Risk based asset management for wastewater systems

Gestion patrimoniale des systèmes d'assainissement fondée sur l'analyse de risque.

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RESUME

Les plans d'investissement élaborés actuellement par les services d'eau et d'assainissement tendent à sous-estimer le coût de maintenance de leurs infrastructures souterraines. Le but de la gestion patrimoniale est de trouver un équilibre entre la nécessité de limiter les défaillances et le coût que cela induit, en allouant les investissements de sorte que les opérations de maintenance soient très majoritairement planifiées, et le moins possible consacrées à remédier à des événements imprévus.

Définir clairement le niveau de qualité du service qui doit être assuré à l'usager est la première étape d'une gestion patrimoniale orientée vers la prévention des risques de défaillance ; ce niveau de qualité de service doit tenir compte de l'état des infrastructures.

Cette communication insiste sur l'importance de la gestion patrimoniale pour les systèmes d'assainissement, et retrace l'évolution qui a conduit au concept de Système d'Aide à la Décision fondé sur la gestion du risque. La mise en oeuvre de stratégies de gestion patrimoniale dans un cas réel en Italie est aussi abordée

ABSTRACT

Current investment plans by water and wastewater utilities tend to underestimate the cost of maintaining their buried infrastructure. The asset management goal is to find the balance between cost and limiting the number of system failures by maximising planned maintenance and minimising unplanned maintenance in capital investment decisions.

The definition of clear levels of service to be reached or provided by the utilities is the first step of a risk based asset management strategy - levels should be based on the physical condition of the system and all its components.

This paper describes the importance of asset management concerning sewers and the evolution of the concept of management using a Decision Support System (DSS) approach to risk based management. The application of asset management strategies to a real Italian case study is also introduced.

KEYWORDS

Asset management, condition assessment, risk, sewer.

1 INTRODUCTION

The need for accurate assessment of sewer condition is increasing world wide in order to manage system degradation with reduced resources. Problems encountered due to poor asset condition that arise in old sewer lines are numerous. Examples of these problems are major collapses of pipelines due to groundwater infiltration, and exfiltration of sewage into the groundwater and the surrounding soil causing significant and long lasting environmental pollution.

Cracks, settling, tree root intrusion, and other disturbances that develop over time deteriorate pipelines and other conveyance structures that comprise wastewater collection systems, including stormwater, sanitary and combined sewers. Leaking, overflowing and ineffective wastewater collection systems can lead to the release of untreated wastewater into receiving waters.

Multi-objective risk based approaches (including operational risk, economic risk, social and environmental risks) connected to urban drainage failures are available in the literature and have sometimes been tested in real cases (Kenneth Harlow, 2005, Digman et al, 2004, Fenner, 2000); however, they are quite often limited by insufficient system knowledge needed to evaluate the possible consequences of failure, or the transition from reliable systems to failure – prone systems, or failure evolution paths and criticality of the system.

In the water and wastewater field the risk based management of structural and hydraulic performance risk is focused on prevention and mitigation of damage.

Risk based asset management supported by condition assessment of wastewater systems is the current approach in asset management field. However the history of asset management started long time ago.

In the past, and nowadays as well in many realities, network management was based on a reactive approach: operational quality of the system was ensured by technical operators running from one side to another of the network repairing and rehabilitating the failing components. The following step drove utilities to a proactive approach: why do we wait for system’s failures when it is possible to prevent them? A proactive and preventive repair strategy for urban drainage systems is often more cost effective than the traditional approach of reactive sewer maintenance. The most advanced utilities, started a process of data collection, hydraulic modelling, digitalisation of all the possible information related to the reliability of the managed system. This choice turned to be economically convenient in the long term even if lot of resources needed to be invested at a first phase of system inventory. Not many utilities could afford such expensive investments especially if compared with the budget usually directed to water and wastewater systems maintenance. Results start telling that was the right direction and convincing more and more managers: a slow mind – changing process started.

At the same time multicriteria decision support have been developed by researchers. Those data-hungry systems while promoting data collection, were also taking advantages from the increasing data availability. The 5th Framework programme of the EU supported research centres in developing integrated software dealing with public sewer and storm water networks of any dimension. The creation of new software started all over Europe. The final products have been Decision Support System (DSS) to enable municipal engineers to establish and maintain effective management of their sewer networks. Software, like the ones of the CityNet cluster, include analysis of problems caused by ageing, structural failures, inflow/infiltration, exfiltration (leaking) and insufficient capacity which can cause floods, pollution of receiving waters, pollution of ground water and soil, treatment plant impacts and increasing maintenance costs [Sægrov, 2006].

The ultimate output of the DSS is to provide the most cost-efficient system of maintenance, repair and rehabilitation of sewer networks, with the objective to guarantee security of sanitary sewage collection and storm water drainage in order to meet social, health, economic and environmental requirements. This has to be done within the context of integrated catchments management and the strategic objective of ensuring security of water resources.

The circulation and application of these instruments to real case studies highlighted how different priorities can have components with the same characteristics if operating in different conditions. It is not only the component performance driving the maintenance decisions but also the evaluation of damage produced by failures if occurring to that component in defined local constraints. Risk based asset management sprouted from this basic understanding: the weak point of a system performance is not simply the consequence of its aging process, the weak point is the combination of the aging process and the severity of consequences of failures likely to happen in connection with aging.

2 ASSET MANAGEMENT OF WASTEWATER SYSTEMS

An infrastructure asset is any capital asset that is operated as a system or network, such as a sewer collection system.

Asset management implicates a structured format, a sort of flow chart of actions to be undertaken and organised. The starting point is the definition of levels of service and the identification and valuation of the asset. A risk analysis has to be developed including failure impact evaluation based on system condition assessment. At the same time the financial management of the system identifies the budget needed to meet level of service goals. Tradeoffs between costs, acceptable system conditions, severity of consequences of probable failures are made looking at different maintenance strategies.

Moving form the general definition to the specific field of wastewater networks, a basic level of service to be defined by utilities is to deliver reliable sewer collection services at a minimum cost, consistent with water quality and quantity standards, maximum water levels, allowable discharges, overflow frequency discharges and structural condition standards. The performance of the sewer system is evaluated against its ability to transport without hydraulic overload creating minimal ecological damage and retaining good structural integrity.

Level of services can be derived directly from regulations as EN 752, the Water framework Directive (Directive (2000/60/EC)), or for Water pollution coming from urban waste water and certain industrial sectors in the Urban Waste Water Treatment Directive(91/271/EEC), or levels of service can be left to the discretion of the individual utility aiming to solve specific tasks.

A fundamental step is to monitor the asset in order to determine and measure the system performance and asses if level of service are met.

To that purpose the utility has to define performance goals for sewer system inspection, cleaning, maintenance, rehabilitation and goals for the reduction of severity and number of blockages, for maximum hourly and monthly peak flow volumes, for maximum frequency of flooding events in the system in a given time, maximum emergency response time to emergency calls.

Asset identification and evaluation is the process of identifying and numbering the primary components in the sewer system.

A strategic task has to be planned at this stage: the development of a complete asset database where components are named with unique identifiers and where components can be linked with visual inspection records, hydraulic and GIS models, information systems and aggregate data for financial, economic, technical, environmental and management use.

Complete a sewer system database is an expensive and time-consuming undertaking that must be carefully planned.

The sewer asset capitalized amount, at the sub-system or at the system level, is calculated as the asset acquisition cost, plus capital improvements reporting the accumulated depreciation.

Sewer systems possible defects and misfunctions are numerous and varied. So are failures. The utility can only address defects and misfunctions for which there is information available about their possible occurrence, intensity and probability, and which are to be considered as failures. A defect or misfunction becomes a failure when it impedes to meet levels of service. The potential impacts from sewer failures should be assessed on a system-wide basis. The goal is to identify those areas of the system that will have the most impact if a failure occurs, and focus asset management resources to minimize the risk.

Failure severity should be characterised by using severity factors such as location within the system, intended service function, proximity to public areas or environmental resources, hydraulic stresses, surrounding environment. Critical areas can be classified by zones, individual segments, or sub networks within the sewer system.

Condition assessment is performed to identify assets that are under performing.

To understand when and where different rehabilitation technologies can be employed requires specific knowledge of the asset's condition: as the sewer infrastructure deteriorates the extension to which work is required and the methods available for repair change. Knowledge of system condition is essential to rationalize not only what to do but when to do it. Inspections are required as very effective approach in precisely locating and aiding in the identification of common problems and defects first and to develop reliability study with data collected secondly.

A key question that needs to be answered lies in what kind of data are required from CCTV inspections in order to guide the wastewater utilities managers to plan them. The defects are characterized based on a standard notation system that is used by all field inspectors. The defect data gathered in the field are entered into the asset management system to allow analysis of the overall structural integrity and operating condition of each component. Some asset management and inspection software applications (like the ones developed by IBAK in Germany) automatically evaluate the types and distribution of defects found in each component and assign a condition rating, while others allow the collection system manager to assign the rating manually.

When identifying and assessing which approach to adopt in managing the system, a major factor to consider is whether a proactive or reactive approach has to be taken; for example, whether the components will be left to operate to failure, or whether a component will be replaced or proactively maintained before an unacceptable failure occurs, and in the later case whether condition monitoring or active protection techniques will be introduced to mitigate risk (Burn S. et al.2005).

Planning should be performed annually and updated as needed to address changing conditions. Maintenance activities are either planned or unplanned.

The asset management goal is to maximize planned maintenance and minimize unplanned maintenance.

3 WORKED EXAMPLE

This section presents a worked example. The case study is located in Italy. The aim of this chapter is to describe the application of a methodology for the definition of asset management strategies as the topic of an ongoing 2 years research started in March 2006. The current results are strongly influenced by the lack of condition assessment data, but we expect more reliable results in the next six months as consequence of a planned data collection activity.

Correggio wastewater network is the system selected for the application. Correggio is located at 12 km North – East from Reggio Emilia in Emilia Romagna region in Northern Italy.

Correggio is a small town of 20769 population where no major large scale new development is planned. The sewer system is managed by ENIA.

The sewer system has a total length of 92,7 km: the 63% is combined sewer system, 32% is separate system, 2% represents open channels and the remaining 3% is unknown, being located in Correggio downtown. The 78% of the pipes are concrete, while the rest are mainly PVC (Ugarelli et al., 2005).

The drainage system includes 888 pipes and 816 nodes, further subdivided into 769 manholes, 6 ponds and 14 outfalls. There are 2 manholes with pumps stations.

The system has a history of recurrent flooding and has suffered several collapses.

The performance requirements for rehabilitation planning were discussed with the sewerage undertakers. It was decided that both the structural and the hydraulic performance of this system should be investigated. The factors which justify investigation were:

- Existence of serious structural problems in the town centre;
- The extent and scale of past flooding problems.

3.1 Data collection

The Correggio network has been modelled by using the InfoWorks hydraulic model (Maglionico et al., 2004).

The first step done was the creation of a complete asset database with standardisation of information to make use of existing information. The database format and data standardisation selected are the ones provided by the software CARE-S (Sægrov, 2006).

The physical attributes imported from the hydraulic model have been the topology of the network, pipe sizes, pipe shape, invert levels of pipes, pipe material and manholes cover levels. In addition data regarding catchment condition, hydraulic load of surcharge, groundwater levels, traffic and surface loadings, soil type, age and construction techniques, frequency of CSOs have been collected. Operational data such as previous blockages/maintenance/rehabilitation history have been included in the database.

CCTV (Close Circuit Television) inspection data were available for only 20/888 pipes of network. The information have been given in the video record format: relevant CCTV codes (referring to EN13508-2) were established through careful inspection of the 16 CCTV movies available and manually imported into the database.

3.2 Level of service

Three groups of level of service have been used, according to WRc Sewerage Rehabilitation Manual (WRc plc, 2004):

- Public health/flooding: different criteria has been applied depending on the type of land use affected by flood water and depending on whether buildings are residential, commercial or industrial and the depth of flooding.
- Structural: the structural integrity of the sewer have been measured by assessing condition grades to inspected pipes, by calculating pipes probability of collapse looking at pipes material, age and loading condition, and by evaluating pipe frequency of blockages on the basis of historical data.
- Hydraulics: the hydraulic performance of the system has been modelled and compared with observed events referring to self cleansing capacity of pipes, flooding probability, frequency of Combine Sewer Overflows (CSOs).

3.3 Condition assessment

The sewer infrastructure inspected has been classified into the discrete condition states known as structural performance grades or SPG's that have the following implications:

SPG	IMPLICATION
4	Collapsed or collapse imminent
3	Collapse likely in the near future
2	Collapse unlikely in the near future but further deterioration likely
1	Acceptable structural condition

Table 1structural performance grade for inspected pipes

Of the 20 inspected pipes, 8 have been considered in class 4, 6 in condition class 3, 6 in condition class 1.

3.4 Probability of failure

Probability of structural failure is determined through the application of age-related failure prediction due to material degradation. The method assumes that sewer pipes displays an approximately normal and exponential distribution of failure overtime due to material breakdown (Terry, 2005).It assumes that no failures of this type occur earlier than 20 years after installation.

Table 2 below summarises life service data applied to include pipes durability in the model.

Durability is the property to resist erosion, material degradation and subsequent loss of function due to environmental and/or other service conditions.

MATERIAL	FIRST FAIL	REMAINING LIFE	TOTAL LIFE
Concrete	20	90	110
PVC	20	80	100

Table 2material and asset life information for sewer and drainage pipe

Historical data show that users can expect a product life of 100 years or more for concrete pipe. Concrete does not experience significant creep or stress relaxation as it ages, thereby minimizing deflection and increasing service life.

Unlike other pipe materials, PVC sewers has no failure histories in the Correggio systems. Therefore, establishing a realistic predicted life is not possible using statistical analysis of historical field failure data, but literature provides PVC pipes service life evaluations as results of tested sample for selected mechanical properties and joint performance characteristics which might be considered age dependent (Whittle, 2005).

Probability of blockages as been calculated by calibrating the probability function at pipe level with data derived from paper repair logs and from CCTV codes reported therein; thus far 46 blockage events were localized in the period April 1998 - November 2004.

Probability of hydraulic failure has been assessed of the basis on national standards. Using a GIS interface system support the most critical components of the system, at the pipe level, are shown. Criticality is evaluated from the environmental (CSOs frequency and volumes discharged) and hydraulic (probability of exceeding an user defined water level inside pipes and self cleansing capacity of pipes) point of view.

3.5 Risk based financial management

The ultimate aim of the 2 years project is to find an explicit relation between the total cost of maintenance interventations and its effect on the reliability index considered as reduction of deterioration rate of reliability.

The performance objective in the system vary according to the risk associated with the failing elements. To look at the impact of interventation at various points in the deterioration cycle a review was carried out of all sewers inspected to date, that unfortunately was only the 0,25% of the whole pipe collection system. Potential rehabilitation strategies have been assigned on pipe basis. Average cost to rehabilitate each segment was determined for each structural performance grade, according to the end user experience.

A simple function to minimise based on the present value of all sewer condition dependent costs over the planning term (N periods of Δt years) (Burgess, 1994) was applied as first tentative:

$$\sum_{K=1}^{N}[T_k = R_k + W_k + C_k + I_k + o_k](1+r)^{-k\Delta t}$$

where:

R_k: rehabilitation costs,

W_k: the water quality degradation;

C_k: the damages resulting from sewer collapses;

I_k the treatment of clear water entering as infiltration through pipe defects;

O_k the operation and maintenance costs;

T_k the total cost at each time step;

r: annual rate of interest.

Collapse costs were computed using the failure probability assigned to each structural performance grade multiply by the average damage costs associated with the observed sewer collapse incident.

The result was not really sensitive to the degree of rehabilitation selected. This is due to three weaknesses of the approach:

- The economic formula mixes costs of action with cost of damage.
- The method depends on structural performance grade and consequently to availability of CCTV data.
- The method fails to take into account social costs.

After the organisation of the facility data system to the scope of the project, further developments are scheduled for next to 2 years with the challenge to anticipate all the costs that are likely to occur over the service life. The goal is to develop a procedure separating the damage costs from the interventations costs as asset value, inspections as well as scheduled maintenance, repair, rehabilitation, and/or disruption of the service. Estimates are required for useful survival life, salvage credits, residual value, discount rate, and time period of analysis. Optimal time period for life cycle analysis include service life, expected survival time to earliest rehabilitation, time to anticipate capacity increase and any other period consistent with the constraints of the owner of the facility.

Meanwhile the data collection has to run parallel to the method development. To allow a future validation of the research, a CCTV inspection plan for the next 6 months has been defined together with the end user looking at the defined levels of service and system current performance. The objective is to complete the data collection in order to run the procedure, compare the output with results previously obtained for the same system running the software CARE-S (Sægrov, 2006), in order to validate, correct and improve the methodology.

4 CONCLUSION

In this paper the challenge of applying the asset management procedure to wastewater system is described. Asset management goal is to improve system reliability under the budget constraints. Often investment plans by water and wastewater utilities tend to underestimate the cost of maintaining their buried infrastructure and optimisation methodology has to be developed in order to find a balance between proactive and reactive rehabilitation strategies. Optimal solutions have to be evaluated using simple, not data hungry models in order to couple with the common lack of information available.

A first tentative of application on an Italian case study is described, but not consistent results are available since the data collection is not completed yet.

Further developments are scheduled for a 2 years project with the challenge to develop management strategies which allow maintenance activities to be planned across all the sewer pipes in a network by better calculation of annual risk cost of single components. The final goal is to look into risk/vulnerability by analysing the expected operation and maintenance costs following degradation of all actual materials using levels of service as the final measure for the analysis, and provide a service-life analysis based on physical facts on materials.

Uncertainty of any of the procedure elements may seriously skew the outcome of life cycle analysis. Experiences with pipes of different materials in local environmental similar or completely different to the drainage facility of interest should be a major influence in the assignment of expected survival life.

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