Sewer asset management tool: dealing with experts' opinions

C. Werey[1], F. Cherqui[2], M. Ibrahim[3] and P. Le Gauffre[3]

[1] *UMR Cemagref-ENGEES GSP, caty.werey@cemagref.fr, 1 quai Koch, BP 61039, F-67070 Strasbourg Cedex, France, Tlf +33.3.88.24.82.53, Fax: +33. 3.88.24.82.84*
[2] *LGCIE, Université Lyon 1, Université de Lyon, F-69622; INSA-Lyon, F-69621; France*
[3] LGCIE, INSA-Lyon, F-69621 Villeurbanne Cedex, France;

Keywords: sewer network, CCTV inspection, dysfunction indicators, expert opinion

ABSTRACT

Asset management requires the development of performance indicators (PIs) and decision procedures. Within the French RERAU methodology each rehabilitation criterion is assigned a grade out of four possible ones. This grade results from an aggregation of complementary PIs that use information derived from various sources: visual inspection, O&M data, network monitoring, etc.

This paper focuses on the development of dysfunction indicators derived from visual inspection results (WP1 of the French INDIGAU program). Inspection reports provide sequences of observation (defect) codes. On this basis, three complementary procedures are proposed so as to assign a condition grade to the sewer segment: (a) expert rules identifying major defects (b) calculation of a single score and comparison to three thresholds and (c) rules based on the analysis of scores distribution along the segment.

Calibrating procedure b) means defining parameters used in the calculation of a single score and defining three (crisp or fuzzy) thresholds. The calibration also requires experts' judgments that will be used as references. A sample of 45 links has been studied by 8 experts, regarding 10 indicators. The results display a lot of conflicts between experts' opinions. Three types of situation are defined: 1) no conflict, a consensus can be identified; 2) one expert disagrees with a majority, a consensus may be defined; 3) major conflicts between answers.

1. INTRODUCTION

Asset management is an increasing concern for wastewater utilities and companies. Criteria are developed for supporting the definition of investigation and rehabilitation programs. Dysfunction indicators contribute to the calculation of criteria, using expert rules. Indicators based on visual inspections provide major information. However, difficulty remains in the translation of a visual inspection survey into dysfunction indicators (Rahman & Vanier, 2004). In the framework of the French RERAU program (Rehabilitation of urban sewer networks) a methodological approach has been developed (Le Gauffre *et al.*, 2004; Le Gauffre *et al.*, 2007). 10 dysfunction indicators are defined and assessed with visual inspections reports of sewer segments; these dysfunction indicators are assigned a grade $G \in \{1, 2, 3, 4\}$: (from the best to the worst).

The different steps of the dysfunction indicators' valuation are detailed in the 2nd section. The 3rd section presents the ongoing work within the French project "INDIGAU" (Performance Indicators for asset management of urban sewer networks"), dealing with experts' judgment of CCTV reports. The first results and conclusions are presented in the 4th section.

2. DYSFUNCTION INDICATORS VALUATION

Inspection reports provide sequences of observation codes, using a coding system (for example European standard EN 13508-2), that are quantified in order to obtain a score distribution on each sewer segment. The score of a section considers all defects, their gravity and their extent. Moreover, a single score is calculated for the sewer segment: the global density of defects relating to each dysfunction. Three complementary procedures are then executed so as to obtain a condition grade related to the sewer segment: (a) expert rules based on sequences of observation codes, (b) comparison of single score to threshold and (c) rules based on analysis of segment profiles (score distribution), as presented on Figure 1.

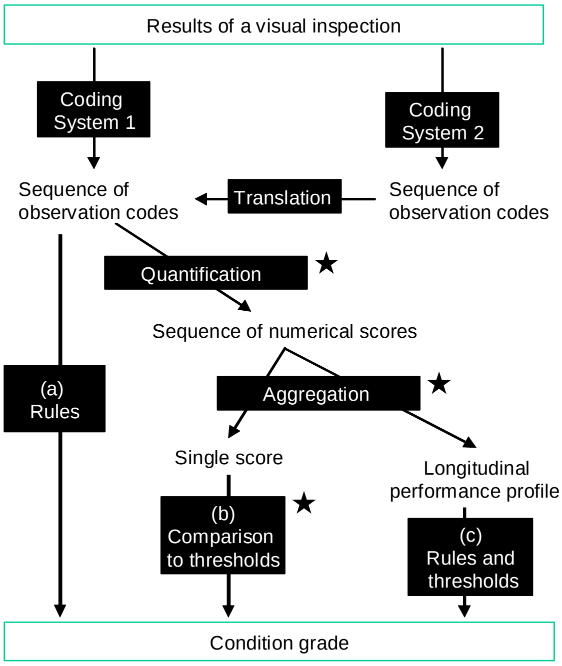

Figure 1. TRANSLATION OF VISUAL INSPECTION ENCODING INTO CONDITION GRADE

The translation of visual inspections into condition grades depends on the coding system that is used. The methodology proposed in the RERAU project needs observation codes using the European standard EN 13508-2. So if the existing data are coded either in a self-made codification (case for the application done in the department of Bas-Rhin (Dorchies, 2005; Werey *et al.*, 2006) or in a national coding (in France, AGHTM, 1999), it is necessary to translate them within the EN 13508-2 codification. We can notice that new material exists since a few time on the market making the inspection directly with this new framework.

When the defaults are available into EN 13508-2 standard, the calculation of the dysfunction scores can begin using tables provided within the RERAU project (Le Gauffre *et al.*, 2004; Le Gauffre *et al.*, 2007) where dysfunction indicators are defined concerning: infiltration *(INF)*, exfiltration *(EXF)*, decrease of hydraulic capacity *(HYD)*, sand silting *(SAN)*, blockage *(BLO)*, destabilisation of ground-pipe system *(SPD)*, ongoing corrosion *(COR)*, ongoing degradation from roots intrusion *(ROO)*, ongoing degradation from abrasion *(ABR)*, risk of collapse *(COL)*. Figure 2 and Figure 3 present the corresponding tables for the infiltration dysfunction.

Dysfunction	INFILTRATION
Indicator	INF4: Infiltration risk, estimated from visual inspection
Valuation scale	Segment
Valuation type	Observation-based estimation of a dysfunction
Unit or gravity levels	Grades : 1/2/3/4
Valuation	1 – coding Ci of observations Oi according to EN 13508-2 ; 2 – translating Ci into scores Ni according to the following table ; 3 – calculation of **density** D = N / LT, with N = Σ Ni, and LT: length of the segment (m) $Ni = \alpha^n \times P \text{ (or } L_i)$, with n = 0, 1, 2 or 3 and α = 2, 3 or 4; 4 – comparison of D with thresholds S1, S2, S3 : level 1 if D ≤ S1 ; 2 if S1 < D ≤ S2 ; 3 if S2 < D ≤ S3 ; 4 if S3 < D.

Figure 2. DENSITY CALCULATION FOR INFILTRATION (LE GAUFFRE *ET AL.*, 2004)

Observation Oi	Code Ci	1	α	α^2	α^3	← Gravity Extent ↓
Deformation	BAA		BAA			P
Fissure	BAB	BAB B		BAB C		L
Break/collapse	BAC			BAC A	BAC B/C	P
Missing mortar	BAE		BAE			P
Defective connection	BAH			BAH B/C/D		P
…	…					

Figure 3. DEFECTS CONTRIBUTING TO INFILTRATION (LE GAUFFRE *ET AL.*, 2004)

3. ELICITING EXPERTS' OPINION

We present here the first results of the expert survey we made within the INDIGAU project. For each dysfunction indicator, experts' opinions are used for calibrating thresholds for the 4 different states presented in the previous part. Then we will use either a crisp approach (Ibrahim *et al.*, 2007) or a fuzzy approach (Le Gauffre *et al.*, 2008) for threshold determination; these methods offer the possibility to take into account simultaneously false positive and false negative errors between the expert valuation and the calculated scores. Figure 4 illustrates the assignment errors related to score value comparison to thresholds.

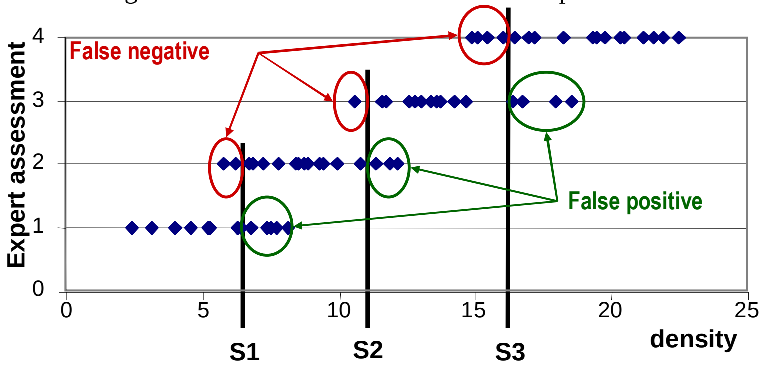

Figure 4. EXPERTS' OPINION VERSUS CONDITION GRADES OBTAINED BY COMPARING SCORES WITH THRESHOLDS (63 SEWER SEGMENTS); IDENTIFICATION OF ASSIGNMENT ERRORS.

In the present application we gathered data on 45 links within 3 different utilities and we asked each of the 8 experts involved in the project to valuate 22 links, that is to say to assign a grade to each dysfunction indicator for each link. This means that for each link we expected 3 or more answers. Thus we want to take into account in our model the gap between calculated scores and expert's opinions and also the fact that on a same link different experts can propose different results.

First of all, the four grades have been defined and discussed in accordance with experts' opinion. These grades are defined in the Table 1.

Table 1. DEFINITION OF EACH GRADE

Grade	Definition
G1	no or few noticed defects (regarding the considered dysfunction)
G2	situation with low gravity, link to be kept under watch
G3	situation with a certain gravity, intervention to be prioritized
G4	unacceptable situation in any context, action needed

Next, a sample of 45 links was built up: one third of the sample in the French coding system, the second third in EN 13508-2 system after recodification from French system, the last third available directly in the EN 13508-2 system.

Then, each expert had to answer in a spreadsheet; the generic response sheet is presented in Figure 5. Each answer with Grade 3 or 4 must be justified, following procedures (a) *major(s) defect(s) or combination of defects*, (b) *density* or (c) *concentration of defects* presented in Figure 1.

Link id: CG03 *Time spent:* 20 minutes
Expert id: FJ + MW

PI	*G*	*Judgment justification*				
		Density	Concentration of defects	Major(s) defect(s)	Combination of defects	Comments
INF	**G3**	**X**				
EXF	**G2**					
HYD	**G2**					
SAN	**G1/G2**					
BLO	**G1**					
SPD	**G3**	**X**				
COR	**G1**					
ROO	**G3**			**BBA A 4.7 + BCA E A 23.7**		
ABR	**G2**					
COL	**G4**					**Risk of road collapse + BAP 18.9 + BAH B 24.5**

Figure 5. EXAMPLE OF EXPERT'S JUDGMENT OF A LINK

4. RESULTS OF THE SURVEY

We now describe the results of the expert valuation we have just collected on 33 links on which we have 3 or more answers. Conflict between experts occurs when the difference between 2 answers is 2 or more levels; in fact when difference between experts' opinions is 1 level, consensus may be obtained at the middle of the levels (*i.e.* consensus of D1 + D2 is D1/D2).

Table 2 presents the answers for link 12. It illustrates the situations observed for the 33 links.

Table 2. EXPERTS' JUDGMENT FOR LINK 12, GRADING OF EACH DYSFUNCTION INDICATOR. THREE CASES ARE IDENTIFIED: 1) A CONSENSUS IS OBTAINED (WHITE COLUMNS); 2) ONE EXPERT DISAGREES BUT CONSENSUS IS KNOWN (WHITE COLUMNS AND BLACK CELL); 3) CONSENSUS IS DIFFICULT (GREY COLUMNS).

Expert	*INF*	*EXF*	*HYD*	*SAN*	*BLO*	*SPD*	*COR*	*ROO*	*ABR*	*COL*
X1	G3	G3	**G4**	G4	**G4**	**G3**	G1	G1	G1	**G4**
X5	G3	G3	**G3**	G3	**G1/G2**	**G2**	G1	G1	G1	**G3/G4**
X6	G4	G4	**G1**	G4	**G3**	**G1**	G1	G1	G2	**G1**
X7	G3	G3	**G4**	G4	**G4**	**G2**	G1	G3	G2	**G1**
X8	G3	G3	**G1**	G2	**G1**	**G2**	G1	G1	G1	**G2**

Three cases occur. In case 1, a consensus is identified, there is no conflict; consensus can be "no dysfunction" as for *COR* and *ABR* in Table 2 or consensus can be "major dysfunction" as for *INF* and *EXF*. In case 2, consensus is also known because only one expert disagrees and this answer may be excluded. For example, in Table 2, *SAN* is assigned grade G3/G4 and *ROO* is assigned G1. In the last case (case 3), consensus is hardly known since there are major conflicts between all experts (*HYD*, *BLO* and *COL* in Table 2); further investigations are needed in order to conclude (ask other experts to assess this link, question again experts, characterize expert behaviour to see if expert is optimist or pessimist, etc.).

If we now consider all the 34 links, the number of links for each case is presented in Table 3.

Table 3. COMPARISON OF EXPERTS' JUDGMENTS FOR 34 LINKS; CASE 1: CONSENSUS, CASE 2: ONE OPINION DIFFERS, CASE 3: NO CONSENSUS

Cases	*Dysfunction indicators*									
	INF	*EXF*	*HYD*	*SAN*	*BLO*	*SPD*	*COR*	*ROO*	*ABR*	*COL*
1	23	19	20	18	20	19	31	33	27	17
2	6	10	5	5	9	7	3	1	6	10
3	5	5	9	11	5	8	0	0	1	7

For *COR* and *ROO*, there are no major conflicts, however there are few defects concerning these dysfunctions: grade G1 and G2 have been assigned by the experts. At the opposite, *SAN* presents many conflicts so as *HYD*, *SPD*, and *COL*. From Table 3, we can conclude that experts agree with each other in the majority of links; however there is a surprisingly high rate of conflict. Discrepancies between experts' judgement must be investigated and although further work is needed, several directions have been identified:

- expert’s background: an expert may be “lax” (few D3 or D4) because the asset stock of its utility is in poor condition and rehabilitation budget is slim…
- expert’s skills: an expert may be mainly preoccupied with some aspect such as hydraulics (HYD, BLO, etc.) and not with some others such as water tightness (INF, EXF);
- human error: a major defect or a harmful combination of defect may have been omitted;
- interpretation differences: each procedure (a, b, c, Figure 1) may not have the same limits and meanings for each expert.

Taking into account these different points of view will be our challenge but we will first of all have to consolidate these results by presenting them to the experts to validate or not their positions.

When we look at the results, expert by expert, we see different behaviours as we mentioned it already before. Let us have a look to the answers given for INF presented on Figure 6. First of all, it is noticeable that results are well spread between grade 2 and grade 4; grade 1 results are considered less interesting because the aim of the INDIGAU project is to provide a support for the prioritization of rehabilitation projects. Expert 6 may be identified as more severe than other experts: he often gives the highest grade amongst other answers. On the contrary, expert 2 may be considered as less severe than others: he has never assigned grade 4 and often gives the lowest grade. Some other experts, such as expert 8, appear as “moderate” because they often give median answer. The study of other indicators shows that experts are not always optimist, pessimist or moderate; it depends on the considered dysfunction.

5. CONCLUSION – OUTLOOK

We have reported an ongoing work that aims at calibrating dysfunction indicators based on the results of visual inspections. In a first step, three complementary procedures have been proposed for making the most of the observations, and rules have been defined for translating defect codes into deduct values that can be aggregated in a single score. This score may be compared to thresholds for assigning a grade to each link. Calibration requires experts’ opinions used as references. We have shown that eliciting a reference condition grade from experts is not obvious. Further works will go on with the elicitation of reference values and calibration procedures will be implemented within crisp and fuzzy approaches.

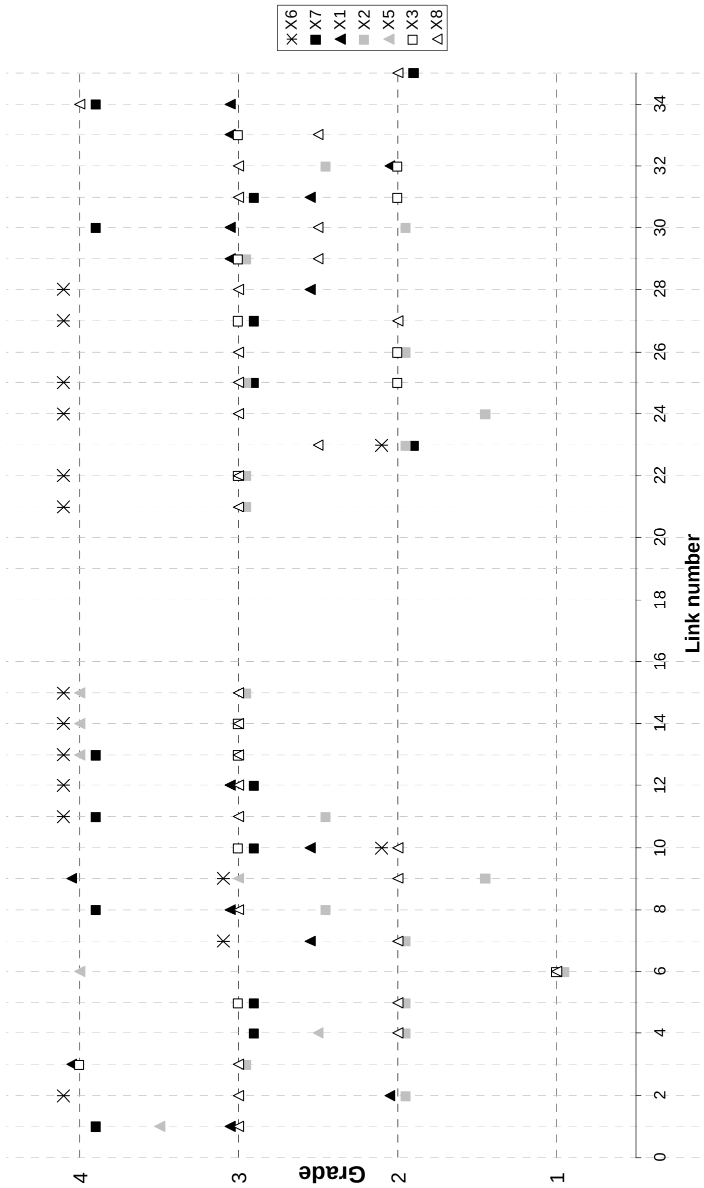

Figure 6. RESULTS OF EXPERTS' OPINION FOR *INF* INDICATOR AND FOR 30 LINKS *(PLEASE ROTATE THE FIGURE FOR BETTER UNDERSTANDING)*.

6. ACKNOWLEDGEMENTS

The research presented in this paper is carried out in the frame of the INDIGAU research project (www.indigau.fr) supported by the French National Agency for Research – ANR, within the PGCU-2006 program. The authors thank the experts of the utilities that are involved in the project: *Brest Métropole Océane, Communauté d'Agglomération Caen la mer, Communauté Urbaine de Strasbourg, Conseil Général du Bas-Rhin, Grand Lyon, Lille Métropole Communauté Urbaine, Nantes Métropole Communauté Urbaine*.

7. REFERENCES

AGHTM (1999). Les ouvrages d'assainissement non visitables : fiches patho-gnomoniques. Techniques Sciences et Méthodes, octobre 1999, 23-90

Dorchies, D. (2005). Etude de l'applicabilité de l'outil d'aide à la décision RERAU pour la réhabilitation des réseaux d'assainissement sur l'inventaire du département du Bas-Rhin, *Mémoire de fin d'études, ENGEES Strasbourg, UMR Gestion des Services Publics*, 62 p.

Ibrahim M., Cherqui F., Le Gauffre P., Werey C. (2007). Sewer asset management: from visual inspection survey to dysfunction indicators. *2nd Leading Edge Conf. on Strategic Asset Management, Lisbonne, Portugal, October 17-19, 10p.*.

Le Gauffre P., Ibrahim M. and Cherqui F. (2008). Sewer asset management: fusion of performance indicators into decision criteria. Pi08 – Performance Assessment of Urban Infrastructure Services, Valencia, Spain, 12-14 March. In press.

Le Gauffre P., Joannis C., Breysse D., Gibello C. and Desmulliez J.J. (2004). Gestion patrimoniale des réseaux d'assainissement urbains. Guide méthodologique. Paris, *Lavoisier Tec&Doc*, 416 p., ISBN 27430-0748-6.

Le Gauffre P., Joannis C., Vasconcelos E., Breysse D., Gibello C., Desmulliez J.J. (2007). Performance Indicators and Multicriteria Decision Support for Sewer Asset Management. *Journal of Infrastructure Systems, ASCE*, **13**(2), June 2007, 105-114.

Rahman, S. and Vanier, D.J. (2004). An evaluation of condition assessment protocols for sewer management. Report B-5123.6. Ottawa (Canada): CNRC-NRC. Available online at: http://irc.nrc-cnrc.gc.ca/pubs/fulltext/b5123.6/b5123.6.pdf.

Werey C., Dorchies D., Mellac Beck I. (2006). Sewer asset management: assessing criteria for a multicriteria decision support on a county level data base. *Joint int. conf. on Computing and decision making in civil and building engineering, Montreal, June 14-16,* 886-895.