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REPORT

D16, December 2003

WP 6, Delivery 16
Procedure for Choosing the Right Sewer Rehabilitation Technology

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CARE-S - Computer Aided REhabilitation of Sewer networks

COMPUTER AIDED REHABILITATION OF SEWER AND STORM WATER NETWORKS
RESEARCH AND TECHNOLOGICAL DEVELOPMENT PROJECT OF EUROPEAN COMMUNITY

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CARE – S

Computer Aided REhabilitation of Sewer networks.
Decision Support Tools for Sustainable Water Network Management

WP6 – Multi-criteria Decision Support

Demonstrator D16

Procedure for choosing the right sewer rehabilitation technology

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Dresden, December 2003

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1 Introduction

The CARE-S project is funded by the European Community and aims to develop methods and software that will enable engineers of the water undertakings to establish and maintain an effective management of their sewer and storm water networks, rehabilitating the right sewers at the right time. The results shall be disseminated as a manual on Best Management Practice (BMP) for sewer network rehabilitation.

This project is organised in the following Working Packages (WP):

- WP1: Construction of a control panel of performance indicators (PI) for rehabilitation;
- WP2: Description and validation of structural condition;
- WP3: Description and validation of hydraulic performance;
- WP4: Rehabilitation technology information system;
- WP5: Socio-economic consequences;
- WP6: Multi-criteria decision support;
- WP7: Elaboration of CARE-S prototype;
- WP8: Testing and validation of CARE-W prototype;
- WP 9: Dissemination;
- WP 10: Project management

TUD is responsible for WP6, which is divided into three sub-tasks, each one with its specific objective, schedule, deliverables and methodology.

Task 6.1:

Choosing the right sewer rehabilitation technique, in economic as well as technical terms, is done from a set of candidates fulfilling the requirements under specific local conditions. Direct rehabilitation costs will be systematically analysed and documented for a variety of open trenching and no dig rehabilitation technologies. Beyond these direct costs, the support system will have to take into account a multitude of other factors, which are usually collected by wastewater companies preparing a public tender on a specific rehabilitation 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. These costs are elaborated in WP5. Sub-task 6.1 is scheduled for the first year of the project.

Task 6.2:

Selecting cost-efficient rehabilitation projects is required because the total cost of all viable rehabilitation projects usually exceeds the available budget. So the projects must be ranked by efficiency criteria in order to spend the money on those projects promising the most positive effects. Cost reductions from shared costs due to simultaneous rehabilitation of different systems will lead to an earlier date for optimal action. Other rehabilitation projects may have to be postponed due to lower cost-efficiency. The more efficient the projects are the more can be spent on other rehabilitation projects thus increasing overall cost-efficiency. With regard to the public interest, rehabilitation projects should be ranked on the basis of a comprehensive set of criteria and procedure as well as results should be transparent and easy to understand by political decision makers and the public. Multi-criteria methods will be prepared for wastewater network rehabilitation projects, tested and included in CARE-S. Sub-task 6.2 is scheduled for the second year of the project.

Task 6.3:

Rehabilitation programmes and strategies are developed in an interactive learning process, where alternatives are compared, evaluated and improved with respect to their costs and effects in the short and long run. This process needs support from special long-term forecasting and multi-criteria evaluation tools. The forecasting tools developed in WP2 and WP3 for the material and hydraulic deterioration of sewers will be complemented by forecasting procedures for the effects of specific rehabilitation programmes and technologies on a wide range of performance indicators as specified in WP1. A procedure will be established that allows forecasting and evaluating the effects of sewer rehabilitation programmes that are defined for a time period of 10 to 20 years with respect to annual mileage and technologies of rehabilitation of specific types of sewers. The procedure will allow the calculation of the monetary and non-monetary, direct and indirect long-term effects. Rehabilitation programmes will be evaluated according to dynamic investment planning methodology. While the pre-defined alternative rehabilitation programmes may not fulfil all network performance standards at minimum rehabilitation costs, some parameters from the set of rehabilitation options may have to be re-defined in order to meet the performance standards at acceptable costs. This will be facilitated by an interactive procedure to be included in the CARE-S prototype. Sub-task 6.3 is scheduled for the third year of the project.

In Figure 1, a simplified scheme of the general decision framework for sewer rehabilitation is drawn with potential inputs from other WP.

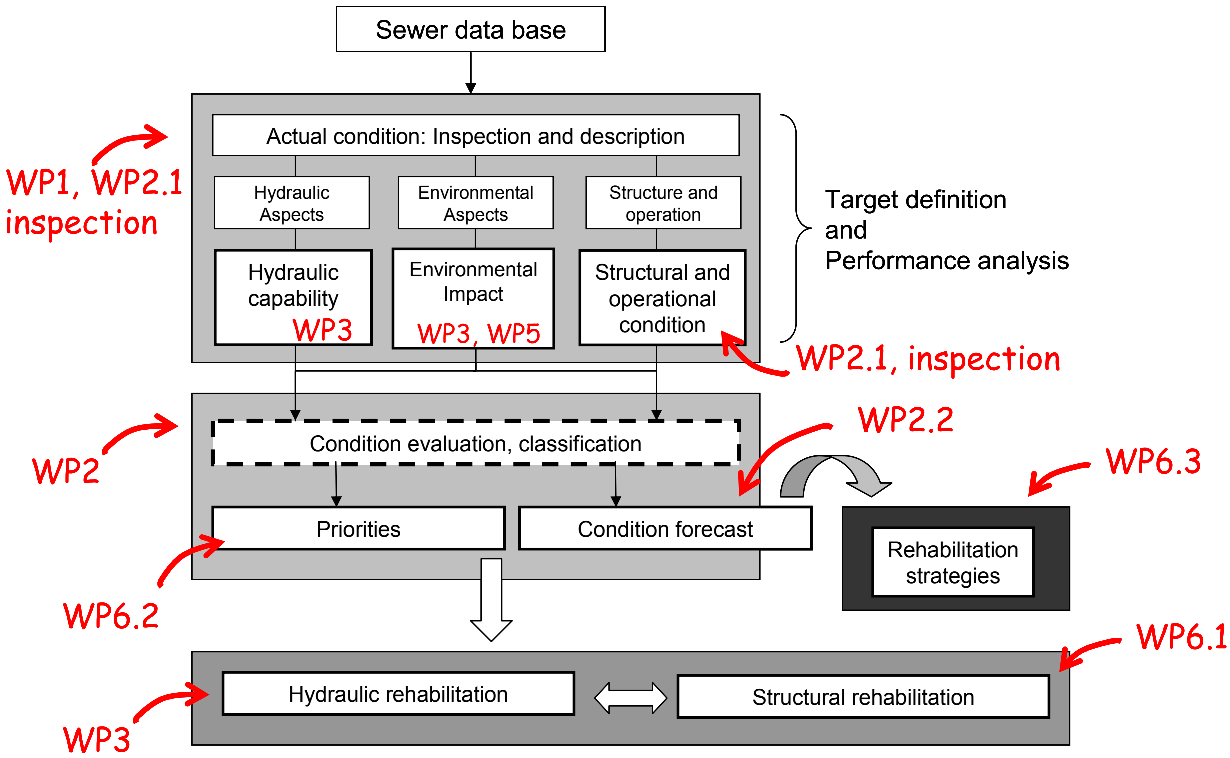


Figure 1: General scheme for inspection, condition evaluation and rehabilitation of sewer networks (following ATV M 149 and DIN EN 752-5)

This report refers to sub-task 6.1, the development of a tool for choosing the right rehabilitation technology.

Partners involved in sub-task 6.1 were asked for specific contributions:

Survey in public works departments or utilities (CARE-S end-users) on the choice of rehabilitation technology for specific cases of deteriorated sewers

TU Brno, see Appendix 1

- Creating of a standardised data set (text, figures, graphs and videos) of recently rehabilitated sewers.
- All 14 end-users should be asked to provide 2 or 3 well documented cases. The questionnaire should be in English and translated by the partners into the language of the end-user, and the answers re-translated into English.
- In addition to specific information on the project, end-users should give reasons why a particular rehabilitation technology was chosen and why other rehabilitation technology candidates were rejected or not taken into consideration.

The contribution was carried out in close co-operation with TU Dresden and CLABSA

Rehabilitation technology catalogue and criteria

CLABSA

- Detailed proposal of a catalogue with rehabilitation technologies and their associated characteristics and critical comparison with the result of our inquiry among the CARE-S partners and end-users for decision criteria
- Contribution to the questionnaire development for the case studies (TU Brno)

Economic evaluation of rehabilitation technologies

WRc, see Appendix 2

- Consideration of direct costs, development of relative costs
- Service life expectancies (prolongation) for rehabilitated sewers (different rehabilitation technologies)
- Development of a procedure for a cost-effectiveness-analysis including net-capital-values and annuities for rehabilitation options.

Using classification codes for automatic pre-elimination of technologies

TU Budapest Schedule: 18th July 2003, nothing received!!

- We expect an expertise on the possibilities of using the classification codes (according to EN 13508 and other models for CCTV inspection) for knocking-out particular rehabilitation technologies under specific circumstances (state of the sewer, environment)
- Comparison of the different coding systems that you have evaluated in sub-task 2.1 with respect to the pre-elimination of particular rehabilitation technologies the above mentioned task.

Methodological comparison: Application of an ELECTRE approach

Cemagref/ENGEES, see Appendix 3

- Comparison of the results obtained in subtask 6.1 with an alternative approach, developed by Université Marne la Vallée for selecting rehabilitation technologies. Application of the method to a pre-selected number of rehabilitation projects with given constraints. (schedule: January 2004)
- List of socio-economic criteria for the selection of the rehabilitation technology (WP5)

2 Decision criteria

The best rehabilitation technology is chosen according to its suitability at a particular site, and its relative advantages compared to other technologies. Thus, criteria are required for the elimination of unsuitable technologies, and for the comparison of suitable technologies.

Information on rehabilitation technologies is coming from a RT data base developed under WP4. The description of technical and environmental conditions of a sewer pipe selected for rehabilitation is coming from sub-task 6.2. The evaluation of rehabilitation technologies for the given conditions is done within WP5.

2.1 Requested information

In a first survey in December 2002, the CARE-S partners were asked for decision criteria that should be included in WP6. Four types of information can be distinguished:

- data coming directly from the end-user's sewer network data base
- information on the sewer's condition, either coming from the sewer network data base or from models developed in WP2
- information on impact to the urban environment and the potential risk of damages, with data coming from the end-user's data base, municipal data bases (urban GIS), or from calculations of social costs or the costs likely to arise from not rehabilitating sewers (WP5)
- information on the rehabilitation options, including technical applicability conditions, technology performance, environmental impact, direct cost and service-life estimates of the new asset

From this set of criteria suggested for sub-task 6.1, expected deliveries from other work packages were formulated and circulated among the partners by posting it on the BSCW server (*Work is underway to match known tool specifications to user requirements. The list below will be used as a checklist and proposed data structures will be circulated by WRc for partner discussion and correction in due course.*):

From end-user's data base
(Information should be stored in the prototype, **WP7**):
- Cross section of the sewer (diameter, shape, material)
- Slope of the sewer
- Combined sewer system or separate sewer system (wastewater, storm water)
- Average number of connections per meter
- Cross section of the connections (diameter, shape)
- Distance between manholes
- Existence of singularities in the sewer and type (rapids, falls, drops, chambers, diversions, weirs, …)
- Structural sewer loads (soil loads, traffic loads, others)
- Hydraulic sewer loads (pressure or gravity flow)

Sewer condition and deterioration rate (WP2)
(From inspection & classification, **WP2.1**, and from modelling, **WP2.2**)
- CCTV classification code and advice, how the code could be used for pre-selection/elimination of rehabilitation technologies (**WP2**, contribution Budapest)
- Detailed description of type and intensity of damage (Maintenance records, e.g. blockages, collapses, de-silting, tree roots etc, could result from CCTV inspection, WP2)
- Necessity of prior sewer maintenance (cleansing, roots cutting, etc.) and its cost
- Condition grade of
  - Sewer
  - Manholes

- Service connection
- CSO
- Pumping station
- Other installations…

- Expected/remaining sewer life of the original conduit

Sewer environment
(Information from end-user's data-base, stored in prototype (**WP7**, classification/ interpretation from **WP5**)
- Location (street type, traffic, vegetation, commercial areas, presence of public transport lines, building density, economic activity, conflicts with other urban infrastructure)
- Soil type
- Weather conditions (temperatures, rain frequency) in the region/season at the time of works development
- Receiving waters quality (**WP3**, external sources)
- Groundwater level (risk of pollution of groundwater or water distribution network,) relative to sewer depth (WP3)
- Risk of moisture/humidity on basements or tunnels (exfiltration) (**WP2** & **WP5**)
- Infiltration (overloading of treatment plants and increased pollution after treatment in those cases with nutrient removal) (WP2)
- Social sensibility (**WP5**)
- Political and social constraints (**WP5**)
- Time constraints (**WP5**)
- Odour in the urban environment (i.e. the degree of ventilation, **WP2**)

Rehabilitation technology (**WP4**)
From CLABSA catalogue of rehabilitation technologies, including information on:
- Range of manageable diameters
- Form of sewer profile
- Type of curable damage
- Material of sewer
- Reduction of hydraulic capacity
- (Reproduction of) static capability (does it meet the structural requirements?)
- Service life expectation (increased for the use of the technique?)
- Requirement of sewage bypass
- Ground space requirement
- Maximum length of reach
- Service line connection technology
- Bending restraints
- Certification of quality of work
- Impact on groundwater (possible pollution of it, due to constructions works, materials used, …)
- Impact on tree roots
- Period of construction work
- Duration of construction work
- Noise emission and vibration
- Direct unit costs
- Percentage of vertical deformation the technique can cope with
- Curing time
- Indirect unit costs impacts (WP5)
- Feasible alternatives (hydraulic rehabilitation or operational measures from WP3 or external sources, including costs)
- Expected sewer life of the rehabilitated conduit

2.2 Development of a criteria catalogue

The first objective is to compare available information on rehabilitation technologies relative to a description of the project(s) proposed. Information on rehabilitation technologies will come directly (or via the CARE-S rehabilitation manager) from the catalogue established in WP4 by CLABSA. The project description is taken from various sources (WP2, WP3, WP5 and end-user's data base) in a pre-defined format via the CARE-S rehabilitation manager.

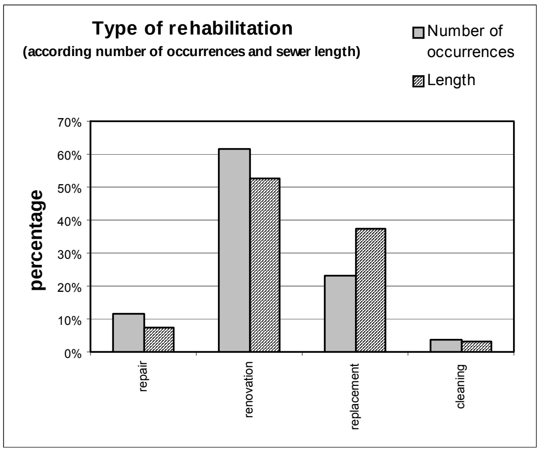
2.2.1 Survey on current practice and available technologies

In close co-operation with the partners from TU Brno and CLABSA, a survey among the associated end-users was initiated, asking for the documentation of two or three recently terminated rehabilitation projects in their networks (see Appendix 1). This was carried out due to the following reasons:

1. To find out which decision criteria are/were used by our end-users for choosing rehabilitated **sewer sections**.
2. To obtain descriptions of applied **rehabilitation technologies** and reasons for their selection.
3. To evaluate the **costs** of the used rehabilitation technology.

Summary of survey results

Co-operating end-users from 9 countries have returned 11 filled questionnaires providing 27 described projects (case studies). The results of the survey give an overview on how rehabilitation technologies are selected today, The majority of the case studies are examples of the application of trenchless technologies (Figure 2).



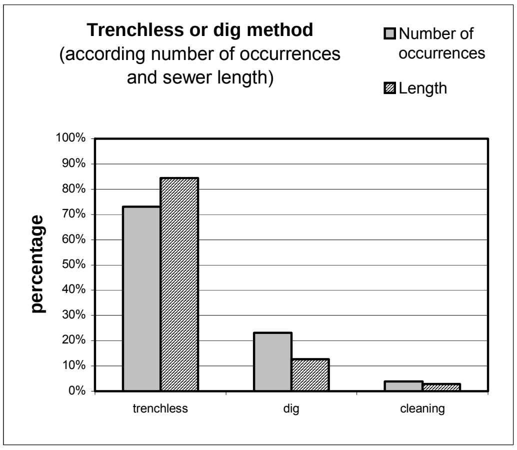


Figure 2: Type and method of rehabilitation for the 27 case studies

A more detailed summary of the survey results is given under Appendix 1.

Rehabilitation technologies

Information on the new technologies is coming from the catalogue of rehabilitation technologies (WP4), including more than 40 currently available rehabilitation technologies (WP4_Rtchart_v2.2.xls, posted on the BSCW server on the 6th June 2003; the latest version of the RT chart is considered for the software). Hydraulic solutions for the rehabilitation of the sewer network must be integrated into the catalogue of rehabilitation technologies. The options for hydraulic rehabilitation are the result of the hydraulic analysis in WP3. Appropriate descriptions of these rehabilitation options must be integrated into the structure of the rehabilitation technology catalogue.

In Table 1, information stored in the rehabilitation technology database (WP4) is set in relation to requested information (according to the listing above) for the description of the projects. So far, no cost information is available in the catalogue of rehabilitation technologies. Based on the findings documented in appendix 2, *Economic Evaluation of Rehabilitation Technologies,* the integration of a cost-factor matrix is proposed for the application of the different rehabilitation technologies under specific environmental conditions. The cost-factor matrix will be a spreadsheet developed by CLABSA under WP4.

2.2.2 Cost evaluation

In general, cost evaluation should give an economic justification of the rehabilitation decision. Different options should be compared with respect to the ratio between costs and service life prolongation for repair, and depreciation plus interest for renovation and replacement respectively. According to the three fields of interest in the decision framework for sewer network rehabilitation, costing approaches with different levels of detail must be included into the decision process.

The choice of the right rehabilitation technology requires very detailed cost estimates, potentially already taken from different previous bids. For the prioritisation of projects, estimates of mean costs for different rehabilitation technologies under specific conditions may be adequate. For the development of long-term strategies for inspection and rehabilitation, unit costs for inspection and mean costs for different rehabilitation technologies should be available.

The most important influencing factors on the unit costs are, for example, diameter, density of service connections, land use above and under the ground (Fig.3).

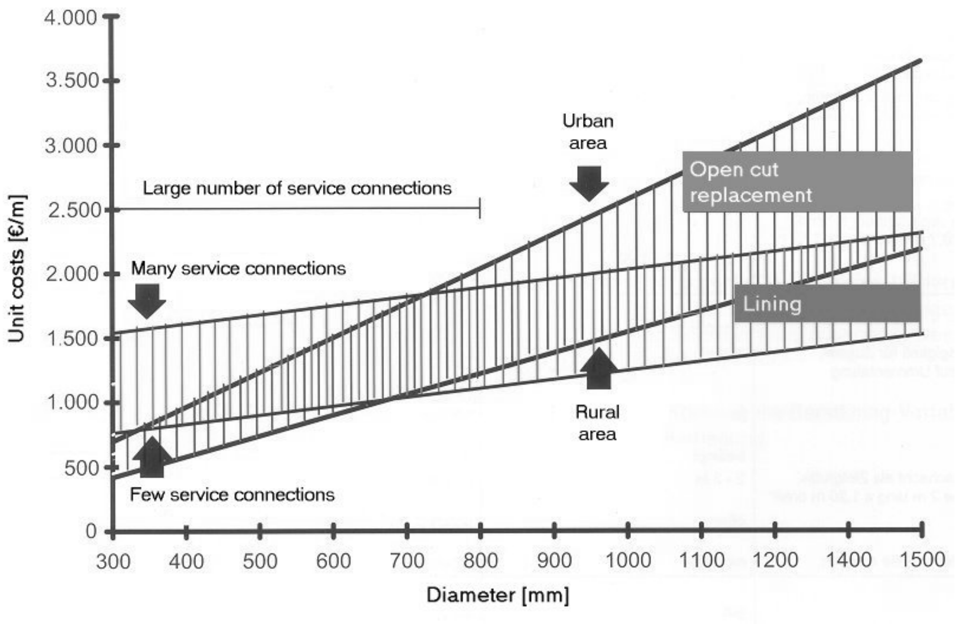


Figure 3: Comparison of costs for lining and open-cut technology under specific conditions (MUV-BW 2000)

The cost comparison should comprise direct and indirect costs. Indirect costs of sewer rehabilitation are mainly due to traffic deviation and business interruptions, or environmental impacts, which could be either capitalised by cost estimates or directly considered, as is possible in the multi-criteria decision support methodology mentioned in section 3.

The annuity of the rehabilitation technology can be calculated by dividing its direct costs by the service life expectation. In a cost-benefit approach with actual values, the annuity is compared with increasing annual maintenance and repair costs of the sewer pipe (Figure 4).

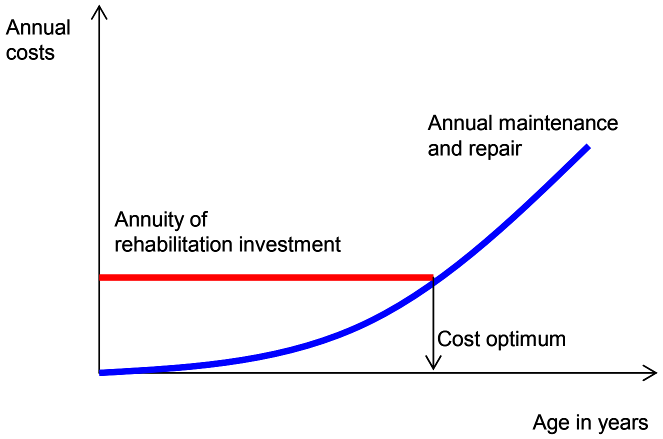


Figure 4: Evaluation of investments on actual values

2.2.3 Structure of the decision procedure

Figure 4 gives an overview, how results from various WP are used in the decision for choosing the right rehabilitation technology in a flow chart according to EN 752-5.

Criteria for the selection of the best rehabilitation technology can be divided into two groups: The first group of criteria is used for the pre-elimination of rehabilitation options at a particular site. The second group of criteria is used for the comparison of the remaining rehabilitation options.

Accordingly, the procedure for choosing the right rehabilitation technology can be divided into the following steps:

1. Pre-elimination

The procedure of pre-elimination can be facilitated by comparing automatically applicability conditions and performance of the technologies with the local conditions at the site chosen for rehabilitation. The pre-elimination can be complemented by setting user defined elimination criteria (thresholds).

2. Ranking

The multi-criteria evaluation methodology for ranking rehabilitation options considers only the options remaining after pre-elimination. The result will be a final overall order of rehabilitation options.

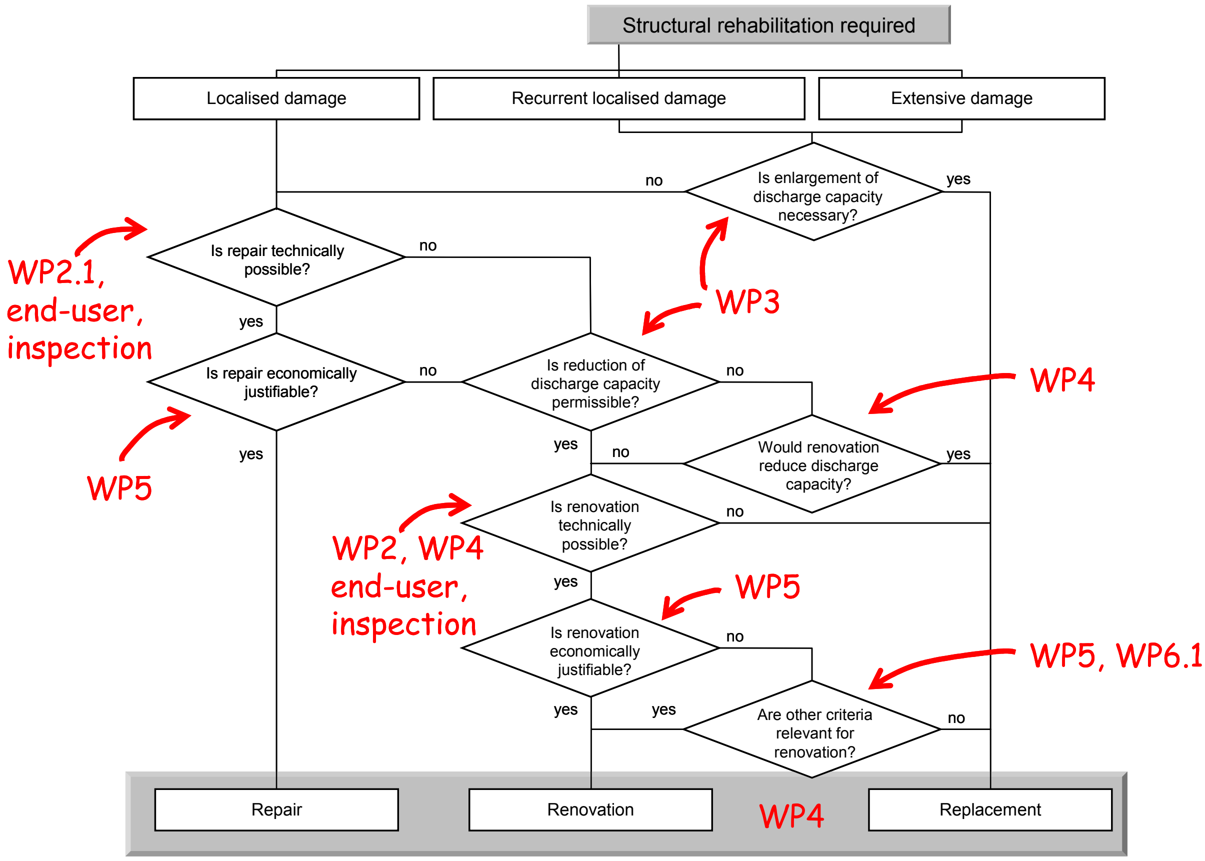


Figure 5: Choosing the right rehabilitation technology according to EN 752-5 and use of results from CARE-S work packages

2.2.4 Definition of decision criteria

According to the identified structure of the decision problem, criteria are used for the process of pre-eliminating unsuitable rehabilitation technologies and/or for the process of ranking the remaining rehabilitation options.

In Table 1, a preliminary list of criteria for pre-elimination is given, with the items according to the rehabilitation technology chart developed in WP4, and the respective information on the particular rehabilitation project. Criteria for the pre-elimination refer to the applicability conditions of a technology under the given internal and external conditions. There are technical, operational, and environmental conditions.

Table 1: Information on rehabilitation technology and project description **(WP4_Rtchart_v2.2.xls)**

	Information on the rehabilitation technology Source: WP4_RT-chart	Project description Source: SRP output file for input to SRT
	Applicability conditions	
1	Diameter (min, max)	Diameter (before, after rehabilitation)
2	Shape (circular, non-circular, man-entry, non-man-entry)	Shape (circular, egg-shaped, other non-circular)
3	Asset type (sewer, manhole, connection)	Sewer/Manhole/Service connection
4	Static function (structural, sealing)	Restoration of load bearing capacity required (Yes/No)
5	Suitable material of current asset	Material
6	Need to cut off service connections	Number of service connections
7	Under groundwater level/leakage admissible	Groundwater level, sewer level, Sensitive to groundwater quality?
8	Minimum temperature	
9	Suitable kind of soil	Soil type
10	Working space required	Availability of working space in the urban environment of the sewer
	Technology performance / characteristics	
11	Maximum length	Length
12	Working speed (length/units per day)	Time constraints (max d)
13	New asset material	Material
14	Diameter after rehabilitation (not changed, reduced, increased)	New diameter
15	Hydraulic performance after rehabilitation (diameter, slope, roughness: not changed, reduced, increased)	New diameter, new slope, new roughness, Failure type

16	Digging needs (without surface damage, pit damage, trench)	Availability of working space in the urban environment of the sewer, Number of service connections, Traffic load in the location, Existing flora to be protected? Sensitive buildings or infrastructure around? Noise and tremor a problem? Business activities affected?
17	Processing through manhole?	Availability of working space in the urban environment of the sewer
18	Need of cleansing	
19	Digging need for connections reinstall	Number of service connections
20	Possibility of work interruption	
21	Excess ground permeability during grouting	Sensitive to groundwater quality
22	Requires man in underground	
23	Straight/curved link	
24	Estimated service life (prolongation) of rehabilitated asset	
25	*Unit costs and cost factors (not yet included in CLABSA table)*	
	Environmental impact	
26	Structural impact on surrounding buildings	Sensitive buildings or infrastructure around?
27	Environmental impact (material, works: none, low, grave)	Existing flora to be protected? Sensitive to groundwater quality? Noise and tremor a problem?
28	Impact on groundwater quality	Sensitive to groundwater quality?
29	Noise	Noise and tremor a problem?
30	Dust	Dust a problem?

3 Multi-criteria Evaluation Methodology

The objective of a multi-criteria methodology for choosing the best rehabilitation technology is to find a transitive[1] overall final order of a finite set of options. Here, a decision support method is sought which selects the "best" rehabilitation technology for a sewer which has already been selected for rehabilitation. 'Best', in this context, could be interpreted as the most cost-effective, or most practical or least disruptive method, or some other such criterion. The set of options i, all rehabilitation options included in the rehabilitation technology (RT) data base (WP4), must be compared with respect to a number of criteria j, by calculating the values e_{ij} for each technology (Figure 6).

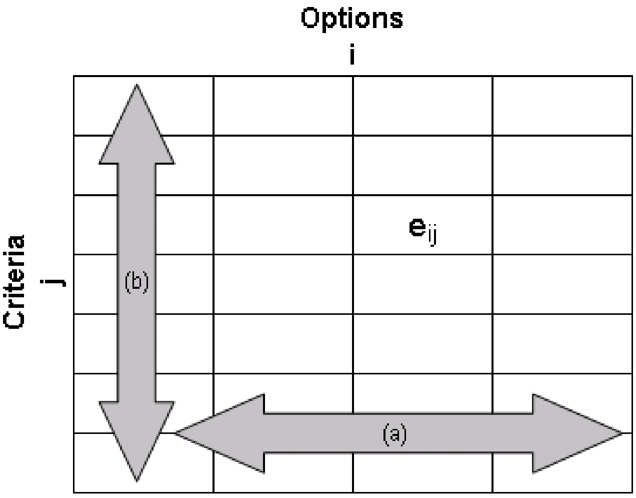


Figure 6: Impact matrix

3.1 Methods

Multi-criteria evaluation methods can be classified, according to the prevailing weighing principle, into substitution methods and elimination methods.

3.1.1 Substitution methods

A very popular multi-criteria technique, the method of average weighting, belongs to the substitution methods, also referred to as aggregation or scoring models. Here, the bandwidth of criteria within the impact matrix (arrow b in Figure 6) is reduced. The overall ranking of options is built in three steps:

1. Transformation of all criteria into a uniform scale (normalisation)
2. Distribution of weights, i.e. relative importance or exchange ratios between criteria
3. Aggregation with a utility function for the final ranking order

Usually, aggregation methods are applied using, in most cases, a monetary expression or dimensionless point scale for the normalisation. In general, the normalisation and the definition of the utility function are prepared by an "expert", whereas the only interaction between the decision-maker and the decision procedure is the assignment of weights. The problem of these methods is the priority and weighting of the individual criteria, since overrating and underrating of certain aspects is most likely to happen (Strassert 1984, Vincke 1992).

[1] A final order of a set of options is said to be transitive if it meets the transitivity condition (e.g. if A > B and B > C, then A > C). It is said to be linear if there is no cycle of preference involved (i.e. 'A > B > C > A' is cyclic and therefore not linear. See also section 3.2.3.)

3.1.2 Elimination Methods

The principle of elimination methods is to reduce the bandwidth of options with arguments (arrow (a) in the impact matrix, see Figure 6) by excluding unsuitable options. There is no final evaluation but a stepwise threshold setting at particular criteria for eliminating undisired options. One of the advantages of elimination methods is the possibility that criteria can have different dimensions. A very popular, non-formalised version of elimination techniques is the verbal discussion / structured interview.

The selection procedure consists of three elementary steps:

1. Setting a threshold value at criterion C_1
2. Observing the consequences at all other criteria
3. Confirming (or rejecting) the elimination threshold and setting the next threshold at the next criterion

The process is repeated until a break-off limit (e.g. a given budget) is reached.

Within elimination procedures, effect control and reasoning initiate a process of balancing advantages and disadvantages that leads step-by-step to a decision.

3.1.3 Balancing and Ranking procedure

The BRP (in Germany known as FAR) presented by Strassert (1995) and Köhl (1998) is a new variant within the field of semi-formalised multi-criteria decision support methodologies. “Basic features of the approach are the pairwise comparisons of options, mixed scales and the so-called balancing principle, i.e. the balancing of vectors of advantages and disadvantages” (Strassert 2000: 1). For any pair of options the relative advantages and disadvantages are balanced and, simultaneously, the different importance of the score is taken into account. In chapter 3.2, the theoretical framework of the approach is briefly explained, following Strassert (2000), who gives a detailed derivation and description of the method. The methodology has been applied in CARE-W for the evaluation of rehabilitation strategies (Herz 2002).

3.1.4 ELECTRE procedure

ELECTRE ("*ELimination Et Choix Traduisant La REalité* "= elimination and choice translating reality) is the French approach to multi-criteria decision methodology, restricted in the planning of engineering infrastructure projects, its first apparition being in the sixties. Most versions have been developed by Bernard Roy and associates (Roy 1993). The method manipulates the criteria into ‘‘concordance’’ and, if evaluations are richer than ordinal rankings, ‘‘discordance’’ matrices. Options are pair-wise judged. The concordance set shows all criteria where an option is preferred or equal to another, while the discordance set shows the reverse outranking. Several procedures are available for sorting, ranking, selecting.

Contrary to the optimization of an economic function, the multi-criteria analysis is not formalized mathematically indeed. It uses models built partially on inevitably restrictive mathematical hypotheses and partially on information collected by the decision-maker. The main characteristic of the analytical multi-criteria methods is to formalize the preparation of the decision by improving the transparency of the decision process and by defining and clarifying the decision-maker responsibility.

In CARE-W WP3 report *Decision support for annual rehabilitation programmes* (Le Gauffre et al. 2002), it is a sorting procedure that was applied: ELECTRE tri. Here we propose a ranking procedure ELECTRE II:

***The objective of ELECTRE II** (Cf. Appendix* **3.I: Details of the method*) is to rank options*, since "best" until "less good".**

The approach used by ELECTRE II is based on:

- concordance and discordance concepts (allowing to take into account the collective self-reliance of the decision-maker in a fine way),
- two types of outranking : strong and weak,
- an outranking algorithm with two simple ordering : direct and reverse.

An example of application is presented in appendix 3.II (Diab, 2000).

3.1.5 Conclusion

The substitution methods offer a logical structure of procedures, which determine a unique result by mathematical operations. However, methodological problems arise from the numerical scores and weights assigned to individual criteria. They blur the contribution of individual criteria to the overall score by compensating for smaller and larger contributions from different criteria. However, there is no way to balance polluted water with clean air or destroyed natural landscapes with quiet vehicles. Another drawback of aggregation procedures is their lack of transparency in the decision process.

Thus, approaches which rely on aggregation are quite suitable for an evaluation that is based on criteria which are measured on a uniform scale, e.g. in monetary terms, since the balance of costs and benefits (or savings), appears to be rather accurate.

The advantage of the concordance analysis (e.g. ELECTRE methods, Roy 1985) compared to scoring models is due to the comparison in pairs of relative advantages and disadvantages of candidate options. There is no direct compensation of criteria by a utility function. However, a number of model parameters must be set/defined by the user (namely indices and thresholds, and the criteria weights).

Multi-criteria decision problems where options must be compared by characteristics with mixed scales are more likely supported by elimination procedures that evade the black-box approach of non-transparent interdependencies determined by criteria weights, normalisation functions and a utility function

For the evaluation of rehabilitation technologies in CARE-S, the formalised balancing and ranking procedure (Strassert 1995) was chosen and will be compared with an Electre procedure. Both methods will begin with a pre-elimination step.

3.2 The Balancing and Ranking Procedure (BRP)

This section gives an overview on the methodological approach of the balancing and ranking procedure. In the next chapter 3.3, the approach is illustrated by an example carried out for the end-user in Dresden.

3.2.1 Preliminary order of options

The procedure starts with the impact matrix (Figure 4). Each criterion C_i yields an individual order of options P_j by means of e_{ij}. For $e_{11} > e_{12} > e_{13}$, the ranking order of criterion C_1 is P_1, P_2, P_3. In general, the ranking order of options P_j will differ for all criteria C_i.

	Technology options			
Criteria	P_1	P_2	P_3	…
C_1	e_{11}	e_{12}	e_{13}	…
C_2	e_{21}	e_{22}	e_{23}	…
C_3	e_{31}	e_{23}	e_{33}	…
…	…	…	…	…

Figure 7: Impact matrix with criteria C and technology options P

Now suppose that the values e_{ij} show that, for C_1, $P_1 > P_2 > P_3$. Then we can write:

C_1: < P_1, P_2, P_3 >, and similarly for C_2 and C_3, e.g.

C_2: < P_3, P_2, P_1 >,

C_3: < P_3, P_1, P_2 >,

In an "outranking matrix" (Figure 8a), the number of pros and cons are counted for each option. The matrix in Figure 8a shows that option P_1 is placed twice (i.e. for two criteria) before option P_2, once before P_3, and vice versa P_2 is placed once before option P_1, and P_3 is placed twice before option P_1 (The table must be read in rows).

	P_1	P_2	P_3
P_1	0	2	1
P_2	1	0	1
P_3	2	2	0

Figure 8a: Outranking matrix

	P_3	P_1	P_2
P_3	*	2	2
P_1	1	*	2
P_2	1	1	*

Figure 8b: Triangular outranking matrix

When the "outranking matrix" is set up, the options must be re-ordered to achieve a triangular matrix (Figure 8b). Triangularisation is the systematic re-ordering of options such that out of a set of p = j! orders, the sum of the values above the main diagonal is maximised. A situation where only zero values are below the main diagonal corresponds to a strong transitive overall final order of options, or total order structure. Normally, this total order structure of options does not exist initially (Vincke 1992, Strassert 2000).

The outranking matrix relates to the majority rule of counting votes (1 criterion → 1 vote). In the context of the balancing principle, the assumption of a majority rule must be given up. The outranking matrix is used instead as a preliminary order of options which is then subject to a screening and balancing process.

3.2.2 The balancing process

Firstly, a new table is introduced. In an “advantages-disadvantages table” the criteria C_i are combined with the result of the pair wise comparison of options P_j/P_k (Figure 9). The column headings contain all possible comparisons in pairs. For n options the number of comparisons is z = n*(n-1)/2. In our case (n = 3), z = 3.

	P_1/P_2	P_1/P_3	P_2/P_3
C_1	A_{P1C1}	A_{P1C1}	A_{P2C1}
C_2	D_{P1C2}	D_{P1C2}	A_{P2C2}
C_3	A_{P1C3}	D_{P1C3}	D_{P2C3}
ΣA_j	2	1	2
ΣD_j	1	2	1

Figure 9: Advantages-disadvantages table

For each comparison in pairs, the scores of e_{ij} must be compared. The comparisons can be made independently from the criteria’s scales. They refer to quantities, rankings or frequencies (cardinal, ordinal, nominal scale). At the bottom of the table two rows show the sum of advantages ΣA_j and the sum of disadvantages ΣD_j by comparison.

In the advantages-disadvantages table, each column represents a separate binary decision problem: in the first column, the comparison P_1/P_2 of the two options P_1 and P_2, the question is whether the two advantages [$_{1/2}A_1$, $_{1/2}A_3$] together are strictly superior (or not) to the disadvantage $_{1/2}D_2$. For “Yes”, P_1 is strictly superior to P_2. If respectively the answer is “No”, then P_2 is strictly superior to P_1. If the answer to the question: Are [A_{P1C1}, A_{P1C3}] strictly superior to D_{P1C2} is “Yes”, the disadvantage $_{1/2}D_2$ loses its importance.

Thus, each comparison result is rated according to a boolean code (1,0), and the results of all comparisons can be drawn to a compatibility matrix C (Figure 10a), and if the compatibility matrix is reordered, to the triangular compatibility matrix C^T (Figure 10b).

	P_1	P_2	P_3
P_1	0	1	1
P_2	0	0	0
P_3	0	1	0

Figure 10a: Compatibility matrix C

	P_1	P_3	P_2
P_1	0	1	1
P_3	0	0	1
P_2	0	0	0

Figure 10b: Triangular compatibility matrix C^T

The triangular compatibility matrix C^T is representing a “strict total order” with a binary relation, which is asymmetric, complete and transitive (Vincke 1992). With this matrix, the overall final order of options looked for is obtained, i.e. $<P_1, P_3, P_2>$ (Strassert 2000).

3.2.3 Operating comparisons in pairs

In practice, the number of rehabilitation technologies to be compared can easily be 5, 6 or more. Then the number of comparisons in pairs z is 10, 15, or more, respectively. Irrespective the number of criteria, the determination of the order relations could become a clumsy job.

Not necessarily all possible comparisons in pairs and corresponding balancing problems must be carried out. For 4 strategies, the number of comparisons would be 10. The number of possible orders of options is p = n! = 1*2*3*4 = 24. These orders are:

P_1, P_2, P_3, P_4	P_2, P_1, P_3, P_4	P_3, P_1, P_2, P_4	P_4, P_1, P_2, P_3
P_1, P_2, P_4, P_3	P_2, P_1, P_4, P_3	P_3, P_1, P_4, P_2	P_4, P_1, P_3, P_2
P_1, P_3, P_2, P_4	P_2, P_3, P_1, P_4	P_3, P_2, P_1, P_4	P_4, P_2, P_1, P_1
P_1, P_3, P_4, P_2	P_2, P_3, P_4, P_1	P_3, P_2, P_4, P_1	P_4, P_2, P_3, P_3
P_1, P_4, P_2, P_3	P_2, P_4, P_1, P_3	P_3, P_4, P_1, P_2	P_4, P_3, P_1, P_2
P_1, P_4, P_3, P_2	P_2, P_4, P_3, P_1	P_3, P_4, P_2, P_1	P_4, P_3, P_2, P_1

If n - 1 comparisons in pairs are already executed, and if all options are considered in the balancing process, the remaining comparisons are given implicitly. For example, if n - 1 = 3 comparisons yield the three orders $<P_1, P_2>$, $<P_1, P_4>$ and $<P_3, P_2>$, then from the 24 orders above, in a first step 12 are eliminated (all orders where P_1 is before P_2), in a second step 8, and in a third step 3 orders are eliminated, respectively. Hence, only one single order, $<P_1, P_4, P_3, P_2>$, remains, that is the final order of options.

Intransitivities occur when the balancing result of three comparisons would give rankings of the form: $<P_1, P_2>$, $<P_2, P_3>$ and $<P_3, P_1>$, i.e. the circular relation $P_1 > P_2 > P_3 > P_1$. Strassert (1999) gives an analytic proof that the number of comparisons in pairs could be reduced down to a minimum of n–1 comparisons, and a methodology how to avoid intransitivities in the final order. For the pre-elimination of options, knockout criteria are introduced (e.g. applicability conditions).

3.2.4 Solving balancing problems

The solution of the balancing problem is the comparison of two options with respect to the set of advantages against the set of disadvantages, presented in the "advantages-disadvantages table". That is the answer to the question: Are the advantages $[_{1/2}A_1, {}_{1/2}A_3]$ strictly superior to the disadvantage $_{1/2}D_2$?

The number of criteria in each comparison with an equal score is not decisive. A dominance check looks for comparisons, where we have only advantages but no disadvantages. Rankings including the inverse of such a dominance order can be removed from the set of possible rankings.

3.3 Example application of BRP

In Table 2, the impact matrix of 4 options and 4 criteria is shown. In the example the knockout-criterion is a maximum of 250€/m for the costs. Thus, option D would be excluded from the set of available options.

Table 2: Impact matrix e_{ij}

Options j / **Criteria i**	**A**	**B**	**C**	**D**
K_1 Costs	150 €/m	200 €/m	50 €/m	300 €/m
K_2 Construction time	5 weeks	10 weeks	20 weeks	30 weeks
K_3 Traffic disturbance	medium	very high	low	none
K_4 Service life	50 years	50 years	80 years	120 years

Subsequently, for each criterion a rank will be assigned to the remaining options. If there are equal criteria values the options get the same rank (Table 3).

Table 3: Ranking of options

Options j / **Criteria i**	**A**	***Rank A***	**B**	***Rank B***	**C**	***Rank C***
K_1 Costs	150 €/m	*2.*	200 €/m	*3.*	50 €/m	*1.*
K_2 Construction time	5 weeks	*1.*	10 weeks	*2.*	20 weeks	*3.*
K_3 Traffic disturbance	medium	*2.*	very high	*3.*	low	*1.*
K_4 Service life	50 years	*2.*	50 years	*2.*	80 years	*1.*

The dominance test is next. For this purpose, the individual options are compared in pairs using an advantage-disadvantage table. If there is one option in all criteria better than any another, that option will be strictly superior to all others in every possible order of options. In the example option A is strictly superior to B, which means option B will never be before option A in the final ranking. There is no obvious strict superiority in the comparisons A-C and B-C. The advantage-disadvantage table is shown below (Table 4.)

Table 4: Advantage-disadvantage table for the dominance test

Comparisons / **Criteria**	**A-B**	**A-C**	**B-C**
K_1 Costs	A_{A1}	D_{A1}	D_{B1}
K_2 Construction time	A_{A3}	A_{A3}	A_{B3}
K_3 Traffic disturbance	A_{A4}	D_{A4}	D_{B4}
K_4 Service life	0_5	D_{A5}	D_{B5}
Result	**A dominates B**	**-**	**-**

Three possibilities out of six possible ranking orders (ABC, ACB, BAC, BCA, CAB, CBA) can be eliminated because option A dominates option B and thus B never will be ranked before A (BAC, BCA, CBA). Therefore two comparisons remain (A-C, B-C). In this example there are no intransitivities (table 4, table 5). Criteria where the compared options have the same value are not be taken into consideration.

Table 5: Pairwise comparison A-C

Criteria	A		C	
K_2 Construction time	5 weeks	Advantage A	20 weeks	
K_1 Costs	150 €/m		50 €/m	Advantage C
K_3 Traffic disturbance	Medium		Low	Advantage C
K_4 Service life	50 years		80 years	Advantage C
Result	**C is better than A,** because the advantages of longer service at 1/3 of costs prevail the disadvantage of longer construction time, which causes only low traffic disturbances			

Table 6: Pairwise comparison B-C

Criteria	B		C	
K3 Construction time	10 weeks	Advantage B	20 weeks	
K_1 Costs	200 €/m		50 €/m	Advantage C
K4 Traffic disturbance	Very high		Low	Advantage C
K5 Service life	50 years		80 years	Advantage C
Result	**C is better than B,** Because the three advantages (costs, service life, low traffic disturbances) prevail the relative small disadvantage of a longer construction time (there are no time constraints here)			

At the end, the final ranking can be stated, in this example it is CAB. The procedure has been finished.

The procedure results ("C is better than A" and "C is better than B") are decisions, that must be made by the user, including the reporting of the argumentation. The automatically performed check for intransitivities avoids inconsistent preferences, and thus subjective decisions.

4 Procedure Development

The working title of the application for WP6 task 1 was WRaP SRT– Weighing and Ranking Procedure for Sewer Rehabilitation Technologies. In the final version of the CARE-S prototype, the software will be referred to as CARE-S - SRT.

For the development of the procedure for prioritising a rehabilitation technology for a selected rehabilitation project, its integration into the CARE-S framework must be defined. The data and information flow will consist of four principal steps (Figure 11):

1. A list of priority pipes is selected in WP6.2, and transferred via the rehabilitation manager (WP7) to WP6.1
2. WP6.1 carries out a pre-elimination of rehabilitation technologies, with respect to their specific performance and the conditions at the particular site. The pipe description including the list of pre-selected rehabilitation technologies is transferred via the rehabilitation manager (WP7) to WP4 and WP5.
3. In WP4 and WP5, direct costs and socio-economic criteria are calculated for each technology and are added to the pipe description file. The file is redirected to WP6.1, again via the rehabilitation manager (WP7).
4. With all decision criteria evaluated now, 6.1 can carry out the final ranking of potential rehabilitation technologies.

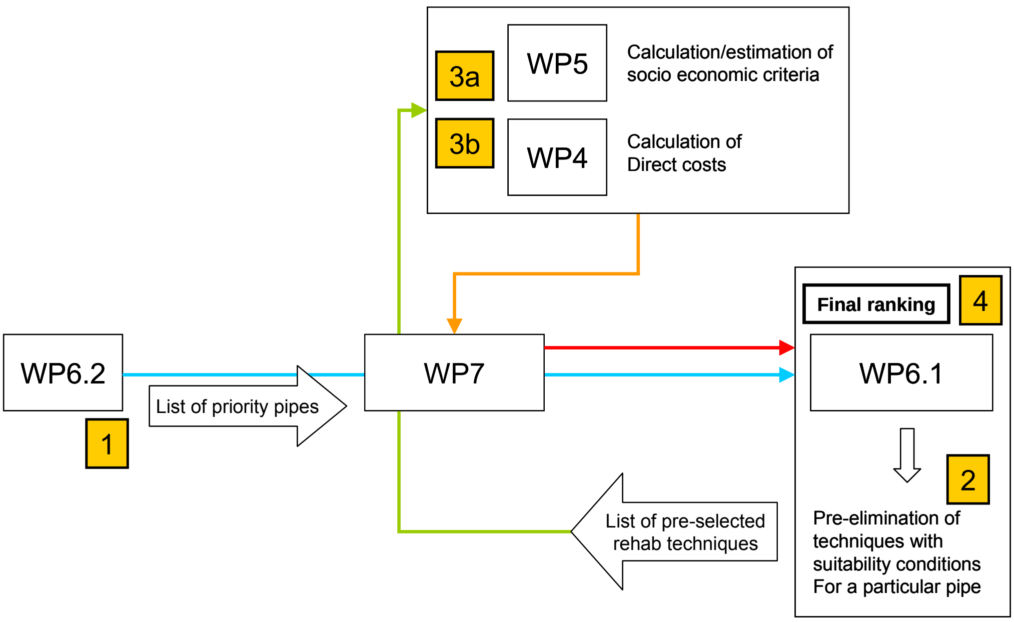
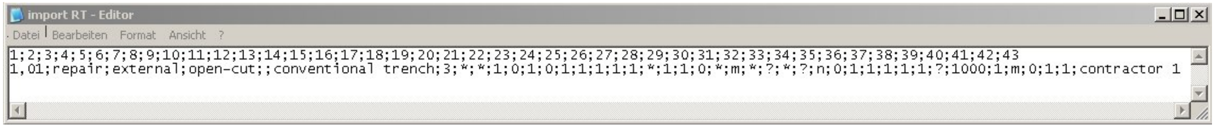


Figure 11: Data and information flow

4.1 Rehabilitation technology catalogue

The rehabilitation technology catalogue which is imported to the CARE-S SRT programme relies on the format of the version WP4_Rtchart_v2.2.xls, posted on the BSCW server on the 6th June 2003. The procedure will be adjusted to the latest version, as soon as the final structure is confirmed by WP4.

The import files' format is csv (comma separated values), with one rehabilitation option per line. A screenshot of an example import file is given in Figure 12 where the first line corresponds to the column numbers in the RT data base. The file will be imported from the CARE-S Rehabilitation manager. An updated example import file will be posted on the BSCW server.



```
import RT - Editor
Datei Bearbeiten Format Ansicht ?
1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43
1,01;repair;external;open-cut;;conventional trench;3;*;*;1;0;1;0;1;1;1;1;1;*;1;1;0;*;m;*;?;*;?;n;0;1;1;1;1;1;?;1000;1;m;0;1;1;contractor 1
```

Figure 12: Screenshot of an example Rehabilitation technology import file

4.2 Project description and decision criteria

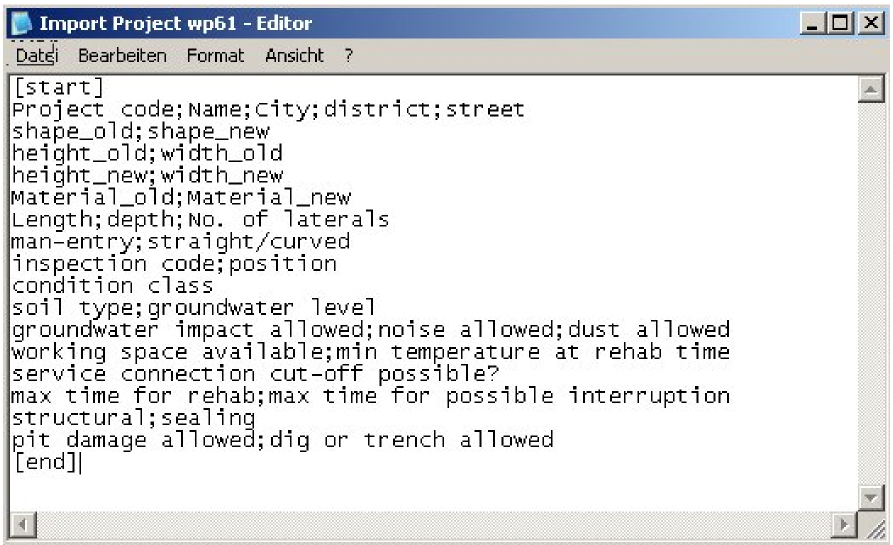
A list of projects for rehabilitation is provided by the multi-criteria tool for the selection and prioritisation of effective rehabilitation projects (CARE-S SRP, to be developed under sub-task 6.2).

4.2.1 Applicability conditions for pre-elimination

The decision criteria for the pre-elimination of rehabilitation technologies are oriented towards the applicability conditions taken from the RT chart. Unknown items are replaced by a question mark (?). Irrelevant fields are filled with an asterisk (*). (1) stands for "Yes", (0) stands for "No".

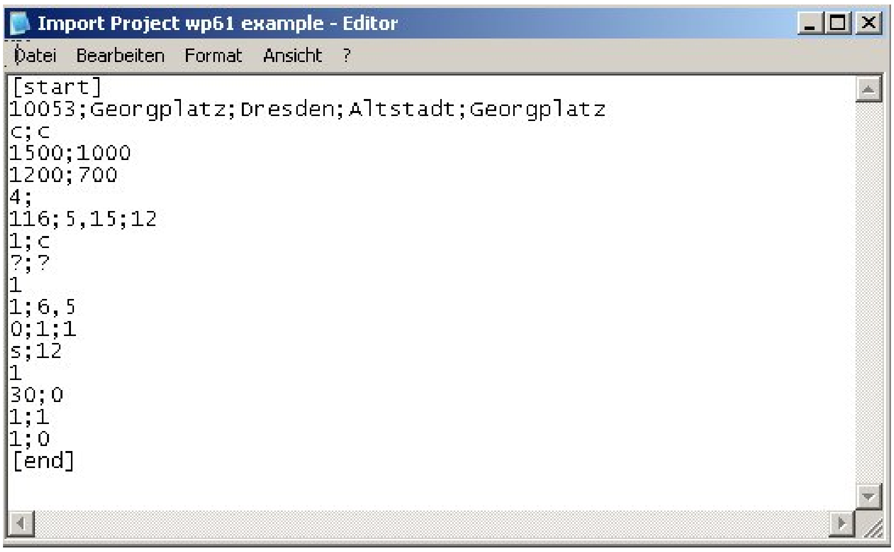
Either a single pipe or a list of pipes, selected by the multi-criteria tool of sub-task 6.2 for the prioritisation of rehabilitation projects, can be imported. Projects must be separated by a [start] and [end] section in the import file. Unknown items are replaced by a question mark (?). Irrelevant fields are filled with an asterisk (*). (1) stands for "Yes", (0) stands for "No".

The structure of the import file is shown in Figure 13, and an example import file is given in Figure 14. Updated example import files will be posted on the BSCW server.



```
Import Project wp61 - Editor
Datei Bearbeiten Format Ansicht ?
[start]
Project code;Name;City;district;street
shape_old;shape_new
height_old;width_old
height_new;width_new
Material_old;Material_new
Length;depth;No. of laterals
man-entry;straight/curved
inspection code;position
condition class
soil type;groundwater level
groundwater impact allowed;noise allowed;dust allowed
working space available;min temperature at rehab time
service connection cut-off possible?
max time for rehab;max time for possible interruption
structural;sealing
pit damage allowed;dig or trench allowed
[end]
```

Figure 13: Structure of the project import file




```
[start]
10053;Georgplatz;Dresden;Altstadt;Georgplatz
c;c
1500;1000
1200;700
4;
116;5,15;12
1;c
?;?
1
1;6,5
0;1;1
s;12
1
30;0
1;1
1;0
[end]
```

Figure 14: Example project import file for one project

4.2.2 Criteria for ranking

For the comparison of rehabilitation options, the direct unit costs and service life expectancy (or prolongation) of the rehabilitation technology are considered. Direct costs are calculated for different external conditions with the costing tool provided by WP4. The service life (prolongation) comes directly from the rehabilitation technology chart.

Thus, four economic criteria can be defined and written as follows:

C1 direct costs in €

C2 service life (prolongation) in years

C3 annuity in €/year

Impacts of rehabilitation technologies on the environment are assessed within the definition of socio-economic criteria. They are determined within an application of WP5 (see CARE-S D13 Report "Rehabilitation impact on socio-economic costs".):

C4 Impact of noise

C5 Impact of dust

C6 Pollution of groundwater

C7 Service interruption

C8 Road/traffic disturbance

C9 Loss of trade

A set of less formalised criteria cover conditions of the site, which have an influence on the decision for particular rehabilitation technologies. These are:

C10 number of service connections & reconnection efforts of the technology

C11 working area required by the technology & urban environment

C12 urban vegetation affected by rehabilitation

The design of the BRP offers the possibility to integrate additional criteria later on.

4.3 Workflow model

After creating a "rehabilitation project", some general information such as project name and description must be given. Subsequently, it is necessary to import the rehabilitation technology catalogue, the project list, and to define constraints for the comparison. The knockout-check is performed then. Automatically those rehabilitation technologies are eliminated, which do not fulfil the required applicability and performance conditions. In addition, rehabilitation technologies can be eliminated individually by the user. The next step is the automatically performed dominance check.

The tool generates now a revised impact matrix consisting of the remaining rehabilitation technologies and all criteria including the according pre-suggested rankings. These rankings can be revised by the user. Then, the weighing and ranking process starts with the first comparison in pair. For this purpose an advantage-disadvantage table is created for each comparison. Here, the user can arrange the order of criteria and determine the "winner". The user must confirm his decision. This process will be repeated until the final ranking has been fixed. During the process, *CARE-S - SRT* checks for intransitivities. Finished decision runs cannot be modified any more, but analyzed. The principal workflow structure is shown in Figure 15.

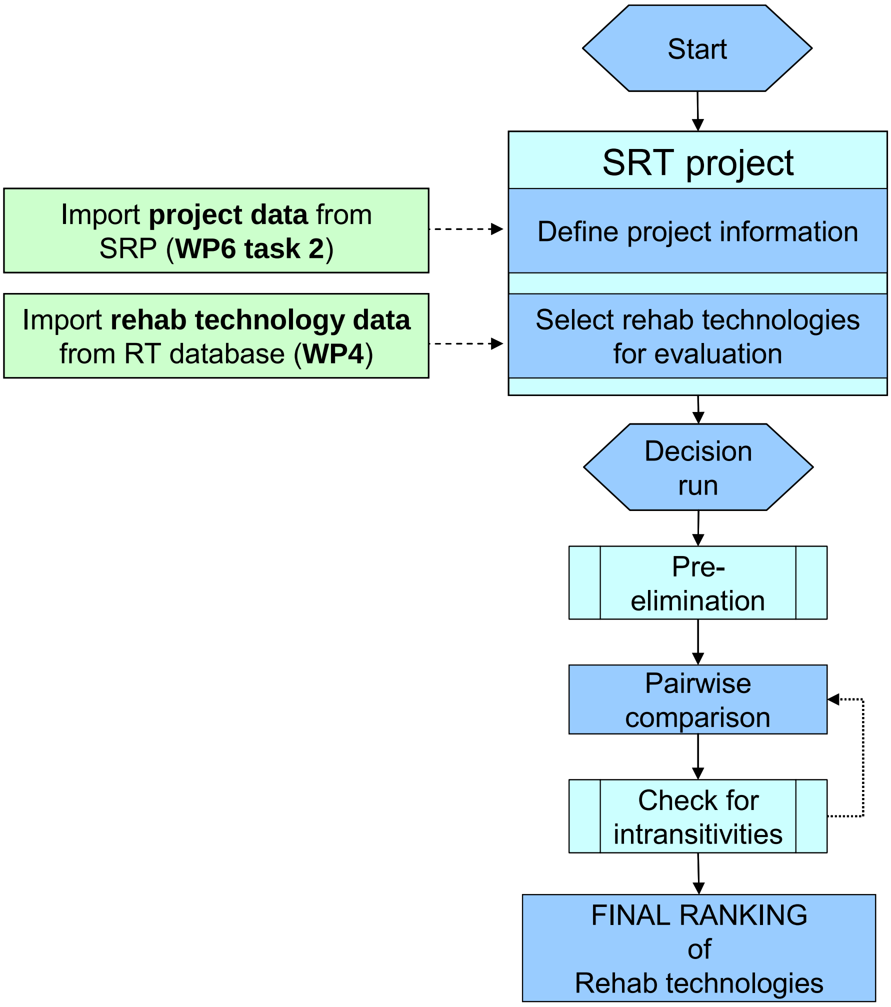


Figure 15: Workflow structure chart of CARE-S – SRT

4.4 Analysis of development system

Before starting the software development, the development system had to be chosen. As there are various systems with different programming languages available, it was necessary to set up a list of general features of the future software to evaluate the development systems. The following reasons finally led to the decision in favour of *Borland Delphi*:

- Applications designed with *Borland Delphi* are compiled into executable files. Therefore, code execution is far faster than in systems using code interpreters.
- Applications designed with *Borland Delphi* are standalone and do not need additional software for execution. This prevents trouble in software usage and maintenance if the additional software is updated. This ensures the usability of the software regardless of software packages and software versions that are installed in parallel. Furthermore, the requirements for the user are kept on a modest level.
- The source code of *Borland Delphi* is, with minor changes, compatible to *Borland Kylix,* which is a development system for Linux. This eases cross platform development and permits the development of Linux versions of the software if there is a need for it.
- *Borland Delphi* includes the mighty relational client-server database system *Interbase* which can be run as a desktop system as well. *Interbase* is available as an open source (Firebird) and causes almost no costs in software acquisition.
- *Borland Delphi* is already the system chosen for the development of the Rehabilitation Strategy Evaluator of CARE-W which applies the same underlying decision methodology.

4.5 Software design

Beside typical data management facilities, the general design of the CARE-S – SRT software consists of two main screens. The first one provides information on the rehabilitation project, including pipe characteristics, failure specification, and description of the environment (Figure 16). Here, the pre-selection of suitable technologies is carried out.

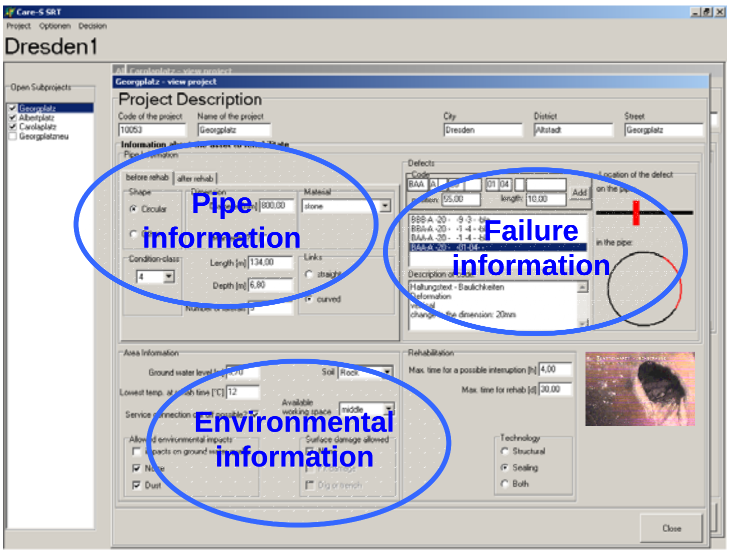


Figure 16: CARE-S – SRT project description screen

On the second screen, the remaining rehabilitation technologies are listed with their advantages and disadvantages, and the ranking process is carried out (Figure 17). A more detailed description of the software is included in the software handbook.

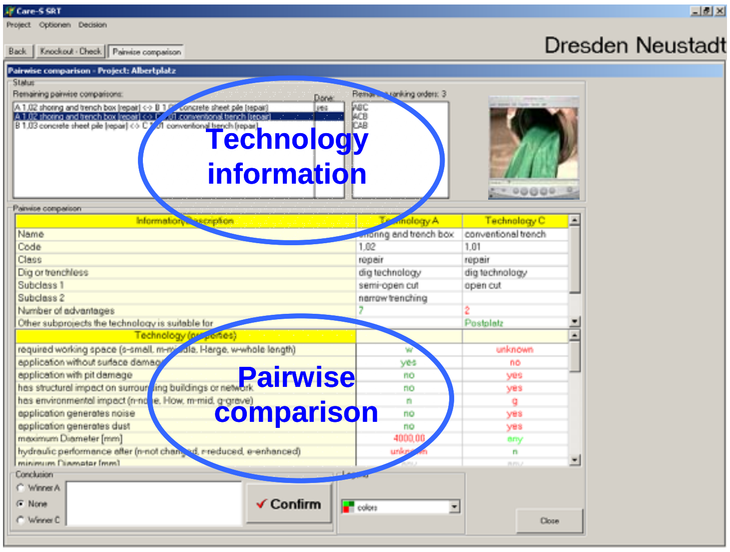


Figure 17: CARE-S – SRT ranking procedure screen

4.6 Testing

By the survey among the CARE-S end-users, 27 case studies were collected. They will be the first test cases for the CARE-S – SRT application. The ELECTRE II approach mentioned in Appendix 3 will be applied to these test cases as well, and results will be compared.

5 Summary

This report refers to sub-task 6.1 “Choosing the right rehabilitation technology for sewer pipes” of the CARE-S project. The developed procedure relies on the access on the rehabilitation technology (RT) data base, developed under WP4. Criteria for the elimination and ranking of rehabilitation technologies are either directly taken from the RT data base, or estimated by procedures provided within WP5.

The methodology chosen for the CARE-S – SRT is the balancing and ranking procedure. It has been programmed and will be integrated in the CARE-S Rehabilitation Manager. The procedure comes to its limits for larger number of options, due to the increasing number of comparisons. The balancing and ranking procedure shows its advantages in the comparison of options by criteria that are measured on different scales. It improves the structure of information used in the decision process, and supports the decision by a clear presentation of arguments and checking for intransitivities within the decision chain.

Alternatively, a concordance analysis was investigated by the partner Cemagref/ENGEES in Strasbourg with Marne La Vallée University (subcontractor of Cemagref). This application provides in- and output-file specifications similar to the CARE-S - SRT.

Due to the report’s early schedule within the project, some of the detailed technical specifications, notably data formats, are of preliminary nature, and will be updated within the progress of the CARE-S project. A description of the software for choosing the right rehabilitation technology CARE-S – SRT will be available as handbook – together with the software. All working steps are explained in detail to ease the first usage. The handbook will be a PDF file included in the software package.

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Appendix 1

Questionnaire

TU Brno

CARE – S

Computer Aided REhabilitation of Sewer networks.
Decision Support Tools for Sustainable Sewer Network Management

WP6 – Multicriterion Decision Support

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WP4-6 questionnaire

The combined WP4-6 questionnaire has been prepared by BUT and CLABSA teams according to the comments of other WP4 and WP6 partners. Finally it has been sent together with an accompanying letter to all partners asking them to fill it in close cooperation with their end-users.

The main aims of the questionnaire were:

- To find out which decision criteria are / were used by our end-users for choosing concrete rehabilitated **sewer section**.
- To obtain description of applied **rehabilitation technology** and reasons for its selection.
- To evaluate **costs** of the used rehabilitation technology.

The following co-operating end-users from 9 countries have returned 11 filled questionnaires including 27 described projects (case studies):

Severn Trent Water Ltd., Birmingham, United Kingdom
Šiaulių vandenys, Šiauliai, Lithuania
The Municipality of Oslo, Oslo, Norway
The Municilality of Bærum, Bærum, Norway
Aalborg Kommune, Aalborg, Denmark
Brno Waterworks and Sewers, joint-stock company, Brno, Czech Republic
CLABSA, Barcelona, Spain
Stadtentwässerung Dresden, Dresden, Germany
Nantes Urban Community, Nantes, France
AMAP, Palermo, Italy
AGAC S.p.a., Rreggio Emilia, Italy

Structure and contents

Questionnaire structure and contents are presented in Appendix 1. It is divided into 5 main parts:

1. Information on rehabilitated asset
2. Sewer condition prior to rehabilitation
3. Information on rehabilitation method used
4. Decision criteria
5. Operator's satisfaction with realisation of the project

1. Information on rehabilitated asset

Besides general description of a project, information about connected inhabitants, objects, sewer system, working impacts, environmental and working constraints are requested in this part of the questionnaire.

Description of asset

27 collected projects consist of 65 links, which represents a continuous section with the same parameters – dimension, material and year of installation. Total length of rehabilitated sewer is 12.352 m; total number of service connections is 493.

Circular cross section is mostly used shape of sewer before rehabilitation as well as after it, there are no essential changes concerning shape of cross sections (see Figure A1-1). Sewer diameters were divided according to Utility Information (UI), Physical assets data, *sewer diameters or equivalent* into 6 categories (in categories up to 150mm and above 2200mm there were no pipes). Length of original and new pipes are listed in Table 1, materials are compared in Table 2 and 3. The diameter of a sewer was decreased in 48% of cases (see Figure A1-2). The diameter reduction is caused especially by lining, which influences material after rehabilitation. Concrete is the most widespread sewer material, but after rehabilitation plastic materials are preferred (compare Figures A1-3 and A1-4).

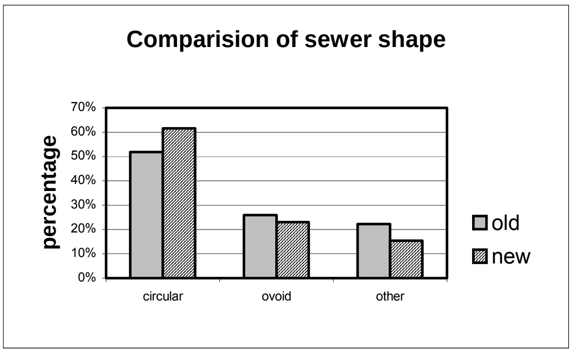


Figure A1-1

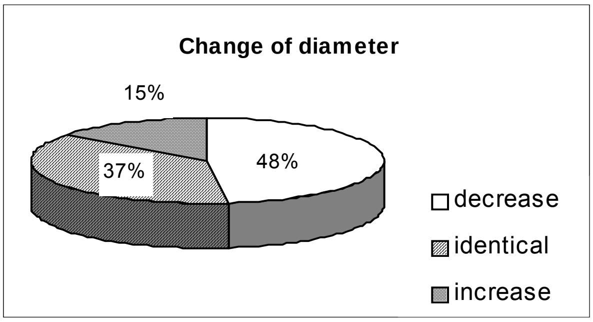


Figure A1-2

Tab. 1: Length of original and new pipe

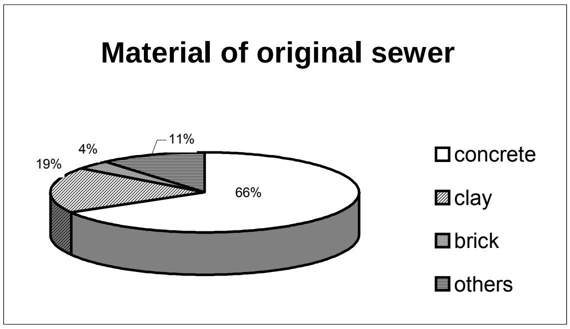
Diameter [mm]	Length-original pipe [m]	Length-new pipe [m]
<= 150	0	0
150 - 450 (incl.)	6725	6789
450 - 900 (incl.)	3974	3830
900 - 1200 (incl.)	412	608
1200 - 2200 (incl.)	791	675
>= 2200	0	0
unknown	450	450
Total	12352	12352

Tab. 2: Material of original pipe

Material - original	Length [m]
concrete	7076
clay	4170
brick	78
others	1027
Total	12352

Tab. 3: Material of new pipe

Material - new	Length [m]
concrete	4785
clay	2886
epoxy resin	591
PVC	1186
polyethylen (PE)	848
polyester	1400
other plastic	656
Total	12352



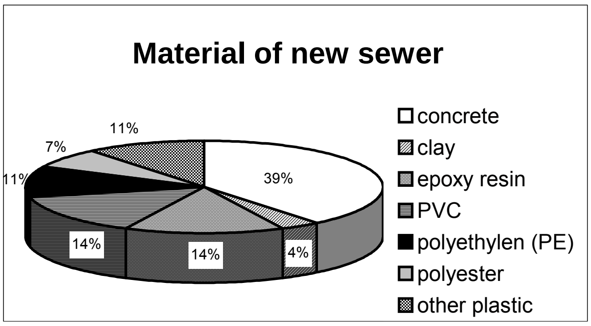


Figure A1-3 **Figure A1-4**

Figure A1-5 shows dividing rehabilitation pipes according to the age of sewer. Categories are consistent with UI, physical assets data, *sewer age*. There were no pipes laid after 1995.

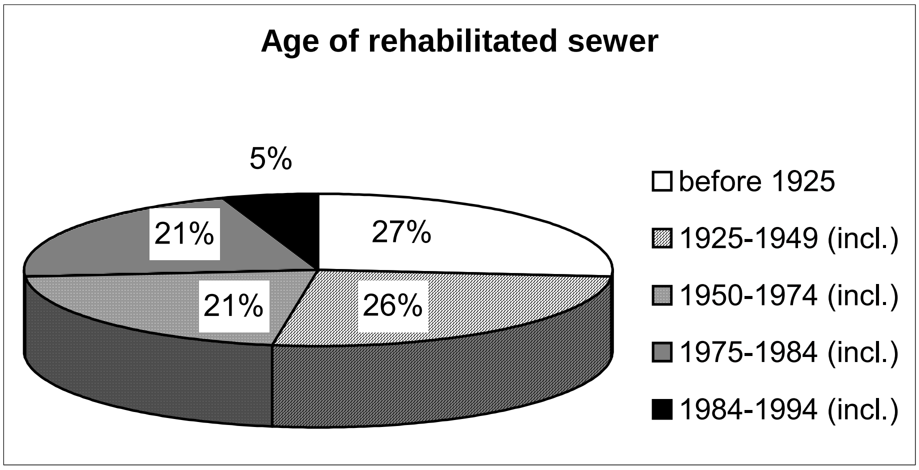


Figure A1-5

Density of inhabitants connected per meter of rehabilitation sewer is in average 2.32 inhabitants/m, density of service connections per 100 meter of rehabilitation sewer is average 7.11 connections/100m.

Sewer system

All 27 projects are of gravity systems; none of them is pressured or vacuum sewer system. Rehabilitation was done in 19 cases for combined sewer system and in 7 cases for separate sewer system, mostly (8) for wastewater sewer and only in 1 case for surface water sewer.

2. Sewer condition prior to rehabilitation

CCTV and visual inspection: was done in 22 cases from the total number of 27.

Sewer diagnosis from the inspection was decoded according to the prEN 13508-2 “Conditions of drain and sewer systems outside buildings - Part 2: Visual inspection coding system”, divided into particular failures and sized down (Figure A1-6). The most occurred failures were surface damage, Break/Collapse and Fissures.

Prior to rehabilitation work was done for 6 cases, as repair, replacement or flushing.

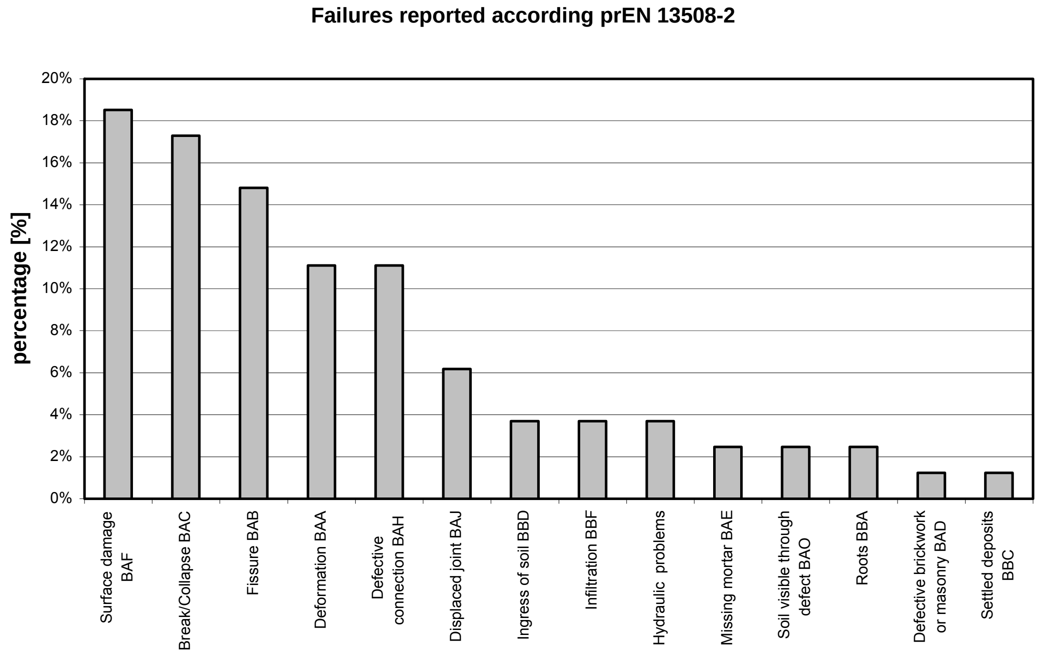


Figure A1-6

3. Information on rehabilitation method used

Here, information on chosen rehabilitation method (its description, available documentation) and realisation of the project (rate of rehabilitation and contractor) are collected. Costs assessment is an important item of this part.

General

All methods described in questionnaires were decoded according to the CARE-S WP4 file RT_chart.v4.xls. 25 structural and 1 operational methods (cleaning) have been found out. Figure 22 shows distribution of rehabilitation technologies according to the percentage number of accuracies and sewer length as well. Renovation is the most used type of rehabilitation method (above 50%). Trenchless rehabilitation methods represented more than 70% of all methods used (Figure A1-8).

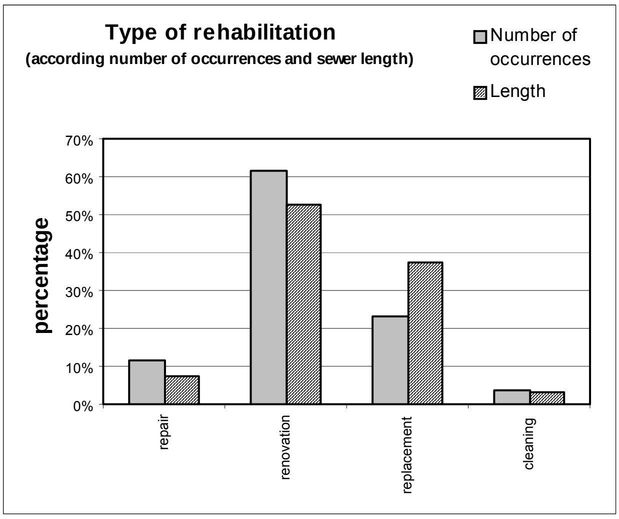


Figure A1-7

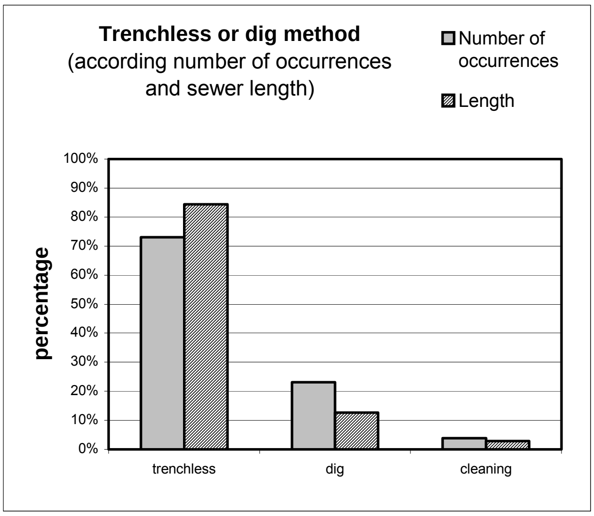


Figure A1-8

Methods described in the questionnaires are as follows:

Table 26

repair	trenchless	man-made repairs	1.2.3.	12%
renovation	trenchless	coating lining	2.2.1.	4%
		sliplining	2.2.3.	12%
		spirally wound lining	2.2.4.	4%
		cured-in-place lining (CIPP)	2.2.5.	40%
replacement	dig	open cut	3.1.1.	24%
	trenchless	on-line replacement (destruction of old pipe)	3.2.1.	4%

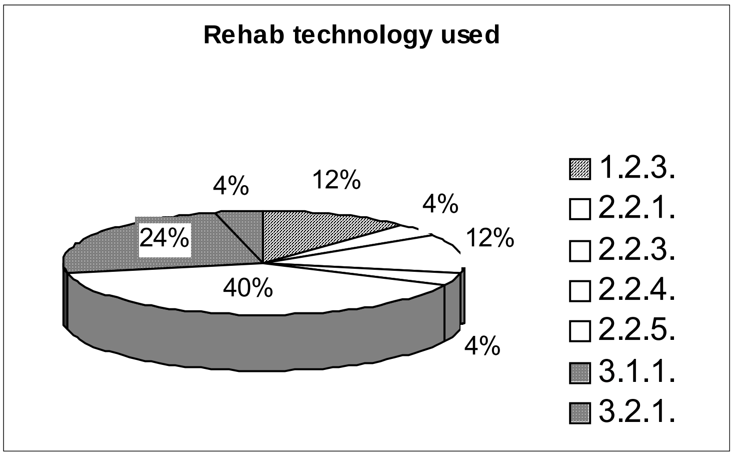


Figure A1-9

Costs [EUR]

Only 20 end-users have filled the information on costs. Average costs per meter for particular type of rehabilitation technology with its min and max value are shown in Figure A1-10. Further, as renovation is mostly used technology, it was reviewed dependence of average costs on pipe diameter. Results are screened in Figure A1-11.

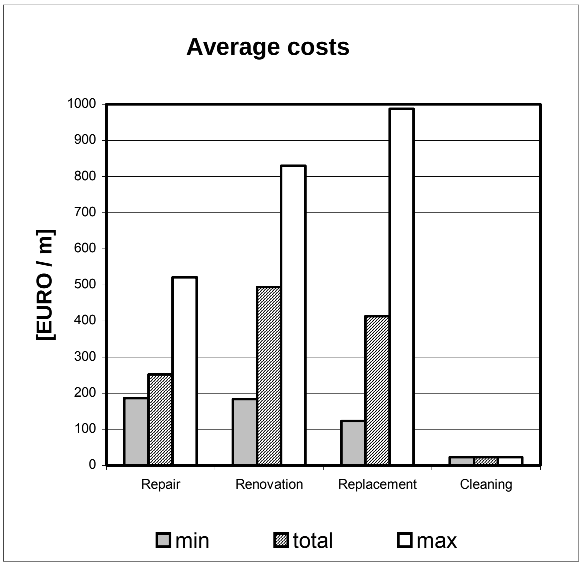


Figure A1-10

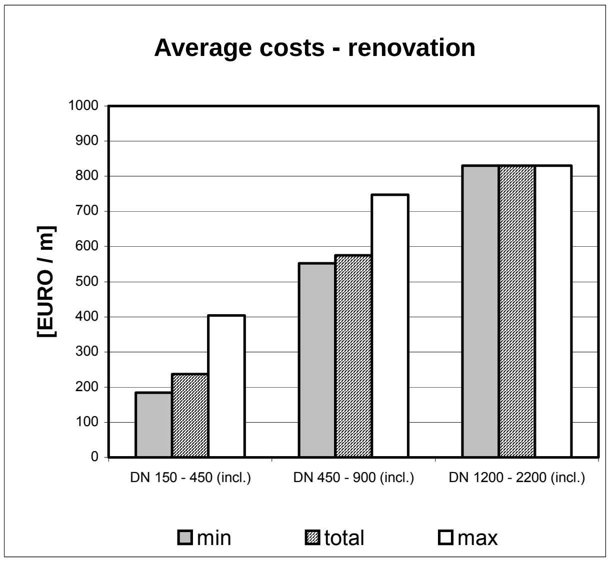


Figure A1-11

4. Decision criteria

The fourth part of the questionnaire included decision criteria for choosing a specific sewer section and a rehabilitation technology. End-users could evaluate the relevance of each criterion by ranking 0 – 10 and they could even add their own criteria.

Both Criteria for choice of sewer for rehabilitation and Criteria for choice of rehabilitation technology were divided into categories according to the diameter and compared (Figures A1-14 and A1-15):

- main axis (left) - bar Figures: there is proportional representation [percentage] of total sum of obtained points
- secondary axis (right) - marks: priority of criterion for end-users (how many times end-users validated this criterion by maximum points -10)

Criteria for the choice of sewer for rehabilitation

Pipe damage, flooding into houses and total costs for rehabilitation are the main criteria from general point of view while coordination with other networks and water pipe failure are the least important. Differences among particular categories are evident A1-14.

Criteria for the choice of rehabilitation technology

Capital costs, service life and minimum of indirect costs are the main criteria from general point of view while range of manageable and watertable are the least important. Differences among particular categories are evident in Figure A1-15.

5. Operator's satisfaction with realisation of the project

The fifth part asks about operator's satisfaction with realisation of the project – the positive and the negative aspects, compliance of expectations and the operational problems after rehabilitation.

End-users were the most satisfied with failure removing while project documentation was in many cases of bad quality. In 54% cases were end-users fully satisfied with rehabilitation.

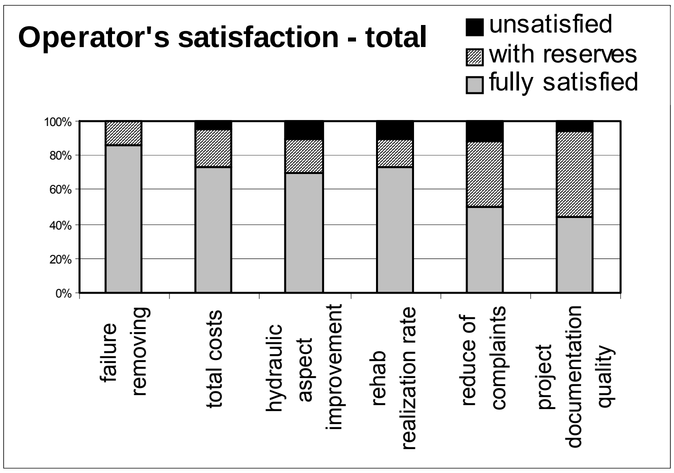


Figure A1-12

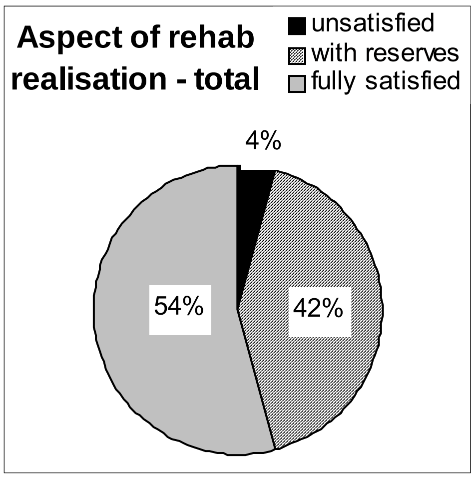


Figure A1-13

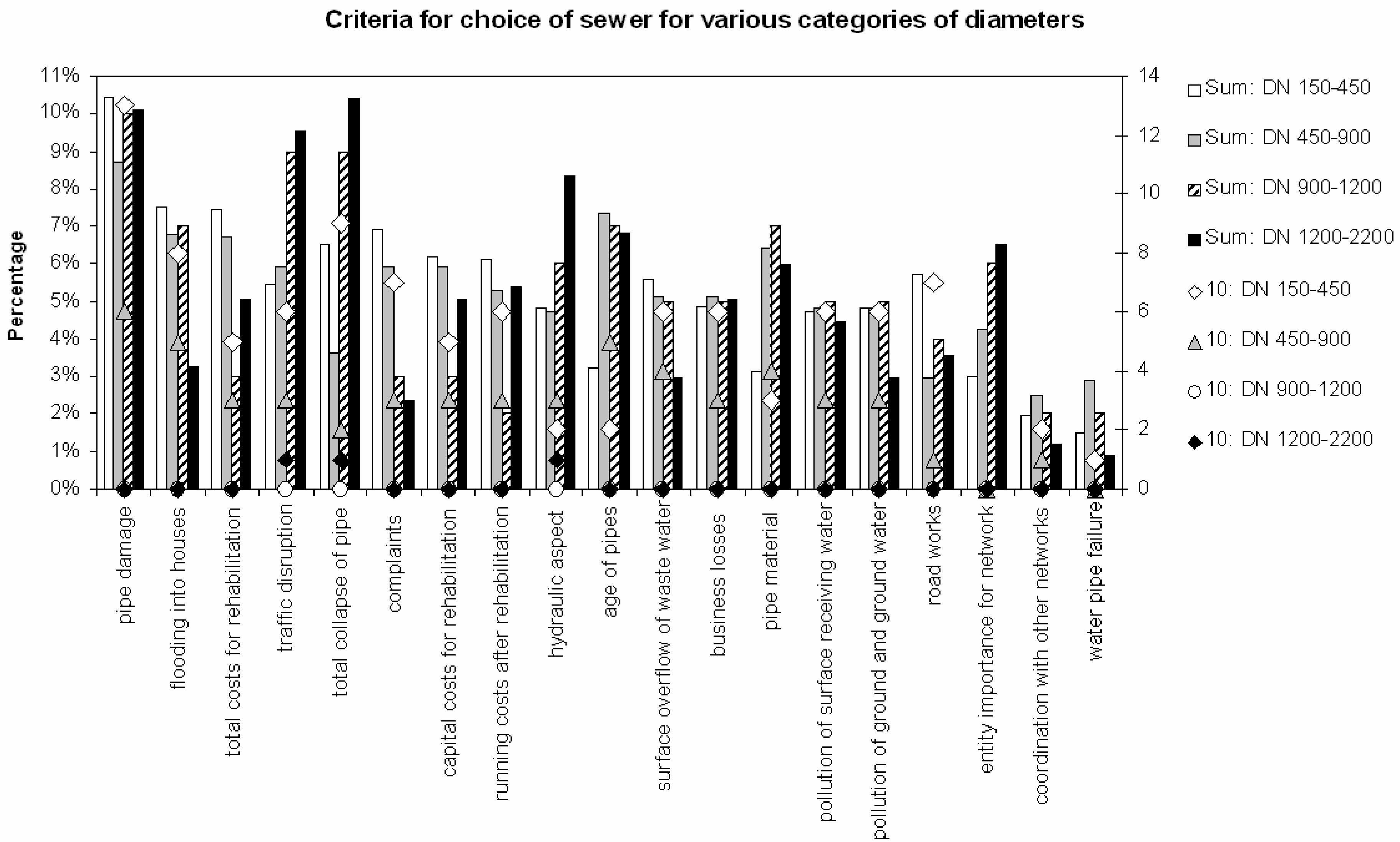

Criteria for choice of sewer for various categories of diameters
Percentage
11%
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
14
12
10
8
6
4
2
0
Sum: DN 150-450
Sum: DN 450-900
Sum: DN 900-1200
Sum: DN 1200-2200
10: DN 150-450
10: DN 450-900
10: DN 900-1200
10: DN 1200-2200
pipe damage
flooding into houses
total costs for rehabilitation
traffic disruption
total collapse of pipe
complaints
capital costs for rehabilitation
running costs after rehabilitation
hydraulic aspect
age of pipes
surface overflow of waste water
business losses
pipe material
pollution of surface receiving water
pollution of ground and ground water
road works
entity importance for network
coordination with other networks
water pipe failure

Figure A1-14

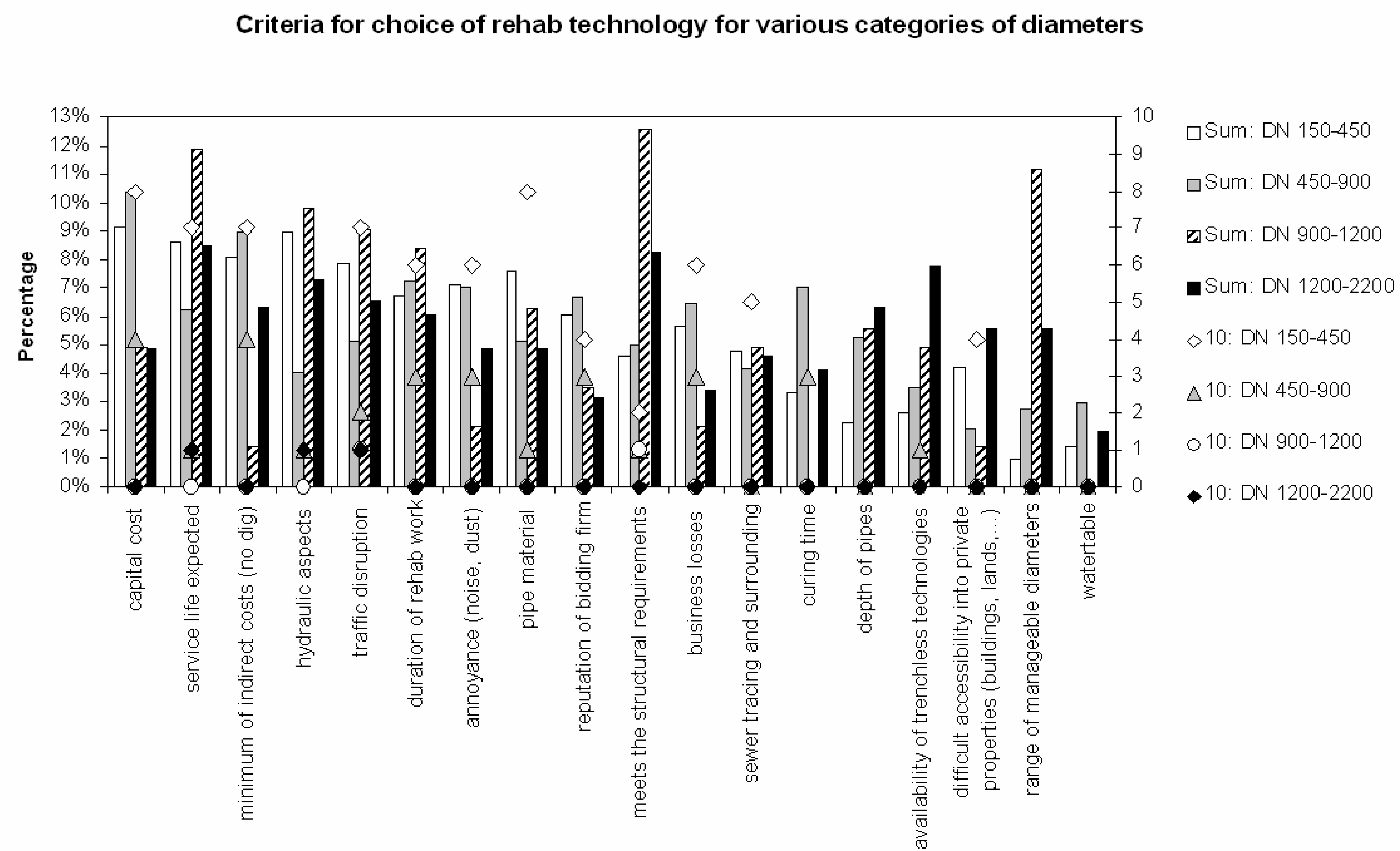

Criteria for choice of rehab technology for various categories of diameters
Percentage
13%
12%
11%
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
10
9
8
7
6
5
4
3
2
1
0
Sum: DN 150-450
Sum: DN 450-900
Sum: DN 900-1200
Sum: DN 1200-2200
10: DN 150-450
10: DN 450-900
10: DN 900-1200
10: DN 1200-2200
capital cost
service life expected
minimum of indirect costs (no dig)
hydraulic aspects
traffic disruption
duration of rehab work
annoyance (noise, dust)
pipe material
reputation of bidding firm
meets the structural requirements
business losses
sewer tracing and surrounding
curing time
depth of pipes
availability of trenchless technologies
difficult accessibility into private properties (buildings, lands,...)
range of manageable diameters
watertable

Figure A1-15

Questionnaire

Information on end-user

Organisation

Name	
City	
Country	
Type of company	

Contact person

Name	
E-mail	
Telephone	
Fax	

1. Information on rehabilitated asset

General

Name of the project	
City and location (street names)	

Description of asset

	parameters before rehabilitation							parameters after rehabilitation				
	Shape (*)	dimension 1	dimension 2	length	material	bed level at the end of the sewer length	year of laying (installation)	dimension 1	dimension 2	length	material	bed level at the end of the sewer length
		[mm]	[mm]	[m]	[-]	[m]		[mm]	[mm]	[m]	[-]	[m]
link 1												
link 2												
link 3												
link 4												
(extend as long as required)...												

(*) Shape: R = rectangular, C = circular, O = ovoid, N = other

Total asset length	[m]	> 100 !
Number of inhabitants connected	[inhabitant]	
Number of service connections	[No.]	

Number of objects in the links:

combined sewer overflow	[No.]	
stormwater tank	[No.]	
manhole	[No.]	
backdrop manhole	[No.]	
chute	[No.]	
storm water inlet	[No.]	
bed-load sampler	[No.]	
inverted siphon	[No.]	
crossing below railway or roadway	[No.]	
flushing object	[No.]	
pumping station	[No.]	
lateral connections	[No.]	
others	[No.]	
others	[No.]	

Sewer system

pressurised system	[yes / -]	
gravity system	[yes / -]	
combined sewage system	[yes / -]	
separate sewage system	[yes / -]	
waste water sewer	[yes / -]	
surface water sewer	[yes / -]	

Parts of asset rehabilitated

only pipes	[yes / -]	
pipes and all objects	[yes / -]	
pipes and some objects	[yes / -]	
- which objects:		

Working impacts

traffic disruptions	[yes / -]	
surrounding building damages	[yes / -]	
business losses	[yes / -]	
annoyance (noise, dust)	[low / high]	
difficult accessibility into private properties (buildings, lands,...)	[yes / no]	
other disturbances (please specify)	[yes / -]	
payment of compensations	[yes / -]	

Environmental / working constraints

groundwater table	[below / at / above]		sewer level
kind of soil			[sand, clay, rock, not relevant...]
position of the pipe (under the road)			[yes / -]
presence of trades			[Number of shops, services,...
street category			[trunk/major/minor/pedestrian zone]
working area required			[m^2]
number of locations (work areas)			[No.]
if trenchless technology used:			
auxiliar digging needed?			[yes ->m^2 surface affected / no]
lenght constructed in 1 working cycle			[average ratio in m] (if known)

Impact on other utility assets

service line affected	[yes / -]	

2. Sewer condition prior to rehabilitation

CCTV and visual inspection

CCTV or visual inspection performed?	[yes / -]	
if yes: please give the Code registered (including the standard used)		
Are the results available?	[yes / -]	
- photographs	[yes / -]	
- video images (tape, CD)	[yes / -]	
- written report	[yes / -]	
- database	[yes / -]	
- others (specify)	[yes / -]	

Sewer diagnosis from the inspection (if done) kind of failure, brief description of the pathology	
Tests done in sewer (if any)	

Prior rehabilitation work

has this asset been rehabilitated before?	[yes / -]	
if yes: year of rehabilitation	[year]	
if yes: type of rehabilitation (flushing, repair, replace, relining etc.)		
if yes: brief description of former rehabilitation		

3. Information on rehabilitation method used

General

Rehabilitation method used Brief description of rehabilitation method used (trenchless or open cut, replace, relining, etc.)	

Documentation obtained by end-user [yes / -]	
project documentation	
photographs, pictures, graphs	
video document	
advertising materials in print	
advertising in electronic format	
advertising web pages	
personal inspection reports	
others (specify)	

Schedules	planned	actual	
Start of the project			
End of the project			
Total duration			[weeks]

Contractor

Name	
website address	

		general	particular (of this asset)
Is contractor's presentation of this method available?	[yes / -]		
photographs, pictures, graphs	[yes / -]		
video document	[yes / -]		
advertising materials in print	[yes / -]		
advertising in electronic format	[yes / -]		
advertising web pages	[yes / -]		
personal inspection reports	[yes / -]		
others (specify)	[yes / -]		

Costs [EUR]	
set up costs (mobilisation)	
rehabilitation of sewer length	
object rehabilitation	
Total costs	0
surface reinstatement (manhole entry included)	

collateral costs and ratios		
Planning costs		
Inspection costs (visual / CCTV)		
Previous cleaning		
Socioeconomic costs and compensations		
Average cost of lining/pipe installation (if known)		[€/m]
Average cost of robotic repairs/reopening of laterals (if known)		[€/unit]

4. Decision criteria

Criteria for having chosen this sewer for rehabilitation

Please, indicate by ranking numbers (0-10, 10 is very important, 0 is not important) the importance of each criterion.

criterion	*rank*
age of pipes	
pipe material	
hydraulic aspect (e.g. diameter, slope)	
entity importance for network	
pipe damage	
total collapse of pipe	
capital costs for rehabilitation	
running costs after rehabilitation	
total costs for rehabilitation	
traffic disruption	
business losses	
flooding into houses	
surface overflow of waste water	
pollution of ground and ground water	
pollution of surface receiving water	
coordination with other networks	
road works	
water pipe failure	
complaints	
others (please specify)	
others (please specify)	
others (please specify)	

Criteria for having chosen this rehab technology

Who chose rehab technology?	[yes / no]
- sewer operator	
- sewer owner	
- contractor	
- public authority, municipality etc.	
- others (please specify)	

Did you put this project out to tender?

Did you determine rehab technology by yourselves?

In case of yes:

Please, indicate by ranking numbers (0-10, 10 is very important, 0 is not important) the importance of each criterion.

criterion	*rank*
minimum of indirect costs (no dig)	
service life expected to be provided (prolonged)	
hydraulic aspects (e.g. change of profile)	
capital cost (investment)	
pipe material	
sewer tracing and surrounding	
reputation of bidding firm	
depth of pipes	
traffic disruption	
business losses	
annoyance (noise, dust)	
difficult accessibility into private properties (buildings, lands,...)	
duration of rehab work	
range of manageable diameters	
meets the structural requirements	
watertable	
availability of trenchless technologies	
curing time	
others (please specify)	
others (please specify)	

5. Operator's satisfaction with realisation of the project

Does rehab realization meet your expectations?

Please, indicate by ranking numbers (0-10, 10 is very important, 0 is not important) the importance of each item.

hydraulic aspect improvement	
failure removing	
rehab realization rate	
total costs	
project documentation quality	
reduce of complaints	
others (please specify)	

Write the positive aspects of rehab realisation:	
Write the negative aspects of rehab realisation:	
Have any operational problems occurred on the rehab entity? Describe them, please.	

Appendix 2

Economic Evaluation of Rehabilitation Technologies

WRc

CARE – S

Computer Aided REhabilitation of Sewer networks.
Decision Support Tools for Sustainable Sewer Network Management

WP6 – Multicriterion Decision Support

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Introduction

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. Task 6.1 will systematically analyse and document direct rehabilitation costs for a variety of open trenching and no dig rehabilitation technologies.

This paper forms WRc's contribution to this sub-task. Our brief for this sub-task was as follows:

"Consideration of direct costs and service life (prolongation) of different rehabilitation technologies. Development of a procedure for cost-effectiveness-analysis including net-capital-values and annuities."

This task 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.

Each of these sections will be addressed in this paper.

Development of relative costs

The first of these tasks is the development of direct costs for sewer rehabilitation techniques. As costs will change over time, due to changing economic conditions, relative costs have been presented here. Where the information is available, costs have been presented as percentages relative to a base line. In this instance the base line is the installation of a new 300 mm diameter sewer pipe by open cut trenching, in a road requiring Type 2 reinstatement[2]. This base line cost is for a sewer pipe that has been installed to a depth of 4m. This has been assumed to be a reasonable average depth for a typical sewer network, but generally smaller diameter sewers would be installed at a shallow depth and larger diameters at a greater depth.

The relative costs given here are based on cost models that have been developed from actual UK sewer rehabilitation contracts. The number of contracts used to develop the costs for each technique varies from 2 to 17. The actual numbers used for each technique are summarised in Table A1 in Appendix A. All the cost models are statistically robust.

The open cut costs have been taken from a UK water industry cost model developed by WRc over a number of years. The costs have been taken from the most recent version of the model, released in June 2003.

The relative costs include all items that can be directly attributed to the use of the technique. The following items are therefore included:

- General items;
- Dayworks;
- Provisional sums;
- CCTV inspection;
- Overpumping of sewage;
- Cleaning existing sewer;
- Traffic management;

[2] A Type 2 reinstatement is required for roads or highways carrying over 2.5 to 10 millions of standard axels. These would typically be minor urban or secondary rural roads.

- Site investigation;
- Installation costs;
- Permanent reinstatement of surface, and;
- Materials.

The exceptions to this are the tunnelling, microtunnelling and pipe jacking techniques. As new installation techniques they do not require CCTV inspection, overpumping or sewer cleaning.

The following items are **not** included in these direct costs:

- Design and supervision;
- Diverting other utilities;
- Land purchase and easement (access charge);
- Removal of obstructions;
- Reconnection of laterals;
- Manholes, and;
- Contingencies.

A proportion of open cut costs were from new installation with the remainder being from rehabilitation work.

The cost to install a new sewer pipe, per metre length, has been compared to the metre length cost for each rehabilitation technique. The costs were all adjusted to a common price base.

The relative costs are presented in the following two tables. Table 1 is concerned with sewer renovation techniques and Table 2 with sewer replacement techniques. The presentation of the tables and the classifications of the techniques follows the format of the rehabilitation chart[3] produced under Work Package 4.

Each table gives the classification and name of the technique and the relative cost as a percentage, per diameter category.

The cost of sewer repair techniques has not been presented. This is because the cost models for the various repair methods are based on a cost per repair rather than per metre length. It is therefore not possible to do a reasonable cost comparison between open cut replacement of a length of sewer and a localised repair.

---

[3] WP4_Rtchart_v2.2.xls, posted on the BSCW server on the 6^{th} June 2003.

Sewer renovation techniques

Table 1 Sewer Renovation Techniques

Classification	Technique			Relative cost (%) Diameter (mm) 300	450	600	750	900	1050	1500
dig technology	open cut		conventional trench	100	132	162	189	216	238	305
trenchless technology	coating lining		reinforced, cementitious	Data not available						
		spray lining (projected)	steel reinforced cement-mortar spray	Data not available						
			fibres (steel, glass) reinforced cement-mortar spray	Data not available						
			polymer lining	Data not available						
	close-fit lining		swaged liners (swagelining)	Data not available						
			folded liners (fold & form lining)	Data not available						
	sliplining	continuous pipe	continuous sliplining	35	47	62	82	108	143	
		long pipes	discrete sliplining, GRP			113	127	142	160	226
			discrete sliplining, Plastic	57	76	101	134	178	237	
		short pipes	segmental sliplining, GRC					142	160	227
			segmental sliplining, GRP & PE			119	141	168	199	335
	spirally wound lining		spiral lining	Data not available						
	cured-in-place lining (CIPP)	thermal cure	hot water cure	43	58	78				
			steam cure							
			UV cure							
			ambient cure							
	pre-cast elements lining		.	Data not available						

Sewer replacement techniques

Table 2 Sewer Replacement techniques

Classification	Technique			Relative cost (%) Diameter (mm) 300	450	600	750	900	1050	1500
dig technology	open cut		conventional trench	100	132	162	189	216	238	305
	semi-open cut		mole ploughing	Data not available						
		narrow trenching	trench box	Data not available						
			concrete sheet pile	Data not available						
			steel sheet pile	Data not available						
trenchless technology	on-line replacement	pipe bursting (pipe cracking)	pipe bursting percussive (Pneumatic)		81	110	149	202		
			pipe bursting hydraulic							
			pipe bursting static							
			Controlled Line and Grade system (CLG System)	Data not available						
			pipe splitting	Data not available						
			pipe eating	Data not available						
			pipe reaming	Data not available						
			Pipe crushing (implosion)	Data not available						
			pipe ejection (modified pipe jacking)	Data not available						
			pipe extraction (modified static pull)	Data not available						
			pipe pulling	Data not available						
	off-line replacement - non steered		rod pushing	Data not available						
		impact moling	pneumatic hammer	Data not available						
			hydraulic hammer	Data not available						
			steerable moling	Data not available						
			pipe ramming (impact ramming)	Data not available						
			auger boring	Data not available						

Classification	Technique			300	450	600	750	900	1050	1500
				Relative cost (%)						
				Diameter (mm)						
	off-line replacement - steered		guided auger boring (guided boring)	Data not available						
		directional drilling	horizontal directional drilling (HDD)	Data not available						
			guided drilling (mini-HDD)	Data not available						
		pipe jacking	conventional pipe jacking			295	300	306	312	329
			low load pipe jacking	Data not available						
			thrust jacking	Data not available						
			microtunnelling	221	257	299	348			
			minitunnelling	Data not available						
			tunnelling							118
			shield	Data not available						

Service Life Expectancies for Rehabilitated Sewers

The second part of this task is the development of service life (prolongation) values for the different sewer rehabilitation techniques. The service life of a technique will be dependent on the material used in the rehabilitation of a sewer, as this will be the resultant material of the asset. WRc has therefore approached this task in terms of the materials used in each technique, rather than the techniques themselves.

The information provided in this paper is based on product testing, known performance and WRc's experience. The asset design lives represent general values only and more accurate values can be determined for particular schemes. Further advise on the selection of appropriate materials for sewer rehabilitation can be found in the Sewerage Rehabilitation Manual[4].

It should also be noted that the asset design lives presented here assume that the rehabilitation work has been completed to a good standard, in accordance with manufacturers instructions.

Typical Asset Design Lives

The asset design life is the length of time a designer can reasonably expect a sewer to operate before there are structural or serviceability problems associated with the age of the sewer. The main factors affecting asset life of a sewer can be reduced down to the type of material used and the ambient temperatures in which a sewer operates. The different materials can be grouped under the generic headings listed in Table 3 below.

Table 3 Generic Material Types

GENERIC MATERIAL TYPE	MATERIALS
Cementitious (unprotected)	Cement Mortar, Reinforced concrete, Glass Reinforced Cement (GRC), Plastic Reinforced Concrete (PRC), Pre-stressed Concrete (PSC), Reinforced Concrete (RC), Pre-cast Concrete (PC)
Thermoset plastics	Epoxy Resin, Glass Reinforced Plastic (GRP), Polyester Resin,
Thermoplastics	High Performance Polyethylene (HPPE), Medium Density Polyethylene (MDPE), Polyvinyl Chloride (PVC)
Clay	Vitrified Clay (VC)
Ferrous	Steel (protected), DI (protected)
Stainless steel	Stainless steel

The generation of hydrogen sulphide (H_2S) in sewers causes significant corrosion to cementitious materials if the sewer surface is unprotected. Examples of protection systems include PVC linings keyed to the inside of concrete pipes in which case the asset life would change to that for thermoplastics. The rate of generation of H_2S increases exponentially with temperature and therefore is much more prevalent in hotter climates. Within Europe the sewers in southern countries will be far more prone to corrosion problems of cementitious sewer materials than more northerly countries. The terms 'cool' and 'hot' are used where 'cool' includes the UK and Scandinavia and 'hot' covers the Mediterranean area. All materials other than cementitious are unaffected by the climate.

Steel and DI may be protected using a variety of different lining materials including

[4] The Sewerage Rehabilitation Manual (SRM), 4th Edition. WRc, 2001.

cementitious and thermoset type materials and the use of cathodic protection. In a sewerage environment none of these protection systems will provide permanent protection but will significantly slow the corrosion process.

The generic materials can be assigned an estimated asset design life based on climate as shown in Table 4 below.

Table 4 Estimate of Material Design Life

GENERIC MATERIAL TYPE	ASSET DESIGN LIFE (years)	
	Cool climate	Hot climate
Cementitious (unprotected)	100+	<50
Thermoset plastics	50	50
Thermoplastics	100+	100+
Clay	100+	100+
Ferrous	<50	<50
Stainless steel	100+	100+

The materials used in the various rehabilitation techniques, and therefore the asset design lives, are presented in the following three tables. The definition and classification of the individual techniques has again been based on the rehabilitation chart[5] produced under work package 4. As in section 2 above, Table 5 contains sewer renovation techniques, Table 6 sewer replacement techniques and Table 7 sewer repair techniques. It should be noted that the asset design life values quoted in Table 7 are for the repair itself. It has been assumed that the remaining sewer is in good condition and is still performing satisfactorily.

[5] WP4_Rtchart_v2.2.xls, posted on the BSCW server on the 6th June 2003.

Table 5 Asset Design Lives for Sewer Renovation Techniques

						Typical asset life (years)	
Classification	**Technique**			**Material**	**Generic material type**	**Climate - temperate**	**Climate - hot**
dig technology	open cut		conventional trench	Any	Any		
trenchless technology: continuous relinings	coating lining		reinforced, cementitious	Cement Mortar, RC	cementitious	100+	<50
		spray lining (projected)	steel reinforced cement-mortar spray	Cement mortar	cementitious	100+	<50
			fibres (steel, glass) reinforced cement-mortar spray	Cement mortar	cementitious	100+	<50
			polymer lining	Epoxy Resin	Thermoset plastics	50	50
	close-fit lining		swaged liners (swagelining)	HPPE, MDPE, PVC	Thermoplastics	100+	100+
			folded liners	HPPE, MDPE, PVC	Thermoplastics	100+	100+
	sliplining	continuous pipe	continuous sliplining	HPPE, MDPE, PVC	Thermoplastics	100+	100+
		long pipes	discrete sliplining	GRP	Thermoplastics	100+	100+
				HPPE, MDPE, PP	Thermoplastics	100+	100+
		short pipes	segmental sliplining	GRC, Gunnite, PRC, RC	cementitious	100+	<50
				GRP, PE, PP	Thermoplastics	100+	100+
	spirally wound lining		spiral lining	PE, PVC	Thermoplastics	100+	100+
	cured-in-place lining (CIPP)	thermal cure	hot water cure	Polyester Resin (WIS 3-34-04)	Thermoset plastics	50	50
			steam cure				
			UV cure				
			ambient cure				
	pre-cast elements lining			GRC, PRC	cementitious	100+	<50
				GRP	Thermoset plastics	50	50

Table 6 Asset Design Lives for Sewer Replacement Techniques

Classification	Technique			Material	Generic material type	Typical asset life (years)	
						Climate - temperate	Climate - hot
dig technology	open cut		conventional trench	Any	Any		
	semi-open cut		mole ploughing	MDPE, HDPE	Thermoplastics	100+	100+
				DI, Steel	Ferrous	<50	<50
		narrow trenching	trench box	HPPE, MDPE	Thermoplastics	100+	100+
				DI, Steel	Ferrous	<50	<50
			concrete sheet pile	HPPE, MDPE	Thermoplastics	100+	100+
				DI, Steel	Ferrous	<50	<50
			steel sheet pile	HPPE, MDPE	Thermoplastics	100+	100+
				DI, Steel	Ferrous	<50	<50
trenchless technology	on-line replacement	pipe bursting (pipe cracking)	pipe bursting percussive	HPPE, MDPE, PVC	Thermoplastics	100+	100+
			pipe bursting hydraulic				
			pipe bursting static				
			pipe eating	HPPE, MDPE, PVC	Thermoplastics	100+	100+
				DI	Ferrous	<50	<50
				GRP	Thermoset plastics	50	50
				PC	Cementitious	100+	<50
				VC	Clay	100+	100+
	off-line replacement - non steered		rod pushing	HPPE, MDPE	Thermoplastics	100+	100+
		impact moling	pneumatic hammer	HPPE, MDPE	Thermoplastics	100+	100+
			hydraulic hammer	HPPE, MDPE	Thermoplastics	100+	100+
			steerable moling	HPPE, MDPE	Thermoplastics	100+	100+
			pipe ramming (impact ramming)	Steel	Ferrous	<50	<50
				HPPE, MDPE	Thermoplastics	100+	100+

Classification	Technique			Material	Generic material type	Typical asset life (years)	
						Climate - temperate	Climate - hot
				PC, RC	Cementitious	100+	<50
				Clay	Clay	100+	100+
			auger boring	Steel	Ferrous	<50	<50
				Concrete	Cementitious	100+	<50
				Clay	Clay	100+	100+
	off-line replacement - steered		guided auger boring (guided boring)	Steel	Ferrous	<50	<50
				Clay	Clay	100+	100+
				Concrete	Cementitious	100+	<50
		directional drilling	horizontal directional drilling (HDD)	Steel	Ferrous	<50	<50
				HPPE, MDPE	Thermoplastics	100+	100+
			guided drilling (mini-HDD)	HPPE, MDPE	Thermoplastics	100+	100+
		pipe jacking	conventional pipe jacking	Clay	Clay	100+	100+
				Concrete	Cementitious	100+	<50
				GRP	Thermoset plastics	50	50
				Steel	Ferrous	<50	<50
			thrust jacking	HPPE, MDPE	Thermoplastics	100+	100+
			microtunnelling	Ductile Iron	Ferrous	<50	<50
				GRP	Thermoset plastics	50	50
				PC, RC, PSC	Cementitious	100+	<50
			tunnelling	Any	Any		
			shield	Any	Any		

Table 7 Asset Design Lives for Sewer Repair Techniques

Classification	Technique			Material	Generic material type	Typical asset life (years) Climate - temperate	Typical asset life (years) Climate - hot
dig technology: external repair	open cut		conventional trench	Any	Any		
trenchless technology: internal repair	robotic repairs		injection in joints, cracks or fractures	Epoxy resin, gel or grout	Thermoset plastics	50	50
			milling robot (mortar, pipes, joints...)	n/a	n/a		
			Root cutting robot (repair/operational)	n/a	n/a		
			pointing	mortar	Cementitious	100+	<50
			rerounding	n/a	n/a		
			connection restoration	n/a	n/a		
	short -liner installed with packers or man-made		Fiberglas & polymer	Glass fibre, carbon fibre or polyester felt with epoxy resin or polyester resin	Thermoset plastics	50	50
			Metallic	stainless steel sleeve with hydrofoam gasket with a polyurethane grout	Stainless steel	100+	100+
	man-made repairs		masonry or bricks works	Mortar	Cementitious	100+	<50
			pointing	Mortar	Cementitious	100+	<50
		invert repair	in situ repair (concrete and mortar)	Mortar, Concrete	Cementitious	100+	<50

Classification	Technique			Material	Generic material type	Typical asset life (years) Climate - temperate	Climate - hot
			pre-cast repair (with pre-cast elements made of gres, plastic, ...)	GRC, PRC	cementitious	100+	<50
				GRP	Thermoset plastics	50	50
	grouting (injection) methods	inside	chemical stabilisation (fill and drain systems)	Composite	Thermoset plastics	50	50
			mortar stabilisation	Mortar	Cementitious	100+	<50
			joint sealing	Epoxy resin, Gel, Grout	Thermoset plastics	50	50
			resin injection	Epoxy resin, Gel	Thermoset plastics	50	50
		outside	compacted filling with structural regeneration through the extrados				
			surrounding soil stabilization				

Cost-effectiveness of Rehabilitation Options

The basic principal of sewer design is to achieve a system which will remain maintenance free for a reasonable period of time. Traditionally, this has been a minimum of 50 years. For the established renovation materials sufficient durability data have been accumulated to justify design life predictions of 50 – 100 years. This assumes that the material has been manufactured to an adequate specification, that design and installation procedures are properly followed and that advice about adverse conditions is heeded. This is particularly relevant for cementitious materials, which must have adequate protection in hot climates.

Cost effectiveness analysis uses direct costs (and indirect costs where available) and normalises these using a non-monetary measure of benefits. When service life is the only measure of the benefit of rehabilitation then, in principal there should be little to choose between the different techniques.

It is evident from this that all correctly designed and implemented rehabilitation options will result in significant prolongation of service lives (by 50 years or more). The net present values of costs after this time are likely to be very low due to discounting. Furthermore, each valid technique should result in a very similar performance of the sewer. Therefore there should be no differences in annual operating expenditure between all of the technically suitable options for rehabilitation.

These factors suggest that an economic comparison of net present costs for different rehabilitation options would always yield the method with the lowest capital cost which is technically valid.

It is therefore concluded that a sophisticated economic analysis would not be useful in selecting an appropriate rehabilitation method for a particular scheme.

However, companies usually have limited budgets which are insufficient to solve all problems with their sewer network. A cost-effectiveness analysis could be developed to ensure that budgets are allocated effectively. Such a method could be based around:

- the likely costs arising from not rehabilitating sewers and
- the costs of sewer rehabilitation.

The latter cost should include both direct capital costs and indirect (social) cost impacts of rehabilitation (investigated under WP5).

Social costs will also need to be considered for the first option. For this an assessment of both the likelihood and consequences of asset failure will need to be assessed. The economic analysis will therefore be closely linked to Risk assessment analysis.

Using the information derived under WP6.2 (and WP5 if available) a series of notional schemes will be developed to trial this approach in WP6.3.

Appendix A – Data used to develop cost models for sewer rehabilitation techniques.

The following table summarises the data that was used to develop the costs models for the various sewer rehabilitation techniques.

The cost models were built using data supplied by various UK water utilities. The costs were taken from actual sewer rehabilitation contracts that had been undertaken by the utility. The costs have been taken from either the Bill of Quantity or the Schedule of Rates from each contract.

Table A.1

Technique	No of Bill of Quantities	No of Schedule of Rates	Total
Cured in Place Pipes	9	6	15
GRP lining	3	4	7
Discrete sliplining, GRC	5	0	5
Segmental Lining, GRC	6	4	10
Lining with continuous Pipes	8	3	11
Discrete sliplining, PE	0	3	3
Pipe jacking	17	0	17
Conventional tunneling	8	0	8
Microtunnelling	7	0	7
Pipe bursting	1	3	4

Appendix 3

Methodological comparison: Application of an ELECTRE approach

Cemagref / ENGEES Strasbourg

CARE – S

Computer Aided REhabilitation of Sewer networks.
Decision Support Tools for Sustainable Sewer Network Management

WP6 – Multicriterion Decision Support

Authors:

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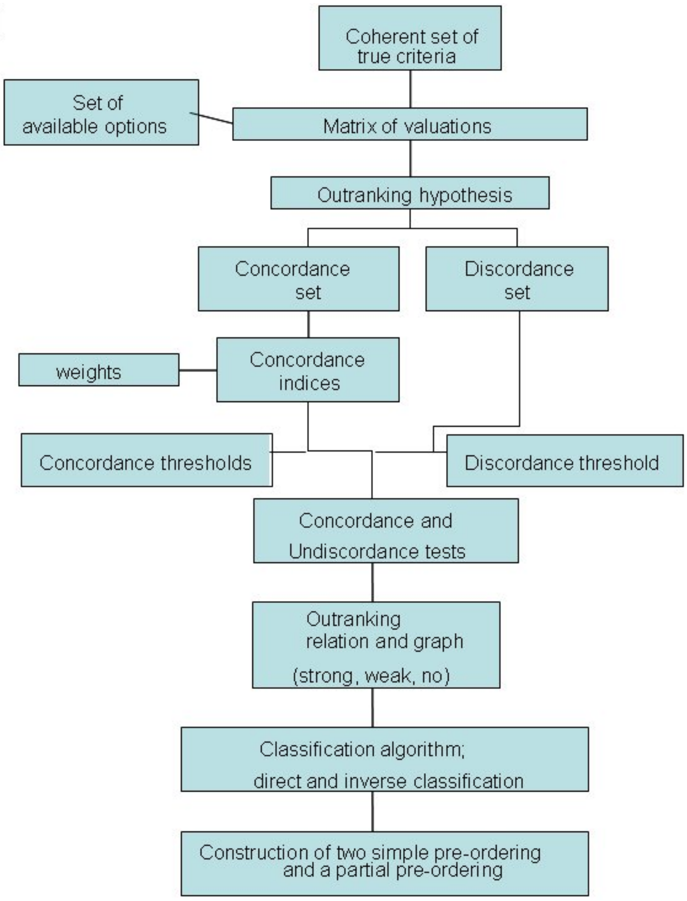
APPENDIX 3.I : ELECTRE II [ROY 1993]

ELECTRE II, developed by Roy in 1973, is a γ reference problem (ranking procedure of all options[6] in relation to each other) for which the objective is the arrangement in classes of equivalence, consisted of actions, these classes being ordered in a complete or partial way.

ELECTRE II method aims at classifying the potential actions, since "best" until "less good", tolerating *ex æquo*. To do it, ELECTRE II uses the outranking relation, *S*. In order to develop this outranking relationship, two concepts are required – that of concordance and discordance. Concordance and discordance tests are fit into each other.

Besides, the distinction is done between two types of surclassement : strong and weak surclassements.



Assume that there exist defined criteria, g_j, $j=1,2,\ldots,r$ and a set of options, A (a_1, a_2, ..a_i, …a_n).

Statement of the development hypothesis of the of the method :

[6] For the CARE-S project, an option is a rehabilitation technique

a_i S a_k (means that " a_i is at least as good as a_k"), $\forall$ ***a_i*, *a_k*** $\in$ ***A***

CONCORDANCE CONDITIONS

Definitions

$A = \{a_1, a_2, ..., a_i, ..., a_n\}$: set of potential options

$F = \{1, 2, 2, ..., j, ..., m\}$: coherent set of criteria

$g_j(a_i)$: option a_i assessment regarding criteria *j*

P_j : weight of criteria *j*

$J^+(a_i, a_k) = \{j \in F / g_j(a_i) > g_j(a_k)\}$: all the criteria for which option a_i is preferred to option a_k.

$J^=(a_i, a_k) = \{j \in F / g_j(a_i) = g_j(a_k)\}$: all the criteria for which option a_i is equivalent to option a_k.

$J^-(a_i, a_k) = \{j \in F / g_j(a_i) < g_j(a_k)\}$: all the criteria for which option a_k is preferred to option a_i.

$P^+(a_i, a_k) = \sum P_j,\ j \in J^+(a_i, a_k)$: Weight sum of criteria belonging to $J^+(a_i, a_k)$

$P^=(a_i, a_k) = \sum P_j,\ j \in J^=(a_i, a_k)$: Weight sum of criteria belonging to $J^=(a_i, a_k)$

$P^-(a_i, a_k) = \sum P_j,\ j \in J^-(a_i, a_k)$: Weight sum of criteria belonging to $J^-(a_i, a_k)$

Concordance indices

The concordance indice C_{ik} is given by :

$$C_{ik} = \frac{P^+(a_i, a_k) + P^=(a_i, a_k)}{P}$$

Meaning of the concordance test

It is necessary to know if the importance of the criteria, for which the option a_i is preferred to the option a_k, is strong enough

Three thresholds are defined : c^+, c^0 et c^-, and always follow the order : $c^+ \geq c^0 \geq c^-$

relation $C_{ik} \geq c^+$ corresponds to the satisfaction of the concordance test of with a strong certainty

relation $C_{ik} \geq c^0$ corresponds to the satisfaction of the concordance test of with a average certainty

relation $C_{ik} \geq c^-$ corresponds to the satisfaction of the concordance test of with a weak certainty

Nevertheless, this relation is necessary but not enough to the satisfaction of this test. There is a supplementary condition :

$$\frac{P^{+}(a_i, a_k)}{P^{-}(a_i, a_k)} \geq 1.$$

To sum up … :

The test of concordance is accepted if:

$$\left.\begin{array}{c} C_{ik} \geq c^{+} \\ \text{ou} \\ C_{ik} \geq c^{0} \\ \text{ou} \\ C_{ik} \geq c^{-} \end{array}\right\} \quad \text{and} \quad \frac{P^{+}(a_i, a_k)}{P^{-}(a_i, a_k)} \geq 1$$

UNDISCORDANCE CONDITIONS (UNDISCORDANCE TEST)

In which limits the opposition of the discordant criteria to the outranking hypothesis should contain itself so that this last hypothesis remains acceptable.

Concordance should not exceed limits fixed for every criterion, two by criterion. These limits are concordance thresholds : D_1 and D_2

$D_2 \leq D_1$.

Il s'agit de définir dans quelles limites l'opposition des critères discordants à l'hypothèse de surclassement doit se contenir pour que cette dernière hypothèse reste acceptable.

To sum up … :

Undiscordance test , for $j \in J(a_i,a_k)$ is given by :

- if $g_j(a_k) - g_j(a_i) \leq D_{2(j)}$, then there is a strong certainty which the criterion j does not present a major opposition to the outranking hypothesis
- if $D_{2(j)} < g_j(a_k) - g_j(a_i) \leq D_{1(j)}$, then there is a weak certainty which the criterion j does not present a major opposition to the outranking hypothesis

STRONG AND WEAK OUTRANKING RELATIONSHIP

Concordance and discordance tests should be satisfied at the same moment to establish an outranking relation. Besides, the method bases on two outranking relations, corresponding to different risk levels :

- a strong outranking S_F translating the assertion "option a_i outrank option a_k" more solidy established (strong certainty on the hypothesis acceptance)
- a weak outranking S_f translating the assertion "option a_i outrank option a_k" less solidy established (weak certainty on the hypothesis acceptance)

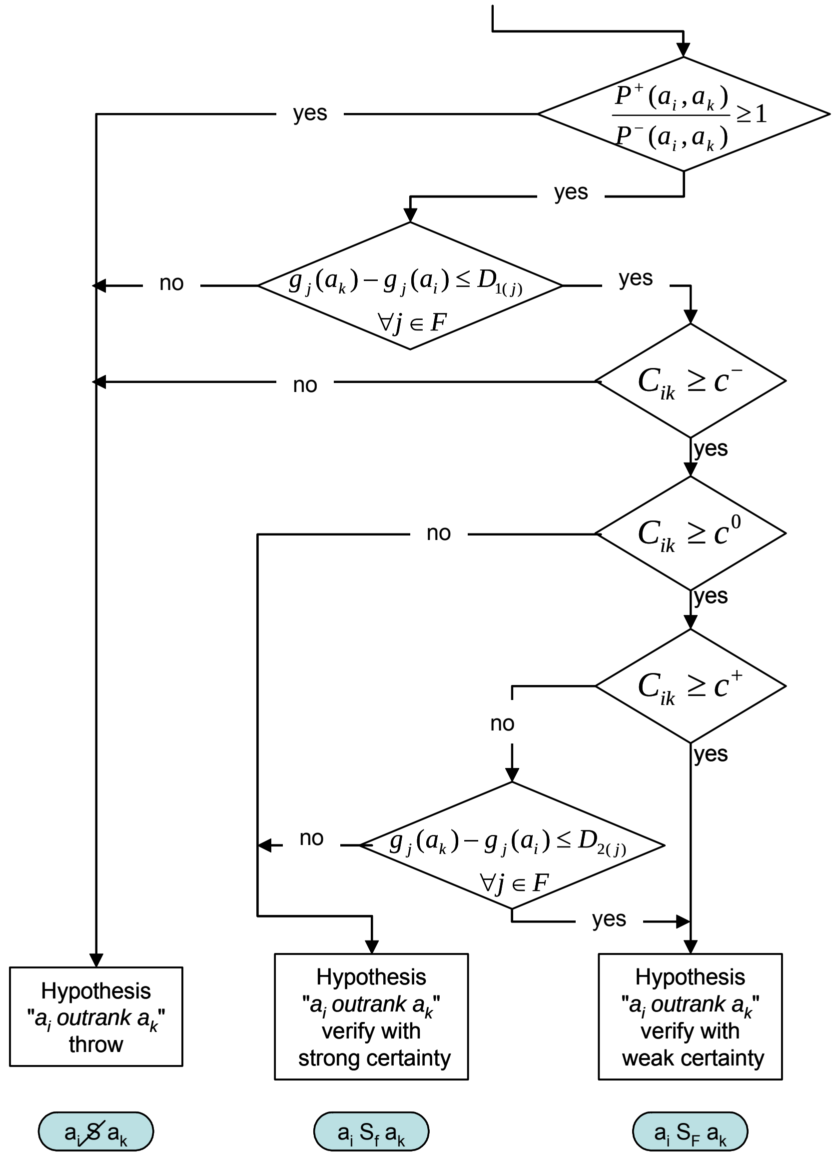
Strong S_F and weak S_f outranking conditions are given by :

- strong outranking : $a_i \, S_F \, a_k$

$$\left.\begin{array}{l} C_{ik} \geq c^{+} \text{ and} \\ g_j(a_k) - g_j(a_i) \leq D_{1(j)} \quad \forall j \in F, \\ \text{and} \\ \dfrac{P^{+}(a_i, a_k)}{P^{-}(a_i, a_k)} \geq 1 \end{array}\right\} \quad \text{and / or} \quad \begin{array}{l} C_{ik} \geq c^{0} \text{ and} \\ g_j(a_k) - g_j(a_i) \leq D_{2(j)} \quad \forall j \in F, \\ \text{and} \\ \dfrac{P^{+}(a_i, a_k)}{P^{-}(a_i, a_k)} \geq 1 \end{array}$$

- weak outranking : $a_i \, S_f \, a_k$

$$\left.\begin{array}{l} C_{ik} \geq c^{-} \text{ and} \\ g_j(a_k) - g_j(a_i) \leq D_{1(j)} \quad \forall j \in F, \text{ and} \\ \dfrac{P^{+}(a_i, a_k)}{P^{-}(a_i, a_k)} \geq 1 \end{array}\right\}$$



EXPLOITATION OF OUTRANKING'S RELATION

The purpose looked for by ELECTRE II is to classify the potential options since "best" until "less good" ones. Three preordering (quasi-order) are established : two simple ordering V_1 and V_2 and a partial ordering $\overline{V}$.

First step before the application of the outranking algorithm : elimination of possible circuits in the outranking graphs. Actions forming a circuit constitute a class of equivalence. Any circuit will thus be replaced by a substitution top.

V_1 : first simple ordering

- In every new step *l*, options already classified are removed by the strong outranking graph. The remaining options constitute the set A_l (subset of *A*). The relations between options are supplied by the graph Y_l, which is a sub-graph of G'_F
- In the graph Y_l, all the top which are not outranking are listed : they form the set *D*,

- The elements of *D* which are interconnected in the weak outranking graph G_f constitutes the set *U*,
- The set *B* contains all the top of *U* which are not outranking by another top of *U*.

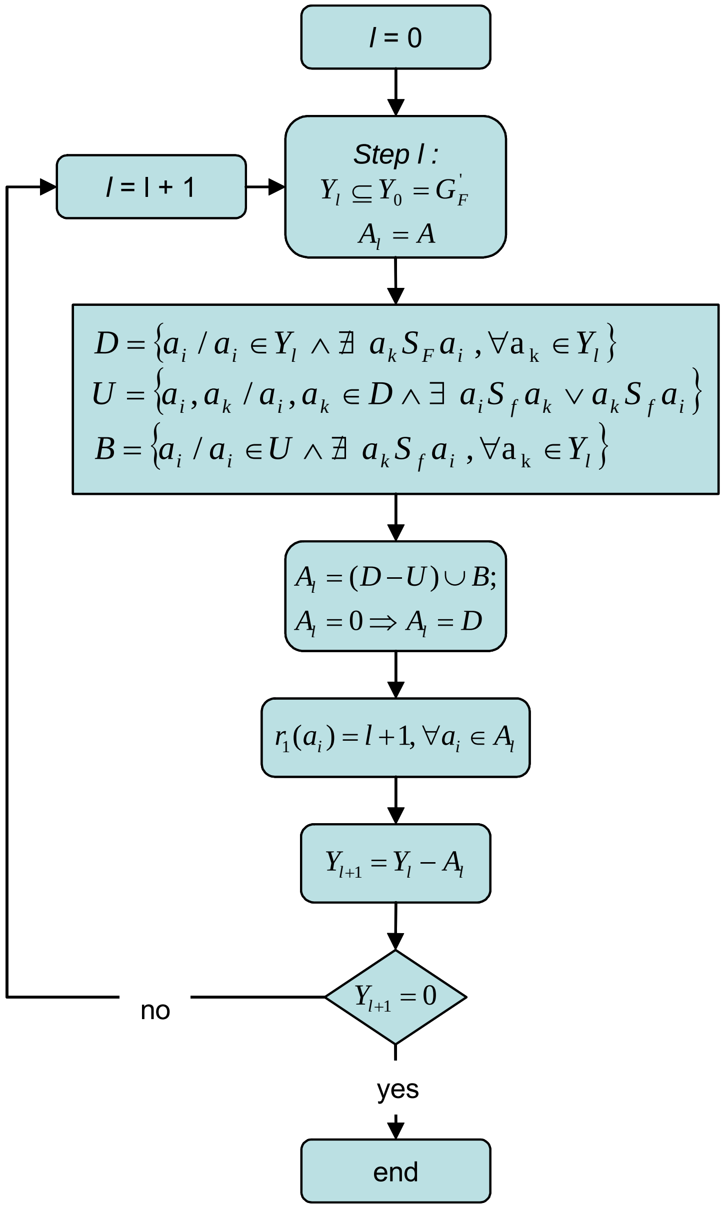
The equivalence class of rank options in step *l*, design by A_l, is given by subset union *U* & *B*. The set *D-U* aggregate all the tops which :

(i) are not yet classified,

(ii) are not outranking by any top of the graph Y_l. Y_l is the reduce graph G'_F without top already classified

(iii) don't have relation like "weak outranking" among them.

- The set *B* aggregate all the tops which satisfy as well previous conditions *(i)* and *(ii)*. These tops have a third condition : *(iii)*, other tops which represents conditions *(i)* and *(ii).*
- For any options classified in the step *l* (constituting the equivalent class A_l) is assigned the rank $_{l+1}$. So in every potential option corresponds a rank obtained by the direct classification. R*ank* $r_1(a_i)$<*rank* ($r_1(a_k)$ *means that option* a_i is "better" than the option a_k
- Tops rank at step *l* are removed from the strong outranking graph. This stage create a new sub-graph Y_{l+1}
- Finally, if Y_{l+1} do not contains top options, the classification is ended; otherwise it continues with the stage *l+1*



This procedure means classifying tops of the graph. This classification is made according to the length of the incidental roads which end in it, in the increasing order of these lengths.

V2 : second simple ordering

The " inverse classification " is based on the same algorithm as *V1* with the following modifications:

- Invert the direction of the arcs in the graphs G'_F and G'_f,
- Once the rank obtained as ($r'_2(a_i)=l+1$), adjust it in the following way :

  $r_2(a_i)=1+ r'_2(a_i)max-r'_2(a_i)$

It means classifying the tops of the graph according to the length of the roads which arise from it, in the decreasing order of these lengths

Final partial ordering

The intersection of the both simple ordering (direct -V1- an indirect -V2- classifications) is a partial ordering. It means that "a_i cannot be compared to a_k" is allowed.

To establish the final ordering, it will be necessary to consider the following rules :

- if a_i is preferred to a_k considering the both simple ordering, it will be the same for the final ordering,
- if a_i is equivalent to a_k considering one simple ordering, but if a_i is preferred to a_k in the other simple ordering, then a_i will be prefer to a_k for the final ordering,
- if in the first simple ordering a_i is preferred to a_k and if in the second simple ordering a_k is preferred to a_i, then a_i and a_k cannot be compared in the final ordering.

Weights

The choice of the decision-maker is going to be translated through the weighty allocation on all the criteria. This choice is due to the current management approach, but can also result from future managements ...

Concordance and discordance indices and thresholds

The concordance indices expresses how much the hypothesis "a_i outrank a_k" suit to the reality represented by the evaluation of the actions. This indication varies between 0 and 1.

Three concordance thresholds are defined : c^+, c^0 et c^-.

The concordance indices gives the opposition measure shown by the discordant criteria to the acceptance of the outranking hypothesis. This indication also varies between 0 and 1.

Two discordance thresholds are defined : D_1 ad D_2 for each of considered criterion.

Concordance thresholds dominant with regard to the discordance thresholds.

Robustness analysis

The robustness analysis tries to elaborate recommendations so synthetic as possible, acceptable for a vast range of parameters. It is possible to overcome the hesitations as well decision-makers as engineer, as for the initial values of the parameters with a robustness analysis.

If by making vary the parameters around their initial value the results are not modified in a important way, the recommendation is sturdy.

The ELECTRE II parameters susceptible to be the object of a robustness analysis are the following ones:

- criteria weights
- concordance thresholds : c^+, c^0 et c^-.
- discordance thresholds : $D_{1(j)}$ et $D_{2(j)}$

APPENDIX 3.II : Example of application for rehabilitation technique choice using ELECTRE [Diab 2000]

Multi criteria analysis is a methodological approach for making decision problems. It helps the decision maker in the management of problems having contradictions. Our aim is not to obtain the best solution but to give few elements permitting the improvement of the decision process by integrating all criteria already defined by the manager of the facility. The principles of these methods were developed by B. Roy (1993).

The principle of this approach is showed on **Fehler! Verweisquelle konnte nicht gefunden werden.**.

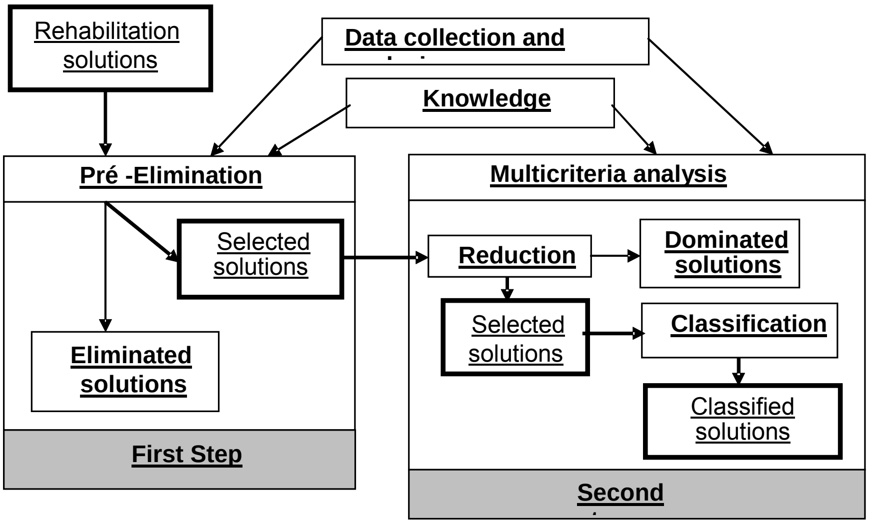


Figure* 18 *: The multicriteria procedure

First step :

An pré-elimination phase in function of imposed constraints is proposed. This analysis is based on compatibility rules between the rehabilitation technologies and the diagnosis results. For example, if the diagnosis shows a structural problem, all non structural solutions are eliminated.

Criteria developed in this step are simple and peremptory. The result of the analysis is a list of potential solutions ; on this list, the multicriteria analysis is done.

Second step :

The multicriteria analysis is based on the performance evaluation of each technique to obtain a classification for the preselected technology. Two stages are required :

- the first permits to distinguish dominated solution in regard of every criteria. In this case, these solutions are eliminated.
- the next stage classifies non-dominated solutions by one of the well-known multicriteria methods (ELECTRE, Promete, …).

For each criteria, the evaluation of the rehabilitation technique performance is done following specific models. Some criteria concern the elimination and the classification criteria. To evaluate each criteria, specific models are developed. When it is possible, two levels are proposed : the first one is based on summarised information and the second on detailed information.

Rehabilitation techniques

Actually, around one hundred techniques are available (FSTT, 1992). They might be set in the following categories :

	Punctual techniques	Continue techniques
Techniques with a cut trench	*Opened trench*	*Replacement*
No-dig techniques	*Grouting* *Sleeve* *Robot milling machine* *Multifunction robot*	*Lining* *Tubing* *Bursting*

For each category, different realisation tools are available. The differences between these tools are little and they don't permit to compare them following rational criteria (the main difference is only the provider or the operator). For example, around twelve lining methods are available ; the principal difference is the way to set them up (tensile or socking), the resin category, the swelling method, polymerisation (heating, lighting, pre-programming).

Criteria

Many criteria were identified to improve the choice procedure and to adapt it for a sustainable realization. Identified criteria are :

Diagnosis	Direct and social costs
Hydraulic performance	Mechanical performance
Abrasion resistance	Service quality
Kind of sewer	Effluent type
Rehab execution complexity	Rehabilitation perennially

These criteria evaluation is detailled by (Diab 2000), some examples are presented in the following part.

THE HYDRAULIC PERFORMANCE

The flow capacity of a pipeline is calculated by using the well-known formula of Maning :

$$Q = K \cdot S \cdot R^{2/3} \cdot i^{1/2}$$

K : roughness coefficient according to Lencaster or Maning (with K = 1/n) ;

S : surface of the pipe ;

i : slope of the network ;

R : hydraulic radius.

To consider these parameters, we based our analysis on theoretical information and case studies (Kinov,1994), (Diab,1994). The Table 7 gives some values.

Table 7 : K values versus the pipe nature

pipeline		K value
concrete	New	Between 75 et 90
	Used	Between 60 et 77 (without curing)
	Damaged	Around 50
Fiber cement	New	Between 95 et 100
	Used	Between 80 et 85 (without curing)
	Damaged	Around 75
Clay	New	Between 95 et 100
	Used	Between 80 et 85 (without curing)
	Damaged	Around 70
PVC	New	Around 100
	Used	Between 90 et 95 (without curing)
	Damaged	Between 80 et 90

The hydraulic performance is based on the evaluation of the flow capacity calculated by using an extension of the Maning formula :

$$Q_1 / Q_0 = (K_1 / K_2) \cdot (D_1 / D_0)^{8/3}$$

with :Q0, Q1 : hydraulic capacity before and after rehabilitation,

K1, K2 : roughness coefficient before and after rehabilitation,

D0 ,D1 : diameter before and after rehabilitation.

Table 8 : K value for a PEHD lining

PEHD lining	New	120
	Used	Between 95 et 100 (without curing)

This analysis is completed by a specific parameter called ‘functional request’. This parameter translates the adequacy of the used technology with the requested results. The results of this classification are given in Table 9.

Table 9: The functional request related to the hydraulic performance

Technology/functional request)	Robot millingt	Robots Muti-function	Grouting	Sleeve	Linning	Tubing	Bursting
transversal section non changed is requested	2	2	4	4	1	2	3
Smaller section accepted	4	4	4	2	1	1	3
Bigger section is requested	4	4	4	3	3	3	1

Note : 1 : the technology is well adapted, the technology is adapted,

3 : the technique is not adapted

4 : not concerned

DIRECT COST

The cost of the rehabilitation includes 4 points :

1 - site installation :

The evaluation of this cost is done in a procedure "case by case" ; it depends on the technology (punctual or continue).

2 - works preliminary :

- derivation of the effluents : the price includes the supply and the installation of the pumps, installation of the backflow pipes and the maintenance of the tools during the field. The price grows with the flow derived and the length of backflow.

- controlling of the pipeline :

  - drain scraping : the price depends on the diameter of the pipe and on the choking up rate ;

  - CCTV : it includes the basic price raised according to the diameter and the material of the pipe

3 - the rehabilitation itself :

Each technology has its own calculation model. For example, the cost of a lining is a function of the diameter of the pipe, the depth of the network and the presence or not of a ground water.

4 - annex work and control

A software based on a method developed by the working group (RES 1995) is used for the modeling of this criteria.

SOCIAL COST

A social cost can be considered as an advantage for a trenchless technology because it reduces the impacts of the neighbourhood and users. But all trenchless technologies don't have the same social costs.

Social cost covers a wide range of impacts. It is not easy to quantify them by using a criteria such as the direct cost, especially when the available information are very subjective and variable following cities, municipalities and countries.

The social cost generated by the rehabilitation grows with the density urban, the duration of the intervention, the works site area. We give the principal permitting the evaluation of the social cost and the following elements (Ait 1997) :

- Noise and vibration :

We can evaluate the cost of the reduction of these bad effects, that means the cost of the devices and solutions intended to reduce the impact of the sound or vibration. On the other hand, it is more difficult to quantify the cost of the embarrassment itself.

- The air pollution :

We don't have model allowing to identify with a sufficient precision the share specifically caused by the rehabilitation. This estimation will be qualitative and take into account the tools used on the work site.

- Embarrassment of pedestrians and cars displacements :

The building site influences in the majority of cases the time of transport of the motorized users, even of the pedestrians. Because it increases the congestion, the building site generates social costs (cost of the time lag, increased energy consumption, etc.)

- Occupation of space :

Knowing the type of the occupied space (circulation or parking) and the area of the work site, we evaluate a total cost of the consumption of space en FF/day, in function of the cost of mobilization of the infrastructures of circulation and/or the cost of neutralization of the space of parking. This price is estimated in Paris between 0,5 and 1 FF/m²/hour.

- Deviations of networks:

Almost all rehabilitation technologies require the deviation of the effluents during work and the neutralization of the branches of the rehabilitated pipeline.

STRUCTURAL PERFORMANCE.

It is a criteria which can be considered as an elimination criteria (first step) and/or a classification criteria (second step). For example, if the diagnosis results show a structural problem in the inspected sewer, We eliminate immediately all non structural solutions. Then, we evaluate the structural performance of all selected solutions. This performance might be defined either in terms of stresses or strengths . But the final aim is to give a safety factor for short and long terms.

Many researches were realized to estimate the mechanical winning or earning obtained by the rehabilitation solution. This earning in safety reserves doesn’t mean a reduction in the stress values in the wall of the pipe but a resumption of new loading applied to the sewer. Under these circumstances, we think that a rehabilitation is complementary to the strength of the old sewer. This means a good transmission of applied loads, this means a perfect grip and sticking between the two structures.

The structural performance, as considered in our modeling, is applied to circular pipes buried in a depth of soil higher than 80 cm (TSM 1991). This model corresponds to the French regulation (CCT 1991) based on the Marston approach (Diab 1992). It is important to say that other methods can be used, like the German regulation based on the ATV approach.

The needed parameters for the modeling are :

- the nature of the two materials,
- the thickness of the two pipelines,

- the Young's modulus of the new pipeline (initial and after five years) and the Poisson ratio.

- the annular stuffiness, the bending conditions and the admitted strength of the new pipe.

The following loading configurations are considered in the modeling :

- the vertical pressure of the backfill (dead loads) (Marston model),

- the vertical pressure of the live loads (Boussinesq model),

- the horizontal pressure of soils around the pipe,

- the pressure due to a water sheet,

* the temporary pressure due the operating conditions (pressure of a grouting in the case of a tubing).

The durability of rehabilitation materials. To estimate the durability of materials used in the rehabilitation, data were collected to justify our estimation in short and long terms**.**

The durability of the used technology for the short term is based on the combination of three parameters. These parameters are the mechanical properties of the used material, the quality of installation and material durability. The results of this analysis are given inTable 10.

Table 10 : short time durability of the rehabilitation

	MECHANICAL PROPERTIES		INSTALLATION FACTORS		DURABILITY		
	Tensile strength	The stiffness	The installation speed	The shock strength	Abrasive strength	Resistance to chemical attacks	Joints state
cement	X	XXX	X	X	XX	XXX	XX
Ductile iron cast	XXX	XXX	X	XXX	XXX	X(*)	XX
Asbestos	XX	XXX	X	XX	X	X(*)	XX
Concrete	XX	XXX	X	X	X	X(*)	XX
GRP	XX(*)	XX	XX	XX	XX	XX(*)	XX(*)
PRC	XX(*)	XXX	X	X	XX(*)	XXX	XX
PVC	XX	X(*)	N/A	N/A	XX(*)	XX(*)	N/A
PEHD	X(*)	X	XXX	XX(*)	XXX	XXX	XXX
PP	X(*)	XX	XXX	XX(*)	XX(*)	XX	XXX

NB:*X : low, XX: medium, XXX: high, (*) : indicates that available data is insufficient to distinguish a value between the two proposed (the lowest value will be considered) .*

The long term behavior : The materials behaviour might be affected by the chemical and biological attacks. The slow absorption of water might provoke the yelding and the relaxation of the rehabilitation. But a good formulation of materials can insure the resistance to the water attacks. At this time, we are trying to integrate this behaviour and all the influencing parameters by using a viscoelastic solution to analyze the long time behaviour

This approach permits to compare the behavior of different rehabilitation pipes in function of the time. The formula permitting to consider the long time behavior is :

$$E(t) = E_1 t^{-m}$$

with : E_1 : initial Young modulus (measured after 1 minute),

t : time,

m : power.

This law seems to be a good approximation for many materials but many researches have to be done to be sure of its reliability

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