Integrated Rehabilitation management for different infrastructure sectors

Franz Tscheikner-Gratl[1], Max Hammerer[2], Wolfgang Rauch[3], Christian Mikovits[4], Manfred Kleidorfer[5]

[1] University of Innsbruck, Austria, franz.tscheikner-gratl@uibk.ac.at
[2] hammerer-system-messtechnik, Austria, max@hammerer.cc
[3] University of Innsbruck, Austria, wolfgang.rauch@uibk.ac.at
[4] University of Innsbruck, Austria, christian.mikovits@uibk.ac.at
[5] University of Innsbruck, Austria, manfred.kleidorfer@uibk.ac.at

ABSTRACT

In Europe our water distribution and wastewater collection networks are near the end of their assumed lifespan or will be in the coming years. Therefore the main focus of urban water management is shifting from construction to rehabilitation. For state of the art Rehabilitation Management lots of different models to simulate the deterioration process are in use. These models depend strongly on the quality accuracy of the available data. Data is seldom available in high quality due to the only recently started information management of the operating companies. Therefore a good data validation and reconstruction of the available data is essential for Rehabilitation planning. The main focus of these models have been the main sewers and the main water distribution pipes, although in average the number of damages in the connection pipes to households is higher (the failure rate up to 4 times). This is addressed by a classification between transport and house connection in the deterioration models. Also the interaction between the different infrastructure (gas, wastewater, water distribution, electric grids and road network) has to be taken into account as well as the changes in environmental factors (climate, population, etc.). These influences will be integrated into the priority model to identify the “hot spots” for rehabilitation in the different networks. All these challenges have been encountered and addressed in the Austrian Research Promotion Agency (FFG) funded research project “REHAB – Integrated planning of rehabilitation strategies of urban infrastructure systems”.

Integrierte Rehabilitationsplanung für verschiedene Infrastruktursektoren

Franz Tscheikner-Gratl[1], Max Hammerer[2], Wolfgang Rauch[3], Christian Mikovits[4], Manfred Kleidorfer[5]

[1] Universität Innsbruck, Österreich, franz.tscheikner-gratl@uibk.ac.at
[2] hammerer-system-messtechnik, Österreich, max@hammerer.cc
[3] Universität Innsbruck, Österreich, wolfgang.rauch@uibk.ac.at
[4] Universität Innsbruck, Österreich, christian.mikovits@uibk.ac.at
[5] Universität Innsbruck, Österreich, manfred.kleidorfer@uibk.ac.at

ZUSAMMENFASSUNG

Unsere Wasserversorgungs- und Kanalnetze in Europa sind beinahe am Ende ihrer angenommenen Nutzungsdauer oder erreichen sie in den nächsten Jahren. Deshalb verschiebt sich das Hauptaugenmerk des städtischen Wassermanagements vom Neubau hin zur Sanierung. Für ein Rehabilitationsmanagement auf dem neuesten Stand der Technik werden viele verschiedene Simulationsmodelle des Alterungsprozesses verwendet. Diese Modelle hängen stark von Qualität und Zuverlässigkeit der verfügbaren Daten ab. Weil das Informationsmanagement der Betreibergesellschaften noch in den Kinderschuhen steckt, sind Daten selten in hoher Qualität verfügbar. Deshalb ist eine gute Datenvalidierung und Rekonstruktion der verfügbaren Daten ein entscheidender Faktor der Sanierungsplanung. Die Modelle betrachten vor allem die Hauptabflusskanäle und die Hauptzuleitungsrohre für Trinkwasser, obgleich im Durchschnitt die Anzahl der Schäden an den Hausanschlüssen höher ist (die Schadensrate bis zu 4x so hoch). Dies wird durch ein Unterleilung zwischen Versrogungs- und Hausanschlussleitungen in den Alterungsmodellen erreicht. Außerdem müssen neben der Interaktion der verschiedenen Netze der Ver- und Entsorger (Gas, Abwasser, Trinkwasser, Strom- und Straßennetz) auch die Veränderungen der Umweltbedingungen (Klima, Bevölkerung usw.) berücksichtigt werden. Diese Einflüsse werden in das Priorisierungsmodell integriert um die “Hot Spots” für die Rehabilitierung in den verschiedenen Netzen zu finden. All diese Herausforderungen hat sich das von der österreichischen Forschungsförderungsgesellschaft (FFG) finanzierte Forschungsprojekt „REHAB – Integrierte Planung von Sanierungsstrategien städtischer Infrastruktursysteme“ angenommen.

Gestion de réhabilitation intégrée dans différents secteurs d'infrastructure

Franz Tscheikner-Gratl[1], Max Hammerer[2], Wolfgang Rauch[3], Christian Mikovits[4], Manfred Kleidorfer[5]

[1] Université Innsbruck, Autriche, franz.tscheikner-gratl@uibk.ac.at
[2] hammerer-system-messtechnik, Autriche, max@hammerer.cc
[3] Université Innsbruck, Autriche, wolfgang.rauch@uibk.ac.at
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[5] Université Innsbruck, Autriche, manfred.kleidorfer@uibk.ac.at

RESUME

En Europe, nos réseaux de distribution d'eau et de collecte des eaux usées arrivent - ou arriveront dans les prochaines années - en fin de vie. La gestion des eaux urbaines ne se focalise donc plus tant sur la construction mais bien sur la réhabilitation. Dans la gestion de réhabilitation de pointe, une foule de modèles différents sont utilisés pour simuler le processus de détérioration. Ces modèles sont très dépendants du niveau de qualité et de précision des données disponibles. Ces données sont rarement de bonne qualité, les sociétés d'exploitation n'ayant démarré que très récemment le processus de gestion de l'information. Une bonne validation et reconstitution des données disponibles sont donc essentielles au planning de réhabilitation. Ces modèles se sont particulièrement concentrés sur les égouts et conduites de distribution d'eau les plus importants, alors que les dégâts sont en moyenne plus nombreux sur les conduites de raccordement au réseau domestique. Par ailleurs, l'interaction entre les différentes infrastructures (réseaux gazier, des eaux usées, de distribution d'eau, électrique et routier) et l'évolution des facteurs environnementaux (climat, démographie…) doivent être prises en compte. Tous ces défis ont fait l'objet d'un projet de recherche financé par l'Agence de Promotion de la Recherche autrichienne (FFG) intitulé « REHAB – Planning intégré des stratégies de réhabilitation de réseaux d'infrastructure urbains ».

1. Introduction

Urban areas and their development strongly depend on the two key tasks of urban water management: supply of high quality potable water and disposal of wastewater and stormwater. These services are central for the human wellbeing as well as for the economic development of urban settlements [1].

In the last decades the main focus of water supply and sewer management has moved from construction of new sewer and water supply networks to rehabilitation and adaptation of the existing infrastructure. Rehabilitation is the term for either repairing, renovating or for replacement of pipes. The main goal is to maintain or even improve the existing service level of the networks in the most efficient way. This is required for drainage and sewer systems and regulated in (inter)national guidelines and technical rules as for example in EN 752 [2]. However the present rate of system rehabilitation does not keep pace with these requirements [3].

Lots of models have been developed to aid the process of asset management and decision making for sustainable rehabilitation planning. Most of these tools are statistical models (for an overview for water supply systems see for example Kleiner and Rajani [4] or Osman and Bainbridge [5]; for waste water collection networks for example Ana and Bauwens [6]), but also physical models exist [7]. These models usually focus only on a specific infrastructure network i.e. either on water supply or drainage networks (stormwater and wastewater collection). This separated view cannot cope with the complex situation. Future Tasks demand an integrated management approach across the different sectors [8].

Furthermore, in the majority of cases not only these two networks have to be considered for management and rehabilitation of urban infrastructure assets. Other infrastructure facilities like gas supply, district heating, electrical and telecommunication grids and of course traffic facilities overlap with water infrastructure since the layout of all these networks is driven by the street network. Mair, et al. [9] show that 78% of all roads are containing 81% and 86% of the water supply and sewer network, respectively. An efficient planning of rehabilitation measures has to take into account different networks to take advantage of the synergies and coherences [10] that a combined planning can provide (e.g. to reduce e.g. the duration of construction or road closures). Additionally integrated planning can benefit from data availability and data reconstruction methods of related networks.

Also the changing environment and its challenges influence rehabilitation management due to its high influence on the costs of future delivery of water services [11]. To improve a prospective design of rehabilitation and adaptation measures of urban water infrastructure the Austrian Research Promotion Agency (FFG) funds the research project “REHAB – Integrated planning of rehabilitation strategies of urban infrastructure systems” [1]. Therein deterioration models are combined with projections for future development of the city (new development areas, growing population) as well as with climate change projections.

Consequently the aim of this paper is to show the methodology of the REHAB Project and first results from our case studies.

2. Concept of the project REHAB

With the influences of an anticipated future (climate change, population change) and an economic model for the different rehabilitation techniques (repair, renovation, replacement) the boundaries for the decision support system of the rehabilitation management are set.
The project consists of following modules (shown in Figure 1):

- Deterioration model to predict the aging of the infrastructure networks and the need for rehabilitation
- Analysis of vulnerability to predict the effects of possible failures
- Priority Model to pinpoint the most urgent areas for rehabilitation

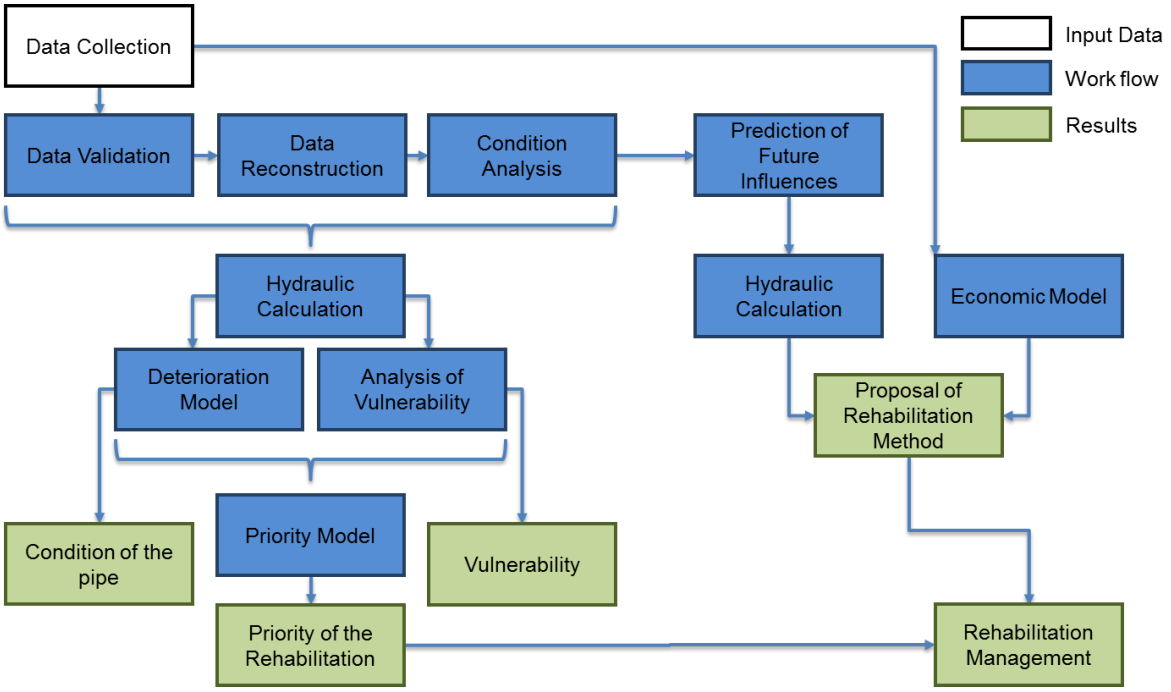

Figure 1: Concept of the Project REHAB

This project started in December 2011; the current status is the deterioration and priority modelling for several case studies in Europe (three municipalities in Austria and Germany). An integrated multi-criteria decision support analysis will be finished until the end of 2013.

3. Data issues

These models depend on the quality and availability of data about the regarded networks. The data collection of all possible influencing factors is a time consuming, difficult task which is nearly impossible to be accomplished completely.
For this project the first step was to determine the optimal dataset for rehabilitation planning (shown in Table 1 and Table 2), which of course was not completely obtainable. The real dataset was of fluctuating quality and differed between the case studies as well as the infrastructure networks.

Table 1: Optimal dataset regarding the networks [12]

Wastewater collection	Water distribution	Gas distribution
Dimension	Dimension	Dimension
Pipe shape	Material	Material
Material	Position (Coordinates) of the Pipes	Position (Coordinates) of the Pipes
Position (Coordinates) of the Pipes	Pipe length	Pipe length
Pipe length	Material of pipe bed	Material of pipe bed
Material of pipe bed	Type of pipe connection	Type of pipe connection
Type of pipe connection	Failure statistics	Failure statistics
Hydrodynamic Model of the network	Hydraulic Model of the network	Time interval between on-site inspections
Time interval between on-site inspections and the derived condition state	Time interval between on-site inspections	Year of construction
Depth of coverage	Year of construction	Depth of coverage
Year of construction	Depth of coverage	
Type of wastewater		

Table 2: Optimal dataset regarding surrounding areas [12]

Transport infrastructure	Position of important objects	Environment
Routes of railway, tramway, etc.	Archives	Weather conditions (Temperature, etc.)
Traffic Volume	Museums	Soil conditions
Road construction	Hospitals	Seismic
Importance of roads	Schools, Universities, etc.	Ground-water level
	Sports Infrastructure	Land use
	Infrastructural buildings	Population density
	Governmental buildings	Vegetation
	Other sensible objects	

A good example for the fluctuating data quality is the nature of the failure statistics of the water distribution network (for one case study shown in Figure 2). These statistics were mostly quite sound regarding the properties of the affected pipe but lacked details of the failure type and the age of the affected pipe.

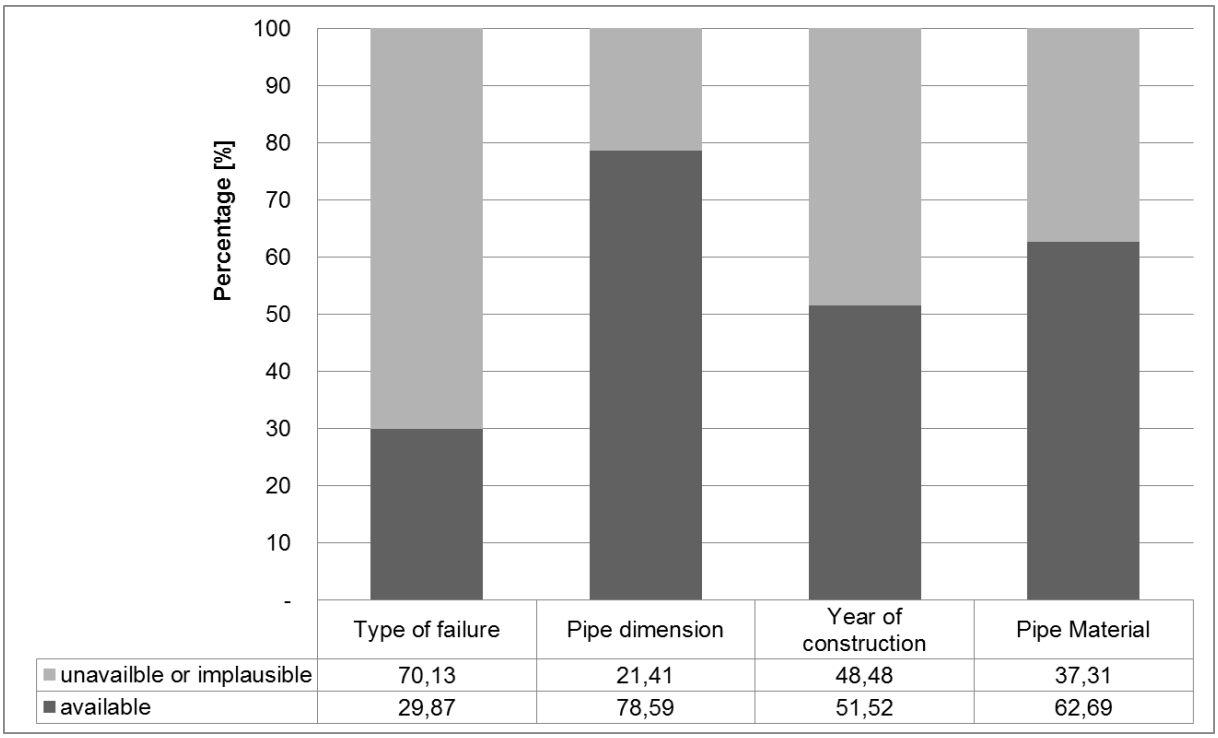

Figure 2: Example of data quality: Water distribution network failure statistics of a case study

4. Deterioration model

For deterioration modelling we chose the approach of a cohort survival model (as proposed by Herz and Krug [13]) as this approach has been proven to be appropriate for calculating the need for future rehabilitation for entire networks [6]. For the water supply networks as well as for the sewer networks these calculations were made. The result of the deterioration model will be the percentage of the network in need of rehabilitation, which will subsequently be chosen by the priority model.

4.1. Water and gas supply

For the water supply network first the existing network was examined and classified by the construction year (separately for distribution pipes and household connections). Figure 3 shows the age distribution of the network. In this case we had a very good data-set in which the construction year is available for 91% of the pipe length. The missing 9% were proportionally distributed among the existing data. Further the data was classified into the different pipe materials (Asbestos Cement, Cast Iron, Lead, Polyvinylchloride, Ductile Iron, Steel and Polyethylene).

For each Material a normal distributed life expectancy with the means and standard deviations of Baur [14] was assumed and the length of failing pipes per year was calculated (shown in Figure 4). We presumed that all the failing pipes are replaced by a material with a higher life expectancy. Further we expected that all lead pipes are to replace immediately due to health regulations. The main focus of these kind of models have been the main water distribution pipes, although in average the number of damages in the connection pipes to households is higher. From the data of our case studies we see that we have in average a failure rate of 0.067 failures per kilometre and year on distribution pipes. For house connection conduits this rate is 4 times higher, but due to the smaller length this rate is not very significant. More informative is the failure rate per house connection and year which was estimated from the existing data of the three case studies. In average 0.6% of all house connection pipes have failures per year. So here a distinction has to be made (compare Figure 3, Figure 4 and Figure 5).

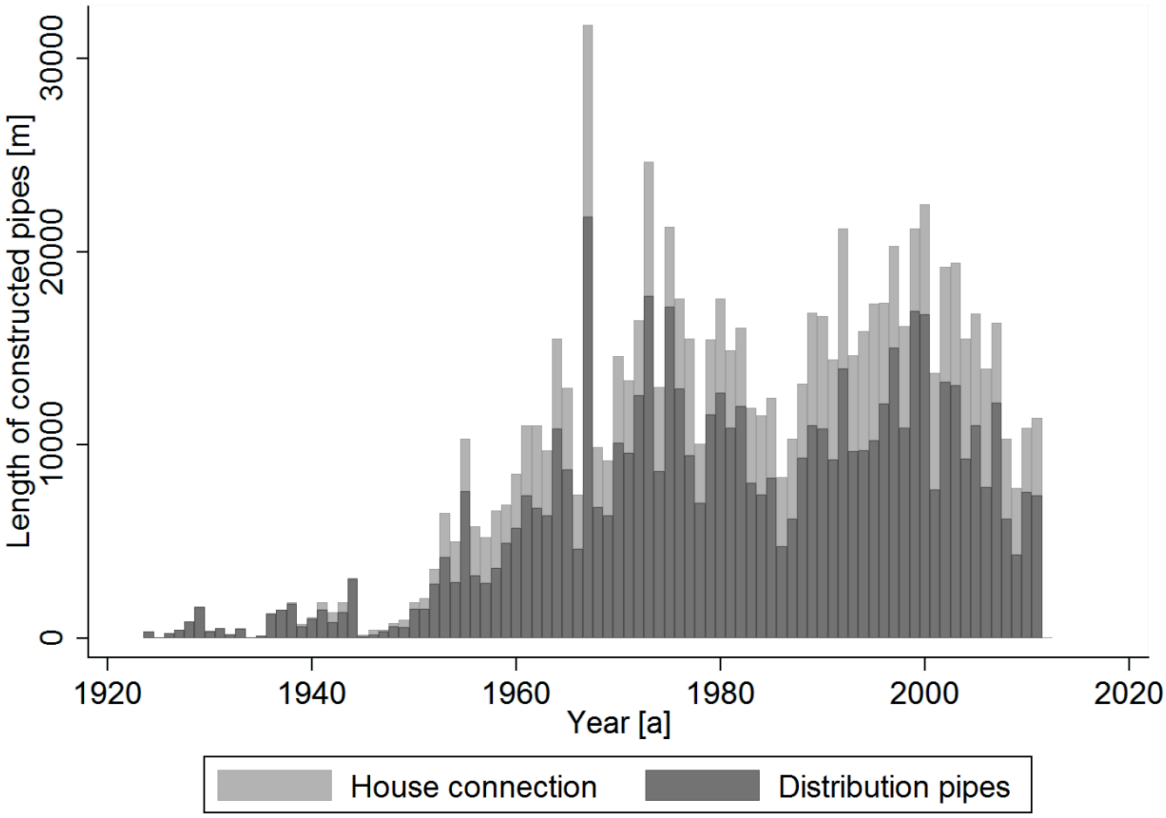

Figure 3: Construction years of a water distribution network

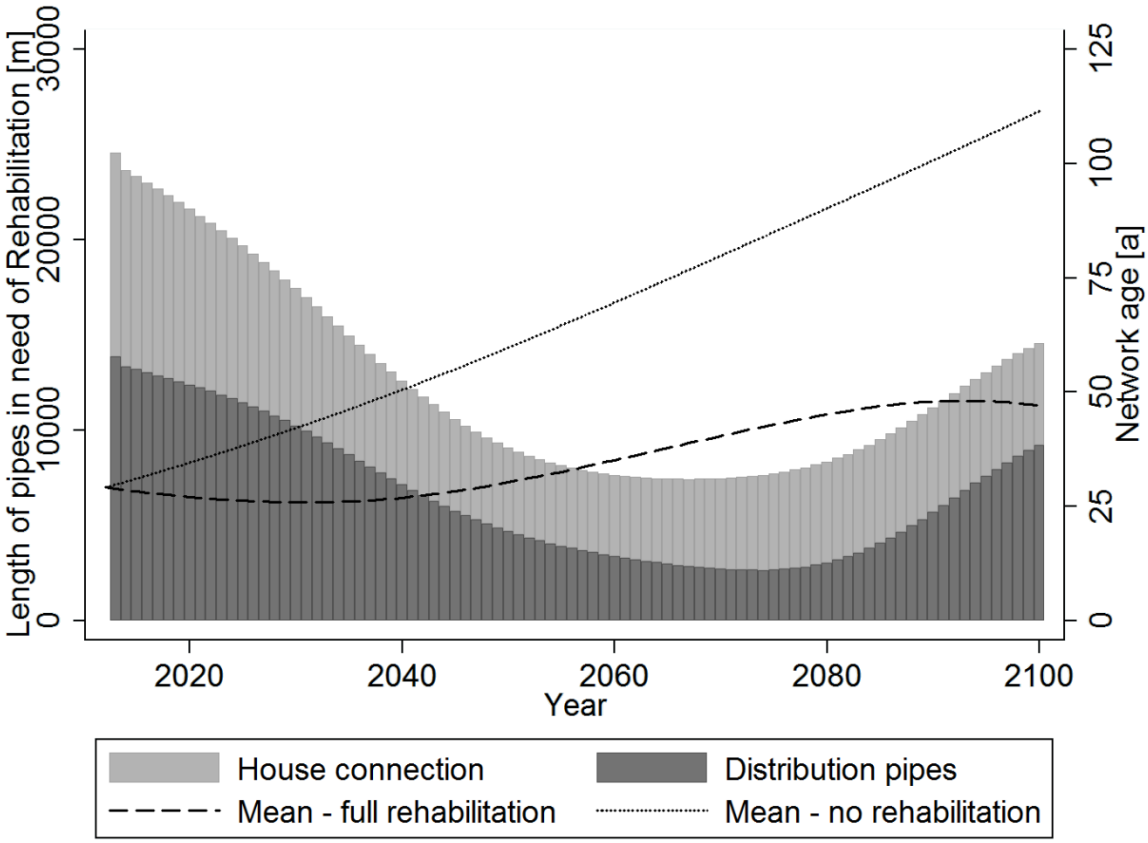

Figure 4: Length of failing pipes per year with life expectancy from Baur [14] and the influence of the rehabilitation rate on the network age

The lower life expectancy of the older pipes constructed before 1965 would demand a high rehabilitation rate in the coming years. Regarding a total length of the water supply network of 851 km, a rehabilitation rate of almost 3% in the next years would be required. This rate decreases to 1.2% until 2060 and then rises again (with taking into account that the replaced pipes are aging as well). Due to the large amount of replaced pipes the mean network age would stabilize until 2040 and then slowly increase until 2080 to around 50 years (due to the higher life expectancy of the replaced pipes). At this time the age of the network would be more than 2 times higher if no rehabilitation measures are taken.

The chosen life expectancy has a major influence on these calculations so choosing them should be one of the main focuses. For example the change of the mean life expectancy of all distribution pipes to 100 years and all house connection pipes to 50 years changes the picture completely (shown in Figure 5). A much lower rehabilitation rate of around 0.6% in the next years would be sufficient. Then this rate would increase to 1.4% in 2080. Due to the small amount of replaced pipes in the next years, the mean age of the network is only marginally lower as it would be without rehabilitation. The mean age would stabilize in 2060 around 50 years. The gap to the scenario without rehabilitation would only be 25 years.

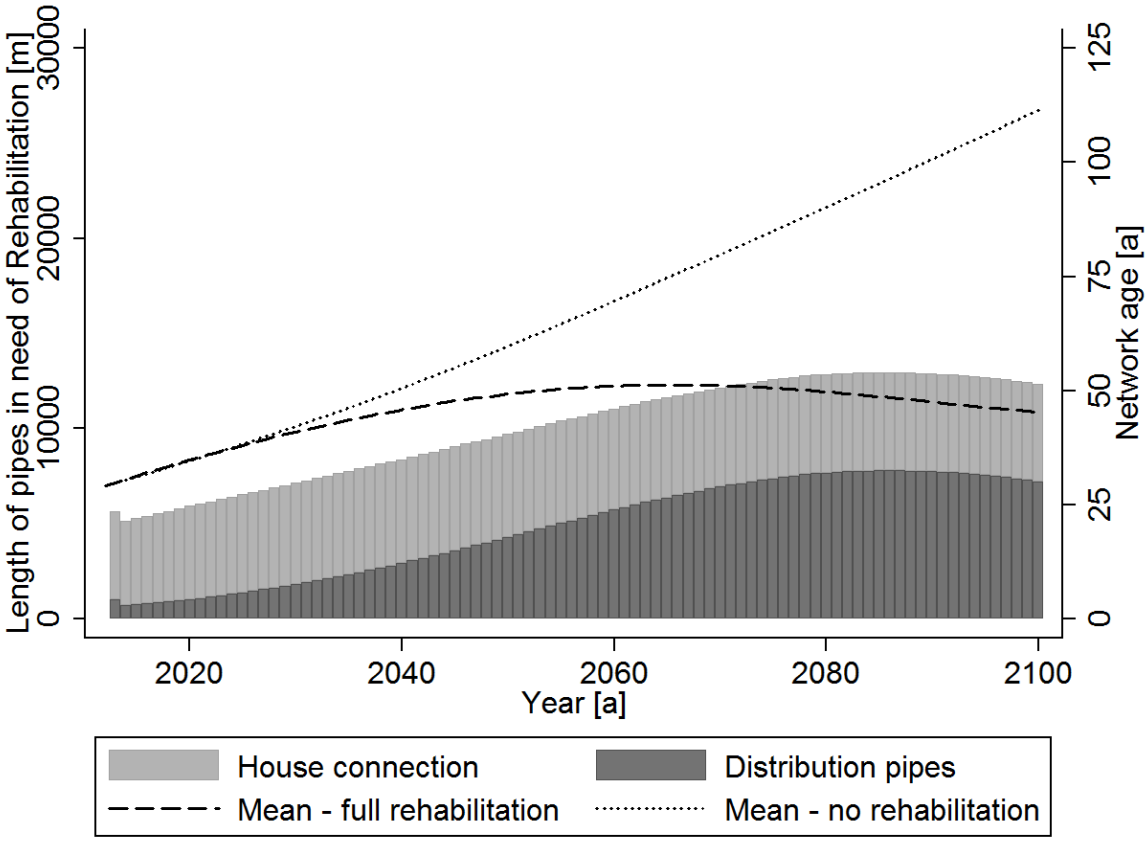

Figure 5: Length of failing pipes per year with a mean life expectancy of 100 years for distribution pipes and 50 for house connection pipes

Therefore the next steps in the project will be the estimation of plausible and usable life expectancies of the already constructed pipes [14] as well as for the new pipes which will replace the failing ones.
Due to similarities between the gas and water distribution system the estimation for gas pipes will be carried out like the method described above – but with different life expectancies

4.2. Wastewater collection

For the sewer systems only the data of one case study was sufficient for detailed simulations. The diameters of the pipes in this case study range between 250 and 600mm. The most used material was concrete and to a smaller proportion clay and polypropylene. The estimation of the condition states was carried through following ISYBAU [15] distinguishing 5 states from immediate action necessary (CS5) until no action necessary (CS0). This rating was reduced to 2 states: acceptable (CS3 or better) and unacceptable (CS4 and CS5) [12]. The transition function between these two conditions is approximated by the Gompertz relation (shown in Equation 1), parameters are determined using the method of least squares.

$$R(x) = A \cdot e^{-e^{B-C\cdot x}} \qquad (1)$$

$R(x)$ ... Percentage of sewers, which stay in acceptable condition (Condition state 3 or better) after x years

A, B, C ... Empirical parameters

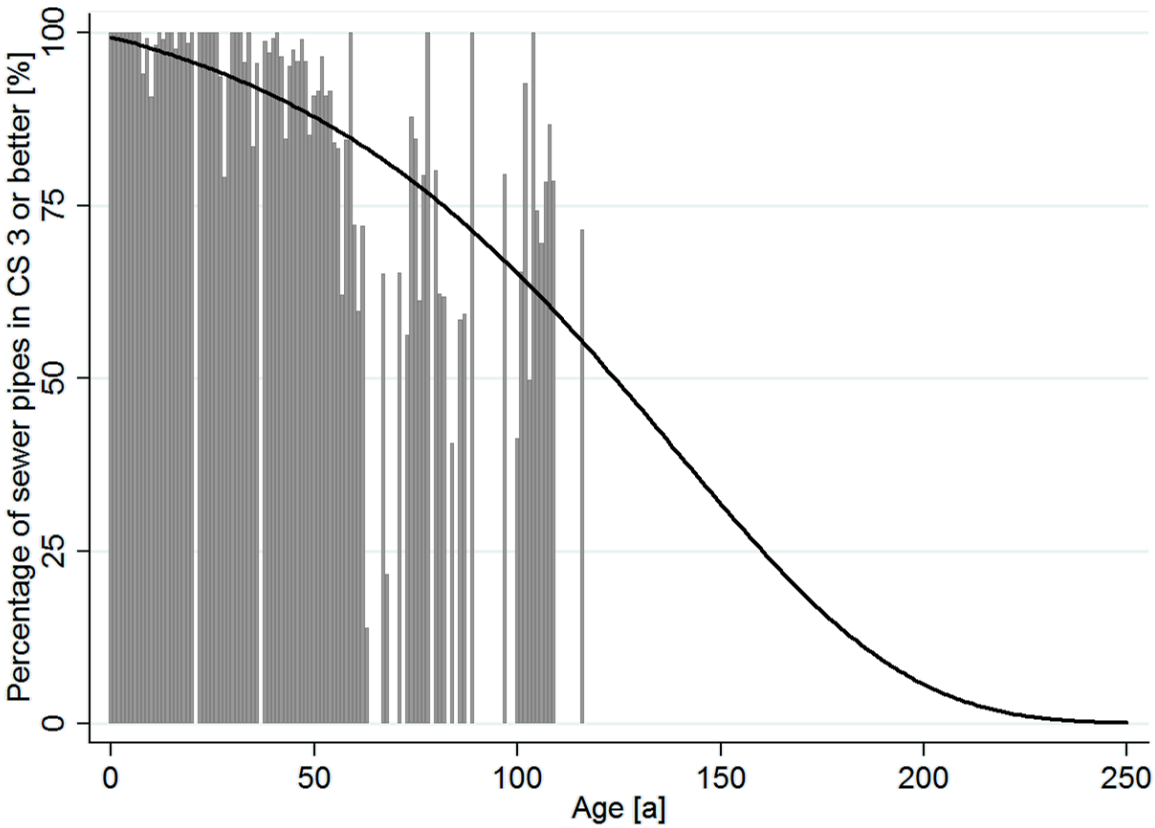

Figure 6: Transition curve between acceptable and unacceptable sewer condition [12]

Figure 6 shows that with this function a mean life time for this sewer network of 125 years is predicted. One of the problems of this prediction is the lack of data for sewers older than 120 years, which results from the fact that the sewer system of the case study currently has no older pipes and if pipe replacement took place it was not recorded in the data-set.
This example was calculated for the entire network and will be estimated in the next steps for different groups of pipes classified into Dimension, Material, etc. as shown by Herz and Krug [13]). With these functions the rehabilitation rate and the length of the necessary rehabilitation for the network can be predicted similar to the water supply system.

5. Priority model

With having the yearly rehabilitation length acquired by the deterioration model - or with the given rehabilitation rate of the operating company (which is mostly less due to budget considerations) – we still have not decided which parts of the network in particular have to be rehabilitated. But it gives us the boundaries for the priority model. Its goal is finding areas with the most pressing problems or where through interaction of different networks (gas, water, wastewater, streets, etc.) rehabilitation now appears to be economically coherent.
The priority model therefore consists of six parts:

- Results of the deterioration model, like the different aging behaviour of different materials
- Environmental influences like groundwater level, etc.
- Interactions between neighbouring networks to accomplish an economic and integrated rehabilitation management
- Passive Rehabilitation driven by land use changes, street or railway construction and repairs, etc.
- The importance of the areas and buildings supplied by the examined network
- Already observed failure rate in the examined area
- The importance of the observed part of the network – estimated by the vulnerability as shown for example by Möderl, et al. [16] (see also Figure 7)

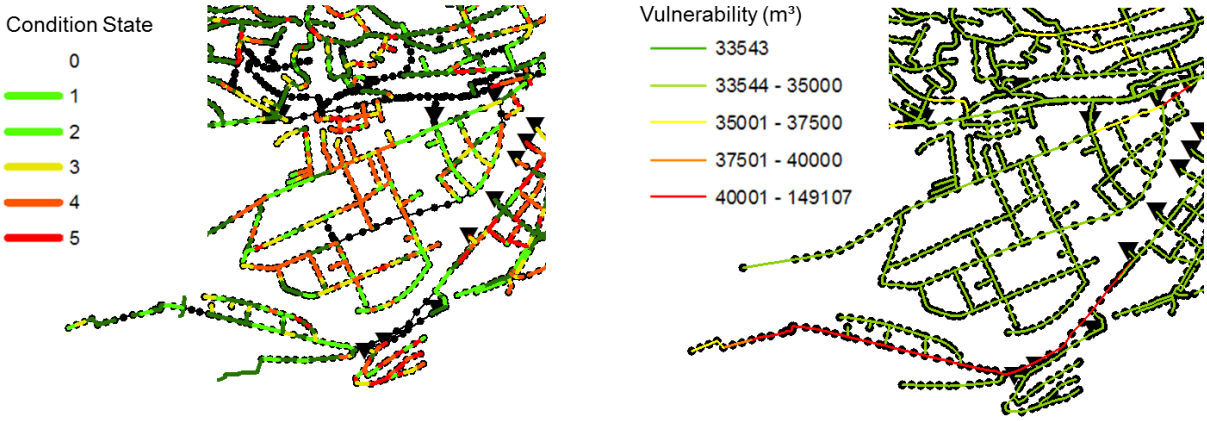

Figure 7: Output of Deterioration Model (Condition states of sewer network) and the vulnerability of the same network to the collapse of a pipe [1]

These parts have to be weighted and incorporated into an integrated planning model to optimize the rehabilitation management. Some of the parameters are valid for the whole network (for example the parameters from the deterioration models) and others have to be examined individually for different areas. In this project the networks will be divided into street strands and their individual properties will be estimated (for example the varying failure statistics for every street shown in Figure 8).

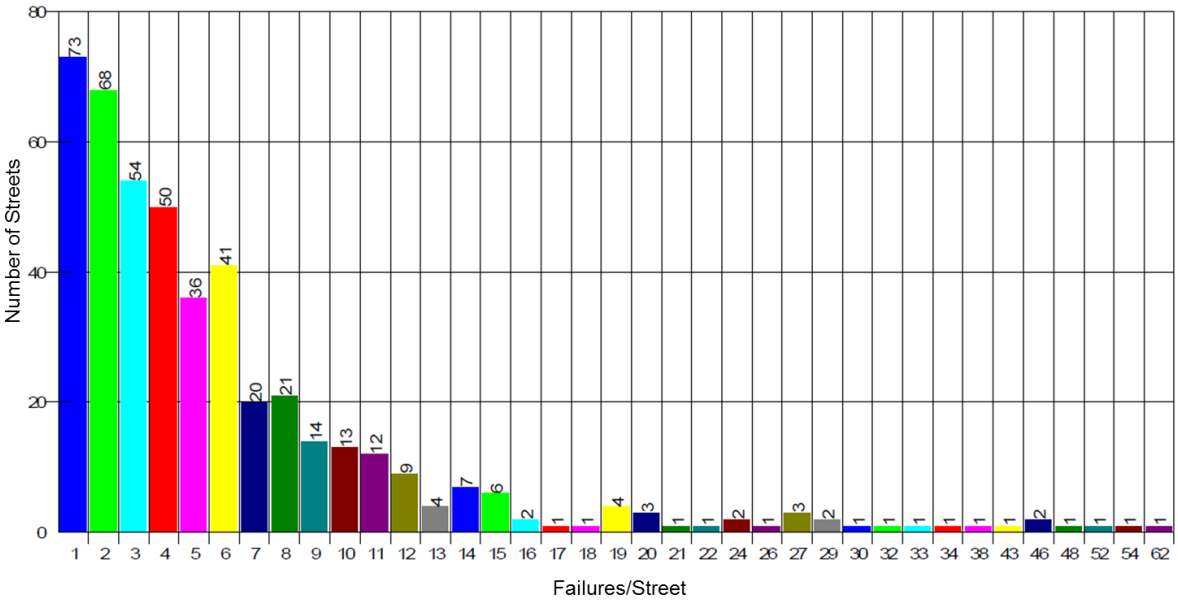

Figure 8: Failure/Street statistics for a water distribution network visualized with PROFI [17]

6. Prediction of future influences

Considering stormwater and wastewater collection the most influencing factors of future development are climatic change and land use change. The water supply system is driven by the demand and is therefore influenced by urbanization

(population in- or decrease). Impact of climate change is very case specific ranging from severe pressure to water resources management in some areas to insignificant effect in other parts of the world. It can also have an impact on the water consumption [18].

Climate change can influence urban drainage system performance due to changing temperature, changing rain intensities and duration or changes in the evaporation (i.e. impact on rainfall runoff behaviors). Especially the changes of the rain intensities and duration can have major effects on the sewer system [19]. Further increase of sedimentation or the production of hydrogen sulfide could be consequences of longer dry periods. The hydrogen sulfide could also affect the pipe material [20] and consequently rehabilitation needs.

Land use change means changing population and changing ground sealing. For example in Austria Hanika [21] predicts an increase of the overall population but additionally great variations between different regions. The conurbations and their surroundings will have increasing population while rural areas will decrease. The development of the population in one of our case studies is shown in Figure 9. It shows that the city after a phase of stagnation from 1970 until 2000 starts to grow again and is predicted to continue. This effect is also observable for the surrounding areas (0-15 or 15 – 30 min by car from the city). Another factor is the change of the population structure from bigger groups to single households.

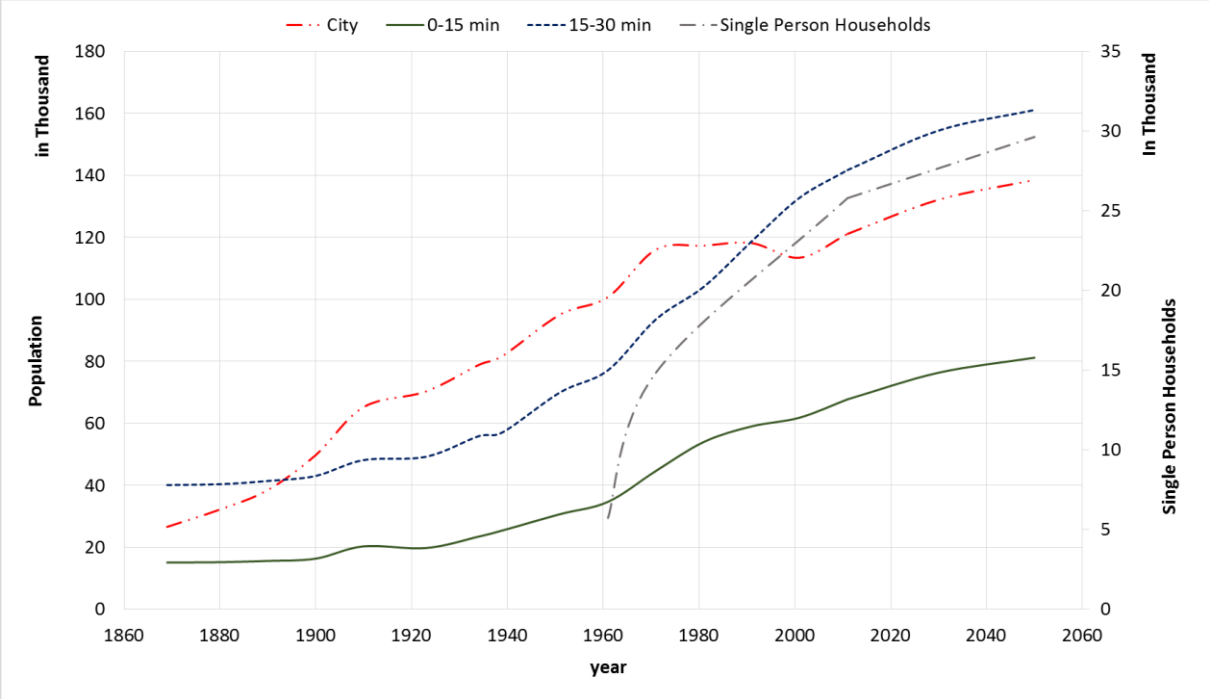

Figure 9: Population development of a case study in the city itself, 0 -15 min driving time from the city, 15 -30 min from the city; Number of single households [19]

By considering these changes future scenarios can be created and implemented into an integrated rehabilitation planning. Figure 10 shows an area in one of our case studies in its present state.

Figure 10: Case study scenario – present; visualized with Google Earth [12]

For modelling the future condition of the network in this area we assumed that the area will be used as housing area (with a runoff coefficient of 0.5). Further an increase of the rainfall intensity by a factor of 1.2 [22] due to climate change is applied. Figure 11 shows the results of a hydrodynamic calculation (using PCSWMM) considering these future conditions for the scenario of a collapsing pipe due to the lack of rehabilitation. The resulting high flooding volume shows the importance of the pipes and therefore the high priority in the network which will influence the priority model.

Figure 11: Case study scenario – possible future; visualized with Google Earth [12]

7. Conclusion and outlook

Only with an integrated approach the meeting of all the different requirements of maintaining the high standard of our infrastructure is possible. The positive interactive effects between the different kinds of infrastructure have to be regarded. This could decrease planning and construction costs of rehabilitation measures by exploiting synergies between the different infrastructural sectors. This is gaining more and more importance in times of low budgets where a foresighted asset management should be able to keep the balance between rehabilitation - maintenance and at the same time low risks (see Figure 12).

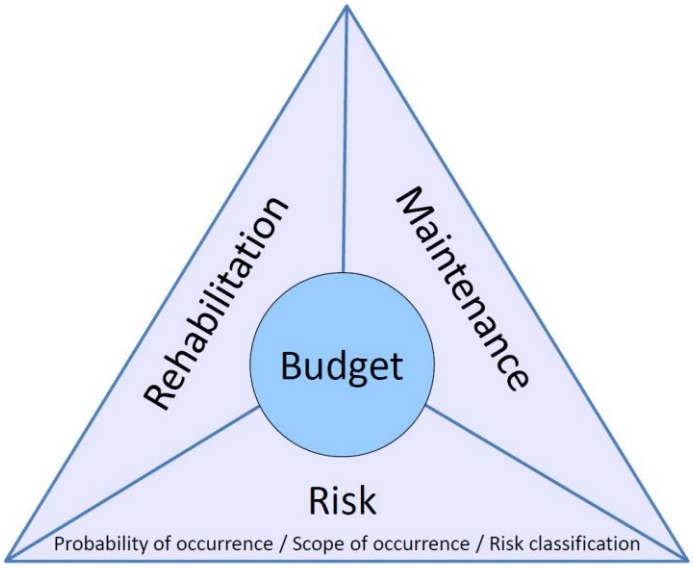

Figure 12: Balanced rehabilitation management [23]

To prevent mistakes in planning the consideration of a wide variety of future scenarios is recommendable.

8. Acknowledgments

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