Technical Management of Sewer Networks
- A Simplified Decision Tool -

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Abstract

Priority of actions and investments in sewer technical asset management may be based on evaluation of sewer performance with respect to the risk and magnitude of failure. The present paper describes a general expert system developed to support operation and maintenance activities on sewers. At this stage the tool was developed to identify the critical reaches of the system and establish priority in sewer cleaning and inspection operations in order to define cleaning and inspection frequency. It aims to reduce the number of structural and functional failures and, as a result, reduce both emergency repair and preventative costs. The selected approach was based in a "failure oriented forecast" taken in account selected parameters and different data: sewer diameter, slope, material, age and depth. The approach was developed for the technical asset management of the collection network explored by SIMTEJO and applied to the Chelas sewer system, one of the three main sewer systems of Lisbon city, in Portugal.

Keywords

Cleaning, decision tool, inspection, maintenance, sewer networks, technical asset management.

Introduction

In wastewater collection systems the technical asset management comprises the core of the management activity, playing a decisive role on the effective procurement, operation, maintenance and rehabilitation of infrastructures. It is also a key component for complying with changing legal and social requirements. In urban areas with large sewer networks, the sustainability of infrastructures largely benefits from the implementation of an asset management system. The efficiency of an infrastructure asset management is largely dependent on the use of decision support tools to plan operation and maintenance activities.

The survey conducted by Black & Veatch (1999) concluded that the most important operation and maintenance activities for US wastewater agencies are sewer rehabilitation, line cleaning, close circuit television inspection and pump station servicing.

According to the Water Research Center (WRc, 2001) sewers are categorized into critical and non-critical depending on the economical impact resulting from their failure. Hor (1992) defines primary sewer as one where failure would have impact on performance elsewhere in the system or where failure would have serious economic impact. WEF and ASCE (1994) classify sewers into class A (critical), B (semi-critical) and C (critical) depending on the relation between preventive rehabilitation and after failure repair.

The majority of the asset management strategies implemented focus on the proactive rehabilitation of critical sewers. This approach is recommended based on the conclusion that failures in these sewers represent the major fraction of the repair costs (Fenner and Sweeting, 1999). For that purpose, several models have been developed to support decisions regarding rehabilitation. The simplest one was developed by the Water Research Center, and consists in scoring the defects observed during sewer inspections. This approach has been implemented worldwide, with minor adjustments by national institutions and local municipalities (WRc, 2001; NRC-CNRC, 2004). More complex and integrated models where developed from these with the purpose of optimizing the solutions taking into account hydraulic, environmental, social and economical constrains in the decision process such as the Burgess model (Burgess, 1988), MARESS (Reyna, 1993), APOGEE (Macgilchrist and Mermet, 1989), Aflak model (Aflak, 1994), PIPES (Lim and Pratti, 1997), RERAUVIS (RERAU, 1998) and CARE-S (CARE-S, 2005).

Non critical sewers tend to be managed reactively because it was proven economical unviable to conduct periodical inspections. However, non critical sewers represent the largest extent of the drainage collection systems. Additionally these sewers are usually smaller diameter pipes, often laid at slack slopes, where serviceability problems of siltation, protruding connections, infiltration, fat deposition, encrustation and root infestation tend to have a disproportionately effect on their performance. Consequently they may be more prone to functional problems such as blockages, clogging, odour impacts and even collapse. Because the service connections are usually linked to these sewers the social consequences of failures (functional and structural) also may be significant. Therefore, water industries face the challenge of starting to deal proactively with these sewers (Fenner and Sweeting, 1999). Additionally, there is a growing demand for conducting periodical sewer inspections to comply with the legislation. Most states in Germany require the inspections of the total sewer network once in ten years (Baur and Herz, 2002). This as led to the development of models to assist decisions regarding selective inspection of sewers, namely AQUA-WertMin (Baur and Herz, 2002) and SCRAPS (Hahn et al, 2002).

Model Development

General aspects

The implementation of the existing models relies on the existence of information about the sewer condition, which is obtained primarily from inspections results. In Portugal, the information regarding the sewer systems is often scarce and dispersed and, in several cases, incorrect. Nevertheless, there is a need to implement proactive strategies for the integrated management of the systems.

The present expert model was developed with the objective of implementing a proactive management plan based in conditions of scarce information available. In order to establish priorities, the model evaluates the risk of failure or performance deficiency of sewer reaches in a scale of 1 to 10, by applying the following general expression:

$$E = K \sum W_i \times P_i$$

with:

E – evaluation result (1 to 10 classification);

K – correction factor, taken into account the know-how about the system (higher than 0);

W_i – weight factor of parameter i (0 to 10 classification);

P_i – ponderation factor of parameter i (0 to 100% ponderation).

Due to the strong economical constrains and performance requirements, sewer systems managers should consider essential to optimize the inspection plans of pipes and manholes. At the same time, there is also a growing need to optimize the operation activities, especially sewer cleaning, which is a requirement for conducting efficient inspections and also play a significant role in terms of the global performance of the sewer system.

The risk of performance deficiency in terms of structural collapse (material durability, corrosion, diameter) and non-self cleaning conditions (slope and diameter) were considered. To establish cleaning and inspection priorities, the risk of clogging and structural collapse in gravity sewers was evaluated in each reach (pipe plus the downstream manhole) selecting the following parameters for the model:

- pipe material and age;
- pipe diameter and slope;
- pipe depth;
- discharge of rising mains upstream;
- manhole characteristics.

Parameters and weight factors

The statistical analyses of the data from Dresden sewer network conducted by Baur and Herz (2002) concluded that the PVC pipes had smaller life spans than concrete and stoneware. However, has the authors point out, the study did not took into account the relations between the variables considered in the ageing forecast. Stein (2005) conducted a study for the TEPPFA-PLASTICS EUROPE Sustainable Municipal Pipes Project which concluded that flexible pipes systems have on average just 20% of the defect rates of rigid pipe systems. Furthermore, considering only the defective sections with defect types that are the main causes of infiltration and exfiltration, such as fissures (BAB), break/collapse (BAC) or defective connection (BAH), defect rates are, on average, 25% of the defect rates of rigid systems.

Distinction between concrete pipes older than 30 years results from the fact of the water/cement relation of the concrete was reduced during the 60's and the 70's (CARE-S, 2005). Plastic pipes structural performance is highly dependent on the bedding and trenching conditions, demanding, among other requirements, a higher compaction degree. Because only in the last decade there has been a generalized increase in quality control and care about plastic pipes placement, it is expect a lower structural performance from sewers constructed before the early 90's. Corrugated pipes however have higher stiffness ratios and therefore are less prone to excessive deformation and structural defects.

Examples of the weight factors to be used in the model for pipe durability are defined in Table 1, representing the structural performance of different pipe materials. It takes into account the mechanical resistance and structural behaviour, and also the chemical and physical performance of the pipe.

Table 1 – Weight factors for durability, according to pipe material.

Material / age	***Weight***
Cement based (> 30 years)	10
Cement based (≤ 30 years)	9
Stoneware / Cast iron	6
PVC/HDPE/PP (> 15 years)	5
Clay	4
PVC/HDPE/PP (≤ 15 years)	2
PVC/HDPE/PP Corrugated	1

A statistical investigation conducted by Davies et al (2001b), showed a decrease of defects rate with the increase of the sewer size. Fenner and Sweeting (1999) also state that serviceability problems, such as siltation, protruding connections, infiltration, fat deposition, encrustation, and root infestation tend to have a disproportionally greater effect in the performance of smaller diameter sewers.

In Table 2 weight factors used in the model are presented, for the risk of failure, taken into account the pipe diameter.

Table 2 – Weight factors for the risk of failure, according to pipe diameter**.**

Diameter	*Weight*
>1600	1
900-1600	3
600-900	5
315-500	8
200-300	10

The siltation in sewer depends on several parameters, including the flow velocity, size, shape and density of the solid particles and type of flow (turbulent or laminar). According to prEN 752:2005 self-cleansing of small diameter drains and sewers (less than DN 300) can generally be achieved by ensuring either that a velocity of at least 0.7 m/s occurs daily, or that a gradient of at least 1:DN is specified. For larger diameter drains and sewers, higher velocities can be necessary, particularly if relatively coarse sediment is expected to be present. Portuguese legislation (DR23/95, 1995) requires, as a general rule, a minimum flow velocity of 0.6 m/s for domestic sewers and 0.9 m/s for combined and storm sewers.

Table 3 defines the risk of sediments build up in the sewer invert, which is directly associated with self-cleaning velocities. It was developed taken into account the relationship between diameter, slope and flow velocities for half-pipe conditions. The higher sediment build up risk (weight = 10) corresponds to negative slopes and the minimum risk (weight = 1) to velocities over 1.5 m/s. Intermediate weight factors relate to flow velocities lower than 0.9 m/s and between 0.9 m/s and 1.5 m/s.

Table 3 – Weight factor for the risk of sediment build up, according to diameter and slope**.**

	Diameter [mm]				*Weight*
	200-300	*315-500*	*600-900*	*≥1000*	
Slope [%]	≤ 0	≤ 0	≤ 0	≤ 0	10
	0 - 0.50	0 - 0.25	0 - 0.12	0 - 0.08	8
	0.50 - 1.35	0.25 - 0.70	0.12 - 0.30	0.08 - 0.225	5
	> 1.35	> 0.70	> 0.30	> 0.225	1

Parameters involved in the abrasion phenomenon include amount, size, shape and hardness of the solid particles, flow velocity, type of flow (turbulent or laminar) and pipe material and surface roughness. In sewer systems, the repetitive cleaning procedures can also contribute to pipe erosion.

Portuguese legislation (DR23/95, 1995) establishes a maximum flow velocity of 3.0 m/s for domestic sewers and 5.0 m/s for combined and storm sewers, at design flows. According to the Federal Highway Administration (FHWA, 1996), the abrasion potential can be defined into four levels:

- Level 1, nonabrasive conditions exist in areas of no bed load and very low velocities;
- Level 2, low abrasive conditions exist in areas of minor bed loads of sand and velocities of 1.5 m/s;
- Level 3, moderate abrasive conditions exist in areas of moderate bed loads of sand and gravel and velocities between 1.5 m/s and 4.5 m/s;

- Level 4, severe abrasive conditions exist in areas of heavy bed loads of sand, gravel, and rock and velocities exceeding 4.5 m/s.

The weight factors due to the risk of abrasion presented in Table 4 are related with flow velocities for half-pipe conditions. It was considered that flow velocities below 1.5 m/s have the lowest abrasion potential (weight = 1), while flow velocities over 5 m/s the highest (weight = 10). Intermediate weight values correspond to velocities in the range of 1.5 m/s to 3 m/s and between 3 m/s to 5 m/s.

Table 4 – Weight factors for the risk of abrasion, according to pipe diameter and slope.

	Diameter [mm]				*Weight*
	200-300	*315-500*	*600-900*	*≥1000*	
Slope [%]	> 15.00	> 7.50	> 3.50	> 2.5	10
	5.25 - 15.00	2.75 - 7.50	1.25 - 3.50	1.00 - 2.50	6
	1.35 - 5.25	0.70 - 2.75	0.30 - 1.25	0.225 - 1.00	3
	≤ 1.35	≤ 0.70	≤ 0.30	≤ 0.225	1

The limits where determined using the Manning-Strickler equation and assuming a value for K of 80 $m^{1/3}s^{-1}$, which is the average of the range of values recommended in prEN 752:2005. It is relevant to state that, at this stage of the model development, the roughness or erosion/abrasion resistance of different pipe materials was not taken into account directly.

Davies et al (2001a) reported that the defect rate decrease steadily to a depth of 5.5 m, below which the defect rate begins to increase with depth. It was suggested that this reflects the decreasing influence of surface factors, such as road traffic and utility/surface maintenance activity, and the increasing effect of overburden factors.

Table 5 presents the weight factors for sewer depth, which are related with the risk of structural collapse.

Table 5 – Weight factors for structural collapse, according to sewer depth.

Depth [m]	*Weight*
> 5.5	10
2 - 5	1
< 2	7

Hydrogen sulphide is responsible for the corrosion problems in sewers, especially for non-protected concrete and metal elements. Parameters on which the concentration of hydrogen sulphide depends include (prEN 752:2005):

- biochemical oxygen demand (BOD), which is a measure of the organic matter within the system;
- wastewater temperature, directly responsible for biological reaction rates and air-water transfer of hydrogen sulphide;
- retention time and ventilation, that control the time and oxygen available for the reactions;
- flow velocity, that affects the rate of oxygen absorbtion, the release of hydrogen sulphide to the atmosphere and the build up of sediments and slimes;
- turbulence, that increase the amount of oxygen absorbed into the waste water;
- pH, that influences dissociation of the sulphide ion species in the bulk water (the lower the pH the higher the proportion of sulphide in the form of hydrogen sulphide);
- existence of rising mains or particular trade effluent discharges upstream of the gravity sewer.

In the developed approach, the weight factors due to the risk of corrosion presented in Table 7 were just related with the risk of sediment build up, considering also that the existence of a rising main discharging upstream represents the highest risk (weight = 10).

Table 6 - Weight factors for the risk of corrosion.

Corrosion	*Weigth*
Forced main upstream	10
Risk of sediment build up 10	8
Risk of sediment build up 8	6
Risk of sediment build up 5	3
Risk of sediment build up 1	1

The model also includes some additional information regarding singularities in the system, namely:

- manholes with descend over 0.50 m, where erosion can take place significantly;
- manholes with retention, where sediments tend to accumulate;
- diameter decrease in the downstream direction, that increase the risk of clogging.

Ponderation factors

Because not all parameters analysed have the same impact in the performance of the sewer, different ponderations where attributed in order to establish priorities for cleaning or inspection activities.

Examples of ponderations for the different selected parameters are presented in Table 7, for inspection and cleaning prioritization.

Table 1.7 – Ponderation factor of the model parameters.

Parameter	*Ponderation [%]*	
	Inspection	*Cleaning*
Material / age	20.0	15.0
Diameter	10.0	15.0
Sediment build up	-	40.0
Abrasion	20.0	-
Depth	10.0	-
Corrosion	35.0	-
Section reduction	-	15.0
Manhole with drop	5.0	-
Manhole with retention	-	15.0

In the absence of specific information and know-how, the correction factor, that allows the introduction of empirical information resulting from the experience of the system manager and operators may be considered 1.

Despite the evaluation of the individual sewer trenches provided by the model, the results should not be considered in an absolute scale but rather as a probabilistic classification for a given area. Therefore, the results where categorized into three risk classes:

- $E > 5.5$ - high risk;
- $5.5 \geq E \geq 3.5$ - medium risk;
- $E < 3.5$ - low risk.

Model Application to a Case Study

SIMTEJO sewer system

The SIMTEJO (Sistema Multimunicipal de Saneamento do Tejo e Trancão), Tejo and Trancão's multi-municipal sewer system was created in 2001 with the purpose to collect, treat and discharge the wastewater generated in the Trancão river basin, in the small river basins on the right shore of the Tejo river between Vila Franca de Xira and Algés and in small water courses from the western part of the Mafra municipal.

The Lisboa, Loures, Mafra, Odivelas and Vila Franca de Xira municipals are all entirely serviced by this system. Besides these five municipals, SIMTEJO also provides service to part of the Amadora's sewer system. Therefore SIMTEJO covers a total area larger than one thousand square kilometres and services approximately 1.5 million inhabitants from six municipals.

With the objective to control pollution levels in the receiving waters the SIMETJO system includes 26 WWTP, 55 Pumping Systems and 125 km of sewers distributed through subsystems like Alcântara, Beirolas, Chelas, Frielas and Bucelas, São João da Talha, Vila Franca de Xira and Mafra.

Chelas sewer subsystem

The Chelas sewer subsystem serves more than 140 000 inhabitants and it is divided into four main trunk sewers with a length of 3300 m and 131 manholes. The system also includes a screening chamber and five pumping systems, and includes various weirs in order to separate domestic effluents from the combined system and transport them to the interceptors or the pumping stations.

The average depth, average slope and length distribution of the sewer reaches are presented in Figure 1.

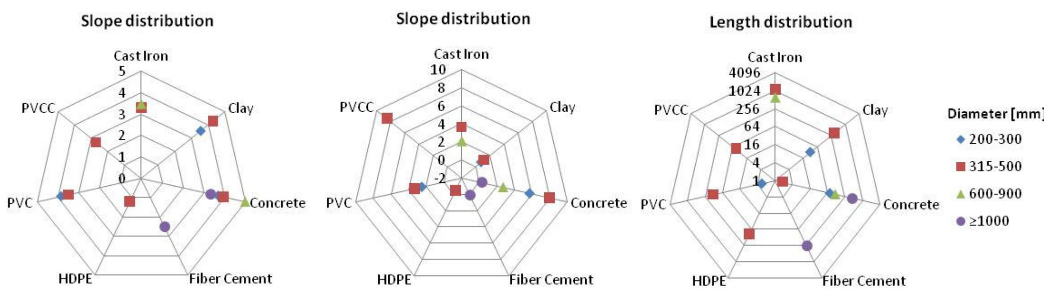

Figure 1 – Depth, slope and length distribution of the sewer reaches of Chelas subsystem.

The model was applied to the Chelas sewer system (SISAQUA et al., 2006). In terms of risk of structural collapse, 10% of the reaches where classified of high risk, 36% of medium risk and 54% of low risk. The cleaning evaluation concluded that 15% of the sewer reaches are classified as high risk, 16% as medium risk and 69% low risk. The main results are presented in Figure 2 and 3 for inspection and cleaning respectively, according to pipe material, diameter and slope. The Figure 4 it is presented an analysis of the cleaning and inspection evaluation related with the average depth.

These results are generally coincident with the experience of the system managers and operators, especially in terms of cleaning priorities, where there is more experience and sensibility.

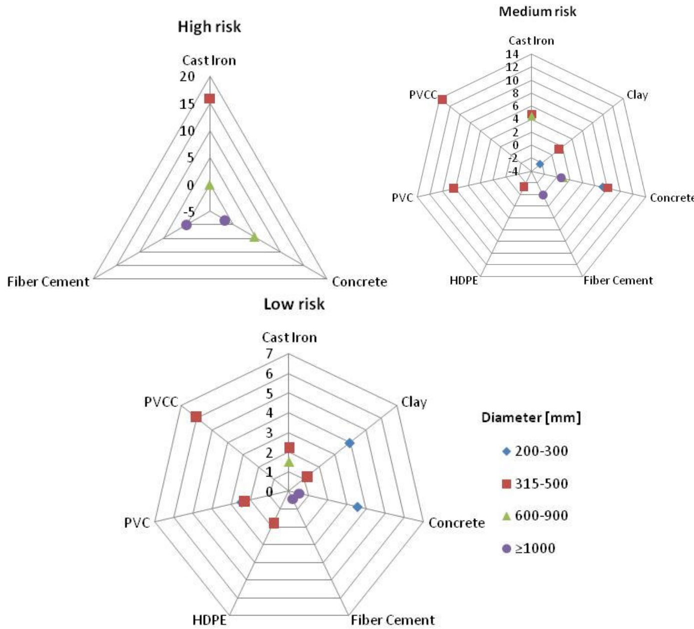

Figure 2 – Inspection evaluation results.

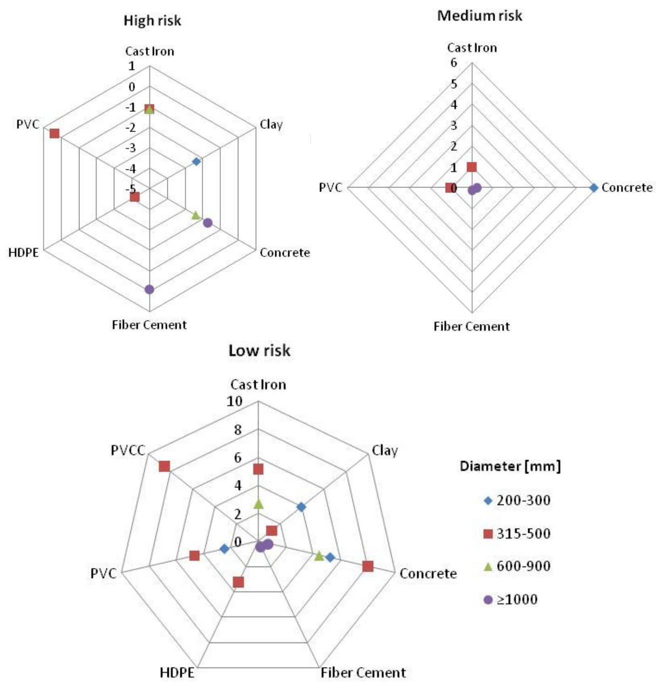

Figure 3 – Cleaning evaluation results.

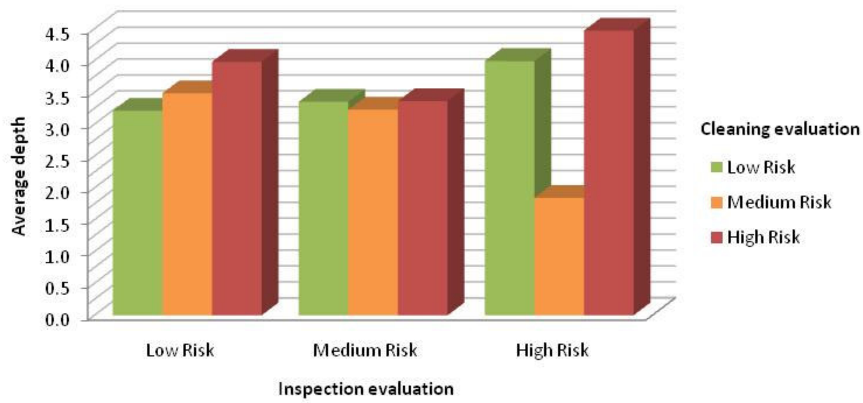

Figure 4 – Inspection and cleaning evaluation according to average depth.

Conclusions

This approach was developed to help SIMTEJO establish operation and maintenance strategies in a scenario of very scarce and incomplete information about the existing system. Due to the scarcity of information and records, it was selected a general expert system using several parameters that are known to influence the performance of sewer networks Parameters or variables such as sewer condition, land use, wastewater characteristics, were not taken into account due to lack of appropriate data.

Because the main objective was the definition of priority interventions based on a "failure oriented forecast", the model does not optimize the results taking into account the economical, environmental or social costs resulting from failures.

Therefore, the presented model, presently in implementation stage, will benefit in future with the following advances or developments:

- calibration of the parameters and weight factors based on the data from the cleaning and inspection operations;
- possibility of increasing the accuracy of the model trough the consideration of further relevant factors, namely the structural sewer condition.

Once the inspections start to allow modelling the sewers ageing, it will be possible to predict rehabilitation needs. This will be the first stage to implement a fully integrated technical management decision tool, which also do require hydraulic, environmental and, eventually, social models of the system.

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