Value of Information for Sewer Replacement Decisions

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ABSTRACT
Decision-making for sewer asset management is partially based on intuition and often lacks explicit argumentation, hampering decision transparency and reproducibility. It is unknown to what extent each information source is appreciated by decision makers. Further insight into this relative importance and into implicit factors, improves understanding of decision-making of sewer system managers. As such, a digital questionnaire (response ratio 43%), containing pairwise comparisons between ten relevant information sources, was sent to every municipality in the Netherlands to analyse the relative importance and assess whether a shared frame of reasoning is present. Thurstone's law of comparative judgment was used for analysis, combined with several consistency tests. Results show that camera inspections were valued highest, while pipe age was considered least important. The respondents were pretty consistent per individual and also showed consistency as a group. This indicated a common framework of reasoning among the group. The feedback of the group showed, however, the respondents found it difficult to make general comparisons without having a context. This indicates decision-making in practice is more likely to be steered by other mechanisms than purely combining information sources.

KEYWORDS
Sewer asset management; decision-making; information; paired comparisons; consistency

INTRODUCTION
Decision-making for sewer asset management is inherently complicated, because of insufficient data and interaction with multiple actors. This causes decision-making to be partially based on intuition and often lacking explicit argumentation, hampering decision transparency and reproducibility. When looking at initiating sewer replacement projects, the current theoretical decision model is usually a combination of various explicit information sources about the sewer system itself and the physical or organizational environment. Replacement is defined here as replacement of a pipe by another, irrespective of the newly installed diameter. A change in functional performance is therefore possible. Examples of information sources are planning of road works or urban water policies. The trade-off of interests, values and information other than conventional camera inspections play a prominent role, which is neglected in these decision models (Kleidorfer et al., 2013; Sægrov, 2006).

Yet, it is unknown to what extent each information source is appreciated or valued by decision makers, i.e. the relative weight of information. Further insight into these relative importances and into implicit factors, creates better understanding of the decision-making behavior of sewer system managers. This understanding is required to increase decision transparency and cost-effectiveness. This empirical testing of the assumed decision model for sewer asset management is a blind spot in research so far. Hence, this study analyzestwo aspects. First, the perceived importance of informationfor hypothetical sewer replacement decisions.Second, the presence or absence of a shared frame of reference for judging about weight of information.This study is considered as a first step in assessing the importance of information versus actor interests in sewer replacement decisions.

METHODS AND MATERIALS

Data collection tool

A digital questionnaire was set up in‘Survalyzer’ (software for online surveys), containing pairwise comparisons between relevant information sources. These sources, the variables, were selected based onVan Riel et al. (in prep.), in which decision argumentation of 150 sewer replacement projects in the Netherlands was analyzed through interviews. Decision argumentation was defined as every possible factor (i.e. information source) that influenced the decision process of initiating a sewer replacement project. The following ten information sources mentioned most often and selected for this article:

- Camera inspection images
- Citizens' complaints call
- Gaps in the road
- Hydraulic model: environmental performance
- Hydraulic model: hydraulic performance
- Pipe age
- Planning of road works
- Planning of urban development
- Soil subsidence differences
- Storm water policies

A maximum of ten variables was selected to minimize fatigue effects when filling in the survey. Soil subsidence differences was chosen as a variable, because it is considered as an important cause for insufficient hydraulic performance in settlement prone areas (Dirksen, 2013) and effect on replacement priorities. This local feature of soil subsidence was taken into account in the questionnaire.

The questionnaire was tested and adjusted twice before it was completed. The final questionnaire started with an introduction of the research and an example how to weigh and fill in the paired comparisons. Second, the respondents were asked about their gender, age, amount of working experience, working at municipality yes/no and settlement prone area yes/no. Then the variables were randomly offered in a complete design (Street & Burgess, 2007) in forty-five pairs, asking respondents for a preference for one variable ineach pair. At the end, the respondents were thanked and asked for feedback.

Sample selection

The target population is Dutch sewer system managers. As such, judgmental sampling was applied. RIONED Foundation (center of expertise in urban drainage in the Netherlands) was asked to distribute the survey, because they have contact data of all urban drainage departments at Dutch municipalities. On 25 November 2013, they e-mailed an invitation for participation in the survey to all 407 municipalities in the Netherlands (one e-mail per municipality). A reminder was sent at 3 December to increase the response.

Data analysis

The intangible property, weight or importance of information, was assessed by applying Thurstone's law of comparative judgment, case V(Thurstone, 1927b).Thurstone's model assumes that a variable's quality is normally distributed on a psychological scale. It describes that different people may have different opinions on the quality of a variable. Each variable's T quality score (the perceived value) is taken to be the mean quality of the corresponding normal distribution. Each respondent N is presented with every $½\cdot(T^2-T)$ possible pair of T items, and is asked which of two items is more favorable to the issue in question. An individual chooses the alternative with the highest perceived utility, which he realizes from the quality distributions of the two variables in the pair under consideration. For each pair of items the proportion is obtained (the empirical probability) of times one variable was judged to be more favorable than the other. From the empirical probabilities of each pair, the mean quality score of each variable can be calculated using the normal cumulative density function.

A respondent is not always consistent in his comparative judgments from one occasion to the next. An inconsistency occurs whenever a circular triad is present in the judgments (Kendall & Babington Smith, 1940). A circular triad is exemplified as follows: item A is preferred over B, B over C, and C over A.The greater the number of circular triads in the data, the more inconsistent the respondent is said to be (Thurstone, 1927a). Next to internal consistency, validity of the results can also be analyzed by determining concordance between judges by applying statistics described byKendall (1938) and Kendall and Babington Smith (1940).

A Matlab code was written for the following analyses. First, the questionnaire results from Survalyzer were converted to a $T\times T$ comparison matrix for all respondents. Second, the mean quality scores per variable were calculated from the empirical probabilities in the comparison matrix. Third, the coefficient of consistence, zeta, per respondent was calculated. Fourth, Kendall's tau test for each pair of judges was applied to assess concordance between respondents. This non-parametric test computes the correlation between ranked data, ranging between -1 for complete disagreement and 1 for complete agreement. Fifth, the coefficient of agreement was calculated to assess concordance for the entire sample. This statistic, u, represents the extent of concordance for all judges together, where $u = 1$ equals complete agreement.

The assumptions underlying the law of comparative judgment, case V are debatable (see Sjöberg, 1962), especially equal and independent variance for all variables and between respondents. Yet, it is a reproducible approach to analyze intangible properties of information that provides plausible results. Next to that, the participants make choices in hypothetical situations, which can differ from their choice behavior in reality. The goal of this study is however,not to mimic reality, but to identify a general framework of judgment.

RESULTS AND DISCUSSION

Sample characteristics

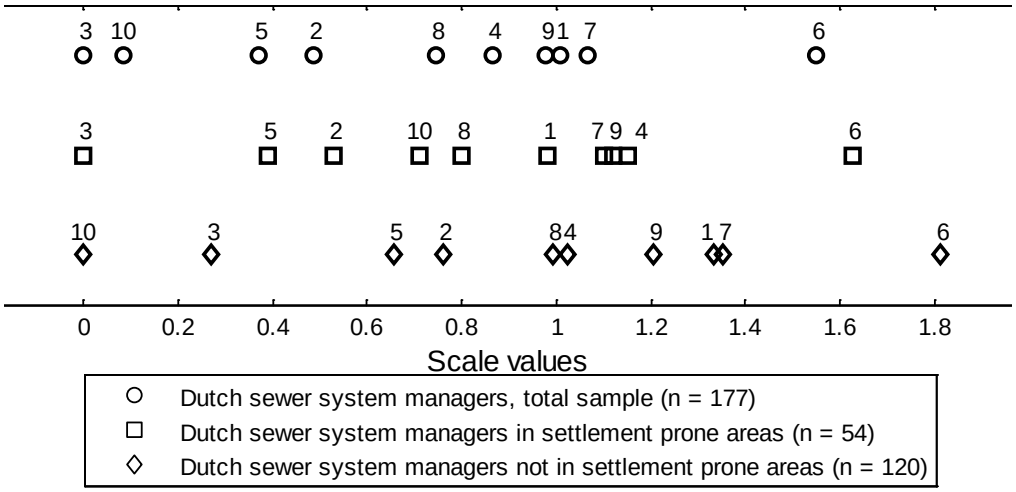
The final response rate was 43 %, yielding 177 completed responses from 407 invitations. 106 respondents (26 %) left the questionnaire before finishing it, resulting in a non-response of 31 %. The average completion time was 10.4 minutes. Table 1 shows several sample characteristics of the 177 completed responses.

Table 1. Sample characteristics (n = 177)

Gender	Male 92 %	Female 8 %			
Age (years)	< 30 3 %	30 - 39 25 %	40 - 49 31 %	50 - 59 33 %	60 ≥ 7 %
Years of working experience	< 10 25 %	10 - 19 33 %	20 - 29 27 %	30 - 39 14 %	40 ≥ 2 %
Work at municipality?	Yes 98 %	No 2 %			
Municipality in settlement prone area?	Yes 31 %	No 68 %	Not working at municipality 2 %		

Variables' quality scores

The ten selected information sources were put onto a relative psychological scale in figure 1. The scale unit is expressed in amount of standard deviations from the mean quality score. The numbers do not have intrinsic meaning: they can be shifted by choosing another zero point or scale size and, thus, only indicate the relative distance between the points. Here, the least important variable is chosen as zero.



1. Hydraulic model: hydraulic performance
2. Hydraulic model: environmental performance
3. Pipe age
4. Gaps in the road
5. Storm water policies
6. Camera inspection images
7. Citizens' complaints call
8. Planning of urban development
9. Planning of road works
10. Soil subsidence differences

Figure 1. Scale values of perceived importance of information for sewer replacement decisions

Figure 1 shows that sewer system managers perceive camera inspection images as the most important information source from these ten variables. This can be explained by the fact that performing and evaluating inspections is normalized and often used in practice as the primary source of information, despite the drawbacks of the method(Dirksen et al., 2013).

Several differences can be observed between the respondents working in areas with and without the influence soil subsidence. First, information about soil subsidence is considered least important for areas without influence of it. This information source is considered significantly more important in settlement prone areas. Second, camera inspections are considered more important in areas that are not prone to subsidence. A possible reason is that the primary failure mechanism in stable soils (pipe degradation) is easier detectable by camera inspection than the primary failure mechanism in settling soils (change of storage capacity and hydraulic performance). Therefore, the usefulness of the information source might be perceived higher, depending on the local soil conditions. Third, hydraulic models to assess hydraulic and environmental performance are also considered more important in areas that are not prone to subsidence. This can be caused by the fact that without the effect of soil subsidence, hydraulic models have a higher chance of producing useful results, since these models omit changing pipe gradients.

Consistency and concordance

Are the respondents' answers trustworthy? As indicated in paragraph 'Data analysis', the spread between the variables is an indication of the perceived quality difference. It is also an indication of the respondents' capability to discriminate between the variables' qualities. This capability is analyzed by calculating the ratio between the number of circular triads each respondent makes and the maximum possible number of triads. This coefficient is expressed as zeta.Figure 2shows these results in a cumulative distribution function, where a zeta of 0 equals complete inconsistency and 1 equals complete consistency.

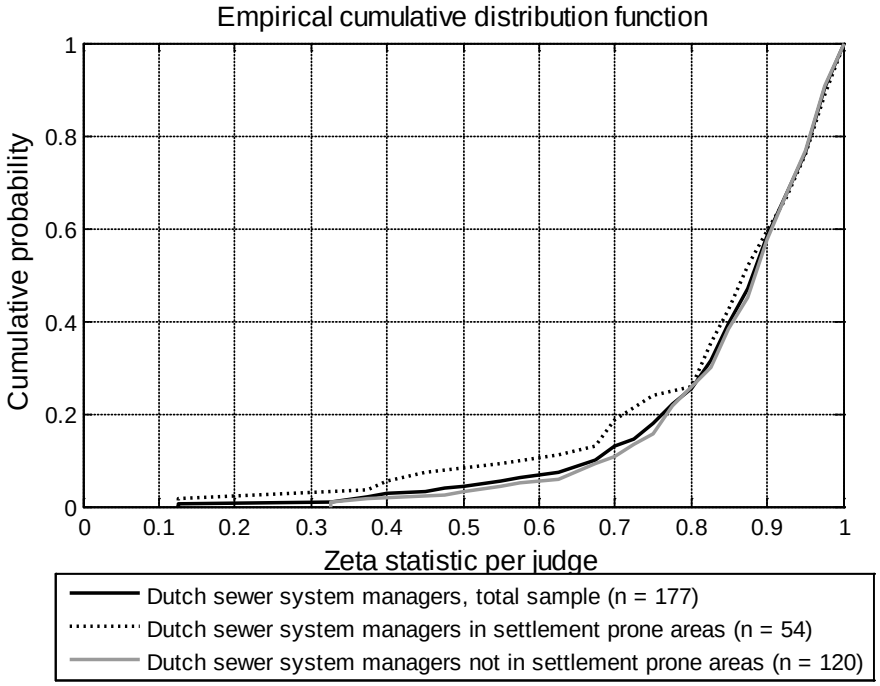


Figure 2. Distribution of coefficient of consistence (zeta) per judge

Figure 2shows that the majority of the respondents, approximately 70 %, have a zeta value of at least 0.8. This means that the group is fairly consistent in their judgments, implying that they are capable of discriminating between the variables. Thus, it is concluded that most of the respondents are trustworthy judges. It also implies that small differences between variables qualities are probably caused by the fact that the quality difference are small, i.e. almost equally important information.

Do the respondents agree with each other, regardless of their consistency? Agreement between respondents wasanalyzedby applying Kendall's tau test for every$\frac{1}{2}\cdot(N^2-N)$ possible pair of respondents.Figure 3shows the results in a cumulative distribution function. Agreement means that respondents agree both in their consistencies and their inconsistencies.

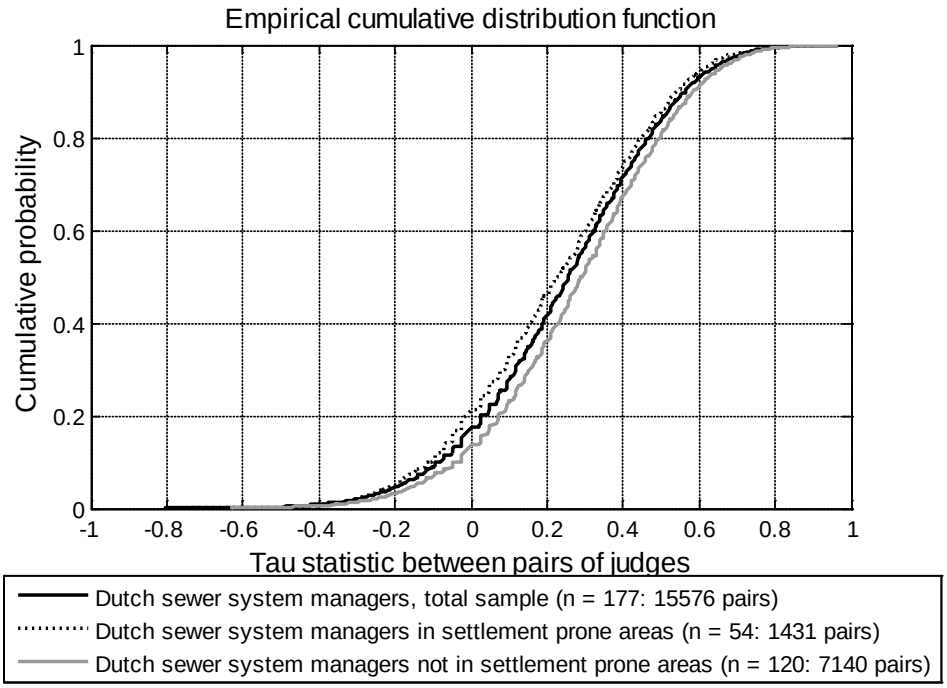


Figure 3. Distribution of tau statistic of concordance between pairs of judges

Figure 3shows that more than 80 % of the pairs of respondents have a tau value between 0 and 1. This indicates reasonable concordance between the judges, suggesting a shared frame of reference for judging the relative value of information. The coefficient of agreement supports this suggestion.

The coefficient of agreement*u* for the total sample equals 0.21.For settlement prone areas: u = 0.19. For areas not prone to settlement: u = 0.24. These results show that sewer system managers in areas not prone to subsidence agree slightly more with each other compared to the other groups. Figure 1 supports this results by a larger spread of the variables. All three*u* values are statistically significant at the 95 % confidence interval ($p << 0.001$). These results mean that the respondents show significant agreement in their judgments, i.e. the judging is not done at random and a common line of thinking is apparent.

Relation to decision-making in reality

The unique circumstances of a real sewer replacement project were omitted in this study. This could decrease the agreement between respondents, because they judge about their

preferences from different perspectives, i.e. they use different frames of reference for their judgments. Several respondents mentioned that in the feedback section at the end of the questionnaire. They found it difficult to make a preference judgment at each pair, because they missed context. In replacement project 1, they would prefer variable A over B, but would choose reverse in replacement project 2. The content of these comments show that deciding about sewer replacement is an art of fine tuning, combining and negotiating about available information and interests of other actors, due to a variety of local circumstances. This does not mean however, that a common frame of reference is absent.

CONCLUSIONS

This study aimed at analyzing the perceived importance of information in hypothetical sewer replacement decisions and the presence/absence of a shared frame of reasoningamong Dutch sewer system managers. It is concluded that conventional camera inspection are valued most and that a shared frame is indeed present. The described results allow to take a peek into the way sewer system managers weigh or value sources of information relevant for initiating replacement decisions. Although this shared frame is present, the respondents' feedback implies that the decision process for sewer replacement cannot be driven purely by combining information sources. This is basically how current decision models portray sewer replacement decisions. The trade-off of interests, values and information other than conventional camera inspections images plays a prominent role, which is neglected in the current decision model for sewer asset management. Therefore, it is recommended to introduce relevant intangible decision factors into the current decision model. To do so, decision processes in sewer asset management should be analyzed in relation to their context, focusing on multi-actor decision settings.

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