CCTV inspection of sewer segments: calibration of performance indicators based on experts' opinions.

Frédéric Cherqui, Caty Werey, Mazen Ibrahim, Pascal Le Gauffre

CCTV inspection of sewer segments: calibration of performance indicators based on experts' opinions

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

[1] *Université de Lyon, F-69000, Lyon, France; INSA-Lyon, F-69621 Villeurbanne, France; Université Lyon 1, F-69622, Villeurbanne, France; LGCIE - Laboratory of Civil & Environmental Engineering.*
[2] *Joint Research Unit Cemagref-ENGEES in Public Utilities Management, 1 quai Koch, BP 61039, 67070 Strasbourg Cedex, France.*

**Corresponding author, e-mail frederic.cherqui@insa-lyon.fr*

ABSTRACT
Asset management is an increasing concern for wastewater utilities and companies. Indicators are developed for supporting the definition of investigation and rehabilitation programs. These indicators are mostly based on visual inspections, which provide major information. However, difficulty remains in the translation of a visual inspection survey into dysfunction indicators. Condition grade of a sewer segment may be obtained by comparison of a single score to thresholds which must be in accordance with practices or opinions of utilities' experts. The confrontation between expert assessments of sewer segments (condition grade) and calculated scores also demonstrates the necessity of considering diagnosis imperfection when establishing thresholds. To fill this niche, an algorithm has been recently proposed (Ibrahim *et al.*, 2007) in order to fix thresholds by minimizing a cost function. This article presents a successful application of the proposed algorithm on 30 CCTV reports of sewer segments located in the urban community of Strasbourg or in the *Département du Bas-Rhin*. For each CCTV, a score is calculated using observation codes converted into numerical scores and in parallel, grade is assessed by several experts (sewer managers of different French local utilities). This method has proved its interest when threshold determination is required to assess indicators. Moreover, this approach is generally applicable to numerous domains, when levels of performance need to be defined.

KEYWORDS
Grade; indicator; misclassification cost; threshold; visual inspection, sewer, expert opinion.

INTRODUCTION
Asset management is an increasing concern for wastewater utilities and companies. Indicators 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 was developed (Le Gauffre *et al.*, 2004; Le Gauffre *et al.*, 2007). 10 dysfunction indicators are defined and assessed from visual inspections reports of sewer segments; these dysfunction indicators are assigned a grade $G \in \{G1, G2, G3, G4\}$: (from the best to the worst). This paper aims at presenting 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 3rd section and they are discussed in the following section.

Sewer segment grading

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.

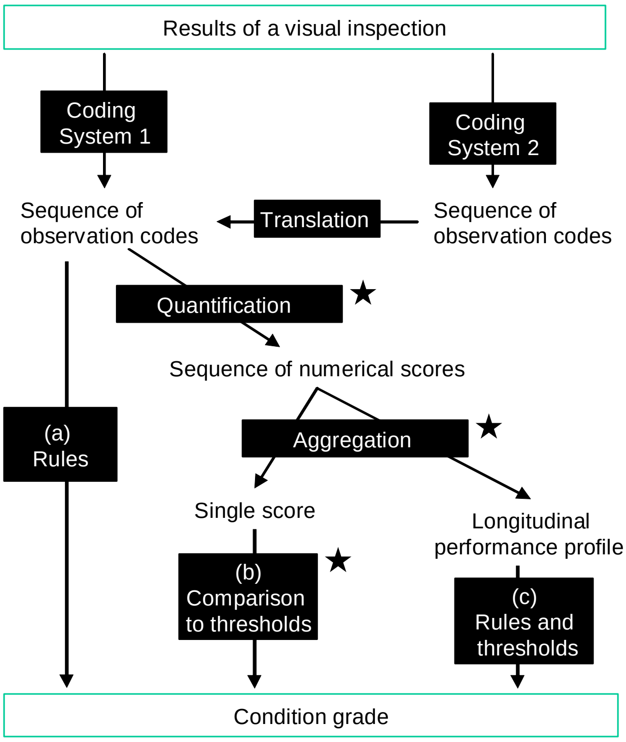

Figure 1. Translation of visual inspection encoding into condition grade.

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 Département 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 recently, new material is available on the market, making the inspection directly with this new framework.

Valuation of dysfunction indicators

When the defaults are reported by using the EN 13508-2 standard, the calculation of the dysfunction scores can start 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 α = 2, 3 or 4 and P = 1, 2, 3, etc.; 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).

DEALING WITH EXPERTS' OPINIONS

Eliciting opinions

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, in the next section, we will use a crisp approach (Ibrahim *et al.*, 2007) for threshold determination. The method proposed offers 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 on a previous theoritical sample.

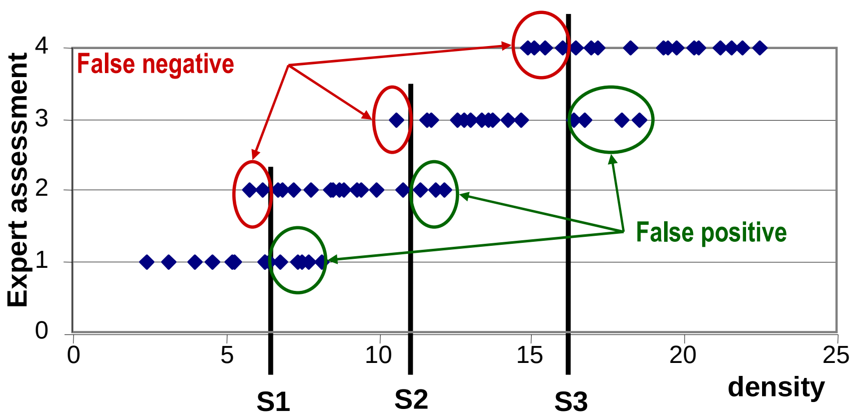

Figure 4. Ideal experts' opinion versus condition grades obtained by comparing scores with thresholds (63 fictitious sewer segments): identification of assignment errors.

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 opinions. We also want to consider 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 as following:

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

A sample of 45 links was built up. The condition of each link is described with a CCTV inspection report, including pictures. Then, each expert had to answer in a spreadsheet; an example of a completed form is presented in figure 5. Each answer with Grade G3 or G4 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 Expert id: FJ + MW		Time spent: 20 minutes				
Indicator	Grade	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			X		Risk of road collapse

Figure 5. Example of expert's judgment of a link.

Results of the survey

Results presented in this paper concern 30 sewer segments: 15 links from *Strasbourg* utility, coded STG and 15 links from Bas Rhin's local council utility, coded CG as *Conseil Général*. For every link, at least 3 expert valuations are available; in some cases more than 3 expert valuations are available thanks to extra work of some experts. We are hoping to complete the results soon, that is to say ask experts for missing valuations and calculate score of others links from other French utilities.

As presented recently (Werey *et al.*, 2008), we identify that 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 1 presents, for example, the answers for link CG12. It illustrates the situations observed for the 30 links.

Table 1. Experts' judgment for link CG12, 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 (Werey *et al.*, 2008), each case is illustrated with the example of table 1:

- In case 1, a consensus is identified, there is no conflict; consensus can be "no dysfunction" (G1 or G2) as for COR and ABR; or consensus can be "major dysfunction" (G3 or G4) 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, SAN is assigned grade G3/G4 and ROO is assigned G1.
- In the third case, consensus is hardly achieved since there are major conflicts between all experts (HYD, BLO, SPD and COL); further investigations are needed in order to conclude (ask other experts to assess this link, question again experts, characterize the expert behavior to see if expert is severe or lax, etc.).

If we now consider all the available links and all dysfunctions, we can notice that most of them are classified in case 1. However there is still a high proportion of link classified in case 3: 15% in average for all dysfunctions but values vary between 0% and 32%. 0% corresponds to COR and ROO; there are no major conflicts, however there are few defects concerning these dysfunctions: grade G1 and G2 have often been assigned by the experts. At the opposite, SAN presents many conflicts (32% of links in cases 3) so as HYD (26%), SPD (23%), and COL (20%). We can conclude that experts agree with each other for a majority of links; however there is a surprisingly high rate of conflict. Interpretation of experts' judgment (Werey *et al.*, 2008) has demonstrated that experts are not always severe, lax or moderate; it depends on the considered dysfunction. Discrepancies between experts' judgments 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 may also be "severe" for several dysfunctions because specific dysfunctions are often observed in the asset stock of the utility.
- 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.
- Some experts may have "recreate" a context accompanying the CCTV report, that is to say for example a pipe break (usually judged as grade G4) has been valuate in grade G2 by some experts because they considered that this break was stabilized and will not get worse.

The next section details the calibration of thresholds used in procedure b (figure 1), for the INFiltration dysfunction indicator.

THRESHOLDS CALCULATION FOR INFILTRATION

The approach described in (Ibrahim *et al.*, 2007) has been applied to the sample of 30 sewer segments. For this purpose the algorithm was coded in Visual Basic and implemented in an Excel spreadsheet. Optimum cut-off thresholds (figure 4) have been calculated depending on α and P values (figure 3) and in accordance with experts' opinions. Table 2 below presents raw experts' judgments available for each different link (in row): as these judgments are used to determine density thresholds, all judgments with a different justification than density have been removed (major defect, etc.).

Table 2. Experts' judgments related to INFiltration dysfunction indicator, for the 30 links. Only assessments based on density are represented.

links	Experts						
	X1	X2	X3	X5	X6	X7	X8
STG01		G3			G4		
STG02		G3	G3		G4		
STG03		G2			G2	G2	G2/G3
STG04		*G1/G2*			G4		
STG05		G3	G2		G4		
STG06		G2	G2				
STG07			G3		G4		*G2*
STG08	G2/G3				G4		
STG09	G3	G3	G3				*G2/G3*
STG10	G3	G2					*G2/G3*
STG11	G2/G3		G2				
STG12	G2	G2/G3	G2				
STG13	G3						G2/G3
STG14	G3					G4	G4
STG15							G2
CG01	G3			*G3/G4*			
CG02	G2	G2					
CG03	G4	G3	G4				G3
CG04		G2					G2
CG05		G2					G2
CG06		G1	G1	G4			G1
CG07	G2/G3	G2		G2	G3		G2
CG08	G3	G2/G3				*G4*	
CG09	G4	G1/G2		G3			G2
CG10	G2/G3				G2		G2
CG11					G4		G3
CG12	G3				G4		
CG13				G4	G4	G4	G3
CG14			G3	G4	G4		G3
CG15		G3		G4	G4		G3

As noticed in the table below, each link is associated to – at least – two assessments for which the main justification for grading is density.

Determination of α and *P* values

The density score of each link has been calculated for α and P varying respectively from 2 to 4 and 1 to 5. $\alpha = 1$ is not considered because it cannot permit to distinguish different gravity of defects and $P = 0$ is also excluded because in this case several links assessed G2 by different experts obtain a score of 0. A consensus value aggregating experts' opinions is determined for each link. Then, for each values of α and P, links are sorted by increasing density and the links which do not respect a sorting rule are counted. The sorting rule is the following: a threshold must belong to a maximum of 2 grades, that is to say:

- for a low densities, grades based on experts' opinions should be between G1 and G2,
- then, for medium densities, expert opinion grades should be between G2 or G3,
- and for high densities, expert opinion grades should be between G3 or G4.

The sorting rule is of major importance and this is a constraint that we decide to apply. It is in fact not coherent to exploit experts' judgments for a link which vary from G1 to G3 or from G2 to G4. This sorting rule is necessary until it becomes possible to use only consensus judgment; however it is not possible yet to exploit only consensus judgment because the number of links is limited. A future survey is planned and it should concern more links. This sorting rule must lead to a graph similar to figure 4 (where expert's opinions are between G1 and G2 for densities below 8, between grade G2 and G3 for densities between 8 and 12, and between grade G3 and G4 for densities above 12); which enables to determine the values of α and P in best accordance to experts' opinions.

Concerning the sample of 30 links, 3 sets of best values have been preferred ($\alpha = 2$ /P = 1; $\alpha = 3$ /P = 1 and $\alpha = 4$ /P = 1) because they lead to the minimum number (6) of links in disagreement with sorting rules (STG04, STG07, STG09, STG10, CG01 and CG08, links in *italic* in table 2). A specific analysis of these 6 links has shown that 6 opinions are at the origin of the problem: X2's opinion for link STG04, X8's opinion for links STG07, STG09 and STG10, X5's opinion for link CG01 and X7's opinion for link CG08. We deal with these results in the discussion section.

Correcting some raw experts' opinions

For each set of α and P values, thresholds have been calculated using the procedure which is illustrated below with $\alpha = 2$ and P = 1. First of all, experts' opinions have been "corrected", that is to say following the work presented in (Werey *et al.*, 2008), experts' behaviors have been characterized (severe when expert is inclined to overestimate the dysfunction grade, lax when he is inclined to underestimated the grade and neutral if no specific behavior is identified). These characterizations were done analyzing one precise expert's answers versus other judgments in all the conflict cases (cases 2 and 3 presented in table 1). Correction was applied to 9 out of 84 pairs of values (density / grade according to expert). We are dealing with pairs of values in considering each expert valuation independently. For example, link STG01 is assessed with 2 pairs of values because 2 experts' opinions are available.

Using experts' opinions

It is then necessary to deal with imprecise answers: G1/G2, G2/G3 and G3/G4 answers. This imprecise answers are needed in fuzzy approach (such as proposed in Le Gauffre *et al.*, 2008), but they are not directly workable here. Each imprecise answer is made crisp with two different procedures;

- A favorable procedure: crisp values are chosen so as to favor the validation of the sorting rule.
- An unfavorable procedure: crisp values are chosen so as to avoid to favor the validation of the sorting rule.

If both crisp values are possible, they are equally spread (2 imprecise opinions "G1/G2" are converted to 2 crisp opinions: G1 and G2).

For each procedure, the total number of problematic dots (which do not respect the sorting rule) is calculated. For $\alpha = 2$ and P = 1, favorable and unfavorable procedure leads respectively to 2 and 6 problematic dots, as shown in figure 6.

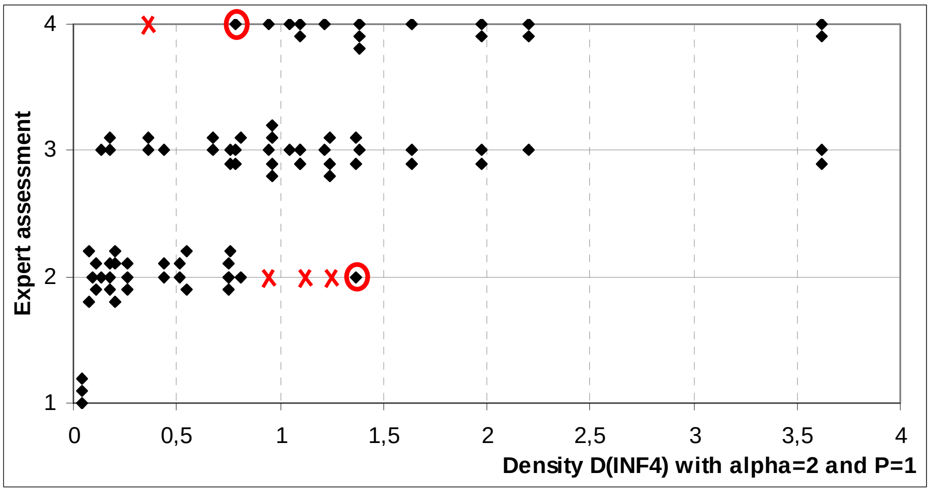

Figure 6. Experts' opinions *versus* condition grade, for 84 experts' judgments on 30 links (dots which were superimposed have been slightly moved in order to see all dots). Dots encircled are the 2 problematic dots common to both procedures and crosses are the problematic dots in case of the 'unfavorable' procedure.

Figure 6 shows that the number of problematic dots is low in comparison with the total number of experts' judgments. For both procedures, problematic dots have been removed and thresholds have been calculated. Table 3 presents a synthesis of the thresholds calculation with a hypothesis of ratio CFN / CFP equal to 2. CFN and CFP correspond respectively to costs (importance) allocated to false positive and false negative errors (figure 4), see Ibrahim *et al.* (2007) for further information upon CFN / CFP ratio. Figure 7 presents the thresholds obtained for $\alpha = 2$ and P = 1.

Table 3. Thresholds (S1, S2 and S3) obtained for 84 experts' judgments on 30 links, and with CFN/CFP = 2. "F" means favourable procedure and "U" means unfavourable procedure.

	$\alpha = 2$ / P = 1		$\alpha = 3$ / P = 1		$\alpha = 4$ / P = 1	
	F	U	F	U	F	U
Problematic dots	2	6	2	6	2	6
S1	0.064	0.064	0.156	0.156	0.285	0.285
S2	0.251	0.745	1.555	1.555	2.632	2.632
S3	1.371	1.371	3.034	3.034	5.363	5.363
MC mini	0.427	0.443	0.427	0.410	0.402	0.397
PE1 [%]	3.66	3.80	3.66	3.85	3.66	3.85
PE2 [%]	31.71	34.18	31.71	34.62	32.93	34.62
PE3 [%]	46.34	43.04	46.34	43.59	45.12	42.31
PE4 [%]	18.29	18.99	18.29	17.95	18.29	19.23

As shown in table 3, thresholds are increasing with α because α is directly connected to the score of each link. However, it is also noticeable that proportions (PE1, PE2, PE3 and PE4) of elements assigned to grades G1, G2, G3 or G4 are stable. More experts' judgments are needed in order to differentiate each value of α.

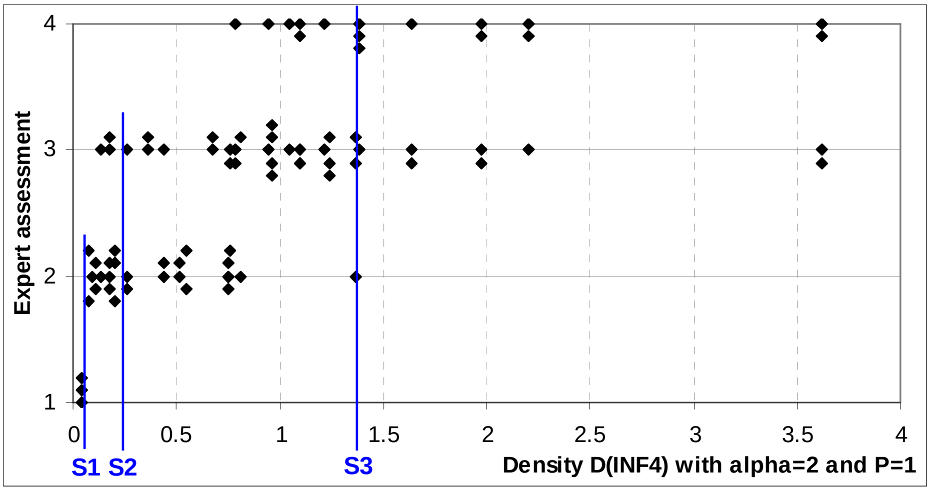

Figure 7. Experts' opinions *versus* condition grade (84 experts' judgments on 30 links). Thresholds S1, S2 and S3 (obtained for CFN / CFP = 2 and for the favorable procedure) are represented on the figure: S1 = 0.064, S2 = 0.251 and S3 = 1.371.

Other experiments were done varying the number of experts' judgment available for threshold determination and the following results were obtained:

- Thresholds variation between the different experiments is not significant;
- Proportions of elements in the different grades (PE1, PE2, PE3 and PE4) vary highly between the different experiment and it is not possible to characterize these variations because they strongly depend on the judgments removed;

DISCUSSION

The methodology developed in this paper enables to define cut-off thresholds by using experts' assessments of dysfunction indicators. Concerning the example presented above, the 4 experts' opinions that disagree with sorting rules (X2's opinion for link STG04, X8's opinion for links STG07, STG09 and STG10, X5's opinion for link CG01 and X7's opinion for link CG08) have been carefully analyzed. X5's opinion may be explained by the fact that justification of grade was ambiguous (density *and* major defects). X8's opinion is not justified for links STG09 and STG10, and so grade justification may not be density. However the 3 other opinions are not understandable and will be discussed with the concerned experts.

Another calibration process was done ($\alpha = 2$, P = 1, CFN / CFP = 2), based on the consensus-synthesis of experts' assessments (30 pairs of values, one per link). Despite the fact that we considered the number of pairs insufficient, results were close to those obtained in Table 3 (PE1 = 3.33 %, PE2 = 33.33 %, PE3 = 43.33 % and PE4 = 20 %). These results confirm the relevance of corrections applied to experts' valuations and the use of the sorting rule.

Concerning the favorable and unfavorable procedures, similar results confirm the low influence of converting hesitations (G1/G2 or G2/G3 or G3/G4) into crisp opinions. There are 13 hesitations and only a part of them create problematic dots.

Last but not least, this experiment proves that it is possible to define cut-off thresholds in accordance to multiple expert opinions. Moreover, thresholds are not significantly influenced by variation in the number of available expert opinions. Yet, some difficulties remain concerning experts' opinions verification and use. The presented case study demonstrated the difficulty to deal with imperfect repartition of expert valuation for a link. This problem should be reduced when enough opinions will be available; then only consensus opinions could be used to determine thresholds.

CONCLUSIONS

We have reported an ongoing work that aims at calibrating dysfunction indicators based on the results of visual inspections. This calibration requires experts' opinions and calculation of defect densities for several sewer segments. We have shown that it is not obvious to manage with imperfect opinions. However, the method proposed in this paper has been successfully applied to a real sample of 30 links assessed by several experts working in different French utilities. Thus, this method has proved its interest when threshold determination is required to assess indicators.

Further works will now focus on two distinct developments: first of all, it is necessary to apply this method on other dysfunction indicators (destabilization of the ground-pipe system, risk of collapse, etc.). Research will also address fuzzy assessments in order to include imprecise transition between the different grades. That is to say it allows defining that a segment may belong to two grades (fuzzy thresholds) when it is difficult to establish a crisp statement. An algorithm for calibrating these fuzzy indicators is under development (Ibrahim *et al*., 2007) and fusion of these indicators is also under study (Le Gauffre *et al*., 2008).

ACKNOWLEDGEMENT

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: *Communauté Urbaine de Brest Métropole Océane, Communauté d'Agglomération Caen la mer, Communauté Urbaine de Strasbourg, Conseil Général du Bas-Rhin, Communauté Urbaine du Grand Lyon, Lille Métropole Communauté Urbaine, Nantes Métropole Communauté Urbaine.*

REFERENCES

AGHTM (1999). Les ouvrages d'assainissement non visitables : fiches pathognomoniques. Techniques Sciences et Méthodes, octobre, 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. LESAM 2007 – 2nd Leading Edge Conference on Strategic Asset Management, IWA International Water Association. Lisbonne 17-19 oct., 10 p.

Le Gauffre P., Ibrahim M. & Cherqui F. (2008). Sewer asset management: fusion of performance indicators into decision criteria. In Cabrera & Pardo (ed.) Performance Assessment of Urban Infrastructure Services. Drinking water, waste water and solid waste. London(UK): IWA Publishing, 195-205.

Le Gauffre P., Joannis C., Breysse D., Gibello C. & 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, 105-114.

Rahman, S. & 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., Cherqui F., Ibrahim M. & Le Gauffre P. (2008). Sewer asset management tool: dealing with experts' opinions. In Cabrera & Pardo (ed.) Performance Assessment of Urban Infrastructure Services. Drinking water, waste water and solid waste. London(UK): IWA Publishing, 125-134.

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.