FACILITY RISK MANAGEMENT OF COMMON CONDUITS

Wen-der Yu, Yi-meng Cheng , Cho-fu Wu, Shyh-shiuh Wang

Department of Construction Engineering, Chung Hua University, Taiwan

Abstract: Common conduits are indispensable for the populous metropolitans and the advanced industrial parks, such as the Hsinchu Science-Based Industrial Park. The various pipelines in the common conduits serve not only as the nerve system but also the circulating system of the industrial parks. The maltiple functions of the common conduits may affect not only the yearly hundred-billion-dollar productions of the high-tech industrial park but also the welfare of millions of people's life. It is therefore very important to ensure the maintainability and successful operations of the common conduits. However, the common conduit is still not popular in many developing countries including Taiwan. Important historical data related to risk analysis of the common conduit are not available. Moreover, the serious damages of infrastructure caused by Chi-Chi (921) Earthquake in 1999 has exposed the insufficiency of risk management in the public infrastructure in Taiwan.Thus, this paper aims at developing a facility risk management method for common conduits. A case strudy of a local high-tech industrial park is performed for illustration purpose. The goal of the paper is to provide a practical reference for developing facility risk management programs of future common conduit projects.

Keywords: Common conduits; Risk management; Risk quantification

1. INTRODUCTION

In the traditional utility systems, the gas, oil, water supply, drainage, sewage, communication, power supply, and other utility pipelines were arranged along the roadways separately by underground construction or overhanging methods. However, either the underground or overhung utility pipelines encountes two major problems: (1) maintainence of the pipelines; (2) protection of the pipelines from human or natural damages. A modern solution for the above problems is to constructed a "Common Conduit" that contains all pipelines within the conduit under the ground. Figure 1 shows an example of a Russian precast common conduit [1]. As numbered in Figure 1, the pipelines contained in a common conduit consist of: (1) steam line; (2) backup steam line; (3) ventilation pipe; (4) forward heating pipe; (5) backward heating pipe; (6) compression liquid pipe; (7) emollient pipe; (8) hot water pipe; and (9) warm feul pipe. A typical common conduit for a metropolitan utitlity system will also contain the water supply pipes, sewage pipes, power lines, cable TV lines, and communication lines. There are several advatages of the common conduit approach over the traditional systems, such as: (1) it provids a convenient way for maintainence of the pipelines; (2) it protects pipelines from damages with precast or cast-in-place structure; (3) it separates the pipelines by the types and risk classifications and thus reduces risk of losses; (4) it provides direct channel for facility rescue and repaire when a disaster occurs. As a result, the common conduit is adopted by more and more modern metropolitans and high-tech industrial parks for their utility systems.

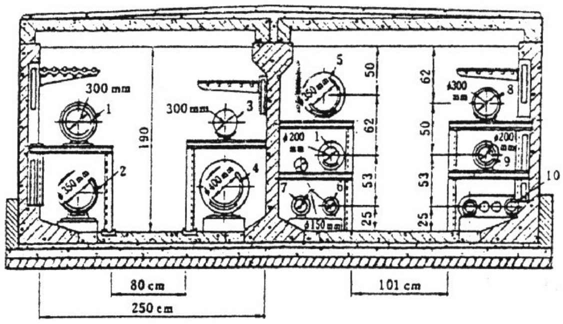

Figure 1 An example common conduit [1]

In spite of the many favorable features mentioned above, the common conduits also confront some problems that need to be resolved before they are successfully applied in utility systems, e.g., (1) higher construction costs of under ground facilities compared with the traditional overhanging systems; (2) concentration of risks by putting the various pipelines together compared with the distributed and isolated pipelines in the traditional systems; (3) determination of the cost sharing for maintenance of the conduit; and (4) liability determination of various pipelines when inter-influential damages occur. An essential issue of the above problems is the determination of risks and the associated costs of the different pipelines in the common conduit. Moreover, some natural disasters such as earthquakes, typhoon, floods, etc., can result in serious damages to the various pipelines to different degrees. Figure 2 shows the damages of roads and underground pipelines caused by Chi-Chi (921) Earthquake. It is, therefore, very desirable to develop a reliable and pertinent risk management system for the underground common conduit facility. Unfortunately, the authors found that there has been no comprehensive academic study conducted on the facility risk management for common conduits. It has made the research extremely difficult due to the lack of required historical data.

Figure 2 Damages of roads caused by Chi-Chi (921) Earthquake

This paper describes a case study of the facility risk management of a common conduit for a high-tech industrial park in Taiwan. The selected high-tech industrial park is an apart of the Hsinchu Science Based Industrial Park. The total length of the main common conduit to be constructed is 13 KM. Several branch conduits are planned connecting to the main conduit. In the following sections, a complete step-by-step case study of facility risk management on the motioned common conduit is described. The primary goal is to provide a reference of practical facility risk management for developing other facility risk management systems in future common conduit projects.

2. ANALYSIS OF COMMON CONDUITS FOR HIGH-TECH INDUSTRIAL PARK

By investigating the exisiting high-tech industrial parks of Taiwan, there are seven common pipelines, including power lines, communication lines, cable TV lines, water supply pipes, gas pipes, drainage pipes, and sewage pipes. The characterisitics, requirements, and the material types of the seven pipelines are shown in Table 1, where "Pressure", "Gradient", and "maintainence frequency" represent the various characterisitcs of the pipelines. The *pressure* type pipelines contain high pressure liquid or gas. The *gradient* pipelines, opposite to the pressure type, require appropiate gradient for the pipes todiliver liquids from higher level to a lower level. The *maintainence frequency* means high frequency of maintainence. The material of the pipelines can also affect the design of the container (conduit). For pipelines of copper and fiber optics, a stronger coverage should be provided to ensure the better protection of the pipeline. This research will focus on the risk management of common conduits with the above seven pipelines.

Table1 Analysis of pipelines for high-tech industrial parks

Type	Material	Characteristics		
		Press.	Grad.	dig freq.
Power	copper	N	N	high
Communi-cation	fiber optics, copper	N	N	high
Cable TV	fiber optics	N	N	medium
Water supply	cast iron, steel	Y	Y	medium
Gas	cast iron, steel	Y	N	medium
Drainage	cast iron, RC	N	Y	low
Sewage	cast iron, RC, pottery	N	Y	low

A typical risk management process consists of three major elements: (1) risk identification; (2) risk analysis; and (3) risk processing. For a complete risk management program, the evaluation of risk processing will be also included to provide valuable reference data for future projects. In the following sections, the step-by-step risk management procedure will be discussed for the common conduits. Since the example project is not constructed, the evaluation of the proposed risk management alternatives will not be discussed in this paper.

3. RISK IDENTIFICATION

The first step of a risk management program is to identify the types and sources of risks for a common conduit. In this research, questionnaire surveys are performed for risk identification. A Delphi two-step technique [2] is conducted for interviewing with the domain expters of common conduits, underground facility engineers, experienced personnel of utility pipeline agencies, and risk management researchers. The results of the questionnaires and interviews identified three major types of risk sources: (1) huamn related risks; (2) natural risks; (3) other type risks. The three risk sources are broken into eight risk factors and the most critical perils that may cause losses of common conduit facility. The results of risk identification for the common conduit is summarized in Table 2.

Table 2 Risk identification of the common conduit

Type	Risk factor	Peril
Human related risks	Saboteurs	1. Repairing costs 2. Operating loss
	Adjacent objects	1. Damage conduit structure 2. Shortening conduit life
	Management	1. Increasing operating costs 2. Service loss
	Different cycle time	1. Damage to other pipelines 2. Increas. maintainence costs
Natural risks	Earthquake	1. Damages to neighborhood 2. Service loss 3. Repairing costs
	Rusting	1. Increasing operating costs 2. Service loss 3. Repairing costs
Other risks	Interactions	1. Service loss 2. Increasing operating costs
	Capacity insufficiency	1. Service loss 2. Increasing operating costs

Table 2 lists the most important risk types, factors, and perils that may cause physical losses to common conduits. The perils are further analyzed to estimate the severity and possibility of losses to conduit in the next section in order to determine the priority of risk control.

4. RISK ANALYSIS

The next step is to analyze the identified risk sources to find a quantitative index for the most cruicial risk factors and perils. There are many existing methods available for the quantitative risk analysis such as statistics methods [3], Monte Carlo simulation [4], fault tree analysis (FTA) [5], faluire mode and effects analysis (FMEA) [6], fuzzy sets [7], and senstivity analysis [8]. Since the common conduit systems are not common in Taiwan, historical risk data are diificult to collect for statisitcs analysis. Experimental anlyses, e.g., FTA and statisitics analysis, are imprectical for quantitative risk analysis of common conduits. Since, the quantitative evaluation of facility risks of common conduits in all its aspects is very complex, especially due to that many required parameter values are not available. Often many variables have large statistical variability while the quantitative effect of various underground conditions, etc. is unknown. Therefore, sensitivity analysis can be a useful tool to determine the main risk-determining phenomena, as well as the aspects that mainly determine the inaccuracy in the risk estimate. In this paper, the sensitivity analysis approach is adopted to quantify the risks confronting the common conduits.

The sensitivity analysis method is a common approach for quantitative risk analysis. The major function of sensitivity analysis is to evaluate the magnitude of influence on a specific factor while a related attribute is varying. While performing the sensitivity analysis, the decision maker should first list the interested attributes and their influential factors. Then, the value of the influential factor is adjusted incrementally with small values. The resulting values of the interested attributes are plotted in a graph to visualize the effects of influential factors. The result of sensitivity analysis can be utilized to determine the priority of risk factors that should be processed first.The proposed method consists of three stages of sensitivity analysis. First, determine the most crucial risk factors for sensitivity analysis by the domain experts. Secondly, perform sensitivity analysis for all risk factors by incrementally increasing the influence level of the influential factors. Thirdly, find the best-fit lines by linear regression. The results of the third step provide the required parameters for judgment of risk priority and for re-usage in future risk projects. Care must be taken that the assumptions made as well as the results are clearly communicated. The risk estimates are, like the ones obtained via statistics approach, just as goodas the available knowledge. That is, the better knowledge and experience provided by the domain experts, the better the risk quantification estimation can be obtained. The results of the sensitivity analysis are shown in Table 3. Where, the first column list all most crucial risk factors, and *X* means the varying percentage of the risk factor, *Y* reflects the percentage of influence as the risk factor is varying.

Table 3 Sensitivity analysis of the risk factors

Risk factor	Base point		Expert A		Expert B		Expert C	
	X_0	Y_0	X_1	Y_1	X_2	Y_2	X_3	Y_3
Saboteurs	0%	0%	5%	20%	10%	30%	15%	45%
Adjacent objects	0%	0%	5%	25%	10%	40%	15%	65%
Management	0%	0%	5%	3%	10%	8%	15%	12%
Different cycle time	0%	0%	5%	2%	10%	5%	15%	7%
Earthquake	0%	0%	5%	25%	10%	55%	15%	95%
Rusting	0%	0%	5%	5%	10%	10%	15%	14%
Interactions	0%	0%	5%	3%	10%	7%	15%	10%
Capacity insufficiency	0%	0%	5%	25%	10%	50%	15%	95%

With the variation/influence data obtained from sensitivity analysis (as shown in Table 3), the linear regression is then performed to find the best-fit linear functions. Assume that the equation for the best-fit function is as described in equation (1):

$$y = b_0 + b_1\overline{X}, \quad (1)$$

where

$$b_1 = \frac{\sum (X - \overline{X})(Y - \overline{Y})}{\sum (X - \overline{X})^2}, \quad (2)$$

and

$$b_0 = y - b_1\overline{X}. \quad (3)$$

In equations 1~3, the $\overline{X}$ and $\overline{Y}$ are mean values. The results of linear regression are shown in Table4, where the coefficients of x in the equations represent the capability of influence on the interested factor. Therefore, the higher the coefficient value can be interpreted as the higher priority for risk control.

Table 4 Parameters obtained from linear regression

Risk factor	Parameters				Equation
	X'	Y'	b_1	b_0	
Saboteurs	7.5%	23.8 %	2.90	0.02	y=0.02+2.9x
Adjacent objects	7.5%	32.5 %	4.20	0.01	y=0.01+4.20x
Management	7.5%	5.8%	0.82	0.00	y=0.82x
Different cycle time	7.5%	3.5%	0.48	0.00	y=0.48x
Earthquake	7.5%	43.8 %	6.30	-0.04	y=-0.04+6.30x
Rusting	7.5%	7.3%	0.94	0.00	y=0.94x
Interactions	7.5%	5.0%	0.68	0.00	y=0.68x
Capacity insufficiency	7.5%	42.5 %	6.20	-0.04	y=-0.04+0.62x

The result of linear regression shows that the top three risk factors that may result in major losses of common conduit facility are: (1) earthquake; (2) capacity insufficiency; (3) adjacent objects; and (4) saboteurs. The results of risk analysis provide the facility managers the most important items for risk control of the common conduits.

5. RISK PROCESSING

As the most important risk factors are identified by risk analysis, the next step for facility risk management is to process the risks confronting common conduits. There are four methods for risk processing [9]: (1) risk avoidance; (2) risk reduction; (3) risk reatention; and (4) risk transfer. The risk processing methods and the suggested alternatives for the common conduits are discussed in the following sections. Due to the limitation of the paper, only partial risk processing proposals are described. Important issues related to the facility management, huaman resource arrangement, regulations and legal aspects are not discussed here.

5.1 Risk avoidance of common conduits

The first option for processing the risks confronting common conduits is refusal to accept risks. An extreme case would be complete refusal of the common conduit projects before they are constructed. In this case, the traditional pipelining methods, such as overhanging powerlines or underground water supply pipes, should be adopted instead of the common conduits. However, refusal of common conduits does not avoid all risks for the pipelines. Rather, the traditional distributed pipeline system may induce more and uncontrollable risks. Actually, the highly risky chracterisitics of the traditional pipelines systems are reasons for adopting the common conduits. Thus, complete refulsal approach is impractical for common conduit projects.

However, complete refusal is not the only alternative for the risk avoidance approach. Partial risk avoidance of the perils could be executed. As a matter of fact, partial; inclusion of utility pieplines is commonly found in the existing common conduit systems. For example, in order to avoid the risk of inter-influence between different pipelines, some highly risky pipelines can be excluded out of the common conduit. In some cases, the gas pipes are not included in the conduits with powerlines. In another case, the powerlines is excluded from the conduit with comminication lines insides to avoid electronic iter-influence.

5.2 Risk reduction of common conduits

Risk reduction is also a common method for risk processing. Usually, the risk reduction refers to action for abating the losses after peril happened. However, a more active perspective of risk reduction is, however, loss prevention via some prearrangement. A popular way to reducing risk exposure for common conduits is to provide a stronger structure for the conduit in order to ensure better protection of the contained pipelines. Another alternative to reducing risks of common conduits is to provide separations between two interactive pipelines.

For common conduits of high-tech industrial parks, there are several interactive pipelines that should be separated to avoid risks. The power lines should be separated from the communication lines and gas pipes. The sewage pipes should be separated from water supply pipes, too. The appropriate arrangement of pipelines in the common conduit is the most important task for risk reduction. Figure 3 shows the example of the separation arrangement between two inter-influence pipelines for risk reduction of a common conduit. In Figure 3, the gas pipe is separated from other pipelines since the gas pipe is considered more risky for causing fire and contamination that may damage the services of other pipelines. Moreover, the communication lines are arranged as far as possible in the same conduit in Figure 3 to avoid the electronic of inter-influence between the two pipelines.

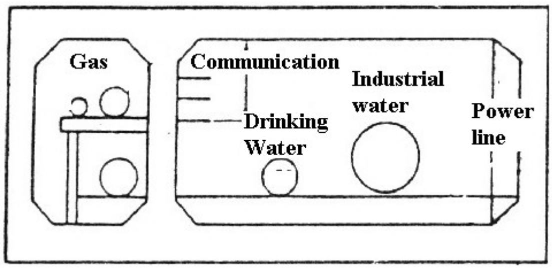

Figure 3 Separation arrangement of pipelines in a common conduit

5.3 Risk reatention of common conduits

The basic idea of risk retention is to accept the risks without any prevention or transfer actions. In almost all public sector projects, such as the common conduits, the public agency acting as client is physically and financially dominant over the supply organizations and therefore may choose to retain a portion of risk, in addition to the risk which it is not possible to transfer. The most significant risks which are retained and which are not capable of transfer for common conduit listed in Table 2 are the management type of risks, capacity insufficiency, and the loss caused by different lifecycle duration among the various pipelines. The loss caused by management defects should be reduced by improving the management operations. The capacity insufficiency may be caused by incorrect prediction of demands. It should only be improved by better study before the common conduit is constructed. The different lifecycle times should be improved technologically by selecting materials with similar lifetime for the various pipelines.

5.4 Risk transfer of common conduits

The most important risk processing approach in risk management might be th risk transfer. There are two major types of risk transfer: (1) financially transfer to the insurance companies; (2) legally transfer to facility management contractors. The former form of risk transfer is commonly done by the arrangement of insurance, but for many public sector agencies the potential scale of financial risk and the indeterminate nature of the range of the impact of risk make this an impracticable proposition, thus usually resulting in self-insurance approach [9]. Moreover, the proprietary rights of the various participants in a common conduit project have made the insurance approach more complex than other public sector projects. Therefore, the risk transfer approach might not be applicable for common conduits. However, the legally transfer with maintenance contract by the individual pipeline owner is feasible and recommended for risk transfer of common conduit.

6. CONCLUSIONS AND RECOMMENDATIONS

This paper described a case study of the facility risk management program for a common conduit of a high-tech industrial park. The main functions of risk management (risk identification, risk analysis, and risk processing) are discussed in details. The specificial requirements and characteristics of risk management of the common conduits for a high-tech industrial parks are investigated via questionnaire surveying and interviewing with the domain experts. A quantitative method of risk analysis, the sensitivity analysis, is adopted to demonstrate the priority ranking of risk factors. Four major risk processing methods are deliberated for common conduits. The method of facility risk management presented in this paper may be used for developing risk management plan of future common conduit projects.

The common conduits are not popular up to date in many developing countries such as Taiwan. As the modernization of the citiy infrastructure and the demands of high living quality, it is foreseen that common conduits will become more and more popular for cities and high-tech industrial parks. However, the Chi-Chi (921) Earthquake occured in 1999 in the central area of Taiwan has exposed the risks of infracture to the environment. If the common conduits were damaged, huge losses will be induced for enterprises and residents. It is therefore desirable to conduct more risk management prpgrams for common conduits so that the required historical data can be collected. Only with more historical data, the reliable and pertinent facility risk management systems can be developed, and the life and property of people can be secured. This paper is a starting point for such a goal.

Acknowledgments

The authors sincerely appreciate the financial support of this research provided by the China Engineering Consultants, Inc., Taiwan. Sincere thanks also go to the Administration of Hsinchu Science-Based Industrial Park, Taiwan for the important data required by the research..

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