Research on Safety of Operation and Maintenance of Utility Tunnel based on BIM and Computer Technology

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Abstract. The purpose of this study is to ensure the safety of operation and maintenance of utility tunnel. First of all, the framework of safety management system in operation and maintenance phase of utility tunnel is constructed by combining BIM technology, and the Access database tool integrates the operation and maintenance data of utility tunnel with BIM technology to establish a BIM-based utility tunnel operation and maintenance database. On this basis, the BIM model of an utility tunnel is constructed by using Autodesk Revit modeling software. Finally, the application of the safety management model in visualization, safety education and fire simulation of operation and maintenance system of utility tunnel is verified.

Keyword: BIM; Utility tunnel; Simulation.

1. Introduction

With the rapid development of China's utility tunnel, a large number of utility tunnel construction has been completed and put into operation [1]. The development of utility tunnel in China should gradually move from "construction stage" to "operation and maintenance stage". However, scale, number and type of pipelines in the integrated pipeline corridor all determine complexity of its operation and maintenance management, so operation and maintenance management of the utility tunnel appears to be relatively difficult. But BIM technology can solve this problem. BIM (Building Information Modeling) technology is mainly used for building model of building project, mainly realizing the visualization of the project, and improving the construction efficiency of the project through data, simulation and analysis of working process [2], [3], and project management through model-based management [4], [5], [6]. It is a very promising technology in the field of architecture because it not only solves multiple hazards, but also supports decision making and enhances value [7]. As an integrated whole life cycle of the pipe gallery, the longest time and obtain economic benefits of operation and maintenance phase, the use of BIM technology and safety management, helps to control maintenance cost [4], [8], [9], and to help users to manage complex data and information [10], in the subsequent management benefit for prevention of accident and emergency decision making.

At present, BIM technology has been widely used in the world, so the results of BIM research are relatively mature [11]. Liu and Issa have developed additional tools for BIM software to accurately predict the risk factors of pipe gallery operation and maintenance. In addition, they integrate BIM and GIS to master information of all pipelines in the pipe gallery, so as to facilitate pipeline management,
realize visual management of pipelines, and improve safety coefficient of the pipe gallery [12]. Akcamete et al. found through the study on the full life cycle of construction projects that the costs incurred in facility operation stage were much higher than those in design and construction stage, and the costs incurred in facility operation stage accounted for more than 60% of total costs in whole life cycle [13]. Harsha Vardhan Reddy and Guduru Penusila combined the construction data of utility tunnel in Dallas and Texas with BIM technology to build a BIM model containing all data information of utility tunnel. By simulating and analyzing the construction stage of pipe gallery project, they concluded that BIM technology could effectively grasp the overall situation of the project and conduct scientific management. Reduce project management costs and improve construction efficiency [14]. Park T and Kang T integrated GIS technology and BIM technology, built a three-dimensional model of the construction project, and used it to optimize the construction scheme of pipe gallery [15]. Bryde D et al., through analyzed the project data of projects using BIM technology, from the quality, schedule and risk management, and application range of indicators to build BIM application standards system [16]. In his research, Sijie Zhang explores the integration of an automated rule-checking framework with BIM so that possible hazards can be detected and prevented [17]. Jiang Tianling, Li Fangfang et al. took ArchiCAD software as the platform to study the optimal design scheme of urban utility tunnel by building a three-dimensional architectural information model [18]. Cao Maochun, dong-xia zhang et al. takes industrial control and comprehensive utility tunnel based on the information of the pipe as the main goal of information construction, build a comprehensive overall architecture of information construction of the pipe rack, the main content of construction of intelligent utility tunnel is analyzed, and the integrated application of BIM and GIS technology is studied in depth, highly affirmed the BIM and prospects of the integrated application of GIS technology [19]. Dong Kexin, Chi Anqi et al. combined BIM technology and sensing technology, and took Navisworks, a visualization software, as the platform for secondary development, to establish an intelligent operation and maintenance management system with monitoring system operation status, accurate fault location and information visualization [20]. Cao Jiantao, Li Tao et al. studied the key technologies of BIM collaborative design platform construction and implementation, BIM 4D virtual construction and BIM operation and maintenance management system framework. It is concluded that BIM technology can improve design efficiency and reduce design errors [21].

On the basis of absorbing the previous experience, this article details the causes that could easily lead to the accident of the utility tunnel, utilized BIM technology from the perspective of safety management, providing a new entry point for the study of BIM in the utility tunnel. The establishment of the security management database of the utility tunnel caters to the trend of big data, which makes the security management of the utility tunnel more efficient. After combining the security management database with BIM, a large amount of data in the database can help BIM distinguish the complexity and danger in the utility tunnel [22], [23]. At the same time, BIM displays the huge information data through geometric forms, which make data information lightweight [24]. In addition, this paper also uses Autodesk Revit modeling software to build a BIM model of an utility tunnel, so that the security management of the utility tunnel is no longer limited to the interpretation of data, but visually reflects the changes of data in the model, and security management vulnerability of utility tunnel will become more clear and direct.

2. Security Management System Framework

2.1. Overall Architecture
The framework of safety management system in operation and maintenance stage based on BIM technology is constructed, which mainly includes the facility layer, data layer, platform layer and application layer. The synergy of the four layers forms an organic whole, as shown in Figure 1.
Figure 1. Overall architecture of operation and maintenance safety management system.
The first layer is the facility layer, which serves as the basis for ensuring the normal operation of
system, including network facilities, operating system, storage system and disaster recovery system.
The second layer is the data layer, which is used to store all data information of the whole system and
can save, modify and read system data, including BIM operation and maintenance model data,
monitoring data, operation and maintenance data, etc.
The third layer is the platform layer, which is the core of the basic framework of the safety
management system in the operation and maintenance stage. It realizes the integration of information
of BIM operation and maintenance model, monitoring data and operation and maintenance data. BIM
operation and maintenance model is used in the platform panel for the 3D display of data, such as the
basic information of equipment and pipelines. Maintenance information of equipment and pipelines,
safety information of utility tunnel, cost information, contract information and administrator
information, etc.
The fourth floor is the application layer, which is the application part connecting the system and
customers. It integrates operation and maintenance system of pipe gallery, including fire protection
system, ventilation system, power supply and lighting system, monitoring and alarm system and
drainage system, so as to realize the safety management and space management of the utility tunnel.

2.2. Utility Tunnel Operation and Maintenance Database

2.2.1. Database Structure. A large number of materials and data are generated in the whole life cycle
of pipe gallery. The information database of the utility tunnel is established to collect and integrate
data of the whole life cycle of the pipe gallery. BIM - based operation and maintenance database data
of utility tunnel is composed of BIM operation and maintenance model and operation and maintenance
data generated in the operation and maintenance stage.
Based on the operational and maintenance perspective, BIM design model, which is established by
applying BIM technology in pipe gallery design stage, through the information transmission and
modified became the BIM construction model. After the BIM construction model is further designed
and information is added to make it reach the depth of the BIM completion model, then the BIM
completion model is treated with light weight. Remove the building information and construction
information of BIM completion model in BIM operational and maintenance model, realize the utility
tunnel construction information generation and transmission in the BIM model, the operational and maintenance model structure diagram as shown in Figure 2. BIM operation and maintenance model generally includes three levels of information, namely: the length, width and height space dimensions of pipe gallery building components, such as key nodes, personnel import and export, material feeding port and air vent. The actual size and position of main components of pipe gallery includes foundation, structural beam, structural plate, structural column, etc. The electrical and mechanical parts of the pipe gallery includes fire, ventilation, monitoring, drainage, power and lighting systems. BIM operation and maintenance model can break the barriers between management gallery construction and operation and maintenance management, connect all links between construction management and operation and maintenance management, and realize data sharing.

**Figure 2.** Schematic diagram of operation and maintenance model construction.

Operation and maintenance data includes: basic information of equipment and pipelines. The six function modules are maintenance information of equipment and pipelines, safety information, cost information, contract information and administrator information of utility tunnel, as shown in Figure 3. The basic information of pipeline includes pipeline number, pipeline name, geometric information and installation location, etc. Basic equipment information includes equipment number, equipment name, manufacturer and installation location, etc. Maintenance information includes equipment number, equipment name, inspection personnel, inspection date, maintenance date and maintenance reason, etc. The contract information includes signing party, signing date and contract documents, etc. The administrator information includes employee number, employee name, contact phone number and department, etc. Mentioned above as shown in Table 1, the facility management information table in operation and maintenance phase of utility tunnel. The safety information of utility tunnel includes data of automatic fire alarm system, environment and equipment monitoring system, and security system, as shown in Table 2.

**Figure 3.** Utility tunnel operation and maintenance data function module.
Table 1. Facility management information sheet for integrated corridor operation and Maintenance phase.

| Basic pipeline information | Basic equipment information | Maintenance information | Contract information | Administrator information |
|----------------------------|-----------------------------|-------------------------|---------------------|--------------------------|
| Pipeline number            | Equipment number            | Equipment number        | Equipment number    | Employee number          |
| Pipeline name              | Equipment name              | Equipment name          | Equipment name      | Employee name            |
| Geometry information       | Equipment model             | Inspection personnel    | Signing party       | Gender                   |
| Installation position      | Manufacturers               | Date of inspection      | Signing date        | Contact phone number     |
|                           |                             | Date of maintenance     | Contract documents  | Photo                    |
|                           |                             | Reason for maintenance  |                     | Subordinate departments  |
|                           |                             | Cost for maintenance    |                     |                          |

Table 2. Safety information table of utility tunnel operation and maintenance stage.

| Automatic fire alarm system data | Environmental monitoring system data | Equipment monitoring system data | Security system data |
|----------------------------------|--------------------------------------|----------------------------------|----------------------|
| Detector number                  | Detector number                      | Detector number                  | Detector number      |
| Detector position                | Detector position                    | The name of the monitored device | Detector position    |
| Whether the alarm(0/1)           | Temperature(℃)                       | The position of the monitored device | Inward number and outward number |
|                                  | Humidity(%)                          | Whether it is running properly(0/1) | Whether the alarm(0/1) |
|                                  | The water level(cm)                  |                                  |                      |
|                                  | Oxygen levels(%)                     |                                  |                      |
|                                  | Whether the alarm(0/1)               |                                  |                      |

2.2.2. Integration of BIM model and Database. Microsoft Office Access is a database management system released by Microsoft, has powerful abilities about data processing and statistical analysis. To meet users' requirements of manual data input, users can also directly import or link data in other applications and databases, such as Open Database Connectivity (ODBC) in Revit to realize data
interconnection between Access Database and BIM model. Using the query function of Access, can quickly query and edit the data and other operations. According to the basic information of equipment and pipeline, operation and maintenance data of utility tunnel should be processed. Equipment, pipeline maintenance information, integrated utility tunnel safety information, cost information, contract information and administrator information at the six function module, the comprehensive utility tunnel operations and maintenance stage facility management information table and the comprehensive utility tunnel operational and maintenance phase safety information in the table data is stored in the Access database, the realization of the utility tunnel operational and maintenance data in Access database to add, delete, modify, and query. Autodesk Revit is used to construct BIM operation and maintenance model of urban utility tunnel to display actual situation of utility tunnel in three-dimensional space. Connect Access database with BIM model, import data into BIM operation and maintenance model, and build pipe gallery operation and maintenance database based on BIM, as shown in Figure 4. BIM - based pipe gallery operation and maintenance database is a BIM operation and maintenance model of information integration. Be able to link the information of each project and operation and maintenance management. Provide complete operation and maintenance data to ensure efficient daily operation and maintenance. Integrate the monitoring system data in gallery into the BIM operation and maintenance database to enhance the risk control ability of the gallery management.

![Figure 4. Operation and maintenance database based on BIM.](image)

2.3. Establishment of Safety Management Model for Operation and Maintenance of Utility Tunnel

This paper build safety management model about operation and maintenance of urban utility tunnel based on BIM database constructed in the previous section, as shown in figure 5. BIM database could also be a three-dimensional visualization platform, taking advantage of it to realize visibility, improving safety education, and doing fire simulation.
Figure 5. Safety management model about operation and maintenance of urban utility tunnel based on BIM database.

- Visualization of operation and maintenance system security. Carrying out real-time monitoring on operation and maintenance system security state of utility tunnel by monitoring system, which is include automatic fire alarm subsystem, environmental monitoring subsystem, equipment monitoring subsystem and security subsystem, each subsystem collect data by sensor. Integrating operation and maintenance data and BIM model, can show accurate location of each sensor in 3D model. When there is accident in somewhere of utility tunnel, could accurate positioning the location of accident in BIM operation and maintenance visual management platform. And the monitoring center will automatic switch to the video footage of the region where accident occurs, in turn, confirming the details of accident and make emergency measures. The combination of visualization and BIM can not only play a role in security management, but also from the perspective of security risk identification, Chan-Sik Park described the great potential of visualization and BIM model combination in Literature [25].

- Safety education. Import BIM model into Lumion to do interactive experience. In the process that train about security for employees, there could create virtual scene by Illustrations of BIM operation and maintenance model via Lumion. It enables trainees to have a more intuitive understanding of equipment attributes, operation procedures and safety hazards, and realize intelligent virtual safety education.
Fire simulation. Import BIM model into PyroSim for fire simulation, which can not only conduct fire research in different states, but also the simulate data could predict the possibility and severity of fire to a certain extent, which is conducive to the implementation of accident prevention work.

3. Establishment of BIM Model
In this paper, the urban utility tunnel project in a new district of a city is taken as the research object, and the BIM-based smart city utility tunnel operation and maintenance safety management model built above is utilized to realize the visual display, safety education and fire simulation for the security of utility tunnel operation and maintenance system.

Autodesk Revit 2016 was adopted to establish the three-dimensional model of urban utility tunnel. Firstly, building structure of the utility tunnel is modeled, in the construction of basic wall and support components, type, size, material and other information of the pipe gallery should be defined according to the actual situation of the pipe gallery. These information will become an integral part of the BIM operation and maintenance database to build the outline of the urban utility tunnel, as shown in figure 5-1. And then build a model of the pipeline and equipment, according to design requirements for the pipeline and equipment layout in comprehensive utility tunnel in the corresponding place, making urban comprehensive utility tunnel BIM model display effect is same as the pipe gallery actual situation, and should added the basic information of pipeline and equipment, maintenance information, cost information to the BIM model by defining the attributes of the building form. The safety information during operation of the pipe gallery is collected through monitoring equipment, and sensor of monitoring equipment is added to the BIM model to acquire location information of sensor. In order to ensure safe of the comprehensive line, reliable use operation inside the pipe gallery, pipe gallery need to set up a lot of affiliated facilities equipment, such as automatic fire extinguishing device, fan, substation, monitoring equipment, the comprehensive utility tunnel therefore need to set up a special node for the use of these facilities, at the same time in order to ensure pipeline installation in the pipe gallery, change, out of the requirement, also need to set up special nodes, such as: import and export, feeding mouth, air vents, such as export, the key nodes. Figure 6 is a complete urban utility tunnel model, including pipelines and equipment, personnel import and export, feeding port, air vent, and outlet.

Figure 6. The outline of the city's utility tunnel.
Figure 7. Complete utility tunnel model.

Figure 8 shows different parts of the utility tunnel. The personnel import and export are used for maintenance and overhaul of the utility tunnel and the entry and exit of emergency rescue personnel. The dog-house is used for the delivery of installation equipment for professional pipelines and affiliated projects. The ventilation opening is used to ensure air circulation in the pipe gallery. At the same time, there is a ladder for people to get in and out. The lead export is used to draw peripheral users of various professional pipeline services from the utility tunnel.

Figure 8. Different parts of the utility tunnel.
In order to meet the safe operation requirements of utility tunnel operation and maintenance system, the pipe gallery is equipped with ultra-fine dry powder fire-extinguishing device, video monitoring equipment, temperature-sensitive smoke detector and evacuation indicator. Figure 9 is the layout of the ultra-fine dry powder fire-extinguishing device. Figure 10 is the layout of video monitoring equipment and smoke detectors. Figure 11 is the layout of evacuation indication.

**Figure 9.** Lay-out of superfine dry powder extinguishing device.
Figure 10. Video surveillance equipment and detectors.

Figure 11. Evacuation indication sign layout plan.
4. Application

4.1. Visualization of Operation and Maintenance System Safety
The BIM model is integrated with the operation and maintenance data of the utility tunnel, and technologies such as the Internet and the Internet of things are utilized to build the BIM-based integrated management platform of the operation and maintenance of the utility tunnel, so as to realize comprehensive management of utility tunnel operation and maintenance system. Based on Internet of things technology, comprehensive utility tunnel internal fire extinguishing equipment, ventilation and drainage equipment, lighting and monitoring equipment to collect safety information of integrated pipe gallery operation and maintenance system. The BIM model has functions of equipment retrieval, operation and control, through the click on the view of the equipment in the BIM model, to be able to get all equipment information, such as equipment model, manufacturer, installation position and maintain, for equipment whose service life is about to expire timely warning and replacement, prevent accidents. Through real-time measurement and collection of data of utility tunnel operation and maintenance system by monitoring system, the operation of utility tunnel operation and maintenance system is visualized. The BIM utility tunnel operation and maintenance management platform is used for visual display of operation and maintenance system, as shown in Figure 12. When an accident occurs at a certain location in the pipe gallery, the location of the accident can be precisely located in the BIM operation and maintenance visual management platform. The monitoring center will automatically switch video images of accident area, so as to confirm details of accident and formulate emergency measures.

Figure 12. BIM operation and maintenance management platform visual monitoring.
4.2. Safety Education
Lumion is a real-time 3D visualization tool. With its powerful rendering technology and animation capabilities, it is able to create virtual reality on the computer and demonstrate architectural visualization through animation.
Many operation and maintenance staff lack professional knowledge and simply train in the form of images and words, which is too abstract to understand. The learning tools of animated videos can stimulate the user's vision when watching and make them actively absorb what they have learned [26]. Use Lumion to render model roaming display, realize the combination of virtual image and real information of BIM model, the properties can make staff more intuitive understanding of equipment and the matters needing attention, through relevant simulation operation, let staff feel the serious consequences caused by unreasonable operation process, realize intelligent virtual education, so as to improve safety management level of the pipe gallery. The rendering tour display of BIM model in this paper is shown in Figure 13.

4.3. Fire Simulation
Pyrosim is a fire simulation software that performs dynamic simulation of complex fire situations and predicts the temperature and smoke spread of fire sites. Imported AutoCAD DXF, DWG or FDS model files directly into Pyrosim, and information of all models would be imported and used for editing and visualization, in line with the concept of BIM technology as a model with multiple functions. The fire simulation process based on BIM technology is shown in Figure 14.
Fire caused by cable compartment of utility tunnel is one of the important factors in fire of utility tunnel. According to the types of pipelines to be accommodated in each compartment of utility tunnel, the fire risk of the compartment of utility tunnel is classified [27]. In this paper, a fire simulation flow chart based on BIM technology is proposed. By analyzing fire development characteristics, smoke diffusion and the change rule of temperature field, etc., the emergency plan in case of fire can be optimized and the level of safety management in the operation and maintenance stage of the utility tunnel can be improved.

Figure 13. Model rendering tour display.
5. Results

In this paper, BIM technology is introduced into the safety management of the operation and maintenance of the utility tunnel in the city, and a safety management system of the operation and maintenance of the utility tunnel in the smart city is built based on the BIM platform, so as to realize the visualization of the operation safety of the utility tunnel operation and maintenance system and enable accurate positioning in case of accidents, improving the traditional safety education mode, the fire simulation based on BIM technology is realized, so as to improve the safety management level of pipe gallery, reduce occurrence of accidents, and promote the economic development of the city. The main conclusions of this paper are as follows:

- Use monitoring and alarm system to collect the operation and maintenance data of utility tunnel, store operation and maintenance data in the Access database tool, and build a BIM-based utility tunnel operation and maintenance database through the integration of BIM operation and maintenance model and Access database, and then build a BIM-based security management model of the utility tunnel.

- Application of safety management model of operation and maintenance of utility tunnel based on BIM. Using Autodesk Revit to construct 3D model of utility tunnel. BIM model is introduced into the integrated pipeline corridor operation and maintenance management platform to realize the visual display of the safe operation of the integrated pipeline corridor operation and maintenance system. BIM operation and maintenance model was imported into Lumion for model rendering roaming display, which realized diversified and real intelligent virtual security education. Imported BIM model into Pyrosim for fire simulation, and realized the predictive analysis of fire temperature and fire smoke spread.

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