Computer Aided Rehabilitation of Sewer and Storm Water Networks (CARE-S)

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Abstract Sewer and storm water systems in cities worldwide suffer from insufficient capacity, construction failures and pipe deterioration. The consequences are structural damage and local floods leading to inflow of water into basements, traffic disturbances, street and surface erosion, and pollution of local receiving waters.

CARE-S is a computer based system developed to meet this challenge. It is designed for sewer and storm water network rehabilitation planning. It provides fundamental instruments for estimating the current and future condition of sewer networks, i.e. performance indicators, selecting and ranking of rehabilitation projects and long-term investment needs. The procedure for selection and ranking of projects is supported by tools for analysis of structural failures and hydraulic performance. Socio-economic issues are also included in the priority ranking process of CARE-S.

Background

Sewer and storm water systems in cities worldwide suffer from insufficient capacity, construction failures and pipe deterioration. The consequences are structural damage and local floods leading to inflow of water into basements, traffic disturbances, street and surface erosion, and pollution of local receiving waters.

The reasons for the problems are the combined effects of ageing infrastructure, urbanisation and climate change. European cities spend in the order of 5 billion € per year for wastewater network rehabilitation. This amount will increase significantly over the coming decades, due to network ageing.

Today, the rationale behind rehabilitation decisions is unclear. Decisions are often made ad hoc and, in the best case, are based on practical experience after failures appear (reactive approach). This is the background for a project in the 5th Framework Programme in EU, Computer Aided Rehabilitation of Sewers and Storm water networks (CARE-S). The project objective is to establish a rational framework for sewer network rehabilitation decision-making. CARE-S aims to improve the structural and functional reliability of the wastewater networks (risk of in- and exfiltration, collapse and blockage due to pipe deterioration, hydraulic overloading resulting in flooding and/or receiving water pollution). This is combined with the analysis and, where necessary, upgrading of the network capacity to take

care of runoff from rainstorms and snow melt in urban areas. The ultimate product will be a Decision Support System (DSS) that will enable municipal engineers to establish and maintain effective management of their sewer networks. In other words: *Rehabilitate the right sewer at the right time by using the right rehabilitation technique at a minimum total cost, before serious failures occur (pro-active approach).*

Some analytical tools to assess the technical or functional state of sewers or the needs for rehabilitation are available or are under development. Usually, though, they do not take into account all aspects of rehabilitation decisions, and they only have been applied for a limited number of wastewater services.

The objectives of CARE-S are to improve these tools, link them and to make them usable for the formulation of a rehabilitation strategy. The DSS will include the following elements (Fig.1):

- a tool generating Performance Indicators (PI) that are relevant for rehabilitation decisions, including analytical and statistical procedures to assess and forecast some of the PIs
- a procedure to define the socio-economic and environmental risks of malfunctioning sewer systems
- a database to be used for choosing an appropriate rehabilitation technology
- a tool to define the best long-term strategy for rehabilitation investments
- several tools that allow to assess the hydraulic, environmental and structural conditions of the network including their change over time.
- a multi-criteria decision (MCD) tool supporting the choice of high priority rehab projects
- a software package, called "Sewer Rehab Manager" that will enable consultants and wastewater service providers to use the above products according to their individual needs and available data base.

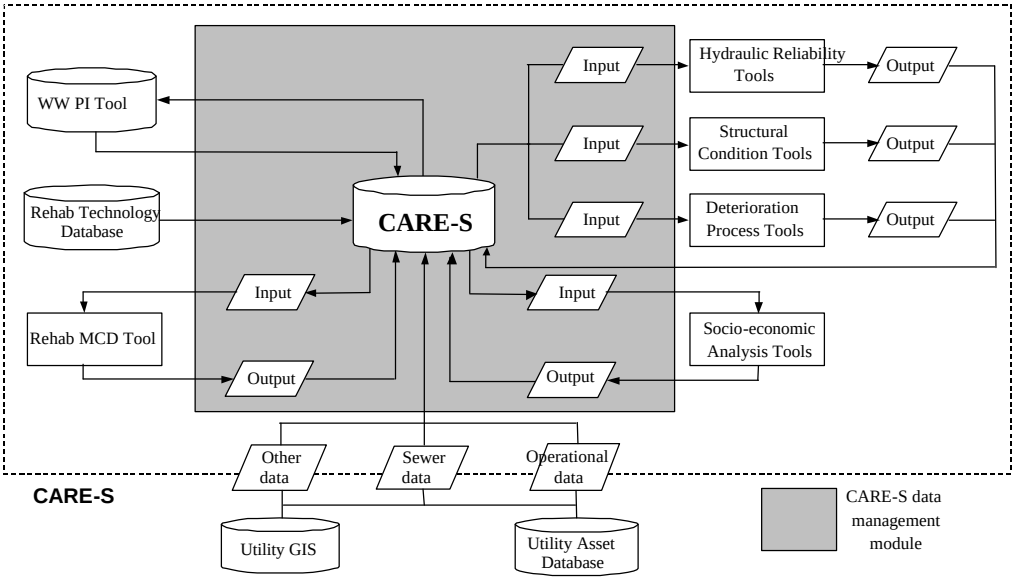

Figure 1. The general architecture of the CARE-S Sewer Rehab Manager

The project is carried out as a joint European initiative supported by the European Commission under the Fifth Framework Programme for Research and Development, and has a budget of 5 million Euro. 14 European and 1 Australian partner are involved, together with 19 cities ("end-users") representing all parts of Europe. CARE-S started 1 October 2002 and will last for three years.

Preliminary results

Construction of a control panel of Performance Indicators (PI) for rehabilitation

A PI (Performance Indicator) tool addressing information relevant for sewer and storm water network rehabilitation has been developed. It is based upon comprehensive and quality-controlled information from 32 project partners and end-users. The final listing includes 41 PI in total. Additionally, a large number of Utility Information (UI) and External Information (EI) have been included in the system. Version 1.0.0 of PI tool and program installation package is completed.

The general criteria for selecting PI for wastewater rehabilitation were among others:

- to represent relevant rehabilitation aspects of wastewater undertakings performance, allowing for a global representation of the system by a reduced number of performance indicators
- to be clearly defined with a concise meaning an a unique interpretation for each indicator
- to be auditable, which is specially important when the performance indicators are to be used by external bodies (i.e. regulators) that may check the results reported.

A questionnaire to verify 35 pre-selected PI was answered by 13 Partners and 20 End-Users. The receivers were asked to rank the PI regarding importance and assess. Based on the answers, the list of PI was extended to 41.

The questionnaire revealed that partners tend to overestimate the importance of PI in comparison with end-users. In general the Partners also tend to be more "optimistic" than End-Users concerning the PI assessment.

PI relies on qualified definitions. Therefore, a glossary of rehab terms has been developed. It includes mainly a set of definitions referred in European Standards, with some additional definitions from WRc Rehabilitation manual.

The first version of the PI tool is currently being tested by 20 End-Users. They will provide information to be used for benchmarking of the CARE-S PI. The benchmarking will thereafter be used to develop a "band of recommended values" for the various PI.

Description and validation of technical tools for structural condition

An analysis of CCTV data classification has been launched. This is used as the input to high level models dealing with the entire system as well as detailed structural models of blockages and in/ex-filtration that are currently being developed.

The structural condition of a pipe depends on material, construction practices, external load and wastewater characteristics. Previous research has shown that pipes laid within certain time periods have been structurally under-designed, and that construction practices

within some time periods have not been appropriate, thus leading to particularly frequent failures. The formation of hydrogen sulphide that occurs in some wastewater networks will lead to a microbiological deterioration and loss of strength for concrete sewers, and is a very important reason for rehabilitation actions. Other reasons are root intrusion and substantial in- and ex-filtration through fissures and leaky joints.

Structural analysis of sewers is normally based on results from CCTV inspection. In Europe there are several systems currently being used for the classification of individual data from such investigations. A standard European code for the description of sewer damages has been developed and recommended to the member States. In general, the condition of sewers is classified according to its most severe damage or overall condition to determine the urgency of rehabilitation and calculate the cost of rehabilitation.

In CARE-S, different models for the classification and assessment of the sewer condition is analyzed and tested with CCTV data together with other types of data, provided by end-users. Aggregated models deal with the entire network. They calculate the distribution of condition defined by classes, and is applied to networks. Detailed structural models deal with issues important for the hydraulic performance and structural condition on a local (pipe based) level and is applied for single pipes or group of pipes. They comprise structural failures, strength reduction due to hydrogen sulphide attack, pipe blockage and in-exfiltration of water. The models are developed or improved and calibrated with such data from the end-user sewer networks. The models allow a forecast of the year in which a sewer will fail or enter a critical class of condition, thus determining the next inspection date or rehabilitation measure. An overview of models is presented in Figure 2.

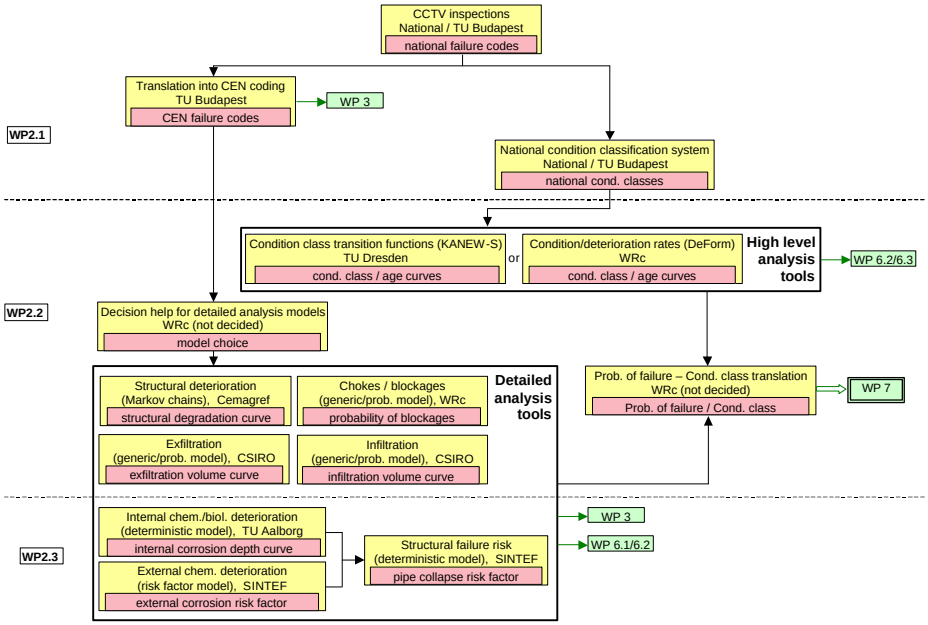

Figure 2 Overview of models for structural assessment of wastewater networks

Description and validation of hydraulic performance

Structural decline of sewers is described by CEN-code classes (e.g. obstacles, roots, displacement of joints, intruding pipes). Their hydraulic effects are modelled using 3-D CFD

software (FLUENT) and "translated" into a simplified 1-D description for application in hydraulic models such as MOUSE, InfoWorks, and SWMM.

A study on best practise on wastewater modelling has demonstrated that single models have reached high levels of reliability. Still further progress is needed on model integration in order to achieve a global control on urban water analysis. It has be decided to include three 1D models as basis for routines develop within CARE-S, namely MOUSE, InfoWorks and SWMM.

The second task comprises the modelling of temporal decline of hydraulic performance using CCTV observations and a 3D CFD software (FLUENT) for parameterization and validation of 1D hydraulic model (MOUSE, InfoWorks, SWMM). Test models at catchments of Palermo, Reggio Emilia and Oslo has been prepared for the testing of the routine that is developed in this work package, and the testing is promising.

As the third task, a procedure developed for assessing compliance of the sewer system with the environmental standard/target/threshold specified by the end-user (effects of rehabilitation works on ground and surface water) using conceptual infiltration/ex-filtration models.

The results on hydraulic performance are also connected to analysis of changes in future structural performance that may affect the hydraulic capacity, and socio-economic consequences. This integration makes it possible to analyse future hydraulic performance and the consequence related to flooding in sensitive areas.

Rehabilitation technology information system

An extensive rehabilitation technology database including available techniques, their advantages, disadvantages and application possibilities has been developed.

There are a variety of methods to rehabilitate wastewater networks. The method to be chosen obviously depends on local conditions, such as the type of the problem, the size of the pipe etc. The rehabilitation costs are linked to the applied method and technology.

The content of the rehabilitation technology information system can briefly be summarized as:

- General survey of available techniques and contractors. Analysis of experiences and results.
- Complete chart for the variety of methods in rehabilitation of sewers. Current state-of-the-art, including rates, range of applicability, limits and restrictions.
- Cost of rehabilitation linked to the applied technology.
- Alternatives for rehabilitation: redesign of sewers, operational methods.
- Criteria for choice-making of suitable techniques related to sewer problems.

Rehabilitation of sewer and storm water networks includes system improvements (detention basins, separation of storm water etc) as well as renovation technology. During the last 20 years, there has been an extensive development of technologies for sewer and storm water rehabilitation. Today, a large variety of methods exist to meet problems in small sized as well as large sized pipelines. Several cities use renovation as their first priority measure against structural and hydraulic decline.

By using the database, the End User is invited to analyze which measures are appropriate to meet various kinds of problems. A list of measures and problems they should apply to is presented, considering their potential for pipe failure in one hand, and their characteristics leading to more or less social disturbance and annoyances on the other hand.

Also, attention has been brought to the innovative question of establishing the explicit links between the rehabilitation techniques (with or without trench) and the other aspects of

wastewater rehabilitation, such as disturbances to the citizens, hydraulic benefits, mechanical benefits and durability, and economical issues.

Socio-economic consequences

Socio-economic consequences including rehabilitation impact on socio-economic cost and quality of life, public acceptance and communication with public is investigated.

Rehabilitation impact on socio-economic costs

Very little quantitative information is available on the direct and indirect costs of wastewater network failures. Information is also scarce and scattered on social costs of rehabilitation works.

CARE-S will help addressing the socio-economic ("indirect" or "external") costs linked to rehabilitation decision: impacts of failures and impacts of rehabilitation works to third parties. The present draft definition of "social costs" considered by the project is: the costs incurred by society as a result of sewerage works and for which utilities or companies have no direct responsibility out of possible compensation. The operational objective of this is to provide guidance and methods for assessing criteria for rehab planning representing social costs. This can be divided in two parts:

The first deals with criteria (on external socio-economic impacts of rehabilitation works) for comparing a limited set of technologies when considering a given single pipe. The technologies are described through outputs of the rehab technology information system. It provides criteria exclusively for selection of technology to specific projects.

The second deals with criteria (on external socio-economic impacts of network failures) for comparing various rehabilitation projects, defined each at pipe level. The failures (or potential reduction of failure risks thanks to rehabilitation) are related to each single pipe (the criteria have to consider the impacts at this scale), and are described through results of the structural condition and hydraulic performance modules.

This task includes definition of a conceptual framework accounting for the links between technical, economic and social aspects, and bases on both synthesis of literature (methods, results of studies) and analysis of real world data (claims, compensations, failure events).

In connection with this analysis of field data, there is also an analysis of utility internal costs of social accompanying tasks linked to failures and works (management of claims…): these costs are on the border between internal and external social costs, they are usually not addressed as such or specifically quantified by utilities. Knowledge about these costs will be collected.

Rehabilitation impact on social life quality

This work aims to achieve a systematisation of:

- What the different users perceive as being the costs, e.g economic, social or personal, of rehabilitation works.
- What are the public levels of awareness to the importance of maintenance actions, repair and rehabilitation of sewer and storm water networks. This identifies a need to evaluate the extent to which individuals are aware of non-intervention possible risks and consequences related to network failures
- What are the levels of public tolerance to a set of interventions in their work or residential area.

Research on these three parameters is developed through the use of public inquiry methodologies (exploratory interviews, focus groups and questionnaire) in areas previously selected (case studies).

Public acceptance and communication with public

Based on the interviews, focus groups and questionnaire surveys, this task aims to provide decision makers with a better understanding of public perception and acceptance concerning sewer systems failures and rehabilitation (needs and impacts). This is meant to enable better communication with the public: prior explanations on projects, public participation …

Multi-criteria decision support

Choosing the right rehabilitation technology

The right/best sewer rehabilitation technique, in economic as well as technical terms, is chosen from a set of candidates fulfilling the requirements under specific local conditions. Direct rehab costs are systematically analysed and documented for a variety of open trenching and no dig rehabilitation technologies. Beyond these direct costs, the support system takes into account a multitude of other factors, which are usually collected by wastewater companies preparing a public tender on a specific rehab project. Although from a financial viewpoint, the waste water company would choose the lowest bid, it has also to consider external costs that are not charged directly to the waste water company, such as increased operating costs and travel times for road users.

Information on the new technologies is coming from the catalogue of rehab technologies, including more than 40 currently available rehabilitation technologies for repair, renovation and replacement.

The correct/best sewer rehabilitation technique, in economic as well as technical terms, is chosen from a set of candidates fulfilling the requirements under specific local conditions. This task has been elaborated by WRc, and has been divided into three discrete sections;

- Consideration of direct costs of different rehabilitation technologies;
- Consideration of the service life of these technologies, and;
- Procedure detailing the elements to be considered when evaluating the suitability of a rehabilitation scheme, based on direct costs.

Wastewater Network Rehabilitation Manager

The procedure for integrating the CARE-S tools into a cohesive rehabilitation planning package has been developed. The CARE-S Procedure is based on the integrated approach for rehabilitation planning described in EN752-5 and allows rehabilitation engineers to use the tools most appropriate to their planning needs and data availability.

The CARE-S Procedure has been presented in a report with the following content:

1. *A Generic Rehabilitation Planning Process*: a description of the general process that would be carried out when planning the rehabilitation of wastewater networks, regardless of the analysis tools available to the rehabilitation engineer. This set the scene for how the CARE-S procedure will improve the planning process.
2. *Applying CARE-S to Rehabilitation Planning*: a description of how the CARE-S procedure may be applied to the generic rehabilitation planning process. This has included the identification and definition of methods or software wools which can be used under the CARE-S “umbrella” to develop rehabilitation plans.

User interface for the Rehabilitation Manager

The user interface can be defined as any element of the Rehabilitation Manager with which the user will interact. This would include a number of functions, such as:

- importing and manipulating data;
- accessing tools;
- editing data;
- displaying data and reporting the results of analysis, and;
- interactive guidance.

Development of the CARE-S Rehabilitation Manager.

The rehab manager software will consist of a central MS Access 2000 (Visual Basic 6.0) database application with the following attributes:

- It will provide a central storage area and reference point for essential CARE-S data;
- It will accept user-validated input data in a pre-defined format. Data source fields will be mapped to fields within the CARE-S database according to the specification of the declared input data source;
- It will provide automatic conversion of data item units to standard CARE-S convention;
- It will allow user interaction with a pre-determined range of tools under the CARE-S umbrella;

The CARE-S team is currently compiling a full listing of all data elements required by the individual tools.

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