Analysis of Microtunnelling Using Process Simulation Module

T. T. Dang[a]*

[a] *University of Mining and Geology, Hanoi, Vietnam*
* thanh.dangtrung@rub.de (*corresponding author's E-mail)*

Abstract

The use of process simulation module can be benefit for planning and operating a microtunnelling project. Thereby, problems at different construction phases can be anticipated and analyzed. Moreover, it has potential to optimize usage of resources, to develop better project plans, to minimize costs or project duration, to improve overall construction project management and to avoid costly mistakes. This research presents an approach for analyzing construction operations with Microtunnel Boring Machines (MTBM) utilizing process simulation module. It helps to analyze the processes and to identify the influence of disturbances on the productivity of MTBM operations. In view of these objectives, the MiSAS (Microtunnelling: Statistics, Analysis and Simulation) module is introduced and applied. The MiSAS simulation module allows to evaluate the impact of the disturbances and predict the resulting tunnel advance rate. Within the paper an actual microtunnelling projects at the city of Recklinghausen, Germany, is used for the case study.

Keywords: Microtunnelling operations; Process simulation module; Microtunnelling: Statistics, Analysis and Simulation (MiSAS) module; Microtunnel Boring Machines (MTBM).

1. Introduction

Microtunnelling operations involve a complex interaction of processes and the productivity is affected by disturbances, such as weather, limited space, staff absenteeism, regulatory requirements, design changes and reworks. Hence, there is a need for a better understanding the disturbances influencing productivity. The efficiency of MTBM will be increased by that knowledge.

The use of simulation module is a widely used tool for the design, analysis and optimization of technical processes. In general, the simulation model can help to analyze causes for delay, bottlenecks and reduction of productivity during construction operations. Since the early 1990s until 2000, a number of simulation systems and simulation applications were used. Liu and Ioannou (1992) developed a simulation module, called COOPS. The COOPS module are defined via a graphical user interface where the simulator can capture resources, define different resources and can link with the calendars that can be used to pre-empt activities during work breaks. Odeh et al. (1992) and Tommelein et al. (1994) developed an module, named CIPROS. The CIPROS enables the user to relate construction plans and specifications to a construction plan. McCahill and Bernold (1993) developed a general purpose module called STEPS with a library consisting of standard models for common construction processes. Martinez (1996) introduced STROBOSCOPE. STROBOSCOPE is used in the analysis of construction operations. It is designed for modeling complex construction operations in detail and for the development of special purpose simulation tools.

Within this paper, the use of MiSAS module is presented to analyze production under consideration of typical disturbances of MTBM systems. The MTBM with hydraulic spoil removal is the most widely used with many recent innovations and for this reason in the focus of this research.

2. Theories

The paper is describe in brief the methodology in order to develop the MiSAS module. The MiSAS is established based on System Modeling Language (SysML) model. The SysML model describing the microtunnelling process is developed in the first step. The simulation model consists of three types of diagram: block definition diagram (bdd), state machine diagram (stm) and sequence diagram (sd), which are supported in the SysML. The simulation model is used to analyze and understand the entire process involved in microtunnelling construction and identify the model variables for which information needs to be collected. Subsequently, the simulation software AnyLogic is applied to create the MiSAS (Microtunnelling: Statistics, Analysis and Simulation)

simulation module based on the SysML formalization. The implementation of the proposed methodologies, utilizes discrete event simulation (DES) and system dynamic (SD) modelling. The simulation module allows to evaluate the impact of the different ground conditions, disturbances and predict the resulting tunnel advance rate. The detail of the procedure in order to develop the MiSAS module, the papers of Dang (2013; 2014a; 2014b) are recommended for further reading.

3. Introduction MiSAS module

This section will introduce the MiSAS module in detail. All the components of the developed module MiSAS and the entire of Graphical User Interfaces (GUI) have been designed and implemented utilizing AnyLogic simulation software. The author proposed in this study the development of a graphical interactive environment for the simulation of tunnels construction with MTBM. Here, the user will input the information through the GUI. There have been twenty-one Active Object Classes (AOC) used to design and code in order to develop the module MiSAS. Thirteen of the AOC are designed in order to represent the behavior of the devices in microtunnelling (e.g. the behavior of MTBM, separation plant, crane, etc.). Three of them are designed to analyze the output results (e.g. rate of progress, prediction of the total time of a project with and without disturbances, 3D animation simulation, etc.). Six of the AOC have been coded and GUI developed to input the data and information. The role of six GUI is to input, define the various resources, activity durations, disturbances, site layout. Fig. 1a and b depict twenty one AOCs and an example of the interface of an input resource specification of the MiSAS module.

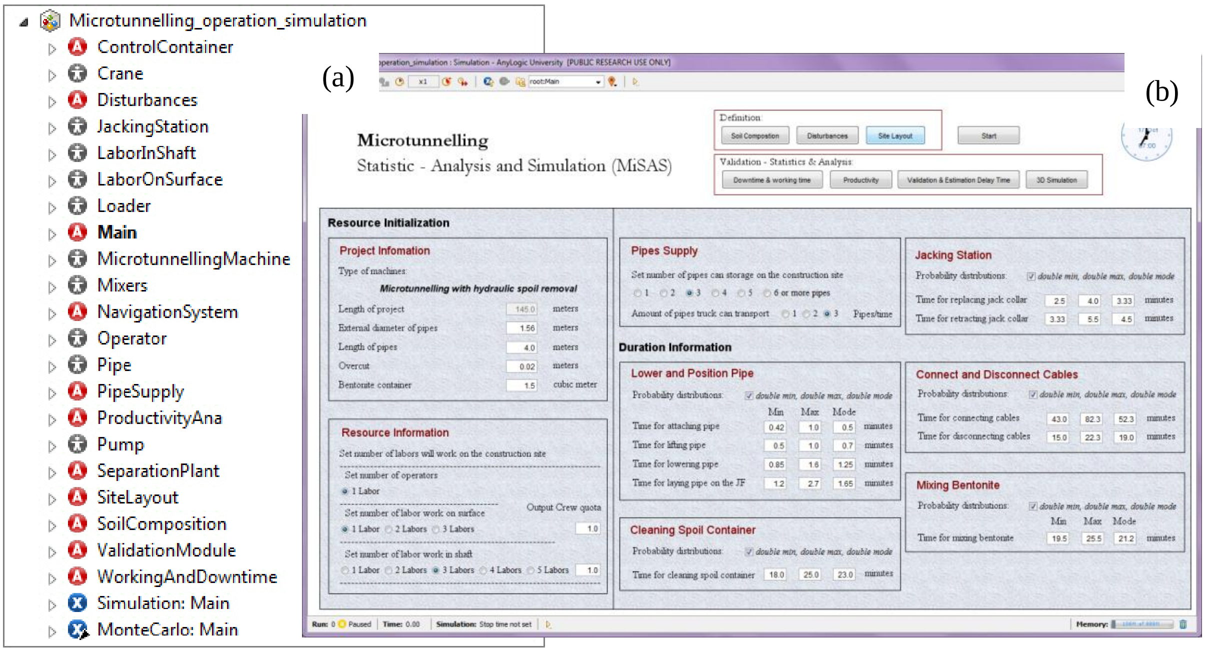


Fig. 1. a. Twenty-one AOC of MiSAS and b. An example of the GUI for resource specification

3.1. The GUI - Input Resource specification

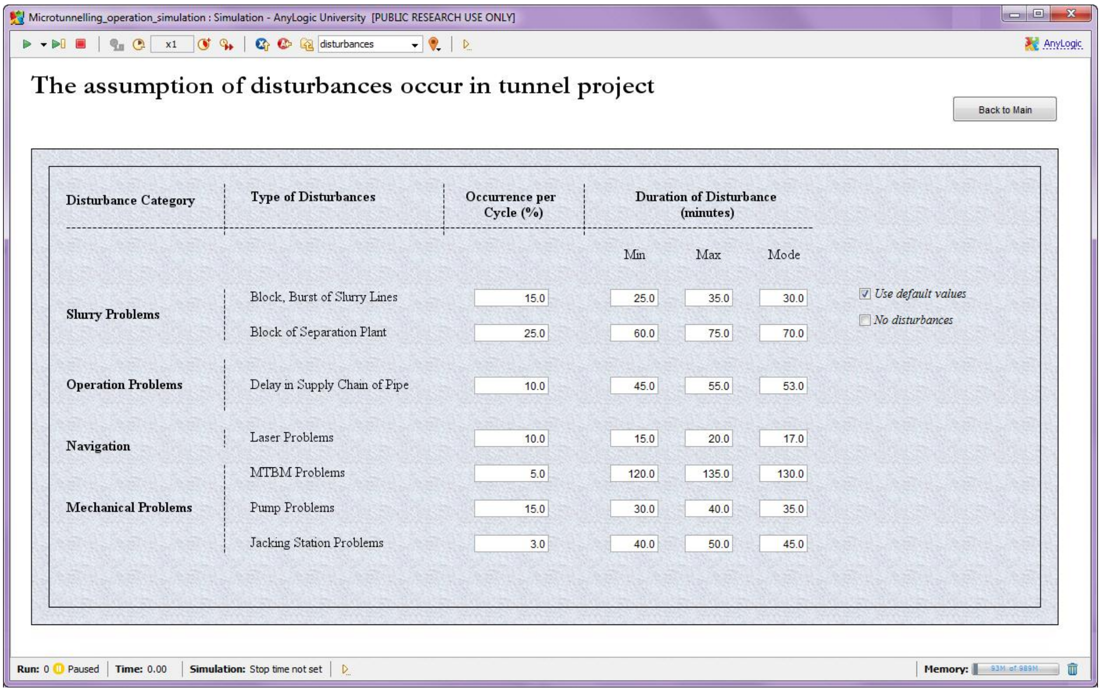
The GUI of input resource specification is depicted in Fig. 1b. The screen allows the user to: 1) Define the quantity of laborers working in the construction project; 2) Input of the activity durations (e.g. the time to connect and disconnect cables, the time for mixing lubricant and so on); 3) In addition, the definition of the project is also used (e.g. length of the project, attributes of type of pipe, and so forth). 4) Run simulation analysis and link to other interfaces such as: 3D animation, statistics analysis of the data during running MiSAS module.

3.2. The GUI - Input disturbances

The GUI of input disturbances form as depicted in Fig. 2. It describes and imputes the most common types of disturbances that normally occur on the job site. The screen allows the user to: 1) Define the type of disturbances that may occur. The type of disturbances used in this research are: slurry problems, navigation errors, mechanical and operation problems. Define the duration time to repair the disturbances. Define the occurrence per cycle. As the disturbances are stochastic. Therefore, the GUI of input disturbances may help the user to input their forecast about the percentage of disturbances that may be expected per cycle. The value of the occurrence per cycle depends on the experiences of the user.

3.3. The GUI - Static analysis and statistics

The static analysis and statistics extracts data from all of the system's component. Fig. 3 depicts the main menus for the static analysis and statistics. Different types of reports are obtained, there are: 1) rate of progress; 2) prediction of the productivity of microtunnelling with and without disturbances; 3) estimation of the productivity with different soil components; 4) evaluation of some information, which are helpful for microtunnelling (e.g. prediction of the total volume of lubricant support for project, estimation of the volume of spoils that need to be excavated, etc.).



Disturbance Category	Type of Disturbances	Occurrence per Cycle (%)	Duration of Disturbance (minutes) Min	Max	Mode
Slurry Problems	Block, Burst of Slurry Lines	15.0	25.0	35.0	30.0
	Block of Separation Plant	25.0	60.0	75.0	70.0
Operation Problems	Delay in Supply Chain of Pipe	10.0	45.0	55.0	53.0
Navigation	Laser Problems	10.0	15.0	20.0	17.0
	MTBM Problems	5.0	120.0	135.0	130.0
Mechanical Problems	Pump Problems	15.0	30.0	40.0	35.0
	Jacking Station Problems	3.0	40.0	50.0	45.0

Fig. 2. The GUI for defining disturbances

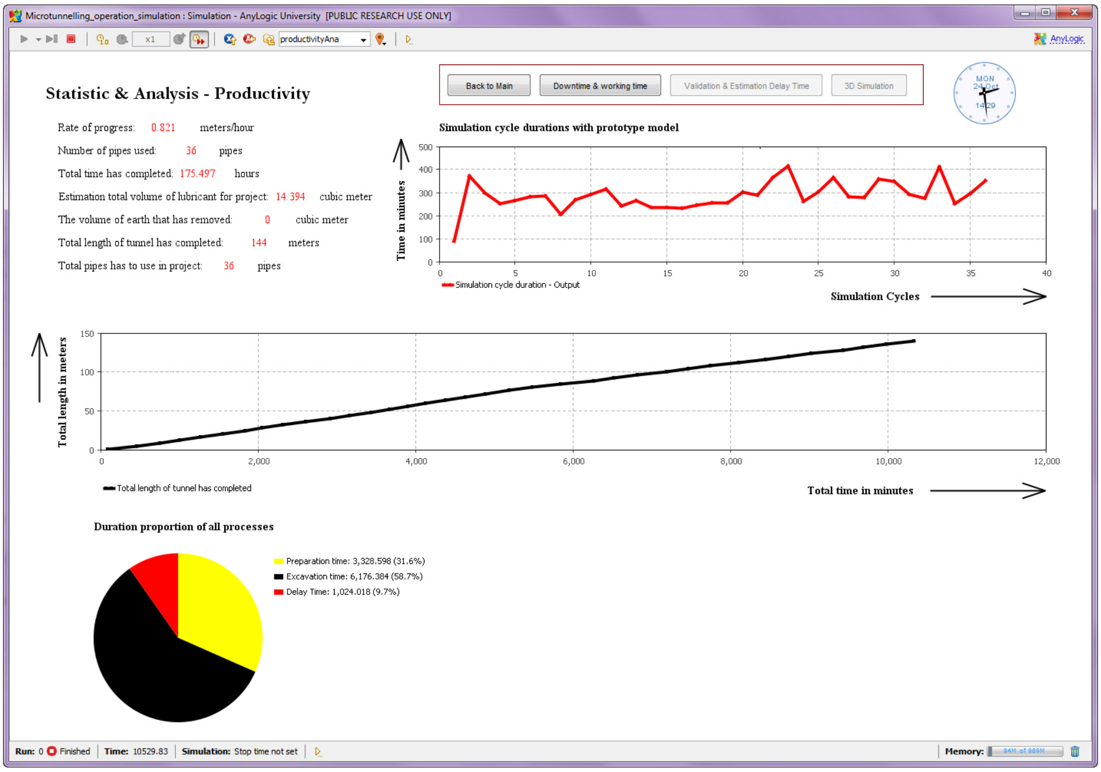


Fig. 3. The GUI - Static analysis and statistics

3.4. The GUI - Dynamic analysis and statistics

The dynamic analysis and statistics supports animation to present the overall system dynamics, the interaction between laborers and resources, the delay associated to the individual resources. Fig. 4 illustrates a screenshot of a layout of a tunnel construction with MTBM after 10 cycles of simulation. It also depicts animated screens of the overall activity of MTBM, resources, laborers.

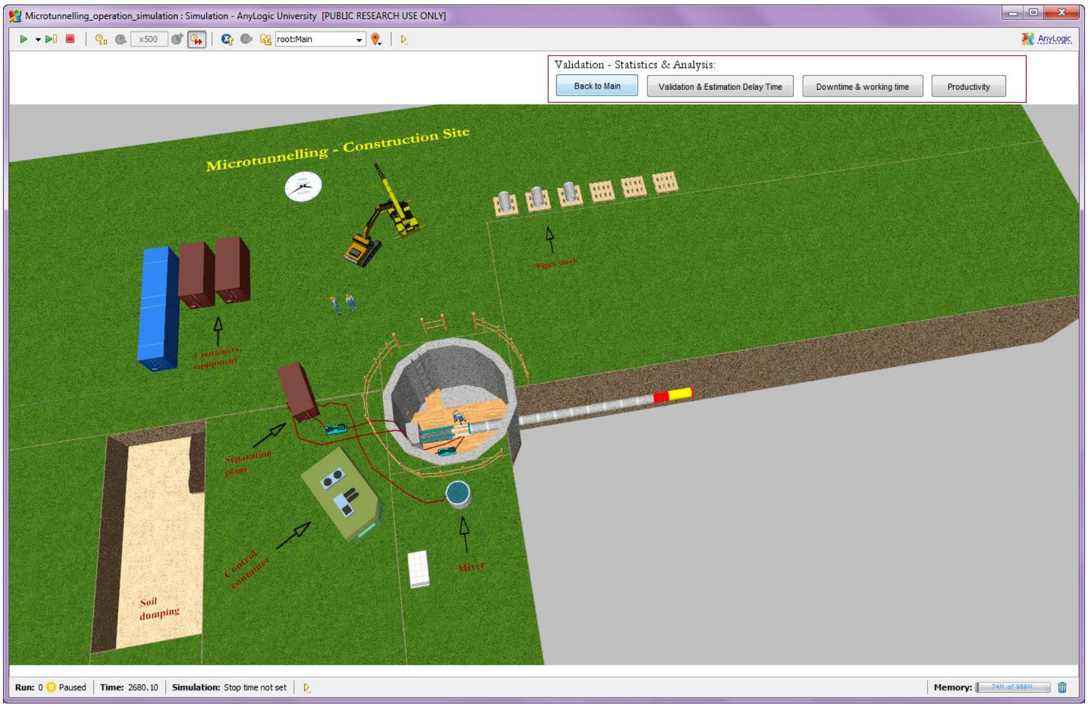


Fig. 4. The GUI - Dynamic analysis and statistics

4. Case study

The application of the MiSAS module has been executed on the three different microtunnelling projects in Germany. This paper presents the data, which has been collected in a project located in Recklinghausen City, Germany, named BV Recklinghausen V.5.1. Details of the microtunnelling project, including the general information, ground conditions, activities duration and disturbances will be discussed.

4.1. Project description

The tunnel went along the road ”Im Reitwinkel” as shown in Fig. 5. A 79.44 meters long drive completely through fine sand and silt. The depth to the axis was approximately 7.4 meters, grade 1.4‰ and the pipe size was 1.8 meters internal diameter, 2.2 meters external diameter, 3.5 meters

(a) Site plan and position of bore holes

(b) Simplified long section

Fig. 5. Details of BV Recklinghausen V.5.1.

length. Excavation was carried out by the microtunnelling machine VSM 1800 with an outside diameter of 2.20 meters using hydraulic spoil removal. The position of the construction site was easily accessible. The whole tunnel of project Recklinghausen V.5.1 will encounter the types of soil conditions which are fine sand and silt. That is a good soil condition in order to execute jacking processes. The average time for jacking processes based on the data collected from the job site ranged from 85.00 minutes to 99.00 minutes.

4.2. Duration data collection

The input data duration used for running the simulation model must be collected. In order to collect duration information, the eleven important durations affecting the productivity of the microtunnelling construction are collected. There are: 1) attaching pipe; 2) lifting pipe and go to shaft; 3) lowering pipe; 4) laying pipe; 5) replacing jack collar; 6) connecting cables and hoses; 7) jacking processes; 8) retracting jack collar; 9) disconnecting cables and hoses; 10) time for cleaning spoil container; 11) time for mixing bentonite. The activities duration is archived within two weeks by using a stop watch at the job site as shown in Table 1.

Table 1. Duration information of job site: BV Recklinghausen V.5.1

Activity number	Activity	Minimum value (min)	Mode value (min)	Maximum value (min)
1	Attaching pipe section	0.30	0.50	0.70
2	Lifting pipe go to shaft	0.50	0.80	1.00
3	Lower pipe	0.90	1.20	1.50
4	Laying pipe	1.00	1.70	2.00
5	Replace jack collar	10.00	12.50	15.00
6	Cables connect	12.00	15.00	16.30
7	Jacking forward	53.00	95.00	165.00
8	Retract jack collar	11.00	13.30	15.00
9	Disconnect cables	23.00	25.00	27.50
10	Time for clean spoil container	15.00	23.00	27.00
11	Time for mixing bentonite	13.00	15.00	16.00

Note: Lowest value: The minimum value; Highest value: The maximum value; Mode value: The most likely value.

4.3. Simulation results

The application of the module to the project are described in this section. The simulation module is performed to evaluate and analyze the impact of the disturbances on the productivity of MTBM. The simulation experiment consider the disturbances occur during jacking processes. The mean time between failure (MTBF) are generated by the triangular distribution. The assumptions input values made for the applications in this paper shown in Table 2.

Table 2. Configuration of disturbance simulation

Type of disturbances	Mean cycles between failure (%)	Time to repair (min)		
		Min	Max	Mode
Blocking, Burst of Slurry Lines	15	65	85	70
Blocking of Separation Plant	35	60	75	70
Laser Problems	10	15	20	17
MTBM Problems	5	220	250	235
Pump Problems	15	50	60	55
Jacking Station Problems	3	40	50	45

Table 3. Overall simulated microtunnelling process productivity in project BV Recklinghausen V.5.1 with disturbances

Total sim. Time unit (min)	Cycle number	Productivity for one pipe (3.5m)	Productivity per time unit
4621.5	22	210.07	0.00476035919

Fig. 6 shows the change of productivity of the tunnel in the sub-project BV Recklinghausen V.5.1 considering disturbances. Table 3 displays the productivities obtained from the simulation. The comparison with the case without disturbances was carried out. After 22 cycles, the average simulated duration with disturbances is 210,07 min for one pipe of 3.5m length (compared with 159.925 min for one pipe without disturbances), that means that it is ca. 27.1% higher than the average productivity obtained without disturbances. The total time to finish the project with disturbances is 4621.50 min. The total time is 1103.15 min (ca. 18.4 hours) higher if compared with the total time to finish the project without disturbances which is 3518.35 min.

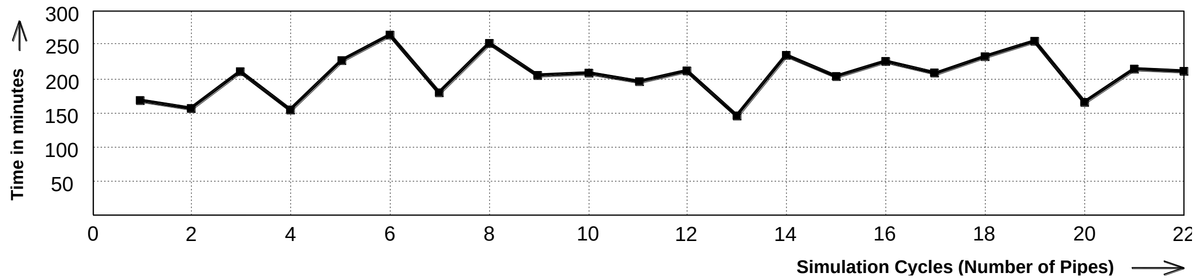


Fig. 6. Simulation cycle durations considering disturbances in project BV Recklinghausen V.5.1

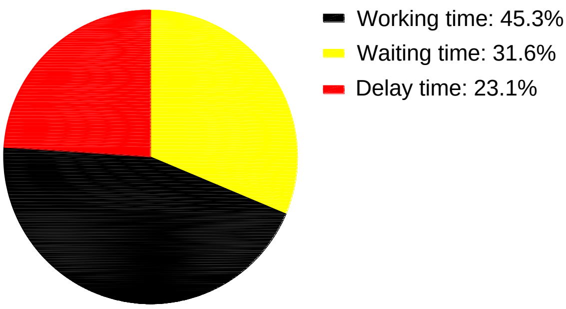


Fig. 7. Utilization of MTBM (as% of total time) considering disturbances in project BV Recklinghausen V.5.1

The simulation results in Fig. 7 also represent the working time, waiting time and delay time of the MTBM. The results show that the working time of the MTBM is 45.3%, as shown in Fig. 7, black area. The waiting time for jacking processes is 31.6%, represented in Fig. 7, yellow area, and the delay time (because of the occurring disturbances) is 23.1%, represented as red area in Fig. 7.

5. Conclusions

In the research, an appropriate and adaptable simulation module for microtunnelling construction operations based on a formal model description of MTBM with hydraulic spoil removal was introduced. The simulation module focuses on the evaluation of the effect of different disturbances on the productivity of the microtunnelling process. In specific applications, the MiSAS module helps the manager or engineer to analyze the possibility of multiple approaches to execute the tunnel construction with MTBM. Using MiSAS, it is also shown that the best allocation of resources can be determined based on productivity. Overall, the MiSAS simulation module accomplishes the initial objectives as defined. It provides a set of flexible and powerful analytic techniques that can be customized by any user according to the specific applications that are desired.

References

Liu, L. Y. and P. G. Ioannou., 1992, Graphical object-oriented discrete event simulation system. In *Proceedings of the 24th Conference on Winter Simulation, Association for Computing Machinery, New York, USA*, pp. 1285–1291. ISBN: 0-7803-0798-4.

Odeh, A. M., I. D. Tommelein, and R. I. Carr., 1992, Knowledge based simulation construction plans. *In Proceedings of the 8th Conference on Computing in Civil Engineering*, Volume 7, ASCE, New York, USA, pp. 1042–1049.

Tommelein, I. D., R. I. Carr, and A. M. Odeh., 1994, Assemply of simulation networks using design, plans, and methods. *Journal of Construction Engineering and Management*, 120(4), 796–815.

McCahill, D. F. and L. E. Bernold., 1993, Resource-oriented modeling and simulation in construction. *Journal of Construction Engineering and Management* 119(3), 590–606.

Martinez, J. C., 1996, STROBOSCOPE - State and resource based simulation of construction process. *PhD. Thesis, The University of Michigan.*

Dang, T. T., 2013, Analysis of microtunnelling construction operations using process simulation. *Ph.D. thesis, Bochum Ruhr Univ., Germany*.

Dang, T. T., 2014, Advancement simulation of microtunnel boring machines. *Proc. Of 3rd International Conference on Advances in Mining and Tunnelling.*, 253-259.

Dang, T. T., Le, L. H and Le, T. K., 2014, Multi-method simulation of the construction process in microtunnel boring machines. *Proc. Of 3rd International Conference on Advances in Mining and Tunnelling*., 265-271.