SELECTION OF REHABILITATION TECHNIQUES IN PRESSURISED PIPES: *CONCEPTUAL METHOD AND CASE STUDIES*

Grilo, T. V.[(1)] **and Covas, D.I.C.** [(2)]

[(1)] Master Student in Civil Engineering, Instituto Superior Técnico, Technical University of Lisbon (TULisbon), Av. Rovisco Pais, 1049-001 Lisbon, Portugal. E-mail: tomazvg@gmail.com

[(2)] Assistant Professor, Civil Engrg. Dept., Instituto Superior Técnico, Technical University of Lisbon (TULisbon), Av. Rovisco Pais, 1049-001 Lisbon, Portugal. E-mail: didia.covas@civil.ist.utl.pt

ABSTRACT

The present research work aims at the development and the application of an operational decision support model for selecting of the best water supply system (or wastewater pumping system) rehabilitation technique for pressurised pipes. Thus, a thorough review of the state of the art rehabilitation techniques has been carried out. Six different techniques have been identified, divided in two main groups: internal lining techniques (i.e., cement lining and spray lining) and relining techniques (i.e., ordinary relining, pipe bursting, rolldown and sublining). The decision support model is part of the rehabilitation process (methodology) that can be divided in four main stages (steps): Stage I – System characterization; Stage II – Strategic decision; Stage III – Implementation; and Stage IV – Monitoring, evaluation and revision. The operational model refers to the Stage II. This model consists of two flowcharts according to the type of landscape-area were the pipe is installed (i.e., rural or urban area). This decision support model was applied to six different case studies: two relinings, one pipe trench intervention, one sublining and one by-pass created with relining presented by EPAL, S.A., and one pipe-bursting presented by SANEST, S.A.. The application of the model to these case studies was of the outmost importance for its preliminary validation, although partial because only six case studies were analysed, giving the practical insight that this research work needs. These case studies allowed testing and improving the model during its development. Finally, it should be emphasised that rehabilitation should be an effective, fast, minimum disturbance and economically advantageous process. The operational model has been developed based on these four aspects in order to complete the rehabilitation process of water supply systems in Portugal.

Keywords: rehabilitation, water supply system, lining, relining and operational model.

1. INTRODUCTION

In developed countries, most water supply systems have been designed and constructed decades ago and, currently, water utilities have the challenge of keeping their systems operational, efficient and reliable to supply water in quantity and quality to populations. The ageing of water infrastructures and equipment is natural and inevitable and, as these components reach the end of their useful life, leakage levels increase, breakdowns and supply interruptions become more frequent, and maintenance costs raise. As a consequence, water utilities must face the unavoidable choices to repair, rehabilitate or replace. Questions like what, where, when and how arise (Vanier, 2000). Utility engineers are required to make a series of decisions which must be based on information about the buried pipe infrastructure which is as often inaccurate, incomplete and out-of-date.

The current research work aims at the development a decision support model to assist engineers and water utility managers in the selection the most appropriate rehabilitation technique for buried pressurized pipes, and the establishment of criteria for selection of the most adequate rehabilitation method. An extensive state-of-the-art review has been carried out about existing rehabilitation techniques for pipes and storage water tanks, respective advantages and disadvantages and current selection criteria. A methodology has been established and a decision support model developed to select the most appropriate rehabilitation technique for pipes according to each case. The model is based on the advantages and drawbacks of each technology according to pipe's age, material, diameter, average operating pressure, expected useful life, connection type between rehabilitated pipes, connection type on new and old pipe, and past technique application. The model has been tested with six different case studies, five from Lisbon water utility – EPAL, S.A – and one from Lisbon sewage water utility – SANEST, S.A.. Results of the model were compared with implemented techniques. Conclusions and recommendations to use the developed methodology to other case studies are drawn, well aware that these may have different characteristics than those used for the testing the model and, therefore, may require eventual adjustments of the model.

2. REHABILITATION ATTITUDES AND MODELS

Water utilities can have two attitudes towards rehabilitation: reactive or proactive. In the reactive attitude, the rehabilitated pipes are selected according to emergency criteria (e.g., pipes that have failed or more often repaired) and to the forecast of road works (determined by other infrastructures' needs). This approach brings about a very low rehabilitation rate and the average network condition is very likely to create financial problems involving large investment in the following years. In the proactive attitude, water utilities plan the investment after assessing the structural condition of the pipes and forecasting their degradation. This policy requires a good knowledge of pipe network characteristics and failures, available in a computerized database, such as a Geographical Information System (GIS) (Saegrov *et al.*, 1999; Engelhardt *et al.*, 2000; Eisenbeis *et al.*, 2002).

Recently, water utilities have started to realize the importance of having a proactive rehabilitation strategy to avoid future serious financial problems and, the tendency, today, is to start to develop short and long-term investment planning. However, adopting a pro-active strategy is not a straightforward task, and it requires the support of computer based decision models. Several conceptual and operational models have been developed in universities and research centres which can be classified in two types. (Eisenbeis *et al.*, 2002).

The first type of models is for assessing the structural condition of pipes based on statistical analysis. These models try to correlate recorded pipeline problems with network characteristics such as pipe type and age, water chemistry, soil type and operating conditions. They use data maintenance records (long term records), and can be described as a two step procedure: the analysis of main factors (e.g., material, diameter, soil, traffic, location) and the assessment/forecast of pipe condition by means of statistical models (Poisson or Weilbull) or others. Examples of such models are: “AssetMaP” (Lyon, France) (Malandain *et al.*, 1998); “Failnet” (Cemagref, France) (Eisenbeis *et al.*, 1999); “GIS and cluster method” (Water Research Center, UK); “Utilnets” (Germany) that determines service life of pipes by deterministic models; “SDSS” links GIS with Mathlab to assess pipe vulnerability (Makropoulos, Butler, 2006)

The second type of models is for assessing and exploring rehabilitation strategies based on technical and economical assumptions. These require the accurate description of pipe network and integrate economical data. Examples are: “EPAREL”, a reliability module to be associated with EPANET (Rostum, Schilling, 1999); “KANEW” (Dresden university, Germany) (Herz, 1998; 2002), “EPAREL”, a reliability module to be associated with EPANET (Rostum and Schilling, 1999); “GAasset”, an optimisation tool to determine engineering activities and timing based on the whole life costing (Exeter, UK) (Miller *et al.*, 2001); “WARP”, an integrated water mains renewal planner (Kleiner *et al.*, 2001; Rajani, Kleiner, 2001; Rajani, Kleiner, 2002).

The most comprehensive example of a prototype model is CARE-W (Computer-Aided REhabilition of Water networks), developed as a multinational research programme aimed to develop methods to assist engineers to define and implement effective management of their water supply systems (Conroy *et al.*, 2002). Tests carried out with CARE-W in different water utilities have shown that some modules require a complex and time-consuming data preparation either because models require a huge amount of data (which is someway inevitable) or because data exist but information systems are not prepared to interact with CARE-W toolkit. This discourages utility engineers to use developed rehabilitation models, in particular in Portuguese water supply systems in which data do not exist, or exist but information is spread in different databases.

3. REHABILITATION TECHNIQUES FOR PRESSURISED PIPES

When a “pipe” is assessed as deficient, numerous rehabilitation techniques can be applied. The choice of which to use will be based on system impositions or on the cost and benefit of each particular rehabilitation solution used. The number of choices is ever increasing but can be split into the following main categories: *replacement* or *(re)lining*.

The *replacement* of a pipe traditionally consisted of creating a trench that covers the main allowing the necessary work to be undertaken. This technique has a number of disadvantages: the sound, noise and visual pollution; the cost of reinstating the road surface and the disruption of traffic. There are two variations: narrowing trenching methods that minimize the trench width and, no-dig techniques that eliminate the need for trenching (e.g., pipe bursting) though excavations are necessary to access the buried pipe at either side of installed main and to disconnect and reconnect the house services.

Pipe *(re)lining* can be divided in two main processes – *lining* and *relining* – each of those leading to different rehabilitation techniques. These processes differ on the equipment and materials used. *Lining* consists of internal pipe coating with a material that increases pipe structural resistance or hydraulic capacity. *Relining* consist of introducing a new pipe inside the old one. The most commonly used rehabilitation techniques for each process are summarised in Table 2.1.

Table 3.1 – Most commonly used rehabilitation techniques for pressurised pipes

Process	Technique
Replacement	Open trench
Lining	Cement Mortar Lining
	Epoxy Resin Spray Lining
Relining	Sliplining or Relining
	Pipe Bursting or Burst Relining
	Rolldown
	Subline or Compact Pipe

A brief description of the above referred techniques (including the process and materials used) is presented in the following paragraphs. Prior to the application of any technique, Closed Circuit Television (CCTV) (Figure 3.1 and 3.2) or Picture in Graphics (PIG) should be used for pipe inspection.

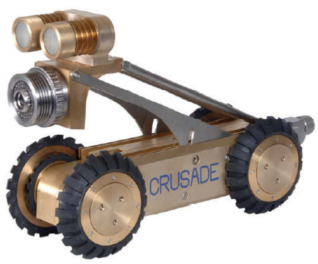

Figure 3.1 – CCTV camera model used on pipe inspections (Crusade Designs, 2007)

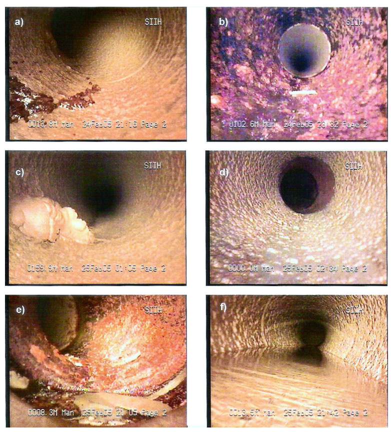

Figure 3.2 – CCTV images inspection (ENGIDRO, 2005)

Except for pipe bursting technique, all the other techniques should be preceded by a smooth bore including a more effective bore on situations were is predicted to wound the new pipe during its insertion in the old pipe.

Cement mortar lining

Internal coating with cement mortar (Brochier, 1996) consists of poring cement mortar inside the old pipe within a thin coat. This material together with the pipe material forms a high resistance and durable set. It can be used on metallic pipes (i.e., steel or cast iron pipes). The protective action is mainly based on two agents: passive and active. The passive is made on the mechanic of the metallic pipe wall. The active one is made throughout the chemical conversion of the cement's coat through the iron oxide between this coat and the iron pipe wall, due to the interaction of water that spreads out on to the interior of the mortar. The mortar is composed of equal shares of Portland cement and quartz sand. It can be a viable solution for pipes with diameter that can vary from 80 to 2000 mm. On pipes with lower diameter it is needed to open small trenches with approximately 2,00x1,50m spaced of 150 m, retrieving pieces of pipe with 1 m length. For pipes with diameter higher than 600 mm, the length between trenches should be 400 m.

Epoxy resin spray lining

The epoxy resin spray lining (Subterra, 2003) consists of the internal coating of a deteriorated pipe with liquid resin applied with a spray (Figure 3.3). Used resins are epoxy ELC 173/90 (1^{st} generation resins) and ELC 257/91 (2^{nd} generation resins aiming a greater resistance and durability), assuring a durable and corrosion resistance coating. It can be used for water mains, fire fighting systems and industrial supply systems. This technique can also be used for solving water quality problems due to internal pipe corrosion.

Simple relining

The *simple relining* technique, also called *sliplining* (Subterra, 2003) or *pipe relin*ing (Brochier, 1996), consists of the insertion of a minor diameter pipe inside the old pipe (Figure 3.3). It is used when the diameter of the original main can be reduced. The materials that can be used on this process are PVC and PEAD.

Pipe Bursting

In the *pipe bursting* (Subterra, 2003) technique, also called *burst lining* (Brochier, 1996), the existing pipe is split by a hydraulic or pneumatic nose cone attached to the new polyethylene pipe which is, then, pulled through the existing pipeline. Once the nose cone has cracked the existing pipe and pushed the pieces out into the surrounding ground, a void is created for the new pipeline to travel into as it follows immediately behind (Figure 3.5). Pipe bursting offers the opportunity of a size for size on-line replacement of an existing pipe or replacement of the existing pipe with one of a larger diameter thereby increasing flow capacity. It can also be used, not only in water supply systems, but in gas pipes and sewer pumping systems.

Rolldown

The *rolldown* technique (Subterra, 2003) is a close fit polyethylene lining technique which is specifically designed to install structural or non-structural liners for pipes from 100 to 500 mm. Rolldown can be used in curves up to 11º25’ and can be designed as a stand alone fully pressure rated pipe, or as a thin wall lining to eliminate leakage (Figure 3.6).

Subline

The *sublining* technique consists of pre-welding a polyethylene pipe pushing it through a former to fold it into a "Heart" shape which is temporarily held by restraining bands. The reduced cross section creates a clearance to facilitate the installation of the Polyethylene (PE) pipe into the original pipe to be renovated. Once installed the folded pipe is then reverted back to its circular form by pressurisation with water at an ambient temperature which breaks the temporary restraining bands. This creates a close fit within the host pipe, sealing leakage and preventing corrosion. It can be used on rehabilitation for pipes from 75 to 1600 mm diameter. A folded pipe inside the original pipe and the final look of the unfolded new pipe are depicted in Figure 3.7. The technique is shown in Figure 3.8 during its application.

Figure 3.3 – Spray Relining Technique: detail of the spray cannon (Subterra, 2003)

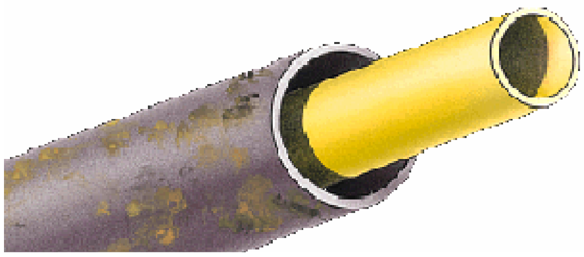

Figure 3.4 – Pipe relining technique (Subterra, 2003)

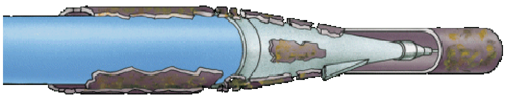

Figure 3.5 – Pipebursting technique: destroying the old main (Subterra, 2003)

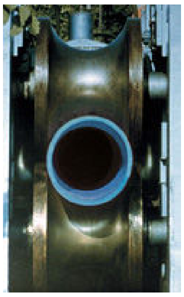

Figure 3.6 – Rolldown technique: detail on the reduction machine (Subterra, 2003)

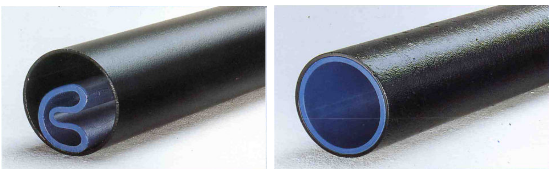

Figure 3.7– Sublining technique: folded and expanded pipe inside of the original main (Brochier, 1996)

Figure 3.8 - Sublining technique, during application (Subterra, 2003)

4. PROPOSED OPERATIONAL MODEL

A rehabilitation methodology composed of four main stages is established. The decision support model for the selection of the most adequate pipe rehabilitation technique refers to Stage II of the methodology. Both the methodology and the operational model are presented in the current section.

4.1 Decision parameters

There are many factors (variables) that can influence the decision on which rehabilitation technique to use in pressurised pipes for every different situation. (e.g., zone type, flow capacity, etc.). An extensive review and analysis of existing techniques has been carried out to identify which are the most important variables. These variables have been grouped in primary variables (1st class), that generally have an important effect on decision and that eliminate, on first hand, a set of possible techniques, and secondary variables (2nd class) that represent the remaining less relevant variables which value can be included in any the former ones. These are summarised in Table 4.1. The attributes of each variable and the correlation between primary variable and the rehabilitation technique is presented in Table 4.2

Table 4.1 – Decision parameters to define the pipe rehabilitation technique

Primary variables (1st class)	Zone type
	Traffic intensity
	Pipe depth
	Soil characteristics
	Structural problems
	Pipe length
	Increasing flow capacity
	Pipe network type
	Obstacles
	Close services
Secondary variables (2nd class)	Seismic zone
	Carried water characteristics
	Open trench possibility

Table 4.2 – Correlation between primary variables and rehabilitation techniques

Primary Variables	Zone type		Traffic		Pipe Depth		Flow Capacity		Length		Soil		Importance		Close Services		Obstacles		Structural problems		Cost(1)	Materials of which original pipe is made(2)
Variable Value	Rural	Urban	Intense	Not intense	Deep	Shallow	Increase	Non relevant	Long	Short	Coherent	Incoherent	Redundant	Principal	Fragile	Non Fragile	Existing	Non existing	Resolves	Non solving		
(1) Cement mortar lining	√	√	√	√	√	√		√		√	√	√	√		√	√	√	√			€€	Cast iron, steel
(2) Epoxy resin spraylining	√	√	√	√	√	√		√		√	√	√	√		√	√	√	√	√	√	€€€	Cast iron, steel
(3) Simple relining	√	√	√	√		√		√	√	√	√	√	√		√	√	√	√	√	√	€€€	Cast iron, steel, concrete
(4) Pipe Bursting	√	√	√	√	√	√	√	√	√		√	√	√	√		√		√	√	√	€€€€	PVC or cast iron/steel with high levels of deterioration
(5) Rolldown	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	€€€€€	Cast iron, steel, concrete
(6) Sublining	√	√	√	√		√	√	√	√	√	√	√	√	√		√	√	√	√	√	€€€€	Cast iron, steel, concrete
(7) Open trench	√	√		√		√	√	√		√	√		√	√		√		√	√	√	€	Any material

Notes: (1) € - less expensive; €€€€€ - more expensive
(2) According to the current need there is still no requirement to rehabilitate mains made of PVC and PEAD

4.2 Proposed methodology for pipe rehabilitation process

Nowadays, in order to be able to provide a systematic strategic support, it is necessary to simplify and separate the different decision processes. A methodology, organised in four stages, has been established, providing orientation guidelines towards the selection of the best rehabilitation technique. Therefore, after choosing the technique, it is important to follow its implementation during the construction phase and the subsequent monitoring and evaluation of the rehabilitated pipe.

Thus on the next sub chapter it is presented the different rehabilitation methodology stages, and the focusing on a decision support model (*Stage II*) as well. This model was developed aiming at a rapid and effective orientation to the user, to have a quick, good and economic response to the problem.

It is important to point out that the presented methodologies try to include the maximum number of cases that can exist. Despite this fact it is possible that cases exist which are not included such as exceptionally large diameters or pressures. The rehabilitation methodology is divided in four different stages:

- Stage I – System characterization
- Stage II – Strategic decision
- Stage III – Implementation (i.e., design, construction and exploration)
- Stage IV – Monitoring, Evaluation and Revision

Stage I is characterized by supporting the model with information like consumers information, utilities financial data, etc. Stage II has some procedures included like variable value data, possible techniques, best functional techniques and, at the end, the cheaper possible technique. The implementation stage has vital importance due to the monitoring during the construction phase. On the last stage, utilities may use evaluation data to revise the technique (and systems) to be able to improve the used technique.

The different stages (Stage I to IV) and respective actions (or procedures) of the proposed methodology that should be presented on any pipe rehabilitation intervention are shown in Figure 4.1.

4.3 Operational model (Stage II)

In Stage II, the user can find the process entitled “decision model” (Figure 4.1). The model was materialized in two flowcharts according to the type of landscape-area were the pipe is installed (i.e., rural or urban area): for “Rural zone” in Figure 4.2 and “Urban zone” in Figure 4.3. These flowcharts constitute operational tools to assist those who want to choose a rehabilitation technique for a particular case.

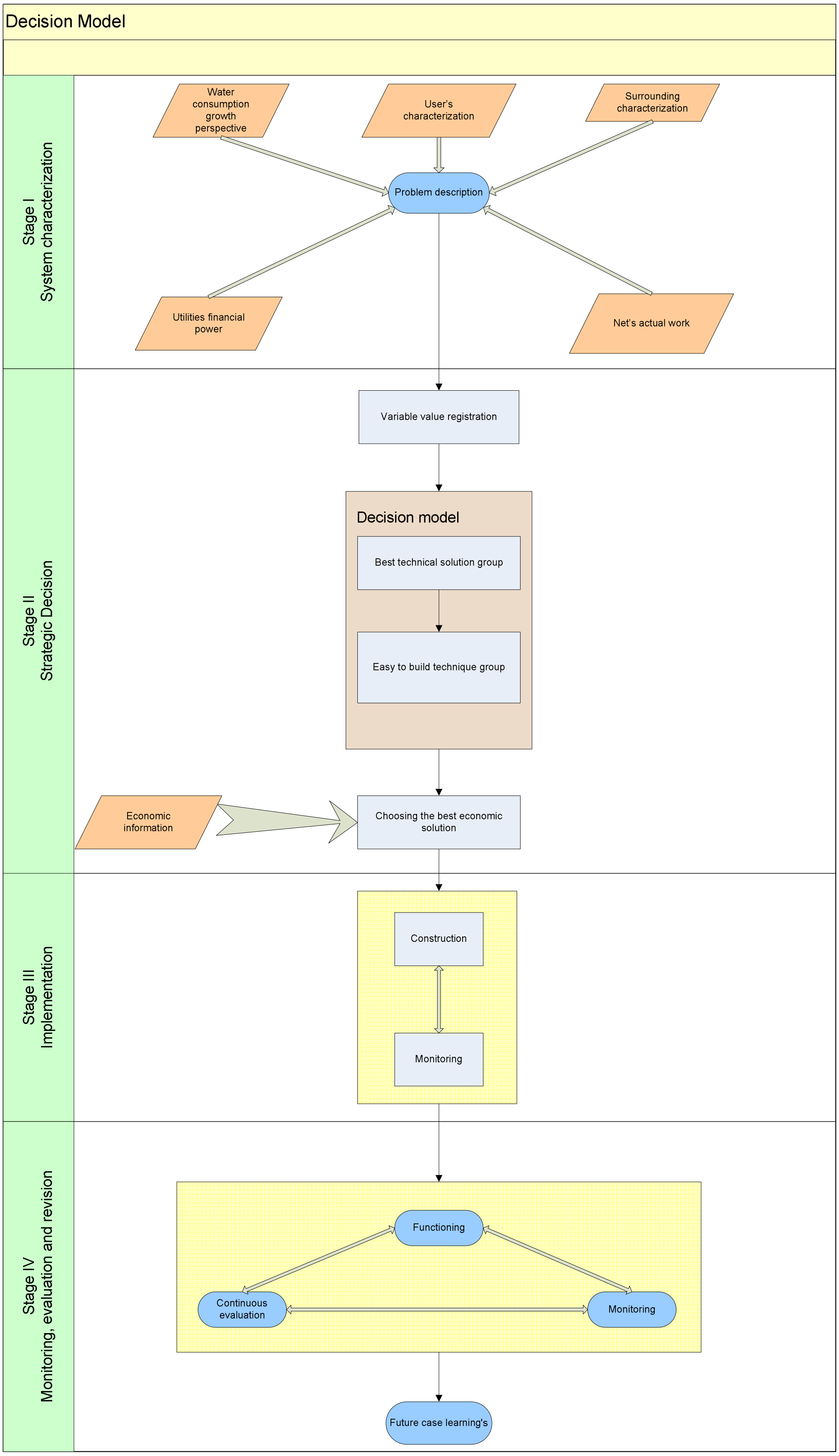

Figure 4.1 – Pipe rehabilitation techniques' implementation methodology

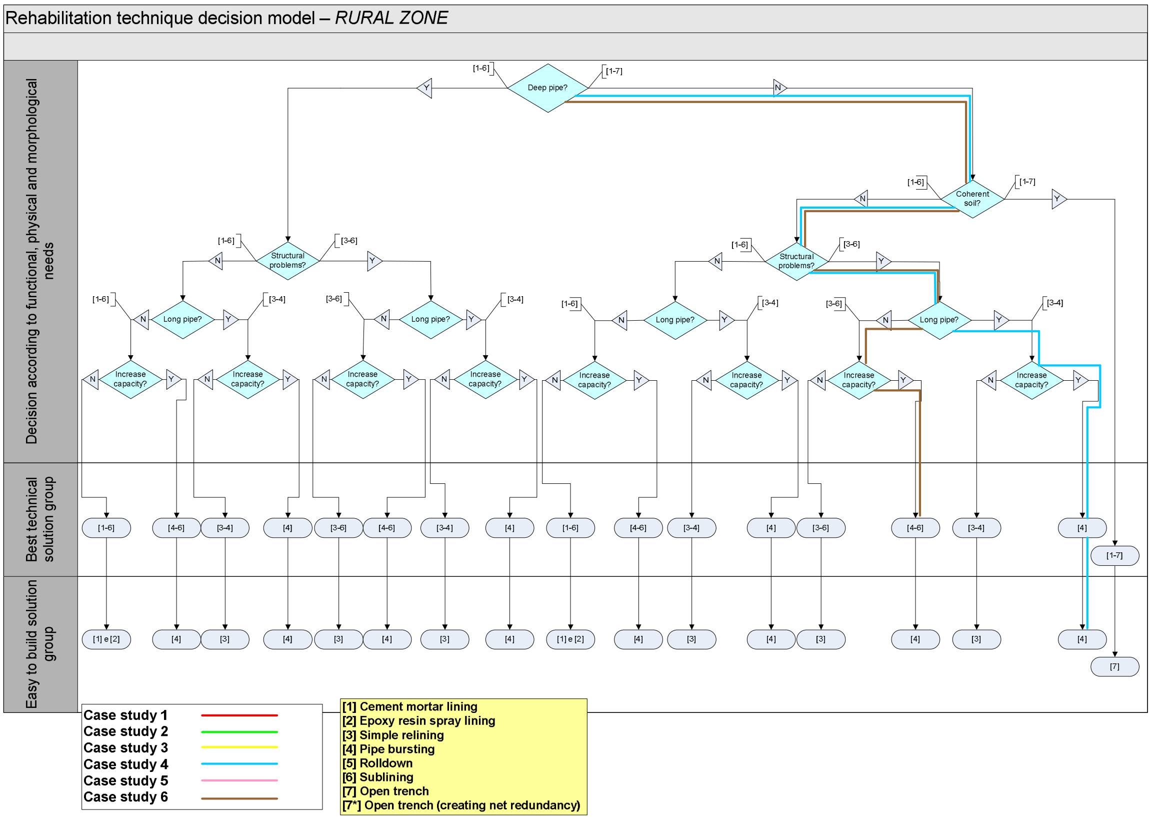

Figure 4.2 – Rehabilitation technique decision model for Rural Zones (Stage II – Strategic decision)

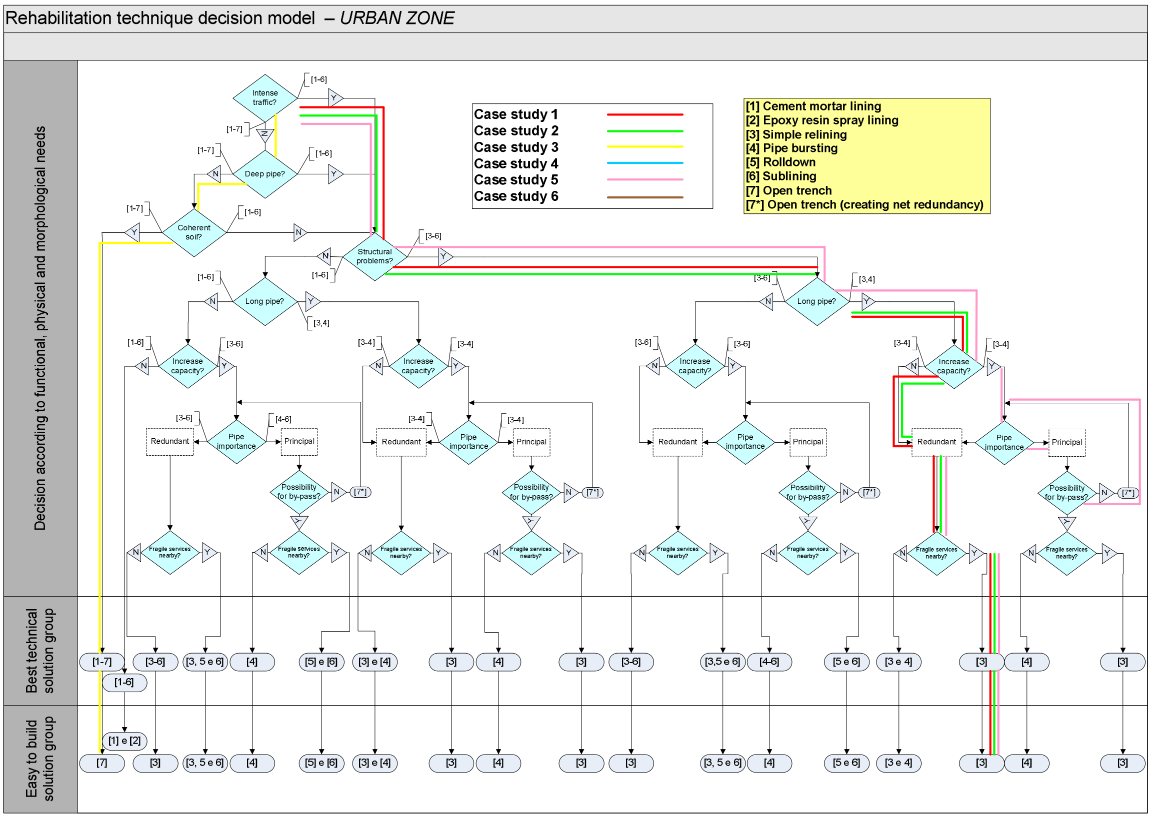

Figure 4.3 – Rehabilitation technique decision model for Urban Zones (Stage II – Strategic decision)

5. CASE STUDY APPLICATIONS

Six case studies concerning pipe rehabilitation of mains located in Lisbon are presented in this section, five of which belonging to Lisbon water utility (EPAL, S.A.). Therefore it was tried with these six case studies to enclose as many techniques as possible to be able to test and to validate the proposed operational model. Cases 1, 2, 3 and 5 are located in urban zones, with different attributes of decision variables leading to different rehabilitation techniques:

- Two simple relining (Case study 1 and 2);
- One open trench (Case study 3);
- Original pipe relining creating net redundancy (Case study 5).

Case study 4 is particularly interesting because it is located in a rural zone, still, pipe-bursting technique is used. Also, Case study 6 is in a rural zone, though with exceptional conditions, not predicted or included in the model for the use of sublining technique. A case study summary, including decision variables attributes and the rehabilitation technique pointed out by the proposed operational model, is presented in Table 5.1. Additionally, the path followed in the model for the six case studies is depicted in the flowcharts in Figures 4.2 and 4.3.

Table 5.1 – Case studies variable value summary

Case study	Zone type		Traffic		Pipe Depth		Flow Capacity		Length		Soil		Importance		Close Services		Obstacles		Structural problems		Used technique
Variable Value	Rural	Urban	Intense	Not intense	Deep	Shallow	Increase	Non relevant	Long	Short	Coherent	Incoherent	Redundant	Principal	Fragile	Non Fragile	Existing	Non existing	Existing	Non existing	
(1) EPAL's Barabadinhos – Monte Arco pipe		√	√			√		√	√		√		√		√			√	√		Simple relining
(2) EPAL's Barabadinhos – S. Jerónimo pipe		√	√			√		√	√		√		√		√			√	√		Simple relining
(3) EPAL's Pr. Do Comércio pipe		√		√		√	√		√		√		√		√			√	√		Open trench
(4) SANEST's Cascais pipe	√			√		√	√		√			√		√		√		√	√		Pipe bursting
(5) EPAL's Av. 5 de Outubro pipe		√	√			√		√	√		√			√	√		√		√		Open trench for simple relining
(6) EPAL's Ota pipe	√			√		√		√	√			√	√			√		√	√		Sublining

6. CONCLUSIONS AND RECOMENDATIONS

Developing several rehabilitation techniques has created the need to systematize and group them in order to facilitate and assist decision making to water utilities. It is also necessary to establish Portuguese terminology that could link Anglo-Saxon commercial technique references. The current research work has achieved this goal.

In what concerns to the development of an effective decision support model for assisting the decision of the best rehabilitation technique, the proposed model is a step forward, constituting a starting point for a project that needs constant improvement, because main decision variables are always changing and novel rehabilitation techniques for pressurised pipes are being continuously developed. Moreover, the model can incorporate new decision variables in order to point out to only one rehabilitation technique, what has not been assured by the current model.

During the development of the current research work, an analysis of various and different case studies has been carried out to be able to test, validate and improve the proposed operational model (Stage II of the methodology). However, it was only possible to analyse five different techniques (six case studies) with the cooperation of EPAL, S.A. and SANEST S.A.. Therefore, only a partial validation of the model was performed.

Finally, as future work the authors suggest the analysis of more case studies, different from the previously presented, for pursuing with the model validation, tuning and improvement in order to achieve a decision support model for assisting the selection of the most appropriate rehabilitation technique for pressurised pipes, as robust and as universal as possible.

7. REFERENCES

Brochier (1996) Reparação e reabilitação subterrânea de condutas

Conroy, P., Kowalski, M., Taylor, K., Hulance, J. (2002). "CARE-W Approach and Software Prototype." Proc. International Conference on Computer Rehabilitation of Water Networks CARE-W, November 1st, Dresden, Germany, 39-52.

Eisenbeis, P., Le Gauffre, P., Saegrov, S. (2002). "Chapter 5 - Water Infrastructures Management: an Overview of European Models and Databases." Assessing the Future: Water Utility Infrastructure Management. AWWA Trends in Water Series , David M.Hugges, ed., AWWA, Denver CO, USA, pp. 61-80.

Eisenbeis, P., Rostum, J., Le Gat, Y. (1999). "Statistical models for assessing the technical state of water networks - some european experiences." Annual Conference of AWWA. Chicago 20-24 June, 1999.

Engelhardt, M. O., Skipworth, P. J., Savic, D. A., Saul, A. J., Walters, G. A. (2000). "Rehabilitation strategies for water distribution networks: a literature review with a UK perspective." Urban Water, 2, 153-170.

ENGIDRO (2005). Empreitada de reabilitação de redes de distribuição de água na cidade de Lisboa; Projecto nº2004/PRR/26 Rua das Pretas; Projecto de Execução: Cláusulas Complementares, Memória Descritiva e Justificativa, Anexos, Medições e Desenhos, Lisboa.

Herz, R. K. (1998). "Exploring rehabilitation needs and strategies for water distribution networks." Jounal of Water Supply Research and Technology - AQUA, 47(6), 275-283.

Herz, R. K. (2002). "Software for strategic network rehabilitation and investment planning." Proc. International Conference on Computer Rehabilitation of Water Networks CARE-W, Nov. 1st, Dresden, Germany, 65-84.

Kleiner, Y., Adams, B. J., Rogers, J. S. (2001). "Water distribution network renewal planning." Journal of Computing in Civil Engineering, 15(1), 15-26, (NRCC-43369) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc43369/.

Makropoulos, C., Butler, D. (2006). "Spatial Ordered Weighted Averaging: Incorporating spatially variable attitude towards risk in spatial multicriteria decision-making." Environmental Modelling & Software, 21, 69-84.

Malandain, J., Le Gauffre, P., Miramond, M. (1998). "Organizing a decision support system for infrastructure maintenance: application to water supply systems." Proc. 1st Int. Conf. on New Information Technologies for Decision Making in Civil Eng. Montreal, Canada, 11-13 October., 1013-1024.

Miller, I., Kapelan, Z., Savic, D. (2001). "GAasset: fast optimisation tool for strategic investment planning in water industry." 4th Int. Conf. on Water pipe systems. Ed. Bhrgroup.

Rajani, B., Kleiner, Y. (2002). "Towards pro-active rehabilitation planning of water supply systems." Proc. International Conference on Computer Rehabilitation of Water Networks CARE-W, November 1st, Dresden, Germany (NRCC-46095), 29-38.

Rajani, B. B., Kleiner, Y. (2001). "WARP - water mains renewal planner." International Conference on Underground Infrastructure Research - UIR 2001 (Waterloo, Ontario, Jun, 2001), pp. 1-5, (NRCC-44680) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc44680/nrcc44680.pdf.

Rostum, J., Schilling, W. (1999). "Predictive service-life models used for water network management." 14th EJSW. Dresden, 8-12 September 1999.

Saegrov, S., Baptista, J.M., Conroy, P., Herz,R.K., Le Gauffre,P., Moss,G., Oddevald,J.E., Rajani,B., Schiatti, M. (1999). "Rehab. of water networks. Survey of research need and on-going efforts." Urban Water, 1, 15-22.

Subterra (2003). Subterra, Services - Rehabilitation. http://www.subterra.co.uk/pipe_rehabilitation_frameset.html (22-3-2007).

Vanier, D. J. (2000). "Advanced asset management: tools and techniques, Innovations in Urban Infrastructure.", APWA Congress (Louisville, 2000), pp. 39-56 (NRCC-44299) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc44299.pdf.