Building a GIS-based Decision Support System for Water Network Rehabilitation Planning in Oslo VAV

Av Jadranka Milina, Ingo Kropp, Matthew Poulton and Yves, Le Gat

Jadranka Milina, Consultant specialist, Oslo Water and Sewage Works, VA-analysis section, Norway
Ingo Kropp, BAUR+KROPP, Bürohaus Lingnerallee, Lingnerallee 3, 01069 Dresden, Germany
Matthew Poulton and Yves, Le Gat, Cemagref Bordeaux, MA – ORBX, 50 avenue de Verdun, GAZINET, 33612 CESTAS Cedex, France

Sammendrag

Utvikling av et GIS-basert beslutningsstøttesystem for Oslo VAVs planer om fornyelse av vannledningsnettet

Vann- og avløpsetaten i Oslo kommune (VAV) viderefører satsingen på å gi et løft til det eksisterende beslutningsstøttesystemet (BSS) for planlegging av fornyelse av vannledningsnettet. Målsettingen med et nytt BSS er å vurdere vannledningsnettets tilstand nå og fremover (dvs. indikatorer som reflekterer ytelse som prognose av nettets bruddrate og forsyningssikkerhet), langsiktig rehabiliteringsbehov så vel som valg av de mest effektive løsninger for ledningsfornyelse vha verktøy som har vært utviklet i EU-prosjektet CARE-W. Det nye BSS vil være bygd rundt en ArcGIS geodatabase.

Summary

Oslo Water and Sewage Works (VAV) continues its efforts to improve the existing Decision Support System (DSS) for water network rehabilitation planning. The goal of the new DSS is to estimate the current and future condition of water network (i.e. performance indicators such as prediction of network failures and calculation of water supply reliability), long-term investment needs as well as prioritizing of rehabilitation projects, by means of the tools which have been developed in the EU's research project CARE-W. The new DSS will be structured around an ArcGIS geodatabase.

Introduction

Oslo, the capital of Norway, launched the first water network rehabilitation plan in 1997. Oslo's waterworks rehabilitation strategy for the period 1997-2007 had led into a budget of 585 million Norwegian kroner: 65% for removal of structurally damaged and weakened pipes, 30% for preventive maintenance, and 5% for additional leakage control measures. A mid-term evaluation of water network renovation plan in 2004 indicated that despite lower realised rehabilitation level, compare to the forecasted needs based on the calculation in 1997 (60% or 31 of 53 km), progress had been made in leakage reduction. The evaluation report suggested an update of rehabilitation needs and priorities for both the short- and long-term perspectives.

In accordance with findings and conclusions in the evaluation report, the first step in the second network rehabilitation plan for the period 2008-2015 has been to throw light on the decision support tools and database technologies, which will form a basis for new aspects and requirements in regard of performance indicators definition, condition analysis for rehabilitation volume and prioritizing, leakage and risk analysis, as well as a life cycle costing model for budget analysis.

Integration of decision support tools to meet the needs of the new rehab plan

Oslo water's distribution system provides services for a population of half a million. Two treatment plants feed the system which contains 18 tanks, 27 pumping stations, 52 pressure zones, which has been partitioned into 72 DMAs and approximately 1600 km of pipeline. Most of waterworks rehabilitation decisions in the past were based on the simple methodologies for analyzing and estimation of rehabilitation or replacement needs, and for creation of a prioritized, pipe-by-pipe renewal plan. Due to the complexity of the deterioration process of water mains descriptive statistics of the available water mains attributes, inventory and historical maintenance data have to be done outside the main Gemini VA database (Powel Gemini, 2006). As opposed to the Gemini VA database tightly controlled environment, the strategic decision to create a geodatabase, which is based on further improvement of the Gemini VA database model, has offered possibilities for data pre and post processing within a very loosely controlled and flexible environment (OsloVAV Water GeoDataBase Model, 2007).

In order to improve the new rehabilitation plan process in general, and decision support system based on data which has been recorded since 1975 in particular, Oslo waterworks has decided to apply a framework which has been developed in research project CARE-W (Computer Aided Rehabilitation of Water Networks) funded under the 5th framework programme of the European

Commission (Sægrov, 2005). The new geodatabase based Decision Support System is a modular system with separate, but integrated components for:

1) Developing of long-term strategic rehabilitation programmes and their consequences by the KANEW-approach
2) Priority setting for short-term rehabilitation investment plans by LEYP-approach (Linear Extension of the Yule Process) using Casses software
3) Reliability/risk analysis by RelNet-/Aquarel-approach

Developing of long-term strategic rehabilitation programmes and their consequences by the KANEW-approach

In 1996 a KANEW study has been carried out to determine the required rehabilitation rates and volumes for the water network of Oslo until 2060 (Herz, 1996; Baur, 2006; Kropp, 2008). For the ongoing development of the new Master Plan for the water network in Oslo, the results of this past study should be evaluated and updated. The main objectives were to revise the existing ageing functions, update the forecast of future rehabilitation needs, and simulate various rehabilitation strategy programs with respect to technical and economical performance indicators. In addition, a data model related to LTP (long-term planning) activities was developed to support the data exchange between the new GIS and the KANEW software.

The revision of the existing ageing functions was done by analyzing the deterioration behavior (breaks on water mains recorded for more than 30 years) and the selection of pipes for rehabilitation within the last 10 years. A sensitivity analysis was performed using two different datasets of pipes. Dataset DS1 consists of pipes which are still active today, whereas dataset DS2 accounts also for the pipe history (including pipes which were rehabilitated in the past,

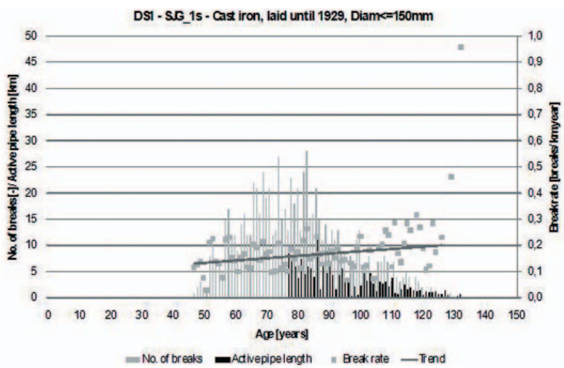

Figure 1. Example for service life sensitivity analysis – pipe class SJG_1s

and thus, are out of service today). This kind of sensitivity analysis was possible only due to the permanent use of the Gemini VA data model at VAV Oslo. Figure 1 shows an example output of the sensitivity analysis with DS1 for pipe class SJG_1s. In the graph the total number of breaks on water mains and the according break rate development over the age are shown. In addition, the current active pipe length (= in operation) was included to illustrate the future potential relation between active pipe's age and deterioration development.

Based on the results of the sensitivity analysis a consistent procedure for the definition of the ageing functions was developed during the project. The process for the development of the new updated set of ageing functions started with the existing service life definitions from the past study in 1996 (initial Set1). These functions were modified according to the new procedure and after some discussions (Set1>Set2>Set3>Set4) the final set of service life functions Set5 was derived. Figure 2 shows an example for the statistics and the according S-curve of pipe class SJG_1s.

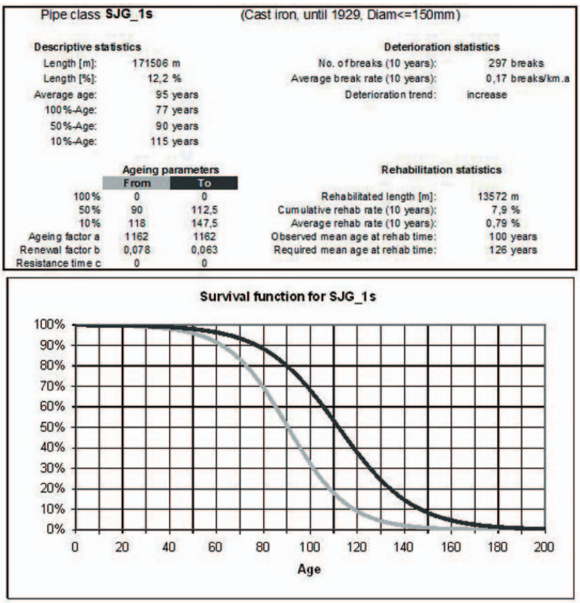

Figure 2. Example for statistics and service life function (S-curve) – SJG_1s

With the revised service life functions for the 9 pipe classes an update of the forecast of the future rehabilitation needs was calculated with the KANEW model, figure 3.

According to these forecast results, five different rehab programmes were simulated with the KANEW model, table 1. The results of the rehab strategy simulations are included in table 2.

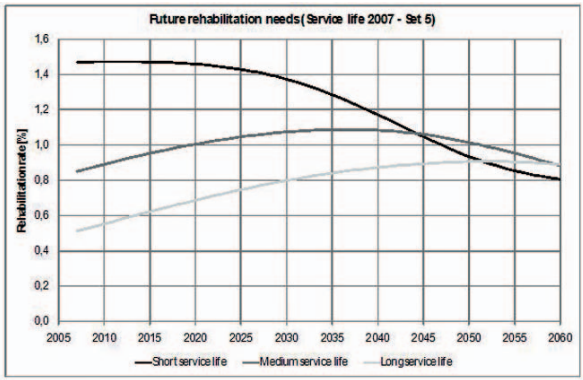

Figure 3. Updated forecast of future rehabilitation needs based on revised service life functions

		Portion of rehab methodologies [%]		
	Rehab strategy scenario	Replacement (SJK service life)	Structural renovation (Plastic pipe's service life)	Coating (average service life expectancy of 45 years)
S1	Do-nothing	15	35	50
S21	Fulfill rehab scenario 1	10	30	60
S22	Fulfill rehab scenario 2	15	35	50
S23	Fulfill rehab scenario 3	20	40	40
S3	Follow-past-rehab	15	35	50

Table 1. Definition of rehab programmes

Indicator		Do-nothing	Fulfil rehab needs			Follow past rehab policy
		S1	S21	S22	S23	S3
Average network rehabilitation rate until time horizon [%/year]	2007	0	0.85	0.85	0.85	0.5
	2015	0	0.90	0.90	0.90	0.5
	2060	1.04	1.12	1.10	1.08	1.1
Total rehabilitated network until time horizon [%]	2007	0	0.85	0.85	0.85	0.5
	2015	0	8.12	8.12	8.12	4.5
	2060	56.1	60.32	59.4	58.5	59.6
Total rehabilitated network until time horizon [km]	2007	0	11.9	11.9	11.9	7.0
	2015	0	114	114	114	63
	2060	788	847	834	821	837
Average Age [years]	2007	53.8	53.8	53.8	53.8	53.8
	2015	61.8	55.6	55.6	55.6	59.5
	2060	54	53.5	53.8	54.2	53.2
Residual service life [years]	2007	55.3	55.3	55.3	55.3	55.3
	2015	49.3	51.9	52.3	52.7	49.9
	2060	42.3	40.2	42.9	45.5	42.9
Total service life = Average age + Residual service life[years]	2007	109	109	109	109	109
	2015	111	107.5	107.9	108.3	109.4
	2060	96	93.7	96.8	99.7	96.1
Technical asset value [%]	2007	50.7	50.7	50.7	50.7	50.7
	2015	44.4	48.3	48.5	48.7	45.6
	2060	44.2	42.9	44.3	45.7	44.6
Cumulated investment costs [Mio. NOK]	2007	0	57	63	69	37
	2015	0	594	656	718	356
	2060	7955	7490	8101	8681	8237
Average unit investment costs [NOK/m]	2007	0	4790	5294	5798	5286
	2015	0	5210	5754	6298	5651
	2060	10098	8843	9713	10574	9841

Table 2. Comparison of results for various rehabilitation strategies (Kropp, 2008)

Priority setting for short-term rehabilitation investment plans by LEYP-approach

The LEYP (Linear Extension of the Yule Process) model is designed to model the failure process of pressured pipes in water networks (Le Gat, 2008). The LEYP intensity function is designed to account for the effect of the previous failures (maintenance records), the ageing of the pipe and explanatory factors which characterise the pipe and its environment (material, diameter, length, age, soil and traffic type, static pressure). The prediction calculation for the water network of Oslo was an iterative procedure, with the results from one or more basiac models being used to determine the exact configuration of others, table 3. Several indicators are used to compare different simulations: observed vs predicted breaks, model parameters (log likelihood, alpha, delta) and two indicators of the ranking performance of the model (A, C), table 3, figure 4, figure 5. Using the LEYP simulations, break predictions were made for each year between 2008 and 2015, and the most relevant candidates for short-term replacement selected. The evaluation of the number of breaks has been compared for different rehabilitation policies *(Poulton et al 2007)*.

Simu-lation	Observed breaks	Predicted Breaks	% error	Log likelihood	alpha	delta	A_L	$C_{L0.5}$	C_{L1}	C_{L5}
1	1483	1546	4.2	-18305	1.43	1.00	0.64	0.2	0.8	11.2
2	1483	1539	3.8	-18961	1.70	1.00	0.66	0.9	3.0	14.9
3	1483	1504	1.4	-18861	1.53	1.00	0.65	0.9	2.8	14.8
4	1483	1507	1.6	-18847	1.53	1.00	0.65	1.1	3.1	14.4
5	1483	1501	1.2	-18868	1.53	1.00	0.65	0.9	2.8	14.6
6	1483	1485	0.1	-18798	1.43	1.00	0.66	0.9	2.8	15.1
7	450	466	3.6	-5840	1.84	1.00	0.72	0.9	2.4	16.9
8	337	315	-6.5	-3949	2.29	1.00	0.65	1.2	2.1	13.7
9	696	778	11.8	-8837	1.46	1.00	0.64	1.7	2.4	13.1
10	1483	1562	5.3	-18663	1.73	1.00	0.68	1.2	2.8	15.0
11	388	338	-12.9	-20504	1.52	1.00	0.69	3.6	9.0	22.2
12	344	338	-1.7	-22707	1.55	1.00	0.71	3.8	7.9	23.3
13	326	331	1.5	-24787	1.62	1.00	0.68	2.5	5.2	18.1
14	292	319	9.2	-26821	1.66	1.00	0.66	5.1	8.9	19.2
15	255	312	22.4	-28600	1.63	1.00	0.66	3.9	5.9	17.7
16	-	-	-	-30114	1.58	1.00	-	-	-	-

Table 3. LEYP analysis - Simulation results for grey cast iron (SJG)[1]

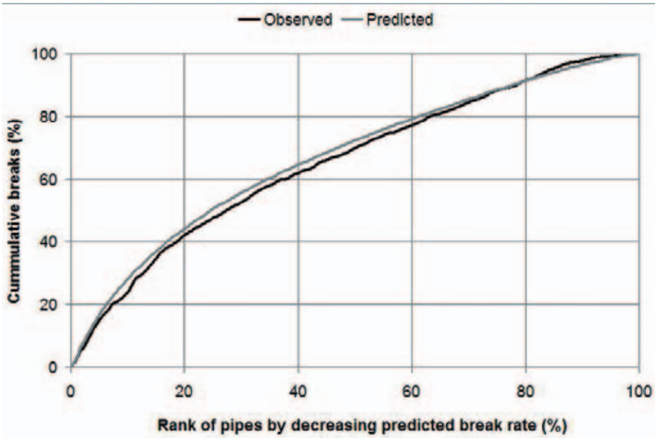

Figure 4. LEYP analysis - Performance curve for SJG – grey cast iron (pipes sorted by predicted failure rate)

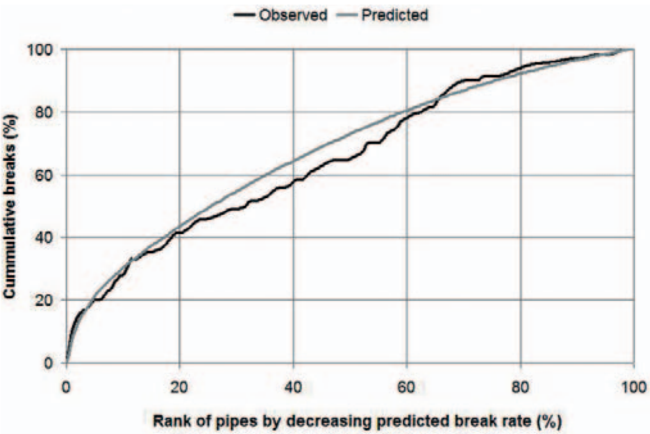

Figure 5. LEYP analysis - Performance curve for SJK – ductile iron (pipes sorted by predicted failure rate)

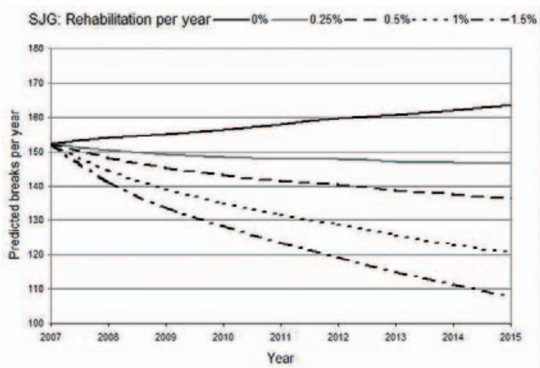

Figure 6. LEYP analysis – Break evolution with different rehabilitation strategies for grey cast iron (SJG)

If **no rehabilitation** is carried out the break rate will increase by **6.5%** between 2008 and 2015, figure 6. If a rehabilitation rate of **0.25%** per year is used, the break rate will stabilise. Any greater rehabilitation rates and the break rate will fall. For realistic rehabilitation rates of between **0.5%** and **1%** per year, this would result in a decrease in breaks of between **8.1%** and **16.7%** over the entire period.

Reliability/risk analysis by RelNet-/Aquarel-approach

Oslo VAV will incorporate reliability and vulnerability as parameter for decision making for the rehabilitation of a deteriorating water distribution network using RelNet-/Aquarel - approach (Sægrov, 2005; Hansen and Vatn, 1999, Eisenbeis et al 2002). As estimation of hydraulic reliability of a water distribution system, which has a large number of nodes and pipelines, is quite cumbersome (figure 7), the incorporation of reliability analysis into decision support system requires some reprogramming of SINTEF's hydraulic reliability tools (based on Mike Urban/Epanet numerical engine and results from LEYP simulations). A more detailed paper about the application of reliability part will follow.

Figure 7. Oslo VAV will incorporate reliability and vulnerability as parameter for decision making for the rehabilitation of a deteriorating water distribution network

Notes

1) Simulations 1 and 2 test the sensitivity of the end-of-service date; this information may be useful in deciding whether further efforts should be made to improve the database quality. Simulations 2 and 3 test the sensitivity of the model to extra covariates; this information may be useful in deciding whether further efforts should be made to include extra (or more accurate) data. Simulations 3-6 test the sensitivity of the model to grouping of quantitative attributes or regrouping of qualitative modalities; grouping may improve the model if extreme values are present or if certain modalities on their own are under-represented. Simulations 6-10 test the sensitivity of the model to considering all three laying periods together, considering the three periods separately or considering them together, but distinguished in the model by an extra covariate. Simulations 6 and 10-15 test the sensitivity of the model to different calibration and validation periods. They also allow the rehabilitation candidates selected by Oslo in the last ten years to be compared with those of the model. Simulation 16 is the final model, optimised from the other simulations and used to make predictions for the entire period of the next Oslo Master Plan (2008-2015).

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