COMPARING RESULTS OF FOUR DECISION SUPPORT SOFTWARE TOOLS ON MAINS REPLACEMENT

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Abstract. Water companies use software tools to support decisions on mains rehabilitation. Four tools for decision support were quantitatively compared in this research. This comparison was done by making four assessments of one water distribution network, with the same strategic boundary conditions. The four tools were able to provide a volume of candidates for replacement that fit more or less to the given condition for a desired volume of replacements. Comparing the individual mains proposed by these tools shows however large differences between the tools. These differences are mainly based on differences in modelling approach and the way these tools have been implemented at water companies.

1. Introduction

Drinking water companies around the world are facing aging distribution networks. The Dutch water companies expect that in the coming decades considerable investments will be required to rehabilitate mains. The pace of main degradation and subsequently the decay of network integrity is difficult to forecast, partly because it has a strong contextual component. Urban environments are subject to multiple stakeholder activities, physical objects sensitive to flooding and demanding customers. On the other hand some rural environments are subject to population decrease. In this perspective answering the question ‘Which mains are to be replaced when and what will be the overall impact on costs, risk and performance?’ is one of the biggest challenges for asset managers in the Netherlands.

Decisions on mains replacement are traditionally based on expert knowledge, in combination with practical considerations and ad-hoc decisions in response to failures. The last years, Decision Support Software (DSS) for mains rehabilitation have become available. DSS support in comparing a large number of possible solutions and relating them to different criteria, often cost and risk orientated. Applying these software tools allows water companies to better objectify, standardize and document the decision-making process. An important question remains that cannot be overlooked: ‘Do these tools select the most critical mains for rehabilitation?’. In a research project finalized in 2012, KWR made a qualitative evaluation of four pilot projects on DSS (Beuken and Blokker, 2013). The main conclusion was that DSS help water companies to make more objective and transparent decisions. DSS require, however, a vast amount of input data and the good quality of these input data is the major prerequisite for obtaining reliable results.

In 2016, several drinking water companies in the Netherlands have implemented different DSS tools and have adopted the results into their asset management activities. Vitens has implemented the DSS tool IMQS. For further improvement of the decision support process Vitens has instigated a project to compare quantitatively the results of this tool with three other tools that are used by four Dutch water companies. The results of this comparison provides Vitens with best practices and stimulates the discussion on the use of DSS. This comparison is done by applying these four tools at the same distribution network. The DSS tools evaluated in this project are: IMQS applied by Vitens, Rasmariant applied by Brabant Water and Waternet, Transparant applied by PWN and WiLCO applied by Dunea.

2. Decision support software applied in the evaluation

The DSS tools are described briefly. For more information, see the websites in the reference section.

2.1 IMQS applied by Vitens

The IMQS Web Platform consists of a number of web-services and components developed for different purposes and can be applied on various types of assets. IMQS maps out asset information from multiple data sources through an integrated web and GIS based application. For Vitens a specific service is composed based on computing the so-called Pipe Replacement Potential for every main. For each main the likelihood and consequence of failure is calculated based on a multi-criteria approach, resulting in the perceived risk for each main expressed as a risk potential. Depending on the available budget for investment the mains are selected for replacement, including ranking. IMQS calculates different scenario's, in order to combine strategic objectives to future Capex, Opex and Customers Minutes Lost (CML). IMQS as applied for the pilot area under this study has a planning horizon of fifty years for budgeting purposes and of one year for the selection of mains to be replaced.

2.2 Rasmariant applied by Brabant Water and Waternet

In Rasmariant the costs of replacement for each main are compared to costs associated with potential bursts (risk costs). The risk costs include the costs of repair, the costs due to damage of objects in the vicinity of a main and monetized costs for CML. The latter is calculated taking the probability of failure of valves into account. Recorded pipe failure data are fitted to obtain a failure probability curve, based on main's age, material and diameter. The failure probability curve, combined with a risk matrix, is used to predict future risk costs. The year of replacement is defined as the year the risk costs are higher than the costs of replacement. As replacements are limited to the total available budget, a further prioritization is obtained by calculating the so-called Risk Reduction Efficiency (RRE) for each pipe. The RRE is the reduction of risk costs divided by the replacement costs. Within a planning horizon of one-hundred years, scenarios can be compared on amongst others CAPEX, OPEX and CML. Rasmariant is applied by Brabant Water and Waternet.

2.3 Transparant applied by PWN

Transparant is a method developed by the drinking water company PWN for calculating the end of service life of mains. Within Transparant all mains are assigned to cohorts and for each cohort the theoretical maximum service life is defined. A reduction of service life for each individual main is made based on factors related to the likelihood of failure and the consequence of failure. This reduction is based on knowledge rules related to the characteristics of the main and its surroundings and derived from expert knowledge. The result is the year of replacement for each main. In a next step the corresponding operating costs, capital costs and performance are computed. Transparant enables a water company to adjust or update the calculation method towards its own situation or with new knowledge. TRANPARANT has a planning horizon of two-hundred years for both budgeting purposes and the selection of mains to be replaced.

2.4 WiLCO applied by Dunea

WiLCO is based on a model using genetic algorithms for calculating an optimal solution for mains rehabilitation. The optimizer defines the solution with the lowest cost within a given set of conditions. WiLCO can also be applied for other types of infrastructure rehabilitation programmes, such as water production plants, roads and railways. The input data for WiLCO consists of mains characteristics, knowledge-based relations, geographical data, cost relations and weighting factors. The most important knowledge-based rules are the so-called degradation curves that relate the age of a main to the expected number of breaks. Other rules relate e.g. breaks to the number of affected connections or the pipe material to the cost of repair. Weights are applied to combine different variables, such as the ranking of important clients compared to regular clients or the associated risk of bursts close to a highway compared to those at regular mains.

WiLCO has three levels of analysis, the first two of which were applied in his evaluation:

- Strategic Model: based on a cohort approach a global analysis of the network is made. Different scenarios for rehabilitation are compared. A typical analysis compares scenarios with different budget constraints and risk profiles. A planning horizon of twenty-five years was selected by Dunea.
- Deployment Model: based on individual mains a more detailed analysis is made in line with the analysis made with the Strategic Model. A planning horizon of ten years was selected.
- Intervention Editor: a GIS based module in which the results of the Deployment Model are compared to practical field information, like clustering of individual works into coherent groups and combining works with third party initiatives.

3. Applied methodology

The four tools were evaluated by making four replacement plans for the entire distribution network of Dunea, see Figure 1, left. The total length of the distribution network is 4,328 km and consists of all distribution mains with a diameter up to 350 mm. In Figure 1, right, the main pipe materials and construction periods are shown. The dominant pipe materials are PVC, asbestos cement (AC) and cast iron (CI), representing respectively 60%, 14 % and 14% of the network's length.

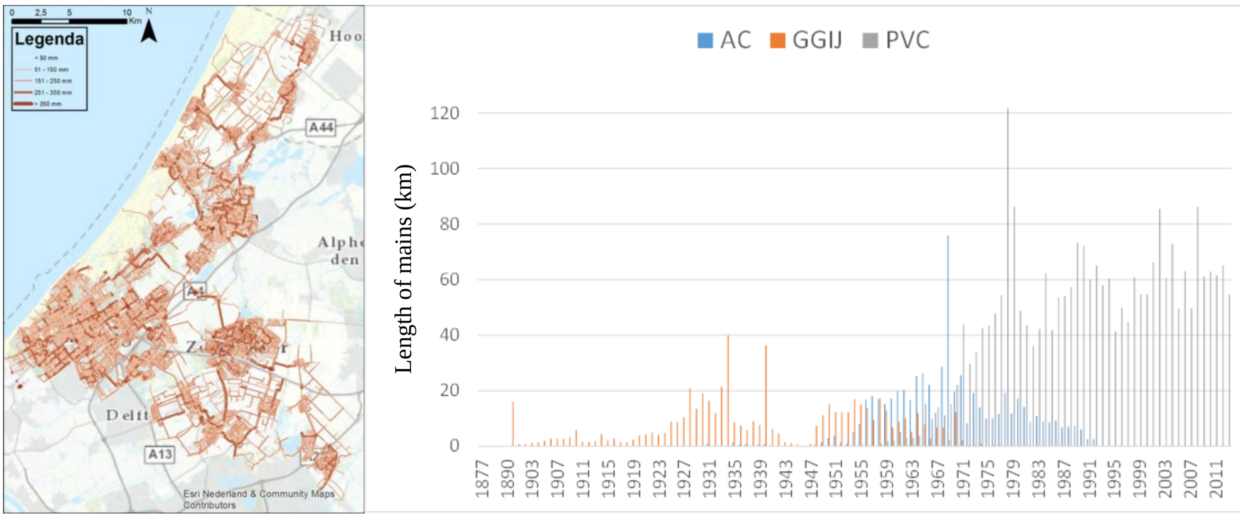

Figure 1 Lay-out of the Dunea water distribution network (left) and the most applied materials (right).

An outline of the required and provided data for the four tools is given in Appendix A. This contains amongst others a database of registered bursts from 2003. For the purpose of this evaluation almost all required data could be provided by Dunea and all tools received the same data set. The data pre-processing, calculation and output processing were done by the individual water companies. See Figure 2 for a schematic of this process. Dunea applied for the scenario used in this study two strategic boundary conditions, maintaining the number of pipe bursts and the value of CML due to unplanned events at the level of 2013. This scenario resulted in a yearly average replacement rate of approximately 21 km and yearly average investments of 6 million €. The other tools do not have an optimization algorithm and therefore based their calculations on a yearly average replacement rate of 21 km (IMQS and Transparant) or on a yearly average investment of 6 milion € (Rasmariant).

Besides these strategic boundary conditions, DSS require information from a tactical and operational level, such as the aging curves, costs data and figures for weighting different types of risks. Within the scope of this evaluation it was not possible to standardize these types of data. Therefore, tactical and operational data from the companies where the tool were applied were used.

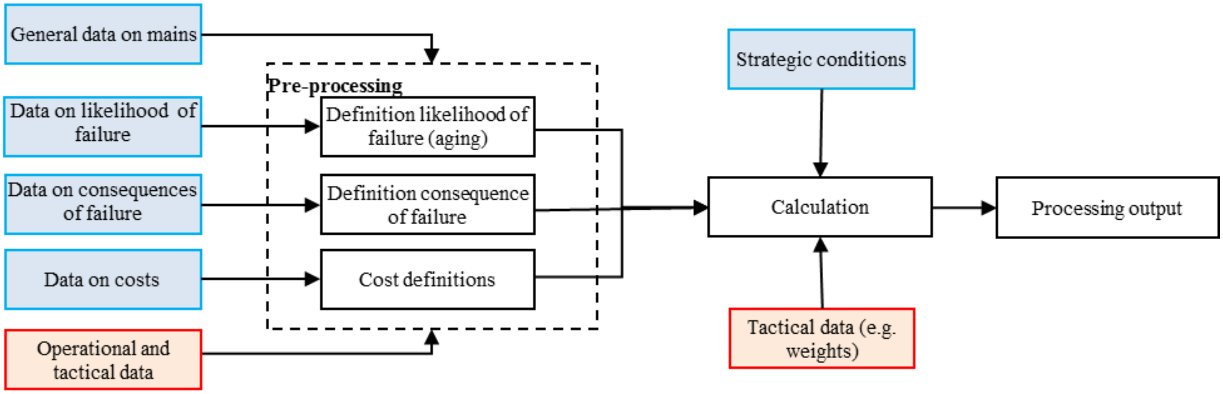

Figure 2 Schematic of the process for the use of DSS. The blue boxes refer to information given by Dunea, the red boxes to information from the companies applying the DSS.

A problem while assessing results from DSS is that no or limited information is available about the current condition of the network, making a proper validation impossible. Therefore only a relative comparison is possible between the tools.

4. Results of the evaluation

Figure 3, left, represents the percentage of the total network length proposed for replacement by each of the tools. The figure shows also the different horizons of the tools. The total replacement proposed by the tools till 2040 is: 11.1% for IMQS (479 km or 19.2 km/year), 14.2% for Rasmariant (616 km or 24.6 km/year), 12.6% for Transparant (546 km or 21.8 km/year) and 13.0% for WiLCO (564 km or 20.8 km/year – based on a period of 27 years). The result of Rasmariant is higher as this tool selects relatively smaller mains with lower replacement costs. Figure 3, right, shows the percentages of mains proposed for replacement that are selected by all four tools. The four proposals for replacement provided by the tools share 60 km, corresponding to 1.4% of the network length, or 10.9% of the average proposed length for replacement of the four tools.

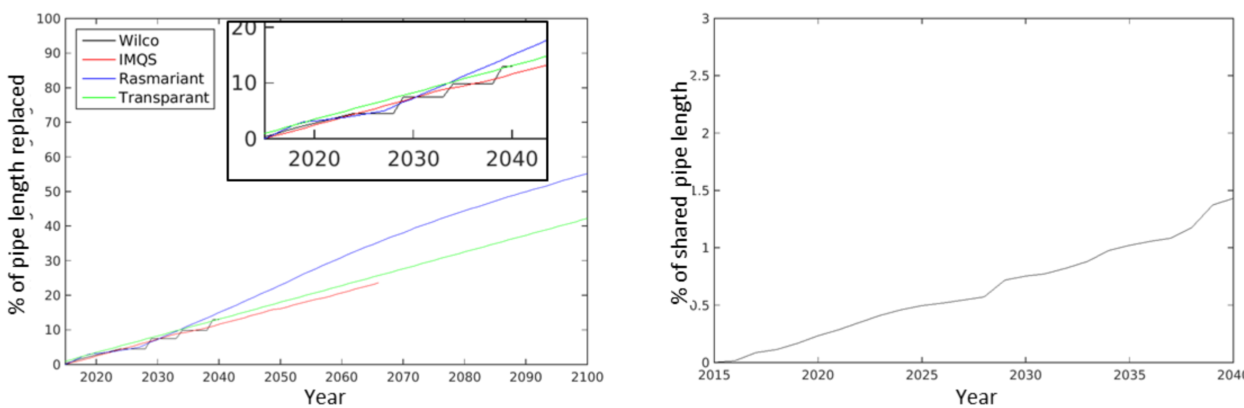

Figure 3 Percentage of pipe length replaced for each tool (left) and the shared pipe replacements by all tools (right).

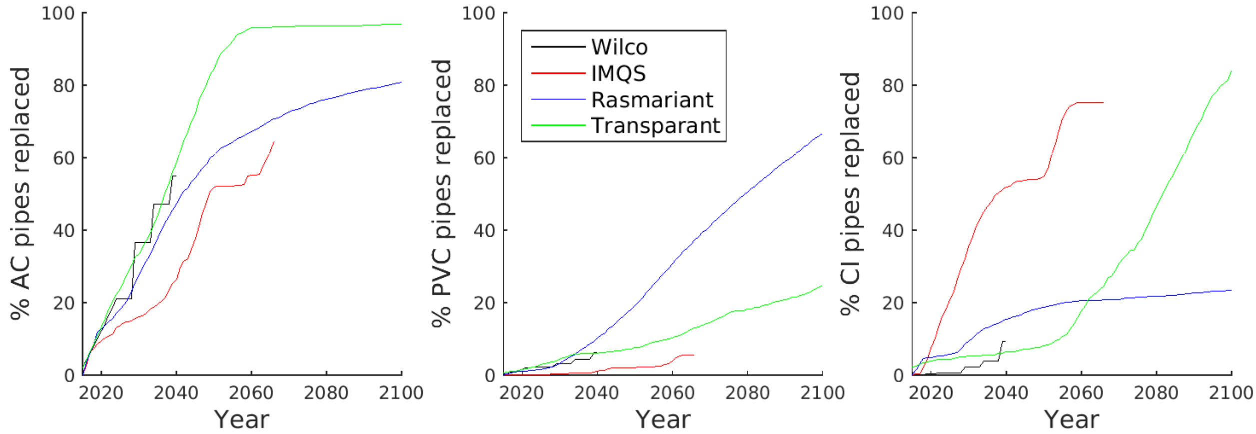

Figure 4 Percentage of pipe length replaced for the materials AC, PVC and CI.

In Figure 4 the proposed replacements for the dominant pipe materials are given. Note that the total length of PVC is a factor four higher than the total length of AC and CI. The following conclusions are drawn:

- the volume of replacements of WiLCO, Rasmariant and Transparant for AC is more or less the same up to 2040, after that Transparant proposes replacement of (almost) all AC mains around 2060;
- the volume of replacements of the four tools for PVC and CI shows a high diversity;
- IMQS proposes replacement of a relatively high volume of CI and a low volume of PVC;
- Rasmariant proposes replacement of a relatively high volume of PVC;
- Transparant proposes replacement of a relatively high volume of CI after 2060;
- WiLCO proposes replacement of a relatively low volume of CI up to 2030.

Figure 5 represents the CML due to unplanned interruptions (pipe failures) as calculated by the four tools. WiLCO has a optimizer that is able to propose scenario's for replacement within strict boundary conditions. The boundary condition related to the constant level of CML is reflected in this projection. IMQS is also able to maintain a constant level of CML, although at a higher level. The results of Rasmariant and Transparant show increasing CML. The calculation with Rasmariant was done with a valve reliability of 95%, meaning that in 5% of the valve operations customers supplied in an adjacent valve section were affected. This additional functionality explains why the CML of Rasmariant is relatively higher. It should be noted that the CML value at 2015 is different for all tools. As all tools applied the same period for interruption due to repair, the different values for the calculated CML are due to differences in the applied burst frequencies for main cohorts.

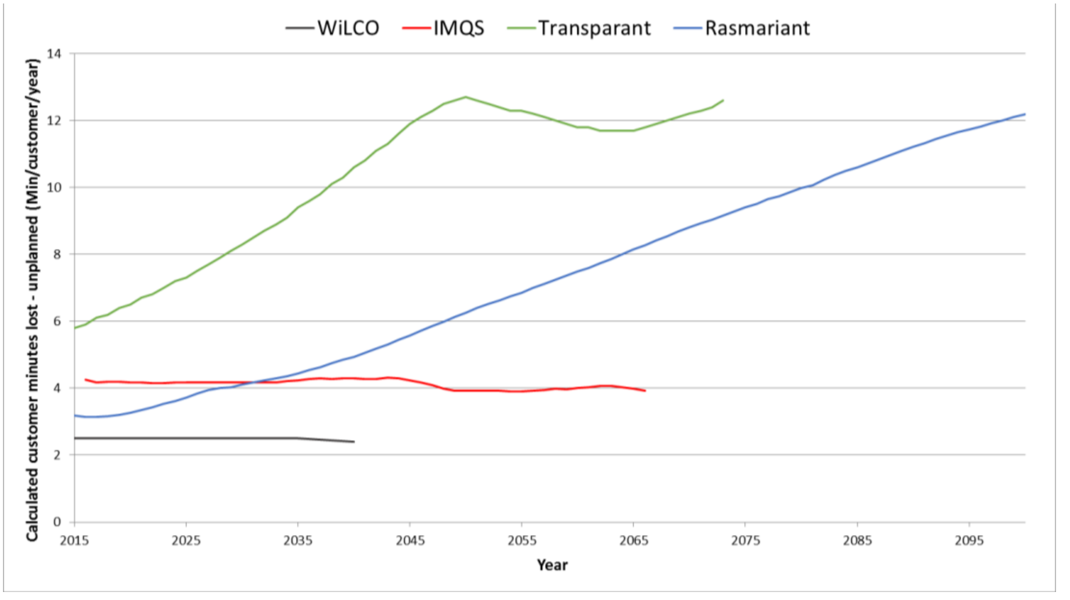

Figure 5 Customer minutes lost (CML) due to unplanned events over time as calculated by the four tools.

Figure 6 shows a selection of the network, containing the town of Nieuwerkerk aan den IJssel. In this area large differences between the results of the four tools are apparent. These differences probably relate to different modelling approaches and different tactical and operational data. It should be noted that this figure represents an area with many differences and that in other areas more correspondence was found. Evaluating the mains selected by the tools, results in the following conclusions for the town of Nieuwerkerk aan den IJssel:

- only one main (50 mm AC from 1957) is selected by all four tools;
- IMQS proposes no other main;
- Rasmariant focusses on replacing PVC mains of an odd diameter (107 mm) and AC mains constructed before 1955;
- Transparant focusses on replacing PVC mains larger than 200 mm and constructed before 1985;
- WiLCO focusses amongst others on replacing PVC mains smaller than 100 mm and constructed before 1980.

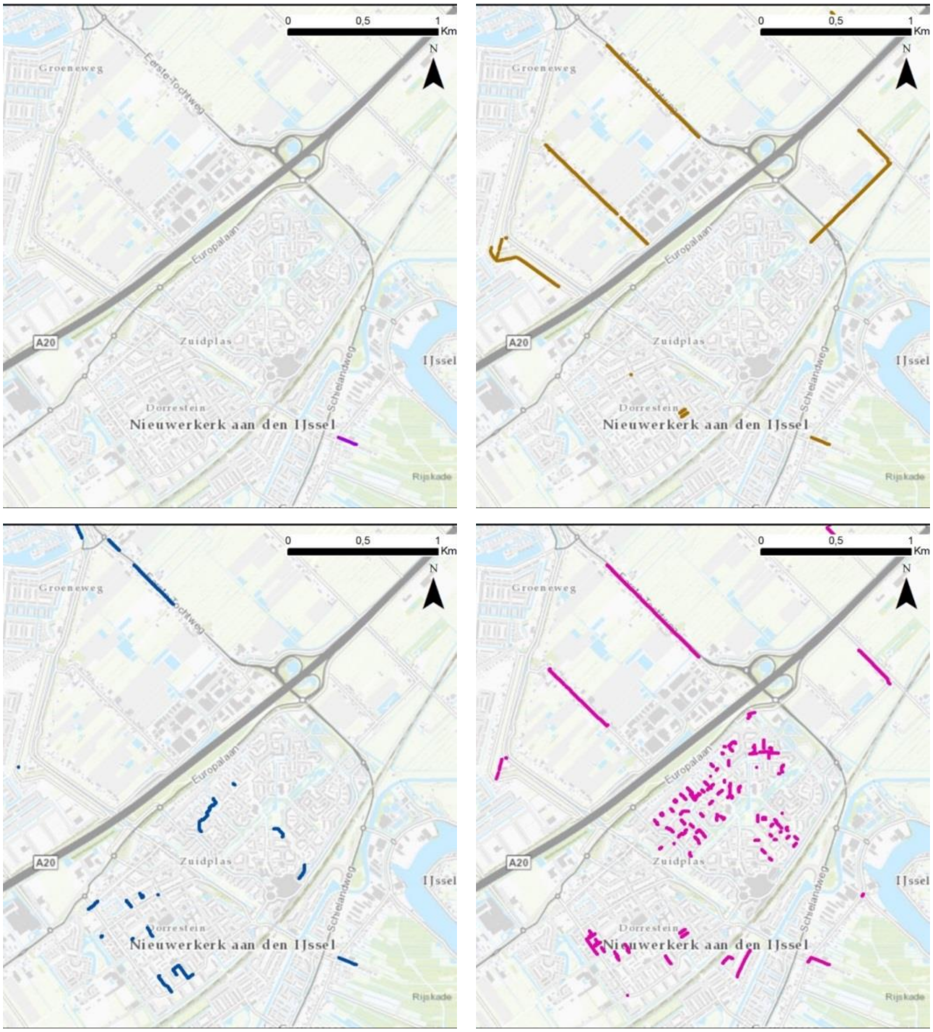

Figure 6 Pipes replaced before 2020 for IMQS (top left), Rasmariant (top right), Transparant (bottom left) and WiLCO (bottom right).

For two mains in Nieuwerkerk aan den IJssel a number of parameters are compared in Table 1. It appears that the assigned current burst frequencies (2015) have considerable variations, a factor of 1.4 for the AC main and a factor of 2.8 for the PVC main. Also the variation of the assumed burst frequencies in 2040 is large, a factor of 2.3 for the AC main and a factor of 3.8 for the PVC main. The costs of replacement of the AC main show limited variation (factor of 1.2) and those of the PVC show more variation (factor of 1.6). The calculated years of replacement also show a considerable variation. For the AC main Transparant, Rasmariant and WiLCO propose replacement in less than ten years, while IMQS proposes replacement after 2065 because of a very low consequence of failure. For the PVC main, IMQS and Transparant propose replacement after more than fifty years, while Rasmariant and WiLCO propose replacement at a shorter term, respectively in 35 and in 20 years.

Table 1 Comparison of results from the tools from two mains (BF: burst frequency in burst per km per year). Factor refers to the maximum value divided by the minimum value. For WiLCO in 2040 no burst frequencies were available.

MainID	Description	Parameter	IMQS	Trans.	Rasm.	WiLCO	Factor
754702	100 mm AC, 1959	BF 2015	0.101	0.104	0.142	0.143	1.4
		BF 2040	0.535	0.229	0.401	-	2.3
		Cost of replacement	56461	50200	58806	55606	1.2
		Year of replacement	≥2065	2018	2020	2016	
739539	110 mm PVC, 1977	BF 2015	0.046	0.061	0.072	0.025	2.8
		BF 2040	0.058	0.133	0.223	-	3.8
		Cost of replacement	9407	9020	14591	10191	1.6
		Year of replacement	≥2065	2129	2050	2034	

5. Discussion of the results

Drinking water companies apply decision support software to rationalize investment decisions on the replacement of mains. The high magnitude of these investments and the large impact on the performance of the network justify a sound system of decision support. Drinking water companies make large efforts in selecting and implementing these DSS. Apart from the costs of these DSS, considerable investments are made in testing and improving information systems. From this research, it appears that there is limited correspondence in the mains proposed for replacement by the four tools. This lack of correspondence is due to different modelling approaches and differences in applied knowledge rules and weights. For example, all tools use different cohorts of mains, with different burst frequencies and different estimations of future bursts. A more uniform approach based on known degradation phenomena and the USTORE database of mains failures could improve this (for more information on USTORE, see Kwakkel et al.). The five water companies involved in this research also claim that the decision making process is still in a process towards maturity, meaning that they are aware that improvements are to be made. As an illustration of this process, Dunea has recently modified their cohort definition as they became aware that the DSS overestimated the number of bursts of small PVC mains.

Drinking water companies could be disappointed that this evaluation of four tools for decision support systems shows a difference in results. On the other hand it can be argued that these tools make a more transparent decision possible, although it is advised to get a better understanding of the impact of strategic options and knowledge on main degradation on the result of these tools. The observed differences can inspire companies to discuss the background of these differences in order to further improve the decision making process.

As the project is not yet completed, focus will be given to understand the differences of the results of the four tools.

6. Conclusion and recommendations

In this research four tools for decision support software were quantitatively compared. This comparison was done by making four assessments of one water distribution network, with the same strategic boundary conditions. The information from a tactical and operational level, such as the applied aging curves, costs data and figures for weighting different types of risks, were specific for the four tools. The four tools were able to provide a set of candidates for replacement that fit more or less to the given condition for a desired volume of replacements. The total length proposed by all the tools up to 2040 was 10.9% of the average proposed length of the four tools. Large differences between the tools were observed by comparing mains proposed for replacement in a specific area and by comparing calculated figures for individual mains.

Based on this evaluation of tools for DSS, the following recommendations are given:

1. Make for each tool an explicit description of the modelling philosophy and the applied information (knowledge rules, weights and cost data, etc). Subsequently, make a quality improvement plan based on the actual quality of information, a sensitivity analysis and the estimated costs of improvement.
2. Adopt a Plan-Do-Check-Act approach, where the condition is assessed (Check) and the results serve for updating (Act) the data and criteria for an improved DSS.
3. Develop a method for defining burst frequencies for cohorts of mains on a scientific and widely accepted basis. As large variations occur in the burst frequencies applied by the four tools, a more uniform method for assigning burst to cohorts would be possible based on the existing system for burst registration in the Netherlands (USTORE).
4. Make an update of this evaluation, with more focus on uniform tactical and operational data, such as the aging curves, costs figures and figures for weighting different types of risks. This assessment could give more guidance whether the different results of the tools are due to the modelling approach or due to the used tactical and operational data.

6. References

Beuken, Ralph and Mirjam Blokker (2013). *Decision support software for mains rehabilitation tested by water companies.* IWA-LESAM 2013: Strategic asset management of water and wastewater infrastructure, Sydney, Aus., Sept. 10-12, 2013.

Kwakkel, Marcel, Irene Vloerbergh, Peter van Thienen, Ralph Beuken, Bas Wols and Kim van Daal (2013). *Uniform failure registration: from data to knowledge.* IWA-LESAM 2013: Strategic asset management of water and wastewater infrastructure, Sydney, Aus., Sept. 10-12, 2013.

IMQS: http://www.imqs.co.za/products/asset-management/

Rasmariant: http://www.rolsch.nl/#home

Transparant: http://www.inzichtindata.nl/EN/projecten

WiLCO: http://www.seamsltd.com/#!product-eda-asset/reywk.

Appendix 1.

Overview of input data of the DSS applied in this evaluation. R refers to required data. O refers to optional data. + refers to data that was available for the pilot. – refers to data that was not available for the pilot.

	IMQS	Rasmariant	Transparant	WiLCO
General data on mains				
Material, length, diameter, construction year, XY-Coordinate	R/+	R/+	R/+	R/+
Location of valve, location of pumping station		R/+		
Location of house connection		R/+	R/+	
Material subtype or wall thickness		R/+	R/+	
Cathodic protection, coating interior, coating exterior, flow, hydraulic gradient, average flow velocity, maximum pressure difference per main			R/+	
Likelihood of failure				
Burst frequency	R/+	R/+	R/+	R/+
Water hammer	R/-			
Position towards ground water table, soil settling	R/+		R/+	
Soil characteristics (calcium)	R/+		R/+	R/+
Presence of trees, soil characteristics (chloride)			R/+	
Presence of soil pollution, hydrogen embrittlement, turbidity during flushing			R/-	
Consequences of failure				
Number of connections per valve section	R/+	R/+	R/+	R/+
Vulnerable customers	R/-	R/-	R/-	
Yearly water consumption per connection	R/-	R/-		
High risk mains (dykes, highways, railways)		R/+	R/+	R/+
Other risks mains (monuments, subsoil infrastructure, etc)			R/+	
Hydraulic Criticality Index			R/+	R/+
Connections affected by multiple interruptions		R/+		
Presence of pipe casing		R/+		
Duration of interruption	R/+	R/+		R/+
Customer complaints, mains under paved streets			R/+	
Costs				
Costs of replacement, costs of repair	R/+	R/+		R/+
Additional costs for replacement and repair for high risk mains		R/-		
Tariff zone				R/+