A SIMULATION-BASED FRAMEWORK FOR CONSTRUCTION PROJECT INFORMATION MANAGEMENT

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ABSTRACT

Modern capital projects generate large amounts of documentation in several different formats and controlled by many different project parties: everything from design drawings to cost estimates, schedules, equipment information, change orders, and work logs. Accessing this documentation can be both difficult and time-consuming. Project managers clearly need efficient methods to manage project information; the current methods focus on capturing and integrating information through a database and CAD drawings, but they are limited in scope, not easy to re-use in other projects, and do not capture the construction process. The solution is a well-structured simulation-based system that can dynamically capture, store, process, and access all project information, from the planning stage through the construction process to the completed project, including all changes to the original plan. The motivation for a simulation-based foundation for this approach stems from its ability to model the dynamic processes involved rather than just the static information.

Keywords: project information, construction process, High Level Architecture, Distributed simulation

1. INTRODUCTION

Complex capital projects can involve thousands of workers, hundreds of millions of dollars, and many years of work. These types of projects generate large amounts of documentation in many different formats and controlled by many different project parties: everything from design drawings to cost estimates, schedules, equipment information, change orders, and work logs. During the construction period, a company generates reports in certain areas, such as workers' time cards and the actual as-built drawings of the project, and projects are also almost never completed exactly as planned; keeping track of changes in the building process is very complicated, adding yet another layer of documentation. However, even this level of documentation is incomplete, especially when it comes to recording the actual building process.

Accessing this documentation can also be both difficult and time-consuming. Because the existing documentation is stored based on the interest of each party (e.g., drawings may be kept with the design consultant, the foreman might have worker records, and the project manager might have the financial information), the project information is disorganized and reconstructing a record of how the project was completed may require hiring experts. This can be a problem, particularly when it comes to settling claims and dealing with quality control, both of which can mean losses of millions of dollars (Akinci 2004).

It should therefore be unsurprising that project managers and contractors are always looking for efficient ways to collect and store construction histories and retrieve them effectively (Hendrickson and Au 1989). Different studies have focused on developing a computer based information system to integrate the collection, processing and transmission of information (Lock 1993). A database management system (DBMS) has become a common solution to overcome some of the limitations of data sharing (Mazerolle and Alkass 1993; Bowler 1994; Dawood et al. 2002). But the current methods do not capture the construction process; existing methods usually focus on capturing and storing physical information from computer-aided design (CAD) drawings, or the scope of the project from as-planned and as-built documents, rather than capturing the actual building process. They are also limited in scope, focusing on small parts rather than the entire project. For example, project managers who are interested in equipment control try to capture information such as working hours, breakdown or fuel consumption of onsite equipment, but estimators are interested in collecting the workers' daily log or material cost (Navon 2005; Fayek et al. 1998). Even integrating the project information database using the Critical Path Method (CPM) does not support capturing the complete operation; a CPM network only describes tasks to a certain level of information, such as duration and resources.

The solution is a well-structured simulation-based system that can dynamically capture, store, process, and access all project information, from the planning stage through the building process to the completed project, including all changes to the original plan. Ideally, the system should integrate this information and present it to the user, providing an overview of the project at every stage for comparison with the project as planned. It should be able to incorporate process models, product models, resource models, and static information in one system. A user should be able to see the resources that completed a given scope of work in a given period of time under the influence of external factors (e.g. weather).

This kind of documentation will be helpful for claims, control purposes, reproducing actual product drawings, operation and maintenance, and planning for future similar projects. It will also increase the learning process in the involved organizations for future projects by enabling access to the information of previous projects (FIATECH 2009). The solution must be easy to use from a manager's perspective, and it must also be reusable for different types and sizes of construction projects.

One promising method for implementing the solution is computer simulation. Computer simulation was introduced to the area of construction research by Halpin (1977) with his proposed CYCLONE system. The proposed system and all derivatives were used in construction research to model real construction processes, leading construction managers to more efficient use of materials, manpower, and equipment (Paulson et al. 1987; Ioannou 1989; Martinez and Ioannou 1994; Hajjar and AbouRizk 2002). Computer simulation has been successfully implemented in the construction industry for many purposes (Sawhney 1994), and has already been effectively used in managing information in the construction domain by integrating database management systems with a simulation model (Moghani et al. 2009). In this approach, a construction manager can use the collected data to re-run a simulation process model and examine the effect of new data on project performance. However, current modeling approaches cannot integrate or assimilate information from different sources and by different participants in an efficient and organized manner. For a more complex project that needs different information from different participants or software, distributed simulation is a new simulation technique that can facilitate modeling effort and integration in the simulation environment.

AbouRizk introduced High Level Architecture-based distributed simulation to simulate construction projects (2006), facilitating integration, collaboration, and reusability of the simulation model. High Level Architecture (HLA) was developed in 1995 by the Department of Defense (DoD) as an advanced technique for integrating simulation models to support reuse and interoperation of simulation models and reduce the cost and effort of modeling in simulation projects (Fujimoto 2003). Under the HLA standard, different developers can build individual components (federates) of one system (a federation), maintaining interoperability between them. This approach allows us to standardize the integration process between different computer software, simulation systems, and from different users; it is therefore a promising implementation for the proposed information management solution.

This study aims to develop an interoperable and reusable simulation-based framework to integrate project information including as-planned, process, and as-built information to enable construction managers to create the real history of the project from planning to completion. This framework will utilize HLA and a software application framework approach (Froehlich et al. 1998) for its implementation to be a reusable, extensible and modular model, with flexibility in representing different modeling approaches and data forms in the same simulation. In this framework a 3D CAD model will be integrated with process simulation model to automatically capture design information and use it for simulation purposes, and a relational database will be the medium for integrating as-built information with the simulation model and updating the process accordingly. The project is under development using the Construction Synthetic Environment (COSYE) as its base; it is focused on repetitive construction such as tunnelling, which lends itself better to simulation planning (AbouRizk and Ruwanpura 1999; Fernando et al. 2003; Al-Bataineh 2008; Marzok et al. 2008). The case studies used or planned are existing tunnelling projects in Edmonton, Alberta, Canada.

2. HLA-BASED TUNNEL SIMULATION FRAMEWORK

COSYE (Construction Synthetic Environment), the simulation environment used as a base for this research, was developed based on HLA standards to facilitate modeling more complex projects, such as tunnel construction, which involves many activities, equipment, materials and human resources.

The HLA standards consist of three main components: the HLA rules (IEEE 1516 2000), the interface specifications (IEEE 1516.1 2000), and the Object Model Template (OMT) (IEEE 1516.2 2000). The HLA rules outline the creation of a federation and federates and cover all their responsibilities to ensure a consistent implementation and proper interactions. The interface specification defines the functional interfaces between federates and the run time infrastructure (RTI). RTI software provides interface services that support federates' interactions and federation management, such as transferring the responsibility of updating an attribute between federates, managing data distribution and assisting with time management in the federation. Any software can interact through the RTI as a single federate. The Object Model Template is a standard for defining and documenting the form, type, and structure of data shared within a simulation, and it consists of three different object models: the Federation Object Model (FOM), the Simulation Object Model (SOM) and the Management Object Model (MOM).

The COSYE Framework is a software application that supports development of federations in Microsoft Visual Studio. In this Environment, the RTI server is a

.NET implementation of the HLA RTI and runs as a windows server, and the COSYE OMT Editor is used to develop and edit OMT documents in Visual Studio (AbouRizk and Hague 2009)

Based on HLA standards, COSYE enables the integration of different computer software and different simulation techniques in a single environment to model all the processes involved in large scale projects. HLA services in COSYE also enable collaboration of different experts to develop various parts of a simulation model. For instance, in the tunnel federation, one may simulate the tunnel construction process while the other focuses on material supply simulation.

In this project, the tunnel federation simulates the whole construction process of a utility tunnel including excavation and lining of the working shaft, the tunnel and the retrieval shaft. Using HLA requires division of the simulation into different federates and the HLA architecture thus helps to create modular, reusable, and extensible modeling elements.

2.1. Brief Overview of Tunnelling

Constructing a utility tunnel occurs in different phases. First, to get access to the tunnel excavation depth, a vertical shaft called a construction shaft is usually excavated. This shaft is the main access during the construction process for lowering the equipment into the tunnel or removing the excavated dirt. Shaft construction is usually done in sections with the depths dependent on the soil type and geometry of the shaft. The excavation and lining processes are done for each section sequentially. After finishing the excavation and lining for shaft sections, the tunnel construction process can start.

Tunnel construction methods vary depending on geotechnical information, availability of equipment, and the geometry of a tunnel. For long tunnels or tunnels with a large diameter, a Tunnel Boring Machine (TBM) is typically utilized for excavation and lining processes while for short or small tunnels, hand excavation is a better option. Before starting the tunnel construction, the tail tunnel and undercut area (an enlargement at the bottom of the shaft used for staging material handling and dirt removal operations) are excavated. The tunnel construction activities are divided into:

1. Excavation of the tunnel
1. Removing the dirt from the excavation area and transferring it to the construction shaft (using muck carts).
2. Hoisting the dirt to the ground level (using a crane, clamshell bucket, gantry, etc.) and transfer it outside the construction area
3. Lowering down the liners and transferring them to the excavation face.
4. Lining the tunnel
5. Extending construction and utility services
6. Excavating and supporting the removal shaft in a case of using TBM.

Figure 1 shows a typical utility tunnel layout.

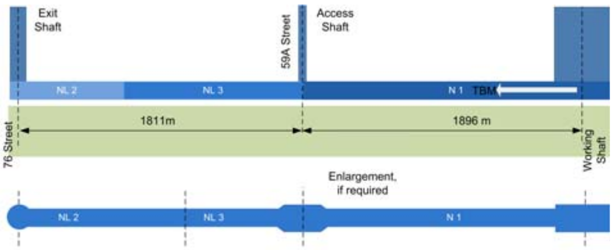

Figure 1: Layout of a Utility Tunnel

2.2. Developing the Tunnelling Product Model

In order to be able to create a generic federation and integrate the CAD model with the simulation, a conceptual project model consisting of product, process, management, environment, and resource models was developed (Figure 2).

The tunnel construction method for utility facilities was investigated, and all the information regarding activities and required resources was collected. In order to develop a product model, the CAD drawings were reviewed and the attributes were defined and added to the project model. It is important to mention that these models are for utility tunnels, and they mostly focus on the TBM (tunnel boring machine) tunnelling method.

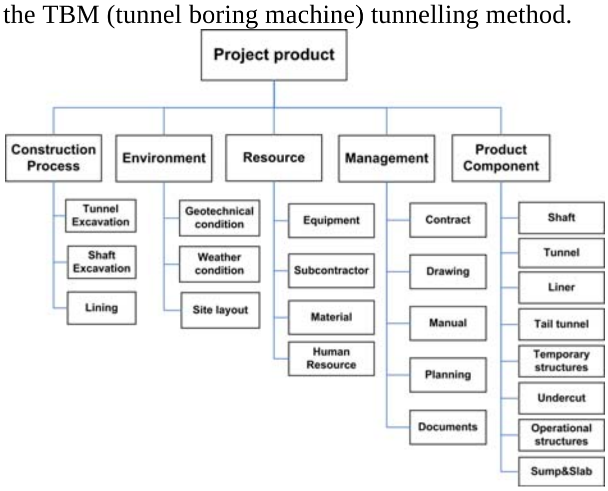

Figure 2: Tunnel Construction Project Model

2.3. Developing a Federation Object Model (FOM) for the Tunneling Federation based on the Product and Process Model

The first and most important task in developing the simulation model based on High Level Architecture (HLA) is to define the HLA federation object model. The FOM is composed of a group of interrelated components specifying information about classes of objects, interactions, attributes, and their parameters. The tunnelling federation object model was developed based on conceptual project models and is still being improved. Figure 3 shows the FOM in the tunnel federation.

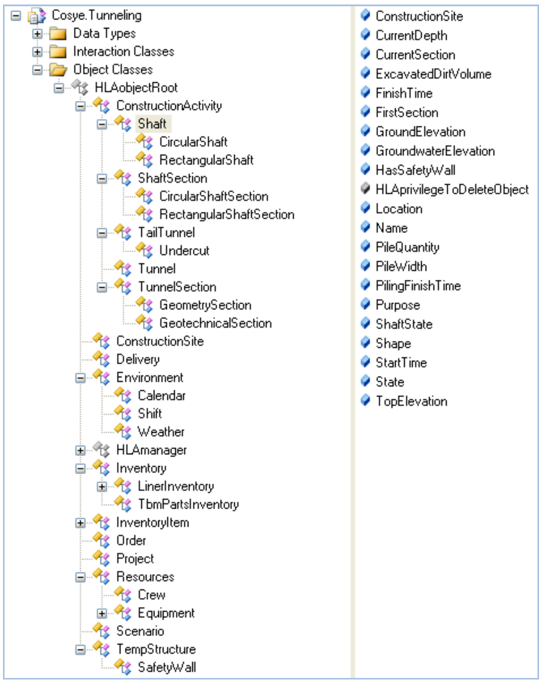

Figure 3: Tunnel Federation Object Model

2.4. Overview of Tunnelling Federation

Figure 4 shows the proposed framework for the simulation model, based on available studies and expert knowledge gathering. Most federates were developed based on a case study for tunnel construction in the City of Edmonton using a specific construction method, and will be used as a base for further development.

The scenario setup federate is designed for the user to configure different tunnel projects and scenarios. In the current federation, the user inputs all necessary parameters at this federate: shift length, shift start time, coffee break duration, lunch break duration, project start date, work status on weekends or holidays; project setting such as number of shafts, number of tunnels, and their attributes like tunnel length, section length, etc.; resource setting refers to equipment information and crew information. This information will be passed to other relevant federates through RTI.

The shaft federate simulates the shaft construction process including preparation, excavation, and lining. The tunnel federate is designed to simulate the complete process of constructing a tunnel including excavation, lining, resetting TBM, and TBM breakdown; it also covers other common activities, like extending utilities and surveying.

The dirt removal federate models the process of removing dirt from the tunnel face to the undercut, dumping dirt from undercut to ground, and loading carts with materials.

The supplier federate has the same responsibility as a supplier contractor: receive a new order from the contractor through the procurement federate, schedule for delivery of a new order and send a response to the procurement federate.

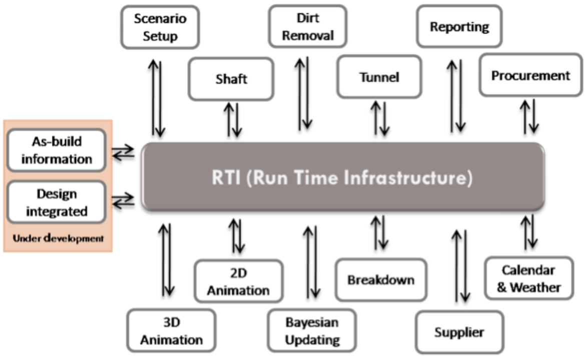

Figure 4: Tunnel Federation

There can be more than one supplier which can join the federation and receive orders from the procurement federate. The procurement federate plays the same role of the procurement office in the tunnelling contractor group. It tracks how many liners are in the inventory; if that level reaches a specific threshold, the procurement federate places an order for the concrete lining segments to the supplier.

The Bayesian updating federate is designed to apply a Bayesian updating method for predicting machine breakdown, TBM advance rate, tunnel productivity, scheduling and cost.

The visualization federate displays a 2D and 3D animation of the construction process as the simulation is running. It is a real time visualization of the entire process and shows the different states of the TBM during tunnel construction, the excavation and lining of the tunnel, as well as traveling muck carts in the tunnel. In current federation, all the mentioned federates are fully functional for the NEST tunnel case study in Edmonton, Canada.

Future development will involve connecting a 3D CAD drawing to the simulation model and extracting as-planned geometry and geotechnical information. This federate will remove the need for manual data entry, especially when new revisions of drawings are released.

Capturing and storing all the as-built information will be based on automatic data transfer from the site and data will be stored in the SQL Server database. Figure 5 illustrates an example of relationship in the database.

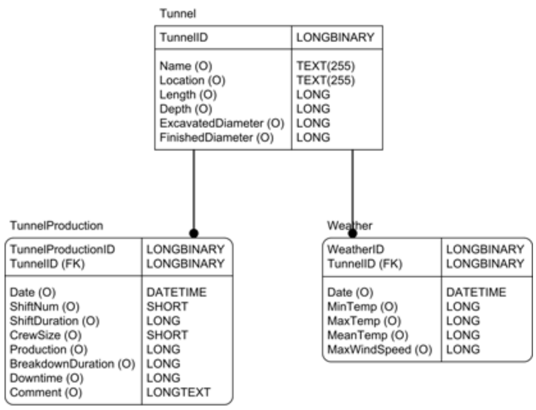

Figure 5: ER Diagram of Database

3. INFORMATION MANAGEMENT STRUCTURE

To fulfill the objective of this research, a vital part of the implementation process is to study the possible ways of representing information within the COSYE environment and create a conceptual structure for the data management plan. We determined the required information by answering the following questions:

- What kind of information will be useful for decision making process and different participants in the project?
- What kind of information from the planning stage will be required for developing the simulation model?
- What kind of information from the jobsite will change the inputs of the simulation model and how can we store it to make it exchangeable with original inputs?
- How can we make the history of projects reusable for future projects or simulation models?

Answering these questions determines the information required from a tunnelling construction project in order for the simulation to be representative. Finally, to collect and integrate on-site process information (as-built) and to be able to store the as-planned data and their relationships throughout a simulation model, an accurate knowledge management system needs to be developed. For this purpose, a comprehensive relational database is proposed to store planning data, actual as-built data, and the history of project process changes. A view of our vision is given in Figure 6.

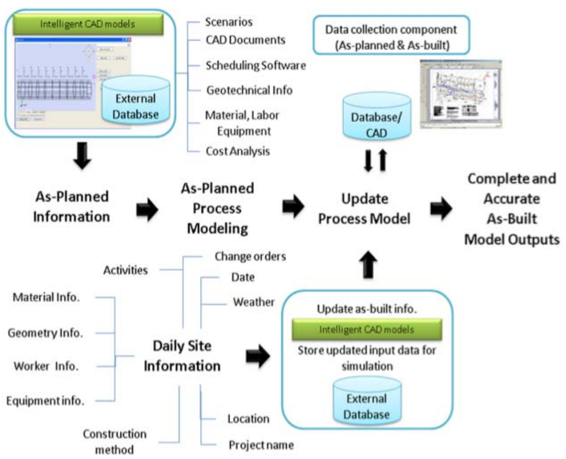

Figure 6: Integrated Framework for Tunnelling Construction

4. FUTURE WORK

In the future, new federates such as a design information federate will be developed to facilitate information transfer from CAD systems to the simulation model, and a relational database will be designed and connected to the federation to store as-built information as the project advances.

To make changes to the process model during the construction phase without a need to re-create the entire model (e.g., adding one removal shaft or changing the construction method of the tunnel), generic and reusable federates are required. To develop such federates; the current FOM needs to expand to provide all the object classes, attributes, and interactions for different tunnel construction methods, activities, equipments, and the required information from the planning and construction stage.

The simulation model and design inputs will then be updated based on new process and information (reconstructed from the beginning of the project but as if the project is going on now – i.e., simulate the simulation) to mirror any changes in design and construction, create an accurate model and verify it. The product/process data integration will be evaluated and adjusted if necessary.

Once the NEST case application is functional, the work will be repeated with another tunnel construction project to identify areas where the framework must be adjusted and an application framework approach as a basis of this research will be utilized to provide a generic framework with modularity, reusability and extensibility.

5. CONCLUSION

The ability to access detailed information of a project along with the actual construction process (as it was built) will be highly beneficial for the management process for different purposes such as quality control, claims, process improvement and future project planning. This paper proposes the development of a generic framework for information management in repetitive construction projects such as tunneling to incorporate process model, product model, resource model, and static information in one system. Deploying HLA-based distributed simulation and using a software application framework enables us to standardize the integration process between simulation systems, different computer software, and project models and supports interoperability, reusability, and extensibility of this framework. While all COSYE development to date has taken place in an academic environment and COSYE itself has not yet been commercialized, development of a full federation typically takes between one half to one full man-year (1,000 to 2,000 hours).

With this system, project managers will have full access to the project data. Moreover, they will have an accurate model at the end of the project for reviewing purposes, documentation for future work, and educational purposes. The system will save time and money, improve training, and increase operational efficiency.

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