Data-driven asset management: toward the deployment of risk-based rehabilitation planning in Lausanne

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Highlights

- Extending the AI-driven Software SEMAplus with a risk prioritization module.
- Selection and analysis of risk criteria as preliminary part of decision making.
- Analysis of multicriteria decision approaches and choice of ELECTRE TRI.

Introduction

Sewer rehabilitation in cities like Lausanne is a significant financial commitment of 10 million euros annually for replacement, renovation and repair of the extensive sewer network. These costs even exceed 100 million euros annually for larger cities such as Berlin. Aging infrastructure, coupled with insufficient planned investments, results in a replacement rate of less than 1 percent, leading to potential issues in the long term. A national study in Germany indicates that around 20% of sewers urgently require rehabilitation (DWA, 2020). Since the 1980s, Closed-Circuit Television (CCTV) has been the industry standard for sewer inspection, providing visual data for planning rehabilitation. CCTV inspections use manual or automatic coding systems (e.g. EN 13508-2) to identify defects, and sewer deterioration models utilize this data. Modeling outcomes aids in short-term program development and long-term investment planning by estimating current and forecasting future sewer network conditions.

Kompetenzzentrum Wasser Berlin and the Berlin water utility collaborated to create SEMAplus, an AI-driven software for sewer inspection prioritization and long-term rehabilitation planning. It comprises two main modules: the SEMAplus pipe simulator, which uses machine learning to assess the current condition of sewer pipes, prioritizing those in urgent need of rehabilitation; and the SEMAplus strategy simulator, which employs a statistical aging model to predict long-term network conditions under various investment scenarios.

However, even with the outcomes of these methods, the decision-making process of prioritizing certain pipes for rehabilitation within the network is still a complex task. Apart from the simulated current conditions of each sewer pipe, the decision maker needs to take all possible social, economic and environmental consequences of a failure into account and weigh them against each other. Therefore, the objective is to assess the risks of pipe failure and prioritize assessed pipes by condition as well as consequences of failure.

The presented work aims at finding a suitable multi-criteria assessment method for the development of a risk prioritization module that is universally usable for sewer networks as well as drinking water networks. The focus hereby lies on preliminary work for selecting a set of criteria within the domain of sewer risk assessment, defining their importance as well as a possible approach to risk prioritization of sewer networks using multicriteria decision analysis. As the SEMAplus software is currently applied to the city of Lausanne in Switzerland, the approaches to risk prioritization are being developed for and in collaboration with its Service de l'Eau.

Methodology

Decision-making for critical infrastructure budget allocation is a complex task. The rehabilitation of pipes in poor condition is economically favored, but the significance of critical infrastructure, identified as "critical assets" in ISO 55000 (2014), is paramount because of the risks it presents to civilization in the event of failure. The risk of pipe failure depends on both condition of pipe and consequences of failure, necessitating a comprehensive risk assessment. This intricate task involves integrating various criteria into decision-making, acknowledging that a single parameter cannot solely guide the decision. Hence, accurate risk assessment requires assimilating extensive data from diverse sources, creating a delicate balance with numerous degrees of freedom. Multicriteria Assessment (MCA) proves valuable, enabling optimal decisions by considering criteria of different natures and units. In the following, a methodology is proposed to account for the complexity of approaching risk prioritization for sewer asset management. It starts with the analysis of domains at risk at a coarse level, followed by an identification of components at risk for possible criteria of these domains. The criteria need to be elaborated and prioritized, and a suitable multicriteria decision approach needs to be chosen.

Level 1 - Definition of domains at risk

At first, in order to define the priority criteria for sewer rehabilitation prioritization, the various external domains at risk need to be identified and their exposure to a risk to be defined. The choice of which areas of risk to prioritise depends on the area and the associated (technical, environmental or political) issues. These priorities may concern known risks considered to be major, but also impacts that are already present in the area and that the manager is seeking to limit or reduce. Priorities should be selected at a very early stage, so that the data to be collected for assessment can be identified as early as possible.

Level 2 - Identification of risk components & elaboration of criteria

For the second step, a higher level of details needs to be assessed within these domains at risk. The aim is the definition of concise rehabilitation criteria for the identified domains at risk. For this assessment, the risk for each identified domain needs to be assessed by analysing the four elements of risk, defined by (Tira, 1997) (R = P.I.V.E):

- The probability of the appearance of a hazard (P)
- The intensity of the hazard (I)
- The vulnerability of the exposed element (V)
- The element value (E)

The probability of appearance of a hazard (P) is deducted from the pipe condition. The pipe condition is being assessed within the previously mentioned SEMAplus pipe simulator and can be, for example, of structural, watertightness or hydraulic nature. The intensity of hazard (I) results from the type of sewer pipe failure (for example structural, water tightness or hydraulic) as well as the extent of failure. The consequences of a pipe failure to external variables with their level of vulnerability (V) as well as their element value for example to the society or economy (E) define the risk resulting from a failure. While the probability of hazard (P) is simulated by the results of the mentioned models, the three elements I, V and E are GIS-related constraints. In order to define potential risks in sewer, it is important to highlight the causal chain leading to a risk according to (Le Gauffre et al., 2007b):

1. Occurrence of defects at sewer pipe (e.g., cracks)
2. Dysfunctions as consequences of defect (e.g., infiltration / exfiltration)
3. Impacts as consequences of the dysfunctions (e.g., pollution of surface waters)

Once the rehabilitation criteria are defined, their importance to the decision maker have to be defined. This could be done by giving weights according to the interest of the stakeholder and / or publicity.

Level 3 - Choice of multicriteria decision approach

Multicriteria decision approaches aim at assisting a decision maker with finding preferred alternatives (e.g., good candidates for pipes to be rehabilitated) among all existing alternatives (e.g., all pipes of a sewer network). According to Roy and Bouyssou (1993), there are generally three types of decision problems: (i) choice problem (selecting the best alternative), (ii) ranking problem (all alternatives from best to worst), and (iii) sorting problem (assigning alternatives to predefined categories).

Case study

In Lausanne, SEMAplus is customized for comprehensive asset management, integrating data collection (e.g., CCTV inspections) to prioritize pipe replacements. A new module rates pipe conditions based on CCTV reports, generating a ranked list for rehabilitation. Advanced machine learning enhances prediction accuracy, aiding on-site decisions. A specific module is also being developed for prioritising the rehabilitation needs of pipes according to the risks and consequences of failure. It will consider additional impact or vulnerability criteria to prioritise rehabilitation investment (e.g. under high-traffic streets or in resource protection areas). At a strategic level, SEMAplus will simulate the future condition of Lausanne's network over the next decade. This simulation will provide valuable insights to justify the importance of proposed investments. Last but not least, SEMAplus will also be integrated for asset management of the drinking water network in Lausanne, providing a complementary and similar approach.

Results and discussion

Level 1 - Definition of domains at risk

At first the domains of the risk priorities need to be defined. For Ville de Lausanne, the assessment resulted in three domains under risk consider as priorities: (i) damages and infrastructure costs, (ii) environmental pollution, and (iii) health and safety risks.

Level 2 - Identification of risk components & proposition of criteria

Secondly, based on the domains under risk, three types of conditions have been selected: structural, water tightness or hydraulic. The structural condition refers to pipe defects leading to a risk of a collapse. The watertightness condition includes a risk of in- or exfiltration and the hydraulic condition considers the risk of decreased hydraulic capacity. The assignment of condition types to the domains at risk resulted in the criteria listed in Table 1.

Table 1. Resulting criteria from the assessment of various risks

Type of condition being affected	Domain at risk	Criteria
Structural condition	Damages and infrastructure costs	Damage to infrastructure (buildings, roads)
Watertightness condition	Environmental pollution	Pollution of water bodies downstream (due to sewer overflow caused by high infiltration)
	Environmental pollution	Soil pollution
	Damages and infrastructure costs	Treatment plant operating surplus cost (due to infiltration)
	Urban image / wellbeing	Nuisance of a hydraulic nature (overflow, flooding, etc.) due to infiltration
Hydraulic condition	Environmental pollution	Pollution of water at location (sewer overflow due to reduced hydraulic capacity)
	Urban image / wellbeing	Nuisance of a hydraulic nature (overflow, flooding, etc.) due to decrease in hydraulic capacity

Level 3 - Choice of multicriteria decision approach

The simplest approach to a multicriteria assessment would be a weighted sum of all defined criteria. This approach is simple, and easy to understand, however remains very limited (compensation between criteria, poor consideration of non-quantitative indicators, etc.). Therefore, many more sophisticated methods have been developed. Figure 1 gives an overview of different methods that can be utilized for a multi-criteria decision analysis approach. Among the outranking methods, the ELECTRE methods have been proven in the past to be well suitable for multi-criteria decision analysis. For example, in Le Gauffre et al. (2007a) ELECTRE TRI has been utilized for a risk prioritization of a drinking water network. And an application of the ELECTRE III and ELECTRE TRI methods have been applied for sewer pipe prioritization (Carriço et al., 2012). ELECTRE was developed by Bernard Roy in the 1970s to solve problems that involve multiple conflicting criteria or objectives. ELECTRE TRI refers to the sorting problem. Hence, it is a categorization technique to assign all observed sewer pipes to fixed categories through predefined boundaries.

In this case study, the ELECTRE Tri method has been selected for classifying pipes into categories according to the urgency of their rehabilitation needs. ELECTRE Tri was selected because it provides a sorting instead of a ranking. By using the same profiles each year, it enables to provide an absolute classification instead of a relative one: that is to say that the classification of a pipe is not affected by the other pipe (i.e. its classification is not based on a comparison to other pipes). The absolute classification is a very powerful approach allowing to inform on the evolution of rehabilitation needs and thus of the evolution of the whole assets. Moreover, with the strong objective to unify asset management approaches for sewer and drinking water, ELECTRE Tri is also chosen to comply with existing drinking water practices based on CARE-W ARP (Le

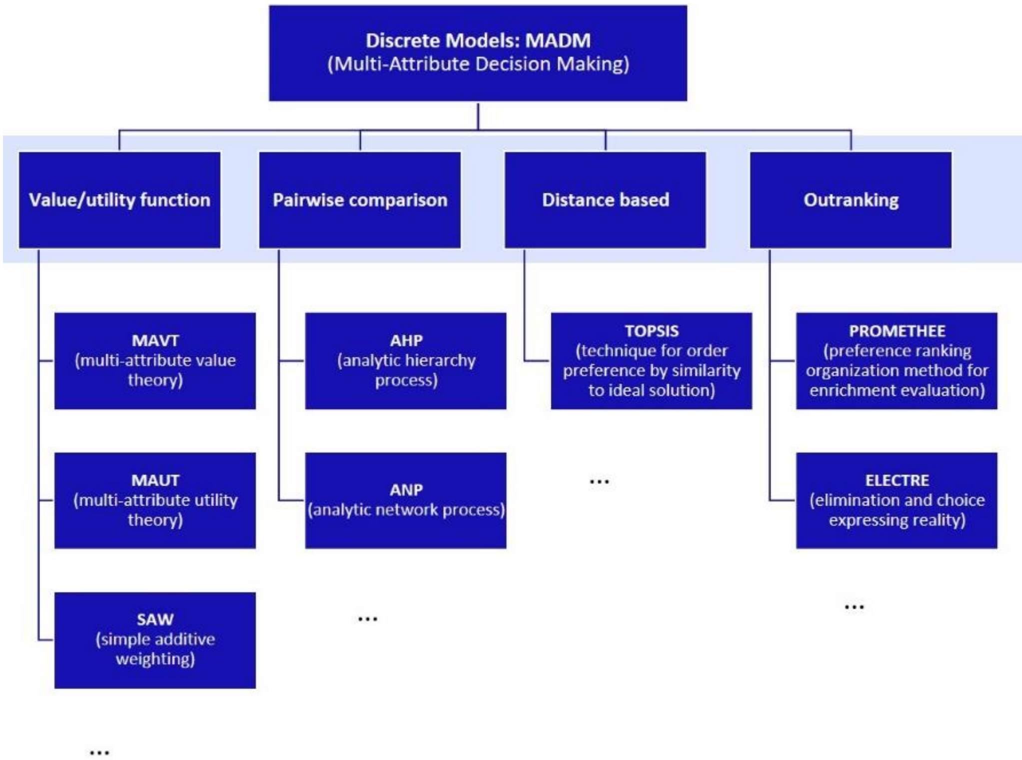

Figure 1: Classification of different multicriteria decision analysis methods; adapted from Gebre et al. (2021)

Gauffre *et al.*, 2007a). Utilizing ELECTRE TRI for the described risk assessment offers several other advantages according to Figueira et al. (2010), Sobrie (2016) including transparency in calculations, accommodating diverse criteria scales and processing both quantitative and qualitative data. The method handles imperfect knowledge and expert biases, incorporating indifference and preference thresholds. ELECTRE TRI considers reasons for and against outranking, addressing concordance and discordance. However, it has limitations, such as possible intransitivity problem. Apart from that addressing complex parameter consequences, particularly thresholds, may require simplification within the tool.

Conclusions and future work

The presented work showed an analysis of risks as an approach to risk prioritisation including preliminary definition of criteria as well as finding a suitable multicriteria decision technique. It can be concluded from the work, that the preliminary analysis of social, economic and environmental influences needs to be assessed carefully in order to obtain accurate results from the risk prioritization. The outcomes of the multicriteria decision analysis are solely dependent on the user's definition of criteria and priorities. Addressing the sorting problem and therefore categorizing the sewer pipes for their risk prioritization has been found most convenient, as there is an absolute selection of alternatives based on predefined boundaries. Thus, the preference of alternatives is not relative to other alternatives. The the proposed approach of this abstract was carried out in a similar way for the risk prioritization of the drinking water network of Lausanne. Upcoming future work will apply this approach to the sewer network data of Lausanne and analyse the transferability of the methods between drinking water and sewer networks. The first results of the application are expected in spring 2024.

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