, substations and storage areas are also located in the common facilities project scope of work. The selected pipe-rack is carrying the pipes and cables from one process plant to the common facilities. The pipe-rack's length is 28 meters, width is 3 meters and the elevation is 7.99 meters from top of foundation and 6.492 meters from the paving. Operations for construction of a pipe-rack normally follow a rigid methodology and sequence with very minor flexibility. For this reason and likewise other simulation models, there are some assumptions made into this model as explained in following;

- The model assumes that all the required materials and drawings are delivered in a timely manner and are available when starting the construction and installation activities. All materials are provided by construction contractor except for steel structure that fabricated by a manufacturer and shipped to site.
- It is assumed that the required resources and machineries are available at the time of construction and installation.
- The steel structure components are connected to each other using bolts & nuts and there is no welding work required at site except for performing any probable repair on damaged members.
- Steel structure elements that need repair work may vary for different manufacturers. For this particular pipe-rack, the average defective steel structure elements are 20% for columns and 25% for the beams and bracings. In fact beams and bracings are more likely to become damaged during transportation and storage due to their fragility. It is also assumed that the required time for repairing the deficient steel elements will extend the duration of installation for that member for about 25%~40%.
- Productivity of the concrete pouring is 160m3 per day with one concrete pump. The distance from batching plant to the pipe-rack location is 1.5Km and 2 concrete trucks (with capacity of 6m3) were used for transportation of the concrete.
- There was not any interruption during concrete pouring for foundation and concrete structure.

- Concrete curing time is assumed to be 27 days as per American Concrete Institute, ACI308 (American Concrete Institute, 1998)
- Productivity of steel structure installation with one team is assumed 60~80kg per hour. The distance from the steel structure storage yard to the pipe-rack location is 1Km.
- Construction labors are working at site 7 days a week and 10 hours a day.
- Since the load bearing capacity of the ground at site location is less than allowable, it needs to be reinforced using concrete piles underneath each column to reinforce the soil load bearing capacity. However, embedding the piles is not in the scope of this research.

One of the important advantages of this model is its flexibility to change the inputs and variables pertaining to the assumptions to suit the special requirements of each particular project.

The simulation has been run for 1000 times and resulted total duration is plotted in this graph and shows the probability of each duration occurrence in 1000 runs. It is interesting that the results of the model as shown in figure 6 were consistent with the actual construction time for the complete pipe-rack construction and erection. The total construction and erection of this pipe-rack took 63 days which in the graph this duration happened in 80% of the probability which authors believe is a good confidence level for claiming that the developed model is validated by a real pipe-rack construction.

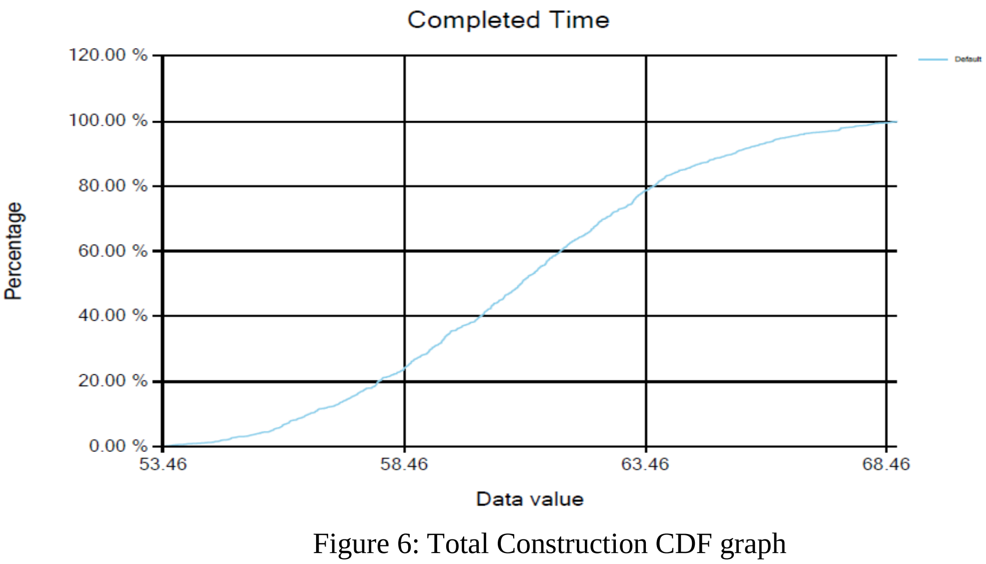

Figure 6: Total Construction CDF graph

5. Conclusions

Pipe-racks are one of the most important and critical elements of oil & gas projects and any delay in construction of these structures may jeopardize timely completion of the entire project. Therefore, having an accurate estimation of the construction duration for the pipe-racks assists

project managers to safeguard on-time delivery of their projects. Pipe-racks are designed and built in different sizes and shapes usually with combination of concrete and steel structural members. The purpose of this paper is to present a model that is developed to be used as a reliable tool for project managers in estimating likely duration of pipe-rack construction with an acceptable level of confidence as supported by their own judgment. The model receives engineering design drawings as inputs and using the characteristics and quantities of materials used in any given pipe-rack, simulates the construction and installation tasks in an uncertain and risky environment. The model interacts with AutoCAD for receiving the simulation variables and carries out the simulation in Simphony software. Since AutoCAD is the commonly used software for engineering design drafting, the model can be used for many other projects using this software for pipe-rack drafting. By use of the embedded module within the AutoCAD software, the simulation parameters are passed to Simphony for carrying out the simulation. Likewise any other theoretical model, there are also some assumptions made within the model. These assumptions are flexible to the modifications and can be adjusted to suit each pipe-rack or project requirements. The developed model has been also validated using a selected sample pipe-rack in an under construction petrochemical plant and interestingly the actual duration of construction is matching the results of the simulation with 80% confidence.

References

Abdel-Fattah, A., & Ruwanpura, J. Y. (2008). *An integrated CAD and simulation model for concrete operations.* Paper presented at the 2008 Winter Simulation Conference (WSC), 7-10 Dec. 2008, Piscataway, NJ, USA.

AbouRizk, S., & Hajar, A. (1998). A framework for applying simulation in construction. *Canadian Journal of Civil Engineering, 25*(3).

AbouRizk, S., & Halpin, D. (1990). Probabilistic Simulation Studies for Repetitive Construction Processes. *Journal of construction engineering and management, 116*(4), 575-594.

AbouRizk, S., & Mather, K. (2000). Simplifying Simulation Modeling Through Integration With 3D CAD. *Journal of construction engineering and management, November/December 2000*, 475 – 483.

American Concrete Institute. (1998). Standard Specification for Curing Concrete (Vol. 308.1-98). Michigan: Farmington Hills.

Dehghan, R., Khoramshahi, F., & Ruwanpura, J. Y. (2009, March 2009). *Developing a General Purpose Simulation Model for Steel Pipe-rack Installation.* Paper presented at the Simulation Multi-conference San Diego, CA, USA.

Hajjar, D., & AbouRizk, S. (1999). SIMPHONY: AN ENVIRONMENT FOR BUILDING SPECIAL PURPOSE CONSTRUCTION SIMULATION TOOLS. *the 1999 Winter Simulation Conference*, 998-1006.

Hajjar, D., & AbouRizk, S. (2002). Unified modeling methodology for construction simulation. *Journal of Construction Engineering and Management, 128*(2), 174-185.

Moorthy, S. (1999). *Integrating the CAD model with dynamic simulation: Simulation Data Exchange*, Piscataway, NJ, USA.

Ruwanpura, J., Aburizk, S., Er, K. C., & Fernando, S. (2001). Special purpose simulation templates for tunnel construction operations. *Canadian Journal of Civil Engineering, 28*(2), 222 - 238.

Schriber, T. J., & Brunner, D. T. (2009, 13-16 Dec. 2009). *Inside discrete-event simulation software: How it works and why it matters.* Paper presented at the Winter Simulation Conference (WSC), Proceedings of the 2009.

Xu, J., AbouRizk, S. M., & Fraser, C. (2003). Integrated three-dimensional computer-aided design and discrete-event simulation models. *Canadian Journal of Civil Engineering, 30*(2), 449-459.

Xu, J., & Aburizk, S. (1999). CAD-based integrated simulation environment. *Annual Conference - Canadian Society for Civil Engineering 3*, 95 - 105.