ON THE POTENTIAL OF INTEGRATED MULTI-UTILITY ASSET MANAGEMENT IN URBAN WATER MANAGEMENT

Franz Tscheikner-Gratl[1,2], Michael Mair[2], Wolfgang Rauch[2], Jeroen Langeveld[1], Manfred Kleidorfer[2]
[1] Sanitary engineering, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[2]Unit of Environmental Engineering, Institute of Infrastructure, University of Innsbruck, Technikerstr. 13, 6020 Innsbruck, Austria.

Abstract

Urban water management addresses the financial and operational management of freshwater, wastewater and storm water systems in urban areas. Beside the fulfilment of the continuous service of modern urban infrastructures in daily business, the systems are facing major challenges especially in a long-term perspective. Firstly, the maintenance and rehabilitation of the aging networks and furthermore the adaptation to a changing environment (e.g. climate change and urban development in the context of population increase/decrease). The focus in developed countries is therefore moving away from construction of new networks to the maintenance and repair and sometimes, even reduction of the existing ones. Urban infrastructure consists of a manifold of different subsystems sharing the same limited public space in urban areas. Those systems are hardly replaceable as a whole. Instead, it is a piecemeal process over decades. This work aims to point out the connections, coherences but also differences between those intertwined urban networks. In this paper, potentials in decision making in asset management, rehabilitation planning and operation of urban water infrastructure are presented when interactions between different systems are considered. It elaborates the idea of integrated rehabilitation management, its problems and gives an outlook on possible solutions.

Keywords: Asset Management; rehabilitation; interdependencies

1 Introduction

Urban water management addresses the financial and operational management of freshwater, wastewater and storm water systems in urban areas. Its continuous operation is crucial for human well-being and economic development; hence, expectations from public on the service quality are high. Drinking water should be provided by the operating company in sufficient quality, quantity and pressure (EN 805, 2000). The urban drainage systems are responsible not only for a continuous removal of wastewater from premises for public health and hygienic reasons, but also for the prevention of flooding in urbanized areas and therefore protection of the urban environment (EN 752, 2008). Besides the fulfilment of the continuous service of modern urban infrastructures in daily business, the systems are facing major challenges especially in a long-term perspective. Firstly, the maintenance and rehabilitation of the aging networks and furthermore the adaptation to a changing environment (e.g. climate change and urban development in the context of population increase/decrease). The focus in developed countries, in which the urban areas already are connected to water systems, is moving away from construction of new networks to the maintenance and repair and sometimes, even reduction of the existing ones. The latter is justified by implementing new decentralized drainage concepts (e.g. blue/green stormwater treatment technologies or reuse concepts).

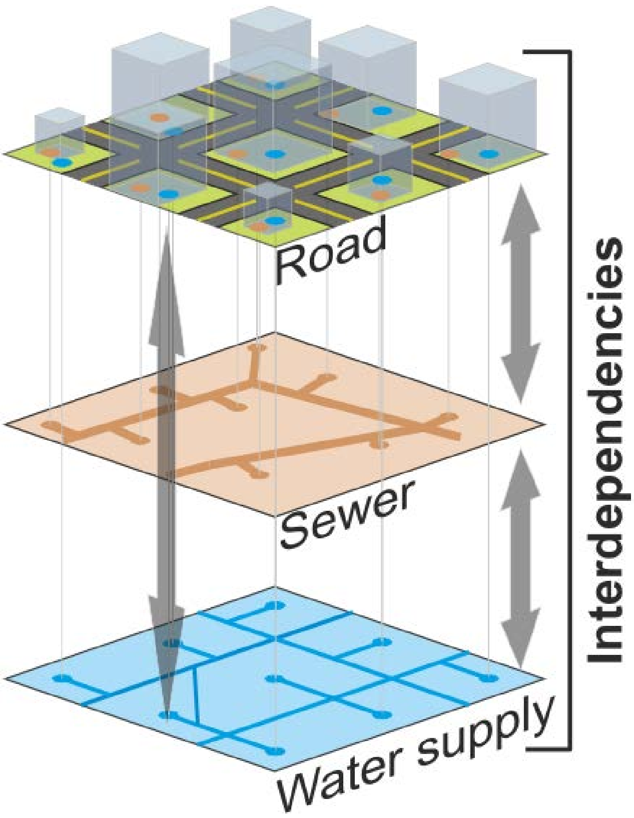

Figure 1. Interdependencies between the different infrastructure networks (adapted from Mair, Zischg, et al. (2017))

Urban infrastructure consists of a manifold of different subsystems sharing the same limited public space in urban areas. Those systems are hardly replaceable as a whole. Instead, it is a piecemeal process over decades. Consequently, in a mature urban infrastructure, nowadays all phases of assets lifetime coexist (Alegre and Coelho, 2012). The existing way of viewing things separately by only focusing on domain specific (e.g. water supply, sewage, storm water) problems does not take into account the interaction and possible synergies between these subsystems (see Figure 1). Planning and managing urban asset maintenance is therefore particularly complex due to this multiplicity of subsystems, with their diverse functions and interactions, as well as the multiplicity of involved stakeholders, as both operators and/or users (Di Sivo and Ladiana, 2011). This work aims to point out the connections, coherences but also differences between those intertwined urban networks. In this paper, potentials in decision making in asset management, rehabilitation planning and operation of urban water infrastructure are presented when interactions between different systems are considered. This work presents a strategic analysis of such interactions, synergies and interdependencies. It elaborates the idea of integrated rehabilitation management, its problems and gives an outlook on possible solutions.

2 Infrastructure data availability and their interdependencies

Nowadays, most of these physical infrastructures are still organized in a centralized structure (e.g. road network, piped network structure in water infrastructure systems), which means, one big system is offering the service for the whole service area. Beside the fact that these systems share large parts of the same service area, also the placement of system elements (e.g. streets, pipes, sewers) at same geographic locations are shared to a certain extent (e.g. pipes and sewers are placed below roads). Mair, Zischg, et al. (2017) investigated the correlation of road, water and sewer networks by systematically analysing detailed datasets of various case studies. The analyses were split into geometric and graph based analyses. The former is analysing the geographic location of the system elements. Results show that, on average, 50% of the street network length correlates with 80%-85% of the total water supply/sewer network infrastructure. This is not surprising, since the accessibility in case of a failure (e.g. pipe burst in water supply systems) is of high importance and therefore such underground systems are placed below roads especially in highly dense urbanized areas. With a decrease in population density, also the total water infrastructure network length placed below streets decreases. A correlation on system element properties (e.g. correlation between street type and pipe diameter) could not be found.

Meaningful propositions and analyses on a multi-utility based approach can only be guaranteed if following conditions are fulfilled:

(1) Detailed, complete and valid datasets of infrastructure networks in the same service area are available
(2) Knowledge of the interdependency of the infrastructure types and especially the capability to quantify these interdependencies (Mair, Zischg, et al., 2017)

Regarding the first condition road network data is nowadays freely available (e.g. OpenStreet map or google maps) for nearly any place on earth. The European Parliament and Council of the European Union (2007) develop an infrastructure for spatial information in Europe (INSPIRE) which also includes the free data exchange of urban infrastructure information including parts of water infrastructures . However, high quality data of various infrastructure types are rarely administrated by one single authority, which implies the need of a collaboration between various authorities in terms of data exchange.

However, high quality data of various infrastructure types are rarely administrated by one single authority, which implies the need of a collaboration between various authorities in terms of data exchange. This is important not only for the management of the data set itself, but even more for planning construction measures in the systems. Water infrastructures and especially the water supply infrastructure is part of the critical infrastructures. Therefore, high attention on the continuous service availability of these infrastructures has to be given, furthermore the elimination of factors which may lead to a service interruption is of high priority (European Parliament and Council of the European Union, 2016). The knowledge of detailed system information in one hand could be considered as such factor which should be eliminated (e.g. scenario of a terrorist attack). This acts contrary to the need of data exchange in projects based on a multi-utility approach and also contrary to the INSPIRE project. Therefore, all stakeholders have to find a way to protect this information, while keeping the possibility for a data exchange of detailed infrastructure information for the purpose of research and management on multi-utility basis at the same time. This is crucial for an integrated multi-utility based asset management as presented in this work within the following sections.

3 Integrated multi-utility approach for asset management

The state-of-the-art projects in rehabilitation management for urban water networks (Saegrov, 2005; Sægrov, 2006) focus mainly on one network at a time while an integrated multi-utility approach is still seldom used (Osman, 2015; Tscheikner-Gratl, Sitzenfrei, et al., 2016). This is caused by the fact that such partitioning into drainage and water supply is present on different levels from operators to research (Rauch and Kleidorfer, 2014). The main idea of this integrated multi-utility approach, to tackle this highly complex problem, is simple. Instead of examining all public networks separately (implementing all available influences but only for this network), which are intertwined in our street networks, a holistic view of the infrastructure is used. Thereby, the road network is considered as a container for all networks together and it is used for prioritization. First investigations with an integrated multi-utility based approach (Carey and Lueke, 2013; Osman, 2015; Tscheikner-Gratl, Sitzenfrei, et al., 2016) focused mainly on the economical view and therefore the savings achieved by coordinated rehabilitation and less on other correlations.

To illustrate the idea of integrated rehabilitation management (Tscheikner-Gratl, 2016), this work will look at the urban infrastructure contained in a street section and its expected service life (LAWA, 2012). If we assume that all of them reach at least the lower threshold we can start to search for points in time, where coordinated rehabilitation could take place (see Figure 2). If we furthermore assume that the lower threshold is the end of the economic depreciation and the higher threshold the end of the technical design life, we can define the period in between as the uncertainty of the technical service life. Of course, the aim for the optimal rehabilitation time should be nearer to the technical design life to obtain the maximum economic value from the system. If we examine each system separately, the optimum for rehabilitation is the end of the technical design life (see Figure 2 - the upper left graph). As such, for the six networks of the street section and an observation time of 100 years, we would need six construction periods. The following periods of the networks with shorter life expectancies, (road network and electric and telecommunication cables) of course depend on the first decision when to replace them. Therefore, different scenarios are possible. If we exploit the full technical design life of the road network, while always replacing the telecommunication and electric cables at the same time, we can reduce the necessary construction periods to three (see Figure 2 - the upper right graph). If we do not want to replace the cables that early we would need four (see Figure 2 - the lower left graph). The lower right graph of Figure 2 shows the optimal solution for this example under the taken assumptions.

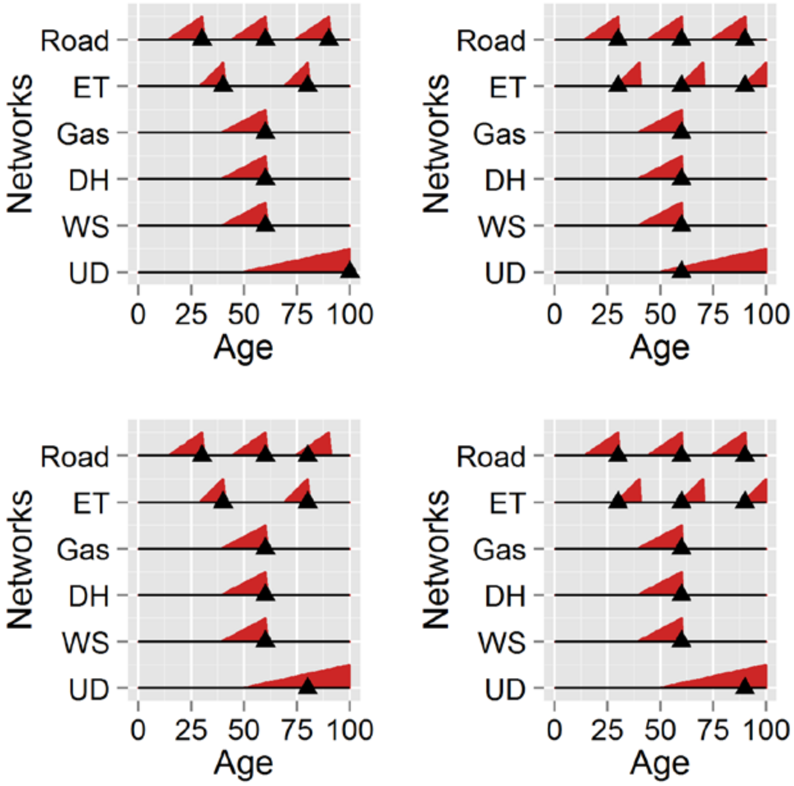

Figure 2. Possibilities for coordinated rehabilitation for the different infrastructure networks (adapted from Tscheikner-Gratl (2016)): optimum for each network separately (upper left graph), exploitation of the full technical design life of the road network, while replacing the telecommunication and electric cables always at the same time (upper right graph), optimum for electric and telecommunication networks (lower left graph), global optimum for this example (lower right graph)

Of course, this very simplified example does not represent the complexity of real systems but it does give a good reflection of the idea of integrated rehabilitation management. By maximising the service life of all network while minimising the necessary disturbances it strives to optimise the overall performance of rehabilitation works in urban infrastructure.

For real systems, the influencing factors multiply as well as the different goals for the different infrastructures (see Figure 3). The intertwined urban networks do not only differ internally in shape, length, construction depth, material, age, diameter and location but also in comparison to other adjacent networks. Focusing on coordinated rehabilitation in time, like explained in figure 2, is already complicated. In reality, the spatial context is at least equally important. This is effective at a small spatial scale in the cross section of a street. It is known that e.g. drinking water companies will place their main pipes under sidewalks to avoid high costs of having to open up the main road. This means that the position in the street cross section plays an important role in the decision making. A second issue related to the spatial scale is the fact that the minimal primary unit (e.g. district for drinking water, subcatchment for sewers) may be geographically different. This is especially relevant when upgrading sewer systems from traditional combined sewers to separated sewers with storm water infiltration. This is ideally done for the entire subcatchment and not for a single street. As such, aligning rehabilitation needs to be done at both the spatial and temporal scale.

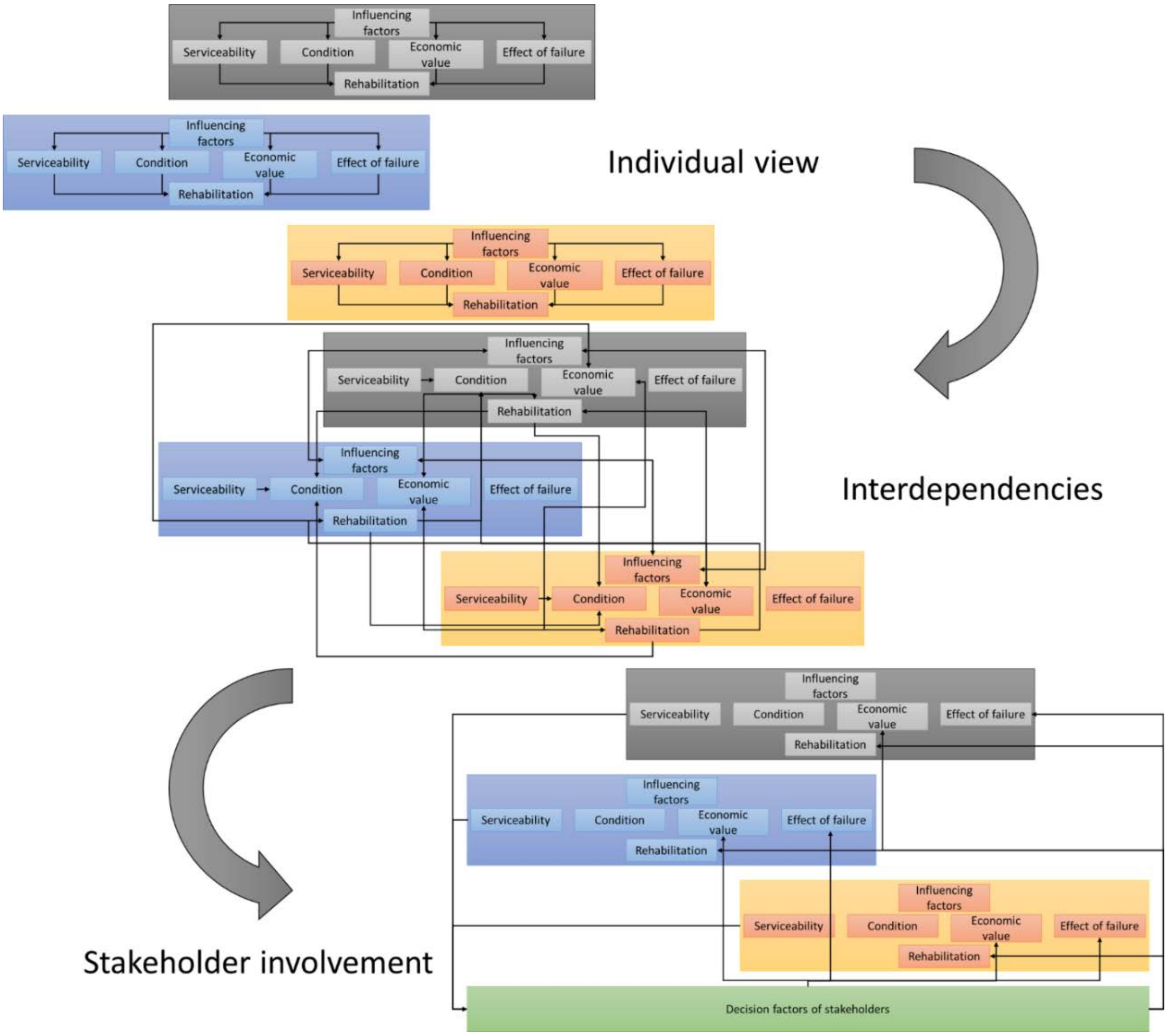

Figure 3. From an individual view to an integrated approach

Influences between the networks depend greatly on environmental factors (e.g. ground water level). Changes in usage (e.g. change of traffic on roads) and rehabilitation works in one network can influence the condition of adjacent networks but also its importance. The interaction between the subsystems ranges from the limitation of functionality by the failure of an adjacent network (for example the closure of a road due to a water main break) or the damaging of the infrastructure due to the proximity of other networks (for example corrosion of steel pipes induced by stray currents of the tram system) to minor influences during the rehabilitation of adjacent networks (for example due to vibrations).

On the other hand, synergies can and should be exploited in rehabilitation management. Costs, especially for excavation and surface reconstruction, can be shared and therefore minimized if coordinated rehabilitation takes place. This is of special importance if we assume that most infrastructure is in public domain, which is often the case. However, the organizational aspects need further research also due to the fact that all public operators have their own budget. Typically the initiator of the rehabilitation project, i.e. the operator of the network that first needs rehabilitation, will have to carry the burden of organising the project and most of the costs. This results in a situation where the operators with the most robust infrastructure can afford to wait until the others take initiative. Moreover, not all infrastructures share the same costs per metre street length. Table 1 gives an overview on typical cost values in the Netherlands. It is obvious that the operator of the most expensive infrastructure has a different share and therefore different relative benefits from cooperating. This different benefits reflect also in different interest and motivation for participating in coordinated rehabilitation measures. This interests have to be recognized and models have to be applied to quantify and value consensus among the stakeholders (Zarghami, Ardakanian, et al., 2008).

***Table 1**: Typical cost values for different infrastructure in the Netherlands*

Infrastructure	*Replacement costs per meter street section (€/m)*
Electricity, Low voltage (0,4 kV)	54.00
Public street lighting	18.00
Gas distribution, low pressure (max 0,1 bar)	37.00
Sewer	451.00
Wastewater pressure main	148.00
Drinking water distribution	79.00
Urban district heating	264.00

Furthermore, we can broaden the context of costs to social costs caused by damages to adjacent assets or due to delays of traffic caused by the rehabilitation measures. Contributing to this highly complex mixture of influences on the networks also a large amount of external influences on the decision making occur. A manifold of networks can mean also a manifold of operators and therefore stakeholders with different views, interests, goals and budgetary possibilities. To improve the communication between different stakeholder groups, it is advisable to objectify discussions by following a structured decision making procedure. The selection of the method to use for rehabilitation planning depends mainly on the available data and resources in time and labour. In some cases, it would be rational to use one of the simplest methods, especially when the data quality is low and no external knowledge is available or affordable. For larger datasets with more influencing factors with better data quality, a more sophisticated method will provide valuable results (Tscheikner-Gratl, Egger, et al., 2017).

4 Conclusion

Reliable data are the foundation of every successful rehabilitation and asset management approach (Alegre and Coelho 2012) and therefore also are data availability and management. On this foundation, the integrated multi-utility approach on the rehabilitation of urban infrastructure networks can be built. Especially for the implementation of deterioration and decision support models data availability is crucial, because the outcome of these models depends on the quality of the input or in other words - you cannot implement what you don't know. Recurring nuisances which have to be considered are missing and implausible data, documentation, models and measurements. The problems of data and data management together with the increasing availability of open source data will be an opportunity as well as a challenge for multi-utility asset management. The goal is the identification, classification and recommendation of data sources for asset management and the development of robust methods, which work with data gaps or failures.

For each examined network, three main questions have to be asked. These questions are about the actual condition of the network, the consequence of a failure and the economic assessment of the network. The condition assessment contains more than structural condition influences by deterioration, is also needs to consider serviceability (e.g. the hydraulic capacity of sewers). The consequence of failure of network elements usually affects the entire network as a whole as well as other infrastructure. Another important factor is the economic value of the network. However, due to interdependencies between these factors the individual view on the networks has to be extended to an integrated view on the entire infrastructure at once.

Asset and rehabilitation management involve multiple stakeholders, which have different goals and expectation, which have to be depicted in an integrated approach (e.g. using negotiation models or serious gaming approaches (van Riel, Post, et al., 2016)). Founding on the aforementioned influencing factors and the stakeholders for the rehabilitation planning a framework for integrated decision support for rehabilitation measures can be developed, when we understand urban network connections and interdependencies. The street network as an unitary urban body (Di Sivo and Ladiana, 2011) contains almost all underground infrastructure in an urban environment. These infrastructures are interdependent either in physical, cyber, geographical and logical form (Rinaldi, Peerenboom, et al., 2001). They can influence each other in case of failure of one network but due to adjacency also in cases of rehabilitation due to effects of rehabilitation or construction works on the condition of nearby networks. A further interdependency is on the economic value provided by the point that combined rehabilitation tends to more economic in overall than individual one, although maybe not cheaper for every stakeholder and not in the same amount. This has the consequence that the implementation of a multi-utility approach might change the optimal rehabilitation strategy. Finding, valuing and implementing of these interdependencies into the rehabilitation management process is one of the main challenges. All these conflicting interests of the involved parties have to be reflected.

References

Alegre, H. and Coelho, S. T. (2012) "Infrastructure Asset Management of Urban Water Systems" in A. Ostfeld (ed.), Water Supply System Analysis - Selected Topics. InTech, 49–74. DOI: 10.5772/52377.

Carey, B. D. and Lueke, J. S. (2013) Optimized holistic municipal right-of-way capital improvement planning. Canadian Journal of Civil Engineering, **40**(12), 1244–1251. DOI: 10.1139/cjce-2012-0183.

EN 752 (2008) *Drain and sewer systems outside buildings*, European Commitee for Standardization.

EN 805 (2000) *Water supply. Requirements for systems and components outside buildings*, European Committee for Standardization.

European Parliament and Council of the European Union (2016) *Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union*, [online] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L1148&from=EN.

European Parliament and Council of the European Union (2007) *Directive 2007/2/EC of the European Parliament and of the council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)*, [online] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:EN:PDF.

LAWA (2012) *Leitlinien zur Durchführung Dynamischer Kostenvergleichsrechnungen (KVR-Leitlinien)*, Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA). ISBN: 978-3-941897-55-7.

Mair, M., Zischg, J., Rauch, W., and Sitzenfrei, R. (2017) Where to Find Water Pipes and Sewers? — On the Correlation of Infrastructure Networks in the Urban Environment. Water, **9**(2), 146–161. DOI: 10.3390/w9020146.

Osman, H. (2015) Coordination of urban infrastructure reconstruction projects. Structure and Infrastructure Engineering, **12**(1), 108–121. DOI: 10.1080/15732479.2014.995677.

Rauch, W. and Kleidorfer, M. (2014) Replace contamination, not the pipes. Science, **345**(6198), 734–735. DOI: 10.1126/science.1257988.

van Riel, W., Post, J., Langeveld, J., Herder, P., and Clemens, F. (2016) A gaming approach to networked infrastructure management. Structure and Infrastructure Engineering, **2479**(August), 1–14. DOI: 10.1080/15732479.2016.1212902.

Rinaldi, S. M., Peerenboom, J. P., and Kelly, T. K. (2001) Modeling and simulating critical infrastructures and their interdependencies. IEEE Control Systems, **21**(6), 11–25. DOI: 10.1109/37.969131.

Saegrov, S. (2005) *Care-W: Computer Aided Rehabilitation for Water Networks*, IWA Publishing. ISBN: 9781843390916.

Sægrov, S. (2006) *Care-S: Computer Aided Rehabilitation of Sewer and Storm Water Networks*, IWA Publishing. ISBN: 9781843391159.

Di Sivo, M. and Ladiana, D. (2011) Decision-support tools for municipal infrastructure maintenance management. Procedia Computer Science, **3**, 36–41. DOI: 10.1016/j.procs.2010.12.007.

Tscheikner-Gratl, F. (2016) *Integrated Approach for multi-utility rehabilitation planning of Urban Water Infrastructure*, innsbruck university press. ISBN: 978-3-903122-05-5.

Tscheikner-Gratl, F., Egger, P., Rauch, W., and Kleidorfer, M. (2017) Comparison of multi-criteria decision support methods for integrated rehabilitation prioritization. Water, **9**(2). DOI: 10.3390/w9020068.

Tscheikner-Gratl, F., Sitzenfrei, R., Rauch, W., and Kleidorfer, M. (2016) Integrated rehabilitation planning of urban infrastructure systems using a street section priority model. Urban Water Journal, **13**(1), 28–40. DOI: 10.1080/1573062X.2015.1057174.

Zarghami, M., Ardakanian, R., Memariani, a., and Szidarovszky, F. (2008) Extended OWA Operator for Group Decision Making on Water Resources Projects. Journal of Water Resources Planning and Management, **134**(3), 266–275. DOI: 10.1061/(ASCE)0733-9496(2008)134:3(266).