An Approach for Defining whether to Replace or Repair applied to the Water Distribution Network of Graz

D. Fuchs-Hanusch*, G. Gangl*, Birgit Kornberger**

* Institute of Urban Water Management and Landscape Water Engineering; Graz University of Technology; Stremayrgasse 10/I 8010 Graz; fuchs@sww.tugraz.at; gangl@sww.tugraz.at;

** Joanneum Research Graz, Institute for Applied Statistics and Systems Analysis, Steyrergasse 25a 8010 Graz, Austria; birgit.kornberger@joanneum.at

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Introduction

The water utility of Graz has been operating its water supply system at a high standard for many decades. Water mains bursts are repaired swiftly and accurately, therefore the end-user is hardly affected by supply interruptions. The economic level of leakage (ELL), as defined by Farley and Trow (2003) as the "level where further investments are not cost effective, to minimize leakages" is reached. The main target in Graz is to pursue and maintain the high level of supply economically, by setting priorities when to repair or replace aging water pipes (Figure 1).

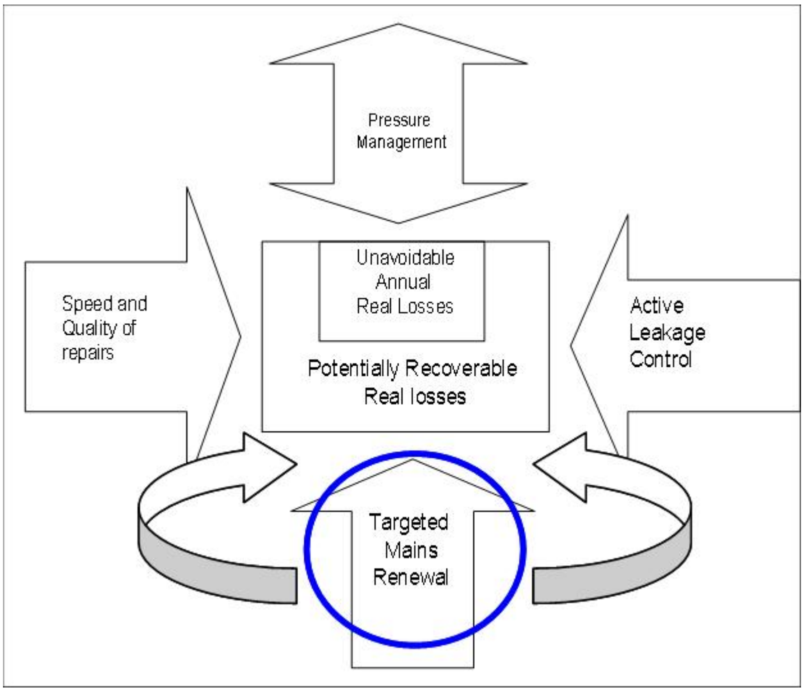

Figure 1: The four Components Approach to Management of real Losses (Farley and Trow, 2003)

The approach of the research project called PiReM "Pipe Rehabilitation Management" was to support experts within this challenge. One target was to develop a decision support system based on the available pool of information regarding pipes, their conditions and the influences which they are exposed to. Besides finding proper models to simulate the aging processes of different types of water pipes, another target was to implement a model for defining rehabilitation priorities based on the guideline W 401 "Rehabilitation Planning for Water Supply Systems" of the German Association of Gas and Water (DVGW, 1997). Several technical and economical criteria listed in the guideline were investigated within the project, whether they apply to the analysed Austrian water networks of Graz, Linz and Villach. In this paper the results of the studies regarding the distribution system of Graz are discussed.

Rehabilitation Management Targets

Long Term Rehabilitation Strategies

The key of developing long-term strategies is to quantify the annual amount of rehabilitation for periods of about 10 to 20 years, which afford a long-term economical operation of the supply system. For our project-partners, one business objective was reducing the amount of the water mains bursts to a constant level. In spite of the high maintenance standard, for some pipe groups, an increase of yearly failure rates was noticeable since the 1990s (Figure 2). This can be blamed on the increase of the average network age which has reached 40-45 years. This increase is a further result of low rehabilitation rates in the past. A constant and low level of yearly water mains bursts would have the advantage of a constant workload and constant costs for the outsourced construction measures. An economical balance between rehabilitation and repairs has to be found while focusing the high quality of supply that the customers are used to.

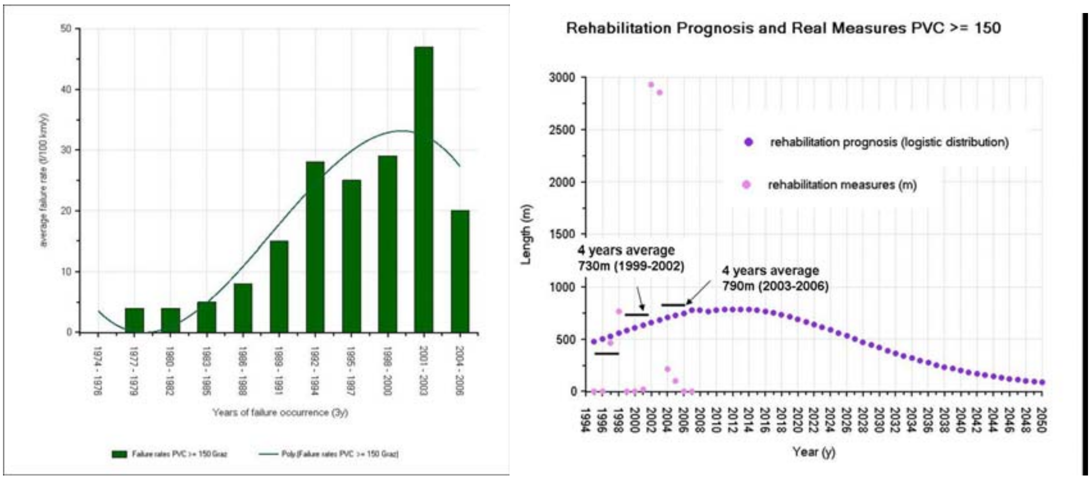

Figure 2: Increasing failure rates and positive effects of the rehabilitation program started 2002

To define long-term future rehabilitation needs, one methodology is to predict hazard rates of pipe groups. Therefore, the hazard rates have to be calibrated to the failure behaviour of the investigated network. Herz (1994) used the cohort survival model to predict the aging processes of Water Supply Systems. Furthermore, Herz defined a special distribution to reproduce the aging processes of main pipes. The cohort survival model was also used within our investigations and it was finally implemented into PiReM Software as the results provide a good overview of long-term rehabilitation needs. The plausibility of the prediction strongly depends on the quality and quantity of the data basis, especially on historic failure and replacement data. The provided data pool was up to this mark (e.g. failure data recorded back to 1974 in Graz, 20 years in Linz and 10 years in Villach), hence, our approach was to find out if aging processes correlate comprehensively. The aim was to define standard groupings and calibrate appropriate aging functions.

The analysis focused on choosing different aging distributions for common pipe groups in the investigated networks, trying to find the most appropriate distributions. The pipe groups were defined with respect to similar failure behaviour, taking materials, diameter and vintage into account. Besides the Herz function, the Weibull, Logistic and Lognormal functions were also used. The investigations have shown a similar aging behaviour for Polyvinylchloride (PVC), Steel (St) and Cast Iron (CI) in the examined systems.

As an example, the QQ Plot shown in Figure 3 indicates that the damage behaviour of PVC pipes follows a logistic distribution, which is quite similar to Herz distribution. It is actually not possible to estimate the Herz distribution out of the recorded data with common statistical methods. Therefore, it has to be calibrated visually defining an optimistic and pessimistic boundary around the empirical data.

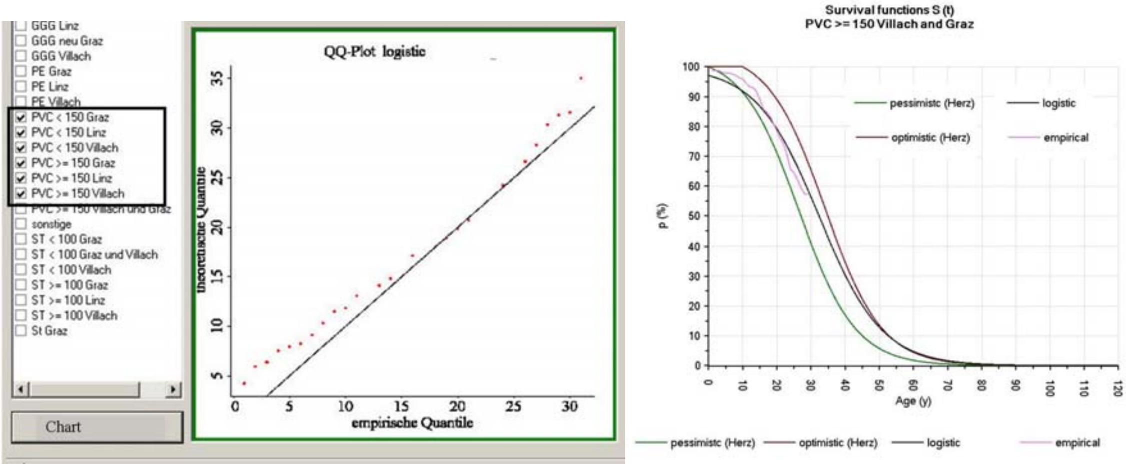

Figure 3: QQ-Plot logistic distribution / applied survival function for PVC Pipes in Villach and Graz

The aging process of Cast Iron pipes as shown in Figure 4 was of special interest in Graz. This special case was also the reason for using lognormal distribution within the investigations. The hazard rate of lognormal distribution increases to a constant level at a specific age and decreases with ongoing age again. This allows the description of an aging process as it is given in Figure 4.

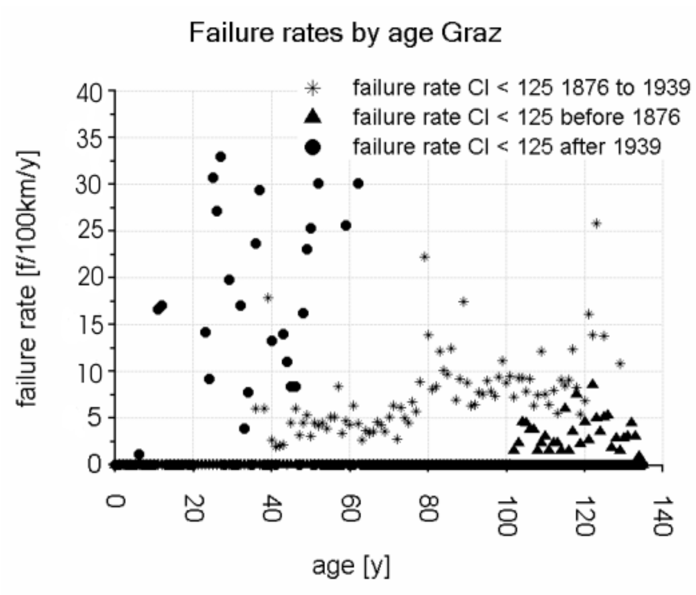

Figure 4: Failure rates per age for cast iron pipes in Graz (Fuchs-Hanusch, et al. 2007)

Finally, a decision support method was defined to be implemented into PiReM Software. Pipe groupings, which were derived from the investigations of the Linz, Graz and Villach networks, are suggested and may be adapted to the characteristics of other systems. The software affords an individual selection of the most appropriate distribution for different pipe groupings (Figure 3; QQ - Plot).

Long-term rehabilitation needs are modelled for each group with the cohort survival model and finally adjusted to budgetary targets using scenario analysis. A rehabilitation programme was elaborated for Graz, which provides a reduction of maintenance costs caused by water mains failure repairs. Hence, groups with the highest yearly failure costs and failure probability (= maximum risk) have the highest priority to be rehabilitated. A priority ranking was made and for each group the necessary annual rehabilitation length for the next 20 years was defined.

In Figure 2 the effect of the group oriented rehabilitation programme on reduction of failure rates of the group PVC >= 150 is shown.

The second step is to charcterize, which pipes of the defined groups with the highest priority have to be rehabilitated first.

Prioritisation based on economic and technical criteria

For the target of prioritising pipes for rehabilitation, the DVGW guidelines W 401 has given a suggestion using a simple point scheme with respect to economic and technical rehabilitation criteria. Each pipe of the network has to be analysed to see whether the defined criteria apply or not.

For example: For each pipe the yearly failure rate of the past 5 years is reckoned and compared with a critical value. Lindner (1999) defined that having reached 4 failures/km/y makes a rehabilitation measure of this pipe segment economic. If the failure rate of the pipe is above the critical value, a defined amount of points is given to the pipe. If the critical level of the failure rate has been reached, the pipe has achieved maximum priority.

The guideline includes “hard” as well as “soft” criteria. An example of a “soft” criterion is the age of the pipe.

Within PiReM project, the main focus of the investigations was on “hard” criteria, like calculating the optimal time of rehabilitation. Some “weak” criteria like the probability of bursts caused by street construction works above a buried pipeline have also been investigated.

Calculations of Friedl (2007) have shown that the traffic load itself, has no influence on asbestos cement pipelines. Addition calculations show that for the materials asbestos cement, polyethylene and polyvinylchloride, a dynamic lorry-load during a renewal of a street body and a remaining covering of 40 cm above the pipeline becomes critical. Dynamic loads from a road roller at a remaining cover of 40 cm also become critical for steel pipes. A renewal can therefore, lead to a break if the compacting load is too heavy (Gangl, 2008).

The investigations defining the most economic and optimal time of rehabilitation, which was the main criterion taken into account, will be discussed in detail.

Economic Optimal Time of Rehabilitation

The approach of Lindner (1999) and the DVGW guidelines W 401 suggested defining an economic critical rate of yearly failures. Failure costs in the investigated networks strongly vary regarding pipe material, diameter or position of the pipe within the street body. The highest failure reparation costs of PVC bursts are mainly caused by the affected pipe length. Hence, methods were chosen which allow a calculation of the optimal economic time of rehabilitation for each individual pipe segment.

Several methods can be found in literature. Most of them are using the cash method comparing the costs of the old pipe with renewal costs until a defined horizon is reached. In Shamir & Howard (1979) and Herz (1996) costs for repair (reparation and street recovering) and costs for renewal (pipe laying, restoration of asphalt cover,…) are only taken into consideration. Schmidt (1999) and Michalik (1985) took pumping costs caused by water losses into account as well. The models are further based on different methods for failure prognosis.

Semlitsch (2000) investigated the influence of pumping costs, caused by water losses during pipe bursts, on the result of the economic optimal time of rehabilitation for Graz. The investigations showed no significant differences in the calculated time of rehabilitation whether costs for water losses were taken into consideration or not. This results of high quality and speed of repairs and low pumping costs in Graz. Furthermore, water treatment is not necessary, as in 98% of Austria.

For calculating the costs of the old pipe, a failure prediction model described in Gangl et al. (2007) was used. The approach of the model is that the time periods between the following failures can be described statistically after the first one has occurred (Figure 5). In Rogers (2007) a similar approach was discussed by showing return frequencies of leakage in two Italian DMAs. The time periods between the recorded failures in the investigated Austrian networks, which are already repaired, are influenced by the maintenance strategy of the supplier. Therefore, a sensitivity analysis on main parameters influencing the result of the economic model has to be carried out.

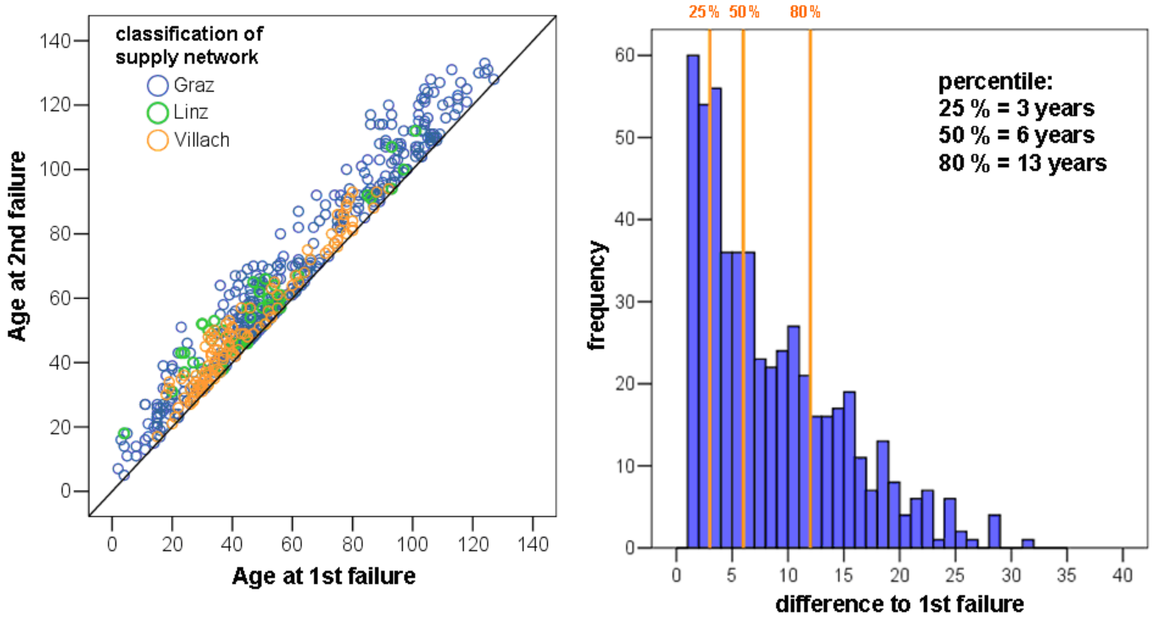

Figure 5: Frequency distribution of time period of 1. failure to 2. Failure (Gangl et al, 2007)

For calculating future failure costs, the rate of price increases has to be taken into consideration. Furthermore, higher operating costs of aging pipes were considered.

With respect to the investigations described above, the following approach for identifying rehabilitation priorities in the distribution system of Graz was set out. The rehabilitation criteria taken into account are shown below:

- Economic optimal time of rehabilitation (costs old/new pipe)
    - o With and without coordinated construction sites
- pipes with high risk of bursts (material dependent with respect to possible street construction works)

- pipes exposed to corrosive soils (dependent on material and corrosion protection)
- unusual pipe diameters and materials (asset management target – reducing obsolescence of stocks)
- age (as aging processes can be described properly in Graz)

For specific criteria, as to figure out pipes endangered by corrosion, GIS analyses were required in the run-up. Therefore, pipes which have a high risk of material dependent corrosion and which are bedded in corrosive soil types were pointed out by overlaying soil maps with network data.

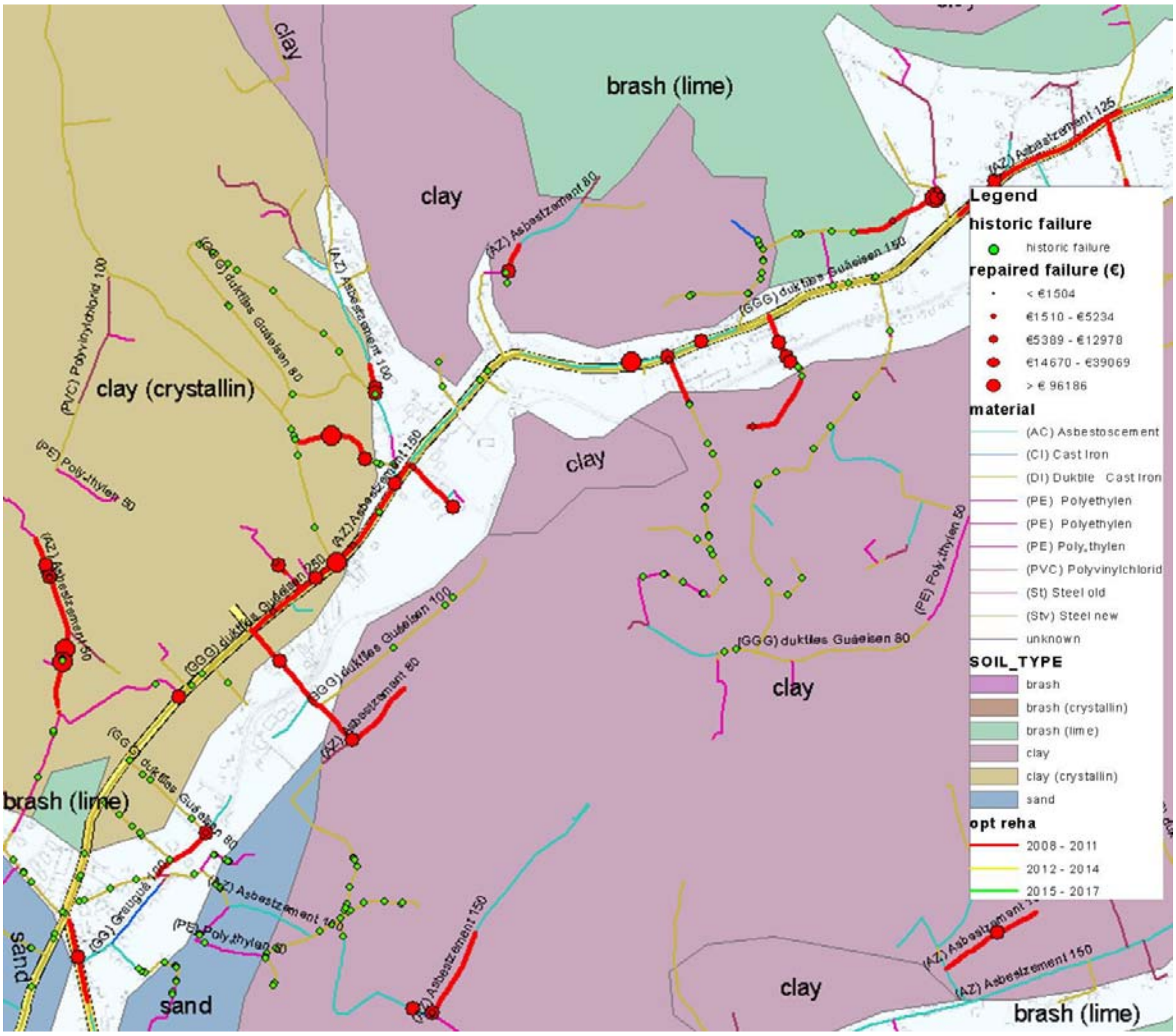

Figure 6: GIS – Map, City of Graz (failure reparation costs, soil type, historic failures and rehabilitation priorities)

The original failure costs from occurred and recorded failures could be used to define the average costs for failures on the investigated pipe segment. The recorded failure costs include costs for repairs (labour and material costs) and costs for street reconstruction. Pipes which had no failures in the last 10 years have been treated as pipes with no failures. They have not been taken into account for the calculations. The calculation period was 25 years with respect to the common amortisation period.

Reductions of rehabilitation costs caused by coordinated construction sites can be estimated up to 30 % as shown in an investigation of the DVGW (Lindner, 1999). The investigations for Graz have shown that this can reduce the optimal period of rehabilitation up to 4 years. These specific results are given as GIS data (priority maps). These maps are provided for the yearly adjustments of construction sites within Graz. These maps show pipes, which are especially endangered to breaks caused by street reconstruction as well.

Generally, the result (priority map) is given in four priority classes (I,II,III and 0). Class I includes mainly results of pipes reaching the economic optimal time of rehabilitation within the next three years.

Pipes of the group “PVC >= 150 mm” actually have left only 500 m which have reached priority class 1. The reason results in the rehabilitation measures of the last 7 years and allows a reduction of rehabilitation in this group. Nevertheless, the progress of the failure rates has to be further observed. Presently, the focus has to be set on “Cast iron CI < 150 mm” and “Asbestos Cement AC <= 100 mm” pipes, which are those groups with the second highest failure rates and are providing 18 km pipes which have reached the economic time of rehabilitation.

The rehabilitation needs simulated with the aging model are adjusted to the suggested pipes of the prioritisation scheme also taking the annual provided rehabilitation budget into account. Further combined with the annually coordination of construction sites the result provides a long-term economic effective rehabilitation programme.

Summary and conclusions

The investigated water supply systems, which provide swift and qualitative repairs, where water loss detection is optimized under the support of DMAs and periodic acoustic leak detection in non metered areas, have their main focus on balancing operation and rehabilitation costs. For the exception Graz, the failure rates suddenly increased in the 1990s. One reason was an increase in average network ages combined with problems with the rather young PVC pipes. Up to 2000 the rehabilitation rates were low (0,4%) and mainly resulted from other construction sites, although the eldest pipes went back to 1872. Therefore, the main target of the started project PiReM, with two other Austrian water suppliers participating, was to define the amount of yearly rehabilitations to keep the high standard of supply and to define where to start first with the rehabilitation programmes.

Within the research, lifetime expectancy models were used for predicting future rehabilitation needs. The aim was to define appropriate statistical distributions to describe the aging processes of different pipe groupings. The research has shown that besides the “Herz” function, which was developed especially for describing the aging of water supply pipes (Herz, 1994), the logistic distribution has the best adjustment for most of the groups. Only the aging process for Cast Iron pipes in Graz follows a lognormal distribution. The Weibull function for Asbestos Cement pipes with small diameter had the best adjustment. The high quality and quantity of data in Graz allowed a proper calibration of the chosen functions. The rehabilitation needs, have been simulated with the cohort survival model on the basis of the defined functions. The rehabilitation measures following the amount of the prognosis have shown the first effects on the reduction of failure rates in critical groups (Figure 2).

The next stage of the investigations was the decision process to filter out pipes that should be prioritised within the defined rehabilitation groups. Therefore, a method provided in the guideline DVGW W 401, was used and adapted. Several rehabilitation criteria and methods to calculate the economic optimal time of rehabilitation were discussed and applied to our project partners’ boundary conditions. The adapted criteria based prioritisation scheme divides the pipes into priority classes (I, II, III and 0) depending on certain criteria. The main influencing factor is the economic optimal time of rehabilitation. It is calculated on the basis of a method, predicting the time periods between the following failures (Gangl et al., 2007).

Pipes which have reached the economic time of rehabilitation (Class 1), would in the long run cause more costs than if being further repaired. For Graz the investigations have shown that around 3% of the pipes reach priority 1 in the next 3 Years. By choosing these pipes for the future rehabilitation programmes, adjusted with the predicted rehabilitation needs in the critical groups and the provided rehabilitation budget, a long-term balanced budget between rehabilitation and repair measures can be reached.

The ongoing project PiReM searches for answers to the questions, how much and which pipes have to be rehabilitated instead of ongoing repairs. The developed approaches and models, which were integrated in the software, provide a meaningful decision support to water suppliers wanting to keep a long-term, high standard of water supply and balancing reparation and rehabilitation costs.

Further Research

In the investigated supply systems, less is known about the failure behaviour after the 5^{th} to 6^{th} failure. First results of a sensitivity analysis have shown a strong influence on the results regarding the time periods estimated between future failures. Further research including a bigger pool of failure data are necessary for a better understanding of the following failure behaviour.

References

Fuchs-Hanusch, D., Gangl, G., Kornberger, B., Kölbl, J., Hofrichter, J., & Kainz, H. (2007). PiReM – Pipe Rehabilitation Management - Developing a decision support system for rehabilitation planning of water mains, Proceedings of IWA Specialist Conference on Efficient Use and Management of Urban Water Supply ; Korea 2007, S. 391 - 398

Friedl, F. (2007). Einfluss der Verkehrslast auf die Schadenshäufigkeit von Trinkwassernetzen, Graz University of Technology, Diplom Thesis, www.sww.tugraz.at

Gangl, G. (2008). Influencing Factors on Midterm Rehabilitation of Water Supply Systems, accepted abstract for poster presentation at IWA, World Water Congress 2008, Vienna

Gangl, G., Fuchs-Hanusch, D., Stadlober, E., Kauch P. (2007). Analysis of the failure behaviour of drinking water pipelines, 4th IWA specialist conference on efficient Use and Management of Urban Water Supply, pp 339 – 346, Jeju City

Herz, R. (1994). Alterung und Erneuerung von Infrastrukturbeständen - Ein Kohortenüberlebensmodell (Aging and renewal of infrastructure – a cohort survival model); Jahrbuch für Regionalwissenschaft 14; S.7-28

Kleiner, Y., Rajani, B.B. (2000). Considering time-dependent factors in the statistical prediction of water main breaks, AWWA: Infrastructure Conference, Baltimore, Maryland, pp. 1-12

Lindner, W. (1999). Kostensenkungspotentiale in der Wasserverteilung, in Qualitative und Quantitative Analyse von Rohrleitungssystemen in der Trinkwasserversorgung; Berichte aus wassergüte- und Abfallwirtschaft, TU München, S 51-61

Michalik, P. (1985). Beitrag zur Ermittlung des ökonomisch günstigen Rekonstruktionszeitpunktes von Wasserversorgungsleitungen unter Nutzung des Datenbankteiles Wasserversorgungsnetze, Thesis, TU Dresden

Rostum, J. (2000) Statistical modelling of pipe failures in water networks, PhD thesis, Norwegian University of Science and Technology, Trondheim

Rogers, D. (2007). Managing leakage economically; Proceedings of IWA Specialist Conference “Water Loss 2007”, Bucharest, Romania, 587-594

Semlitsch, W. (2000). Die Ermittlung des optimalen Rekonstruktionszeitpunktes von Wasserversorgungsleitungen, Diploma Thesis, Graz University of Technology

Shamir, U., Howard, C. D. D. (1979). An analytic approach to scheduling pipe replacement, American Water Works Association, 71, 248-258

Farley M. and Trow (2003). Losses in Water Distribution networks, A practitioner’s Guide to Assessment, Monitoring and Control, London, IWA, ISBN1 90000222 11 6, p 54