The Impact of Lateral House Connections on the Serviceability of Sewer Systems

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ABSTRACT
It remains unknown how lateral house connections affect the performance of the sewer system, since the assessment of serviceability is mainly based on the state of the main sewer system. Further insight into the contribution of lateral house connections to the overall level of service provided can aid to target investments to parts of the system where it is most effective. To this end, techniques from the reliability theory were applied to a commercial sewer maintenance database to quantify the impact of lateral house connections on the serviceability of sewer systems. Analysis of the data showed that the failures follow a Poisson distribution. A comparison of the derived failure rate with values obtained from a different study revealed that the blockage rate of lateral house connections is an order of magnitude greater than the failure rate of the dominant mechanism of main sewer systems, thereby making the impact of lateral house connections on the serviceability of sewer systems substantial.

KEYWORDS
Serviceability, reliability theory, lateral house connections, blockage database, Poisson process

INTRODUCTION
Component failure may seriously hamper sewer systems ability to meet functional requirements. Possible consequences of component failure vary from nuisance due to the temporary inability to discharge wastewater to tangible flood damage to properties. Lately, serviceability has gained attention as an indicator of system performance in sewer asset management(Arthur et al., 2009; Matos et al., 2003). Serviceability is influenced by both the structural and operational condition of the system components. As the sewer infrastructure continues to deteriorate due to external forces, pipe degradation and the build-up of sediments and attached deposits, sewer managers face the daunting task to maximise the serviceability of the system with the available budget. This requires work to be prioritised on components based on the impact that failure has on the capability of the system to deliver a service.

The role of blockages as the main contributor to the loss in sewer serviceability has been reported in several studies (Arthur et al., 2009; Ashley et al., 2004). By analysing sewer flooding databases,ten Veldhuis and Clemens (2011) and Caradot et al. (2011) found that not main sewer blockages but gully pot blockages are the main cause of flooding incidents.

Yet, these studies do not take into account the lateral connections draining wastewater and excess stormwater from dwellings. Therefore it remains unknown how lateral house connections contribute to the overall level of service provided. Further insight into the impact of lateral house connections on the overall system performance can aid to direct investments in sewer infrastructure to the parts of the system where it is most effective. Moreover, the blockage rate of lateral house connections is a blank spot in this research field so far. Hence, this study aims to quantify the occurrence of blockages in lateral house connections. First, acommercial sewer database is discussed. Reliability theory is then used to quantify the blockage rate for a large city in the Netherlands.

METHODS AND DATA ACQUISITION

Blockage database

Data on the blockage rateof lateral house connections were obtained by interrogating the database of a commercial sewer maintenance company. This company specialises in solving sewer defects in and around private and commercial properties. The database in question comprises over 355,000 blockages in the Netherlands since 2011.

The working procedure of the sewer company involves (1) driving a powered sewer router through the blocked pipe until the blockage is removed. When the operator observes a decrease in the resistance and household appliances are able to discharge freely, the problem is considered fixed. (2) In other cases (e.g. pipe collapse), the pipe in question will be excavated or closed circuit television (CCTV) will be used to find the cause of failure.

Data collection during repairs was motivated by the customers demand and the warranty on repairs concerning the reoccurrence of certain failure mechanisms within a specified period. In addition to the appropriate dates and location, information on the object type where the defect was located, applied method and the cause of failure was logged.

Data validation and processing

The validation of data is considered a prerequisite for an accurate analysis. Data can be subject to errors, inconsistencies or outliers. Interferences during data collection or conversion are not the only factors that influence the data quality. For instance, the availability of a fixed number of possible choices for certain input fields, resulted in equipment maintenance to be logged as a blockage as well. Events that met at least one of the following criteria were removed:

- Geocoding algorithm failed to find geographic coordinates associated with an address.
- Blockages that did not occur in buried pipes but in the in-house drainage system.
- A branch office of the drainage company was denoted as address, indicating equipment maintenance
- Cases where the property owner was not home
- Failed date registration
- Subsequent cases related to the same event
- Cases where the date of repair preceded the first call date

Analysis of blockage data

Statistical methods commonly applied in reliability theory were used to analyse the blockage data. From a quantitative point of view, reliability specifies the probability that an item will meet functional requirements within a specified period of time. Although these requirements are not unambiguous, property owners are considered triggered to contract an expert when there is a noticeable reduction in the drainage capacity.

Multiple theoretical models are available to describe the failure rate of repairable systems(Ascher & Feingold, 1984).These models can be divided in two categories, namely models with a time independent failure rate and models with a time dependent failure rate. The former applies to data where the failure rate is constant within the time period under observation. The latter refers to data where the failure rate decreases or increases in time. Based on the widely accepted bathtub curve(Jin & Mukherjee, 2010; O'Connor & Kleyner, 2011), components experience these different patterns of failure rates depending on the phase of their service life.In the flat region of this curve, the times between successive failures are independent and identically distributed. Since this implies that during repairs the state of the failed component is restored to “as good as new”, it is referred to as a renewal process. A trend test can verify whether the time between successive failures, also referred to as interarrival times, are identically distributed. The presence of a trend demonstrates a time dependent failure rate. A test statistic, which can identify such a trend is given by

$$U_F = 2\sum_{i=1}^{n} \ln\left(\frac{T}{t_i}\right)$$

where $t_1, t_2, ..., t_i, ..., t_n$ are the times of failure events,*T* is the end of the observation period,and *n* is the total number of failures. If the failure series end after *n* failures, instead of a fixed observation period, n becomes $n-1$and T is t_n. When events are uniformly distributed over the interval *0* to *T*, this test statistic has a χ^2-distribution with 2*n* degrees of freedom(Birolini, 2007).

An alternative test statistic is the Laplace test. This test is found to be the appropriate for trend detection (Bain et al., 1985) and has beenapplied in the field of urban drainage (Korving et al., 2006; Rodríguez et al., 2012).The test statistic is defined as

$$U_L = \frac{\left(\sum_{i=1}^{n} \frac{t_i}{T}\right) - \frac{n}{2}}{\sqrt{\frac{n}{12}}}$$

The distribution of the Laplace test approaches a standard normal distribution. Lewis and Robinson (1973) and Lawless and Thiagarajah (1996) reported the following adjustment of this statistic to improve performance for more general renewal process models, where x_i is the operating time since event t_{i-1}

$$U_{LR} = \frac{U_L}{\sqrt{\frac{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{\bar{x}^2}}}$$

If no trend is present, all interarrival times are described by a common distribution. A special case of the renewal process is the homogenous Poisson process (HPP). Based on this process, the failure count follows a discrete Poisson distribution with an equal variance and expected value.Interarrival times are exponentially distributed and the probability of at least one failure within a specified period of time *t*is described by

$$\Pr\left(n \geq 1\right) = 1 - e^{-\lambda t}$$

where λ is a positive real number. An unbiased estimate of this parameter is given by the following maximum likelihood estimate

$$\hat{\lambda}_{MLE} = \frac{n}{T}$$

which is equal to the failure rate. The inverse of this estimate is the average interarrival time and is commonly referred to as the mean operating time between failure (MTBF). Goodness of fit tests can be used to test whether the interarrival times are distributed according to the continuous exponential model. The classical Kolmogorov-Smirnov and χ^2 test were selected to determine whether the model fitted the data on a 95% confidence interval.

Additionally, a test for discrete distributions proposed by Klar (1999)was considered, as a comparison, for the Poisson distribution. In a comparison of different tests for Poissonity by Gürtler and Henze (2000), this statistic was found to be universally consistent. The method is based on thedeviation between the integrated distribution function and the empirical integrated distribution function and is given by

$$T_n = \sup_{t \geq 0} \sqrt{n} \left| \psi_n(t) - \psi_n(t) \right|$$

in which $\psi_n(t)$ is the empirical integrated distribution function and $\hat{\psi}_n(t)$ is its estimated counterpart. By means of a parametric bootstrap procedure, the p-value is approximated. Unlike most test statistics, this test is asymptotically distribution-free (ADF) and consistent for discrete distributions. ADF refers to the fact the test does not depend on the probability distribution of the statistic when the null hypothesis is true.Consistency ensures that for a sufficiently large sample size, the test makes no error concerning the null hypothesis and its alternative.

RESULTS AND DISCUSSION

Data characteristics

Close to 21,000 records of blockage events in a period ranging from February 2012 until September 2013are available for the city of Rotterdam.Since the new data collection procedure was introduced over a period of 6 months, the first 6 months were not used in the analysis (August 2011 – January 2012). Figure 1 presents the results of the proposed data validation and selection procedure. This Figure shows that 39% of the initial dataset was suitable for further analysis. The primary cause for omitting events, was due to the fact that the blockage was located in a building sewer system instead of a lateral house connections. Only 6% of the data were omitted based on the validation procedure. The majority of this share could be attributed to multiple cases referring to the same event or the inability to allocate geographic coordinates to an event.

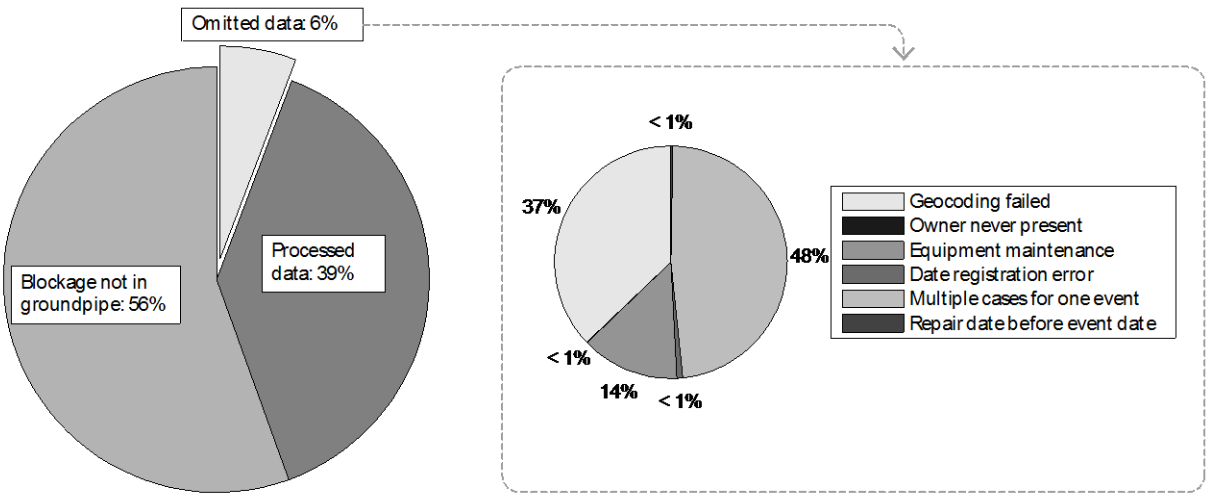

Figure 1. Events removed from the dataset due to data selection and validation

Various housing associations have long-term agreements with commercial drainage companies. This entails the direct forwarding of any sewer related problem from a lessee to the drainage company in question. hence, the number of reported blockages concerning properties from a housing association approximates the total number of events. Therefore, only data pertaining to housing associations were selected for the following analysis.

Blockage rate of lateral house connections

Apreliminary graphical analysis of the data revealed a diurnal pattern in the registration of events in the database. This pattern is depicted in Figure 2 for an arbitrary week. Considerably less calls were registered at night and in the weekends. Moreover, a compensation peak is noticeable on the Monday morning. This pattern is believed to be caused by the difference in time between the occurrence and registration of an event, which is typical for interarrival times of this order of magnitude.

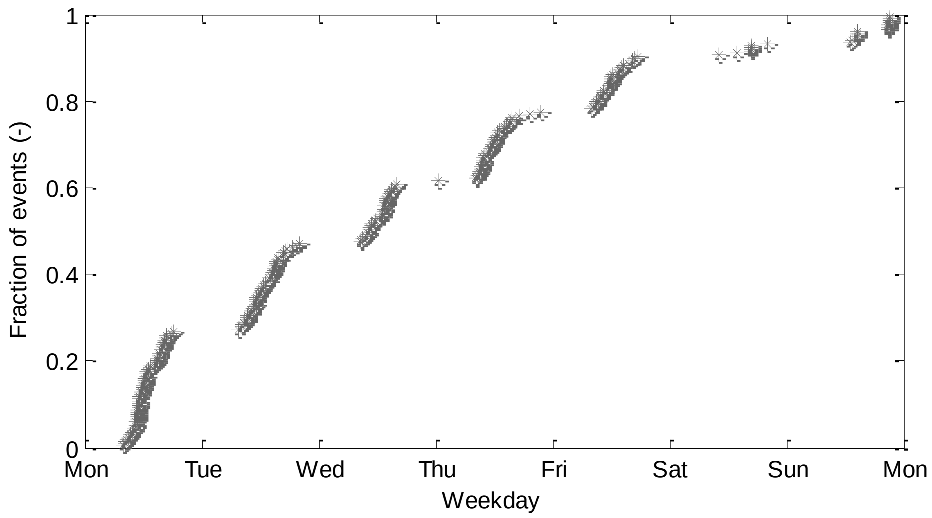

Figure 2. Pattern in the registration of blockage events in the data

Such a pattern in the data may hamper the performance of goodness of fit tests due to the presence of a step in the cumulative distribution function (CDF) of the interarrival times.In order to obviate this issue the data are divided into three categories while preserving the interarrival times. These categories are events during the weekend, during the week 9:00 – 16:30 and during the week 16:30 – 9:00. One of the properties of the Poisson distribution is that the sum of multiple independent Poisson distributed variables is also Poisson distributed. Subsequently, when the data in these categories can be modelled as a Poisson process, so can the entire dataset.

The prior introduced trend tests determine whether the subsets are characterised as a renewal process. Table 1 shows that all statistics for both tests are between the upper and lower critical values for a 95% and 5% confidence level respectively. Hence, there is no significant trend in the data. This implies that the blockage rate is not subject to substantial changes within the period of observation.

Table 1. Test statistics and critical values for the trend tests

Subset		**χ^2 distribution**			**N(0,1)**		
Weekpart	Daypart	Lower crit. value	U_F	Upper crit. value	Lower crit. value	U_{LR}	Upper crit. value
Week	Day	309.33 <	315.99	< 414.46	-1.96 <	1.80	< 1.96
Week	Night	33.97 <	53.39	< 73.81	-1.96 <	0.29	< 1.96
Weekend	Both	2.18 <	13.19	< 17.53	-1.96 <	-0.06	< 1.96

Subsequently, it is tested whether the data can be modelled as a HPP. Power estimates of the goodness of fit tests previously discussed are given in Table 2. For all three subsets respectively, there is insufficient evidence to reject the hypothesis of a HPP at a 95% confidence interval. As a characteristic of this model, the expected time between failures is described by the MTBF.

Table 2. Power estimates of the goodness of fit tests

Subset		**p-value**			**Characteristics**	
Weekpart	Daypart	χ^2 test	K-S test	IDF	λ (week^{-1})	MTBF (week)
week	day	0.89	0.28	0.20	15.47	0.06
week	night	0.50	0.58	0.53	1.07	0.94
weekend	both	0.59	0.52	0.56	0.19	5.15

For the data corresponding to weekdays from 9:00 to 16:30, Figure 3 and 4 are plotted. Figure 3 shows the probability of at least one blockage within a specified period. The exponentially modelled interarrival times, for the housing association under consideration, match the empirical data up onto a large extent. Figure 4 confirms this accordance, by illustrating the ability of the Poisson distribution to fit the number of event occurrences in a period of 12 hours.

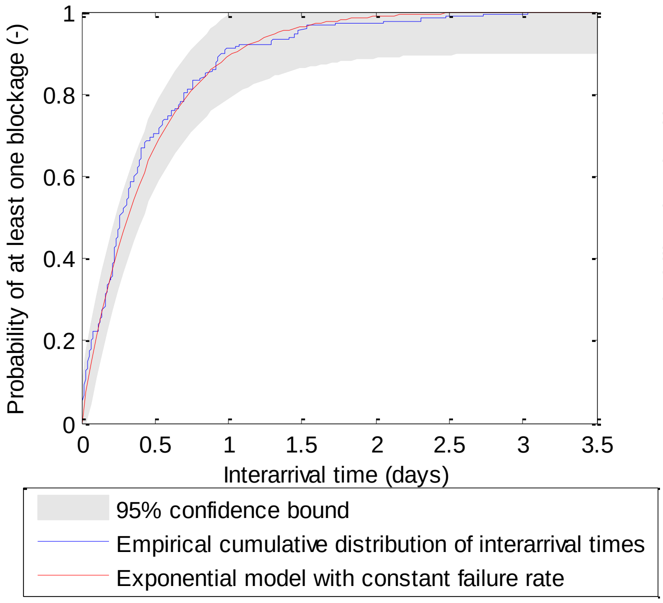

Figure 3. Exponentiallymodelled interarrival times

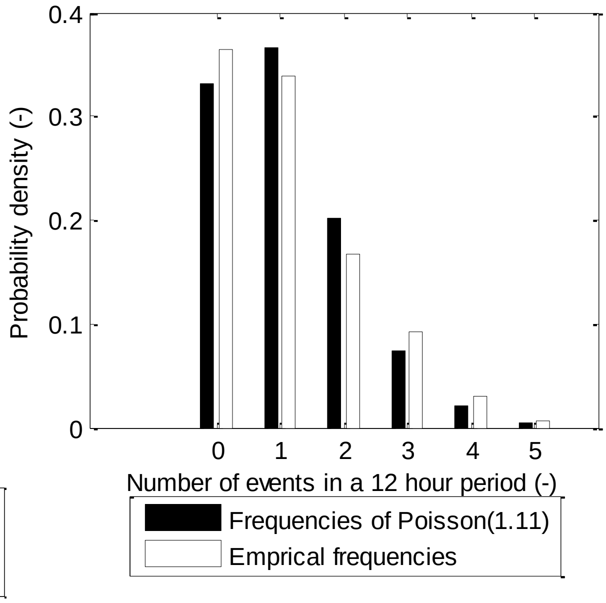

Figure 4. Poisson model of nr events

Impact on the level of service provided

The impact of blockages in lateral house connections becomes evident when the average blockage rate for housing associations is expressed per unit of main sewer length. This allows for comparison with failure mechanisms for the main sewer system. With a mean main sewer length of 5.29 meters per property in the Rotterdam area, the mean blockage rate of 0.51 blockages/day results in a blockage rate of 6.68 blockages/km sewer length/year.

Table 3. Quantification of sewer related flood events(ten Veldhuis & Clemens, 2011)

Flood incidents	**Case study**	
(events km^{-1} yr^{-1})	Haarlem	Breda
Gully pot blockage	0.18	0.28
Blocked sewer pipe	1.00E-03	1.00E-02
Sewer overloading	3.00E-03	7.00E-03

Compared to the values reported in Table 3, for two case studies in the Netherlands, the failure rate in lateral house connections is an order of magnitude greater than the rates reported by ten Veldhuis and Clemens (2011)for the main sewer system.

It should be noted, however, that the event coverage ratio of this type of database is subject to other factors compared to a municipal sewer failure database. In the Netherlands it is often the policy that for defects concerning lateral house connections, the property owner is advised to employ the services of a commercial sewer company. Since there are often multiple commercial sewer companies active in an area, data on blockages are fragmented. Arguably, the public will report all flood incidents in the public area to same local authority. The incentive to report such an eventdepends, however, on the degree to which a person is affected by the event. In that perspective, individuals will be more encouraged to report the blockage of a lateral house connection. Only data pertaining to housing associations were selected for this study, in order to overcome the issue of fragmentation.

CONCLUSIONS

This study aimed to quantify the occurrence of blockages in lateral house connections in order to determine the impact on the serviceability of sewer systems. It is concluded thatthis impact is substantial. Results show the failure rate to be an order of magnitude greater compared to the most dominant failure mechanism of the main sewer system. It remains unclear whether this due to the high coverage of the number of events in this database or the excessive presence of certain failure mechanisms in lateral house connections. Therefore, it is recommended to further investigate the contribution of the individual failure mechanisms.

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