Affecting Factors in Rehabilitating Water Distribution Networks

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Abstract High levels of non-revenue water (NRW) reflect that an area's water distribution networks (WDN) are losing vast volumes of clean water. Therefore, reducing NRW is crucial for sustainable water management. NRW levels in most developing countries are high, ranging between 35 and 50%. While one of the significant causes of NRW is difficulties in rehabilitating old piping networks, studies on factors that are influencing WDN rehabilitation in practice is limited. This study aims to identify affecting factors for WDN rehabilitation. To achieve that objective, a series of individual interviews with industry practitioners that manage WDN are analyzed using the thematic analysis. The major findings from the analysis are: (1) internal and external factors are influencing WDN rehabilitation; (2) internal factors are related to cost, location, and design; and (3) external factors are related to local authorities and surrounding communities. This research adds to the body of knowledge by providing a set of affecting factors for rehabilitating WDN, which can assist researchers and practitioners in developing strategies to reduce NRW for achieving sustainable water management.

Keywords Sustainable development · Water distribution networks · Non-revenue water · Rehabilitation

1 Introduction

Reducing water losses is key to sustainable water management but challenging. Rapid population growth, income growth, and urbanization, in combination with a fixed supply of total renewable water resources, are pressuring numerous nations

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in identifying renewable water resources. On the other hand, high levels of non-revenue water (NRW) reflect vast volumes of water are lost through leaks (real losses) and drinking water not being invoiced to customers (apparent losses) and unbilled authorized consumption [1]. The NRW levels in developing countries, including Malaysia, are high, ranging from 35 to 50% of the water produced [2]. Therefore, the water distribution sector needs to improve the way it uses its water resources significantly, especially in NRW, to attain sustainable water management.

Reducing NRW is compelling to save much money, and significant volumes of water can be used for more productive purposes [3]. One of the approaches for reducing NRW involves repairing and replacing (i.e., rehabilitating) old pipelines of water distribution networks (WDN). However, despite some proposed strategies for NRW management and reduction, most WDN continue to experience high levels of water losses [1, 2, 4, 5]. Furthermore, the study on NRW and the rehabilitation of WDN is limited and yet to be given adequate attention. Therefore, having additional insights into the factors influencing the success of rehabilitating WDN is vital.

This study aims to identify the affecting factors for rehabilitating WDN. To achieve that objective, this study analyzes a series of interviews with industry practitioners that have experience and knowledge in managing WDN. This study contributes to the current body of knowledge by providing a list of factors that are influencing the success of rehabilitating WDN. Researchers and practitioners from both the public and private sectors can use the findings to develop appropriate strategies for enhancing WDN rehabilitation. These results can be utilized in reducing NRW, achieving sustainable water management, and the United Nation's Sustainable Development Goals of responsible consumption and production.

2 Background

2.1 Causes of Non-revenue Water

Water utilities are facing major challenges due to a high level of NRW [1]. NRW is calculated as the difference between the water produced (also known as the system input volume) and the water delivered (also known as the revenue water) as a proportion of the water produced [1]. NRW has three components: apparent losses, real losses, and non-revenue authorized consumption [3]. Apparent losses occur due to unauthorized use, personnel errors, management, and operational errors, and data-handling errors. These losses cost-utility revenue and distort data on customer consumption patterns. Real losses comprise leakage from system elements and overflows of storage tanks. These losses are also caused by poor operations and maintenance activities, lack of active leakage control, poor quality of underground assets, and mainly contain visible and invisible leakage. Non-revenue authorized consumptions include water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups [3].

Due to the high level of NRW worldwide, authorities in water companies seek the most effective NRW reduction activities. Despite some proposed approaches for NRW management and reduction in recent years, most WDN continues to experience high levels of water losses [3]. Experience has shown that the essential contributing factor for water shortage is related to real losses, which is either due to pipe corrosion or leakage from the distribution network [4–6]. Hence, the water distribution system needs to be monitored closely by replacing the existing water infrastructure to minimize physical losses. Reducing non-revenue water in the water services industry is not only crucial for saving water but also essential for securing its future efficiency and development.

2.2 Strategies for Reducing Non-revenue Water

One of the approaches for reducing NRW includes rehabilitation of WDN. Rehabilitation strategies need to be in place to ensure that the WDN continues to operate efficiently and economically within defined operating requirements over an extended period [4]. Prior studies are proposing strategies for rehabilitation and expansion of WDN using several modeling approaches such as the Markov model, Monte Carlo simulation, and PALM+ system [4–6]. On the other hand, other studies have collected data from the literature, industrial experience, and direct data and feedback from industry practitioners to identify key variables in the construction management field of research. Some examples of this type of study with similar methodology include the identification of best practices for: waste management [7], energy efficiency [8], supply chain management [9], and water management in the hospitality sector [10]. Other examples of using this type of methodology include the identification of key challenges for: effective application of anti-corruption measures in infrastructure projects [11]; construction management for rural transit projects [12]; and design-construction interfaces of large building construction projects [13]. Also, this methodology has been used to identify parameters for: public–private-partnerships in developing a developed country [14]; public-housing projects in developing countries [15]; and project success for companies in Brazil [16].

2.3 Positioning of This Study

However, in developing countries, the study on the rehabilitation of WDN is yet to be given adequate attention, and the kinds of literature are limited. Due to urbanization and rapid economic development, the provision of quality water and sewerage services has become more challenging. For example, in 2015, Malaysia's NRW was at 35.5%, and the main factors that contribute to that are physical losses due to the old network of pipes and poor quality by contractors, especially in new development areas, commercial losses, and also lack knowledge and expertise in NRW

[17]. Hence, understanding the affecting factors of WDN rehabilitation is essential to assist in the development of global NRW management.

3 Methodology

3.1 Data Collection

Data on the affecting factors for WDN rehabilitation are collected by interviewing practitioners that have experience and knowledge in managing WDN to maintain a level of quality of the interviewees (i.e., purposeful sampling). Also, this approach has been used to identify success factors in other construction management topics, including design-build public sector projects [18] and highway projects [19]. Individuals from different water distribution organizations are interviewed to ensure the data is comprehensive. Interviews allow industry practitioners to provide implicit knowledge of their situation. Also, open-ended questions encourage participants to contribute as much detailed information as desired while enabling investigators to ask probing questions as a means to follow-up. The open-ended questions are: (1) What are the challenges for rehabilitating WDN? And (2) What are the factors that are affecting the success of rehabilitating WDN? Participants addressed the questions while the investigators took notes and provide follow-up questions. For verification purposes, the notes are summarized and sent to the interviewees. The interviews will be completed by following the principle of saturation.

3.2 Data Analysis

The interview data are analyzed using thematic analysis to formulate lists of affecting factors for WDN rehabilitation. This approach is selected because it can assist in making sense of qualitative data [20]. Other construction management topics that use this method to analyze qualitative data include identifying problems in construction projects [21], attributes of change agents in construction companies [22], and parameters for highway construction projects [23]. The analysis involves coding the interview data, organizing the codes into concepts, forming categories of related concepts, elaborating patterns and linkages between categories, and developing a theme, subthemes, and codes that explain the data. Developing the themes, subthemes, and codes identify the affecting factors for WDN rehabilitation.

4 Results and Discussion

Figure 1 summarizes the affecting factors for rehabilitating WDN from the analysis of individual interviews with industry practitioners of water distribution operators. The factors are themed into two main categories, internal and external factors. Internal factors can be associated with variables that are usually actionable from by water distribution operators (ex. having a good design process for rehabilitating old pipes). On the other hand, external factors relate to those that are often uncontrollable by water distribution operators (ex. customer not paying water bills). The factors are further discussed in the subsequent subsections.

4.1 Internal Factors

Cost is one of the internal factors that are influencing the success of rehabilitating WDN. Similar to other rehabilitating other types of infrastructures, the cost of rehabilitating old pipes is high. To illustrate this situation, the cost can be associated with capital expenditures rather than repairs and maintenance expenses. As the objectives of capital improvements relate to increasing the value of an organization's assets, water distribution operators are expected to make decisions based on the return of

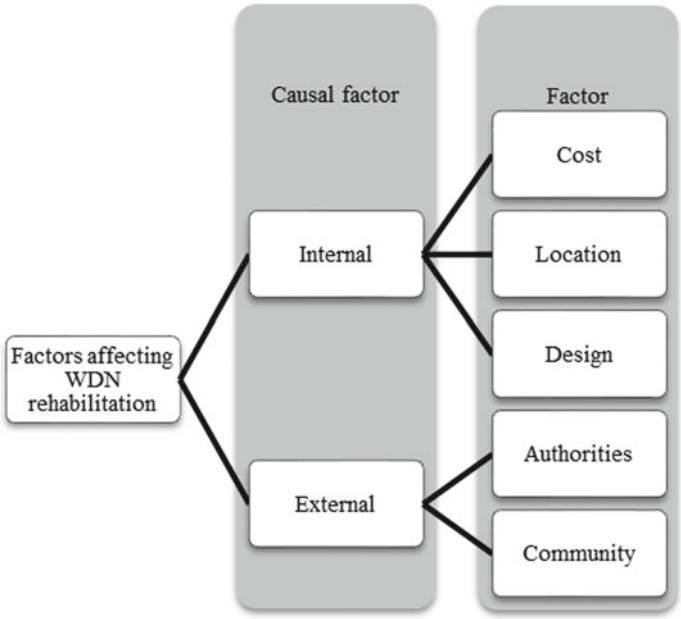

Fig. 1 Affecting factors in rehabilitating water distribution networks (WDN)

investment (ROI). Therefore, operators tend to rehabilitate old pipes partially while targeting an effective reduction of water loss. Also, operators need to balance between the proportionate savings and the costs for rehabilitating larger areas. In other words, water distribution operators need to identify strategies for optimizing the process of rehabilitating WDN. Example of the responses from the summary of interviews that illustrate this factor include:

> To change old pipes, we cannot rehabilitate in small scales, for example, 6 m or 12 m. To make it cost-effective, around 500 m to 1 km needs to be rehabilitated to ensure the new pipes can last longer. Rehabilitating on this scale involves much money.
>
> The cost to rehabilitate old pipes is quite high. So, we can only rehabilitate in smalls scales. So, the critical locations are prioritized first to make sure water loss is reduced. Also, if the process involves rehabilitating a big area, it will take time and money to complete.
>
> The cost of pipes is high. So, the provisions are under capital expenditure, where the return of investment (ROI) will be taken into account.

Location involves the positioning of the WDN' pipes. Specifically, water distribution operators are having difficulties in rehabilitating pipes that are positioned underneath a built facility. While WDN might be designed without any facility on top of them, economic developments are resulting in buildings and roads constructed on top of the WDN's alignment. Therefore, in an attempt to reduce complications in rehabilitating WDN in both the near and distant future, proper urban planning that ensures minimal facilities or obstacles are constructed above this type of network is necessary. Samples of the response include:

> The alignment of pipes is located underneath main roads. Most pipes were designed 20 years ago. The country's economic development results in existing pipes to be located at the alignment of roads. This makes the pipe replacement work difficult.
>
> Existing location of pipes are constructed with another facility such as houses and roads. Before this, the location is easily accessible for rehabilitating. But, after the time being, houses or roads are built on top of it. So, it is difficult to rehabilitate the pipes.
>
> If the existing location is still available and no one had built facilities at the location from the time being, the rehabilitating work will not have difficulties.

Design. This factor consists of having documentation on the current design of WDN as most systems are developed decades before. Without proper information, designers are having difficulties in remodeling existing systems for the rehabilitation process. Also, designers are having challenges in remodeling old networks according to current standards when the process involves explicitly rehabilitating partial sections of the system. Specifically, non-compliance with existing standards can result in problems related to water pressure. This factor also includes deciding between rehabilitating and replacing old pipes as there are situations where the cost of rehabilitating is higher than the cost of replacing old pipes. Therefore, operators need to establish a good design process for rehabilitating WDN. Responses that illustrate from the summary of interviews this factor are:

> There are also problems in the design process. Designers need to observe the existing system before designing the new pipelines to avoid water pressure problems. Modeling or hydraulic analysis needs to be done to ensure the new system works properly.

> Loss of pressure can also be a factor in pipe replacement.
>
> In the case of repeated water loss, the cost of repairing is higher than the replacement of the pipe.
>
> Types of pipes can also affect the rehabilitation process. Usually, old pipes do not adhere to current standards. Choosing an inappropriate type of pipe can have a negative impact during the rehabilitation process.
>
> Problems in identifying the location of old pipelines because most pipes that are being replaced are over 30 years old. So, data and records involving these old pipes are not complete.

4.2 External Factors

Authorities, specifically approval from authorities is one of the external factors that influence the process of rehabilitating WDN. To start rehabilitating old pipes, water distribution operators need approvals from certain government authorities such as administration bodies that control the construction and maintenance of public infrastructures and local governments. Also, operators need to acquire approval from other utility institutions. Conversely, contractors and subcontractors require approvals from the operators. While administrating construction and maintenance of public infrastructure works are more than necessary, the approval process is suggested to take quite some time (sometimes up to a year). Therefore, having an appropriate process for administrating this type of works (including rehabilitating old pipes) is vital. Samples of responses from the summary of interviews that illustrate this success factor include:

> Constraints to get the permit from the government authorities and local government authorities to replace the old pipes.
>
> Constraints due to laws of local government authorities, public work departments, and utility companies to get approval for the new pipeline installation.
>
> There is one time when they apply for a permit, and they take more than one year to give it. So, it causes the work for pipe replacement to be delayed and slow.

Community. On the other hand, communities that surround or use the WDN (i.e., the public) also plays a role in the successful rehabilitation of WDN. As discussed in the previous subsection, water distribution operators rehabilitate old pipes based on their ROI because the work requires a significant amount of monies. However, these operators are facing problems in allocating sufficient funds because users are not paying their water bills. Also, dissenting behavior from the public, such as complaining through local authorities and social media from additional traffic congestion, noise, and dirt from the rehabilitation process of WDN, can result in the stoppage of the rehabilitation works. Similarly, public complaints to local authorities are slowing down and even idling the construction of highway projects [19]. Therefore, awareness from the public on the importance of supporting the rehabilitation of WDN is crucial. Examples that illustrate these results include:

> People need to pay water bills to rehabilitate the pipes.

The first challenge relates to the local community. In detail, there are complaints from the public, such as dirty roads resulted from the rehabilitation process. Although it can sometimes be true, the local community should understand the process and provide cooperation during the process. Sometimes, the public shares information through social media. The public should understand that after the rehabilitation process is completed, then the roads will be fixed.

5 Conclusion

This study identifies the affecting factors for WDN rehabilitation by analyzing individual interview data with seven professionals from water distribution operators using the thematic analysis. The major findings include:

- The affecting factors in rehabilitating WDN is associated with internal and external factors.
- The internal factors are related to cost, location, and design.
- The external factors are related to both local authorities and surrounding communities.

These findings highlight the need for water distribution operators to develop strategies to optimize the process of rehabilitating WDN because it involves high costs, hard to reach locations, and complicated designs. Conversely, the local government can improve the approval process and provide awareness to the public on the importance of WDN rehabilitation work. Research and industry practitioners can use these findings to develop strategies to ensure the success of rehabilitating WDN. The key theoretical contribution of this research is by providing a set of factors that influence WDN rehabilitation in a developing country.

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