Chapter 8

Summary, Conclusion and Outlook

8.1 Summary

This thesis presented an approach to analyze microtunnelling construction processes using computer simulation. The research aims at the development of an appropriate and adaptable simulation module for microtunnelling construction operations. It helps to analyze the processes and to identify the factors which influence the operation productivity of the construction process. In addition, the relationship between different soil conditions, disturbances and the microtunnelling productivity had to be determined.

In the first part of the thesis, the role of the use of process simulation in the analysis and improvement of construction operations was discussed. The fundamental principle of tunnel construction with microtunnelling and the main hitches that exist in typical microtunnelling projects were described as well. In addition, the information gathered about activities and resources (e.g. laboratory, special machinery and materials) used in the microtunnelling project was analyzed. Moreover, the disturbance causes and the influence of disturbances on the construction sequences were also discussed in this part. As a first step, the entire of these information have been used to help building simulation models in the next steps.

In the second part describes the development of appropriate simulation models for MTBM. Based on the Systems Modeling Language (SysML), simulation models, representing the tunnel construction process with microtunnelling, were developed. The simulation models were built by using three types of diagrams, the so-called block definition diagram, state machine diagram and sequence diagram, which are supported in SysML. The diagrams represent the composition, sequence and the interaction within the MTBM. These simulation models are used to help to better understand the process
involved in microtunnelling construction, and identify the model variables for which information needs to be collected.

Based on the developed simulation model, in the third part a simulation module called MiSAS (Microtunnelling: Statistics, Analysis and Simulation) has been developed using AnyLogic simulation software. It has been designed utilizing discrete event simulation, system dynamic and agent based methodologies, which are supported in AnyLogic software. The simulation module has been coded utilizing Java platform. Due to the MiSAS module has to be built accurately, therefore it has to be validated. Numerical examples of three actual cases have been worked out to validate the developed MiSAS and demonstrate its capabilities. In order to validate the module, the output data of the simulation module is compared with the data from actual microtunnelling projects. The three actual projects, namely, "BV Recklinghausen V.5.1", "BV Recklinghausen V.8" and "BV Recklinghausen V.15" in Recklinghausen, Germany have been chosen to get the real data. The real data about probability distributions of time durations of activities, resources and the relationships between model parameters in the construction site are collected. These real measured data were used to be compared with the output data of the simulation module. According to the comparison of output data and real data, the MiSAS module may be adjusted if necessary and simulation needs to be redone to validate the model.

In the fourth part, after the validation and verification of the simulation module, the same structure and logic were used with enhancement of soil composition and disturbances. The enhanced MiSAS module can be modified to include possibilities of soil compositions, disturbances and simulation corresponding to productivity. Therefore, the statistical relationship between soil composition, disturbances and microtunnelling projects productivity can be analyzed, anticipated and studied. Further, the graphical user interface has also been designed and implemented utilizing AnyLogic simulation software to help the user's interaction being as simple and efficient as possible.

The last part involves the performance of experiments and analysis of the results. As an application module, the operational and statistical analysis are performed using simulation. A sensitivity analysis is carried out, using the simulation module with real microtunnelling case data, to identify and analyze the most critical microtunnelling variables affecting productivity of microtunnelling construction process. Critical variables are the variables that have major impact on productivity of microtunnelling construction. On the basis of the obtained results, working time, downtime of the resources, microtunnelling, labors, and the effective resource allocation regarding a real microtunnelling project is determined.
8.2 Conclusion

In this thesis, a methodology for simulating utility tunnels construction with MTBM using computer simulation was described. Within 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 developed. The simulation modules were conducted on the cyclic of the microtunnelling process, including pipe segments preparation to pipe section jacked in place. In mobilization and demobilization stages, activities including digging shafts, hauling MTBM, setting up control console, the cost of the project etc. were not considered into simulation modules due to the non-cyclic nature. The formal model is a simulation model that has been established based on SysML. The simulation module focuses on the evaluation of the effect of alternating soil conditions and disturbances on the productivity of the microtunnelling process.

The conclusions of the study can be summarized as follows:

1. The development of a simulation model capturing the tunnel construction process with MTBM based on SysML methodology has been carried out. Based on established SysML simulation, the simulation module has been developed. The module accounts for the uncertainty involved in these operations and captures the interaction amongst devices and resources. Moreover, it consists of a powerful set of tools that can help the manager to identify the factors which influence the operation productivity of the construction process.

2. The simulation module delivers the manager or engineer the effect of the following variables on the advance rate such as: different soil conditions, disturbances. Furthermore, several sensitivity analysis studies to investigate the effect of the resources on the productivity of tunnel construction with MTBM have been performed. In addition, the simulation module can be used to predict the actual advance rate of the microtunnelling with and without disturbances.

3. 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.

4. The special characteristics of the simulation module makes it more attractive for use than other planning systems. The terms and mode of operation closely resemble the usual practices in tunnels construction with MTBM and its orientation provides the job site manager with more usable information than other systems.

5. In terms of scheduling alternatives for the overall project, the user can easily restructure the approach taken and evaluate the effects of the decision. Through
repetitive analysis of the same tunnel, the best or better alternative can be found. It also helps the user to view the possibilities of the overall of the tunnel construction project with MTBM.

6. Overall, the developed 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.

8.3 Outlook

This research has presented a approach for analyzing the tunnel construction with MTBM by utilizing computer simulation. The research could be expanded to account for the following:

1. As already mentioned in this study, the MiSAS module covers the analysis of the factors which effect the productivity of microtunnelling. The module has not mentioned the effect of the factor e.g. disturbance or soil composition on the total cost of the tunnel construction with MTBM. For future research purposes, the MiSAS simulation can be expanded to include sub-modules to estimate the time and cost of tunnels construction with MTBM. Hereby, the relationship between resources, equipment and productivity can be analysed as well as economical optimum may be achieved.

2. The MiSAS module was only applied for the MTBM with hydraulic spoil removal. For future research work, the simulation module can be upgraded with different types of MTBM, such as: tunnel construction with auger spoil removal and with pneumatic spoil removal.

3. The simulation can be enhanced to predict the jacking force for microtunnelling operations. For future work, the module may be extended to calculate the jacking force for MTBM. This can be helpful for planning, design, and construction phases of microtunnelling projects.

4. This study focuses primarily on the tunnel construction with MTBM without intermediate jacking stations processes. Therefore, the simulation module and algorithm can be extended to include the intermediate jacking stations.

5. The development of a decision support system, which can be used by contractors to estimate projects' markup and by owners to evaluate bid proposals, in a flexible manner.

6. In this the research, the minimum, maximum and the mode likely value of the triangular distribution was decided based on the data from only three construction sites. For future purposes, the time durations of the activities may be modelled by probability distributions, based on the amount of data collected from the construction site. This will help to make the results output more accurate.
7. Within this study, assumptions were made, regarding the pipes handling processes to the construction site. The MiSAS module only assumed two cases during transportation time: with and without disturbance. The module did not mention the pipes handling processes in detail. For future study purposes, the pipe handling material processes may be modelled in detail according to the transporting sequence. This will help to module real world tunnel projects with MTBM more accurately.

8. The effectiveness of the use of process simulation is proven through a lot of studies and research. It is especially useful to describe and analyze construction projects that consist of repetitive construction cycles. For future research works, the use of process simulation can be expanded to encompass different construction operations e.g. the tunnel construction with NATM (New Austrian Tunnelling Method), with TBM (tunnel boring machine) or the construction of highways, bridges, mining, earthmoving, etc.