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MULTI CRITERIA MANAGEMENT OF SEWERAGE SYSTEM: ANALYSIS OF THE FAILURES AND THE CRITICALITY OF STRUCTURES

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The FMEA (Failure Modes and Effects Analysis) was used for management of failure risks of the sewerage system of Algiers. It's based on a multi criteria analysis of failures risks of principal structures, their effects and their criticality. The implementation of criteria is based on the knowledge gained in previous phases of investigations. A criticality index "I_c" has been estimated to highlight the most sensitive structures to previously identified risks. This index is calculated based on three parameters: a "risk", a "severity", and a "detectability period" of the failure. Multi criteria analysis was performed to select and rank the criteria on the basis of scores assigned to each of them (from 0 to 7 according to the defined performance states). Four performance classes were defined according to the values of I_c. Classification scale and graphs representing criticality indices were established. A case study is presented. The results highlight the "black points" of the sewerage system. The most sensitive structures have been identified and the targeted interventions in the medium and long terms have been proposed. The weak points of FMEA were also highlighted.

Keywords: Risks management, Criticality index, Multi Criteria method, Sewerage performance, Severity, Detectability time.

1 INTRODUCTION

The FMEA method is designed to study industrial processes, and on which were particularly available accurate data regarding the history of past failures, their consequences and deadlines of return to service of system after a failure. We adapted this approach to data and available knowledge on the sewerage system studied. The study must be described as sensitivity analysis of works to the risks but not a classical FMEA, although the essential basic principles of FMEA were kept. The principle is to "estimate" a criticality index "I_C" that is based on a set of criteria to highlight the most sensitive works to previously identified risks. The adopted methodology consists in:

- Cut out the Algiers's main system into several entities;
- Define, for each entity, the branches of the network and the particular structures as the storm overflow structures, the pumping stations, etc. (the

elements that are ongoing renovation are not integrated into the study that relates to a current state of risks);

- Define, for each work of each entity, the failure criteria and the associated indicators of risk and severity;
- Define a criticality index, denoted I_c, with associating a "failure risk", a "severity" of the considered failure and a "detectability time".

The criticality index is calculated according to the above three parameters.

As part of the methodological principle defined above, a multi criteria analysis was performed to select and rank the criteria on the basis of scores assigned to each of them (from 0 to 7 according to the defined performance states). The aim is to highlight the most sensitive structures and to propose targeted interventions in the medium and long terms. Four performance classes were defined according to the values of I_c: *little sensitive* structures ($I_c \leq 0.2$), *mildly sensitive* ($0.2 < I_c \leq 0.35$), *sensitive* ($0.35 < I_c \leq 0.5$) and *highly sensitive* ($I_c > 0.5$). Classification grids and graphs representing criticality indices were established. A case study is presented in this paper.

2 METHODOLOGICAL APPROACH

The adopted approach is based on the following essential steps:

- Divide the main structure of the sewerage system into twelve units corresponding to the main sub-catchments of the study area and each comprising several hydraulic structures (collectors, storm overflows, pump stations ...),
- Identification of the main types of failures that can disrupt the smooth functioning of the various structures (clogging or pipe rupture, discharges in dry periods or clogging of the overflow pipes of CSOs which happens at rainy weather, stopping of a pumping station ...). Table 1 gives an example.

Table 1. Example failures.

Element	Failure 1	Failure 2
Pipe element	structural failure	Fouling
CSO	discharges in dry periods	Overflows in rainy weather
Pumping station	Stopping	------

- For each element of the system, evaluation of a criticality index (I_c) based on multiple criteria to highlight the most sensitive pipes or structures to the risks previously identified.

2.1 Criteria Classification and Assessment of Retained Parameters

Risk assessment criteria were defined for each type of hydraulic structure. For this, we first defined three evaluation parameters:

- A "risk" of failure: for example, an approved break about collector may be a sign of poor quality of surrounding soil or excessive surface charge. The pipe portion concerned by a past break will present a "risk" of structural failure more important than another with respect to such a criterion.

- A "severity" of failure: consider and quantify the consequences of this failure. For example, the rupture of a pipe, can it cause damages to property and to persons? And if so, what degree of severity could we attributing to it?
- A "detection period": assign to each structure a period of detectability depending on its location, the impact of the failure or its management system. For example, a default in a pumping station remotely managed will be identified more quickly than in a post unattended.

The combination of these three parameters allow to define a criticality index of a failure by the equation (1) (Stamatis 2003, Diadem Press 2003):

$$I_c = Risk\ x\ Severity\ x\ detectability\ period \tag{1}$$

2.2 Assessment and Performance Scales

For each structure, for each type of failure and for each evaluation parameter, we have defined classification criteria for which we have associated an evaluation scale including a performance and notation scale. Table 2 shows the scale adopted for evaluating pipes failure.

Two aspects were considered:

- *The structural failure*: this criterion represents the elements that lead to think that the section concerned could undergo a break causing a collapse.
- *Fouling:* this criterion includes the silting up of networks near the outlet in sea and the areas of decanting of materials carried during rain events.

3 CASE STUDY

In the context of this paper, we present an application on only a part of the sewerage network of Algiers and by dealing only the pipe sections. (See table 1).

3.1 The Part of Studied Network

The part of the studied combined network is located in the center catchment of Algiers with an area of 1327 ha and consists of 849 m of visitable underground pipes. Figure 1 presents the block diagram.

3.2 Classification Scales - Criticality Indexes

By applying the evaluation criteria of table 2 and equation (1), the values of I_c were obtained. Table 3 provides an example for the "structural failure". The performances scale has been chosen as shown in Figure 2.

4 INTERPRETATION OF RESULTS - DISCUSIONS

The sections most critical with respect to the risk "structural failure" are often characterized by a large size of the upstream catchment.

Table 2. Assessment scale of the pipes failure.

Failure type	Parameter	Criterion N°	Criterion Definition	Performance scale	S	S_{max}
Structural	Risk	A	General diagnosis DHW	Good	1	13
				Average	2	
				Bad	3	
				Undiagnosed	2	
		B	SAFEGE diagnosis and SEAAL surveys	Good	1	
				Average	2	
				Bad	3	
				Very bad	4	
				Undiagnosed	2	
		C	observation of past breaking	No	0	
				Yes	1	
		D	Particular surface load	No load	0	
				Normal load	1	
				Temporary significant load	3	
				Permanent significant load	4	
		E	Age of the pipe	After 1962	0	
				Before 1962	1	
	Severity	A	Upstream catchment size	Small (≤200 ha)	1	15
				Average (201 to 500 ha)	2	
				Big (>500 ha)	3	
		B	Ease of replacement (according Φ)	Easy (≤Φ2000)	1	
				No easy	3	
		C	Ease of works	Somewhat favorable	1	
				Moderately favorable	2	
				Very favorable	4	
		D	Potential Impact	Average	1	
				Strong	3	
				Very strong	4	
		E	Possibility of meshing	Yes	-1	
				No	1	
	Detectability period	---	---	Fast	1	3
				Slow	2	
				Undetectable	3	
Fouling	Risk	A	Slope	High	1	11
				Low	3	
		B	Fouling already observed	No	1	
				Yes	2	
		C	Downstream influence	Any	1	
				Temporary	2	
				Permanent	3	
		D	Special flows upstream	Yes	1	
				No	3	
	Severity	---	Upstream catchment size	Small	1	3
				Average	2	
				Big	3	
	Detectability period	---	---	fast	1	3
				Slow	2	
				Undetectable	3	

S : score, S_{max} : maximum score

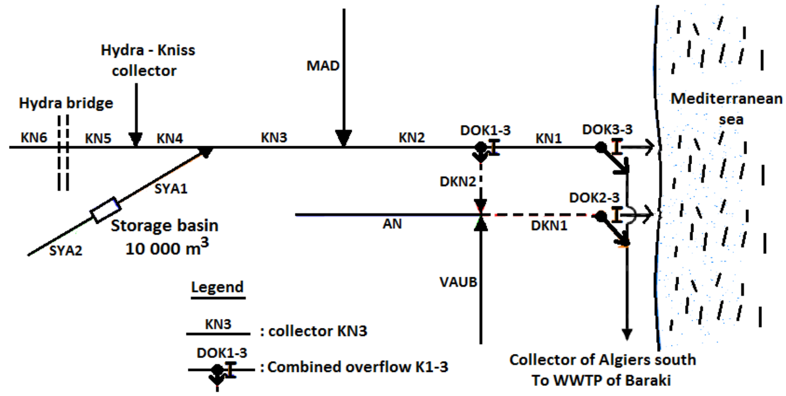

Figure 1. Studied case.

Table 3. Classification scale of the structural failure of pipes.

Pipe	Risk					Severity					DP	I_C
	A	B	C	D	E	A	B	C	D	E		
KN1	2	2	0	3	1	3	3	4	4	-1	3	0,57
KN2	2	2	0	1	1	3	3	2	4	1	3	0,37
KN3	2	2	0	1	1	3	3	2	4	1	3	0,37
KN4	2	2	0	0	1	2	3	1	3	1	3	0,23
KN5	2	2	0	0	1	2	3	1	1	1	3	0,18
KN6	2	2	0	1	1	1	3	4	1	1	3	0,28
DKN1	2	1	0	3	0	3	3	4	3	-1	3	0,40
DKN2	2	1	0	1	0	3	3	4	3	-1	3	0,27
VAUB	2	2	0	1	1	1	1	2	1	1	3	0,15
AN	2	2	0	3	1	1	1	2	1	1	3	0,21
MAB	2	2	0	4	1	2	3	4	3	1	3	0,55
SYA1	2	2	0	1	1	2	3	4	3	1	3	0,37
SYA2	2	2	0	1	0	1	1	4	1	1	3	0,18
Hydra - Kniss	2	2	0	1	1	3	1	1	3	1	3	0,25

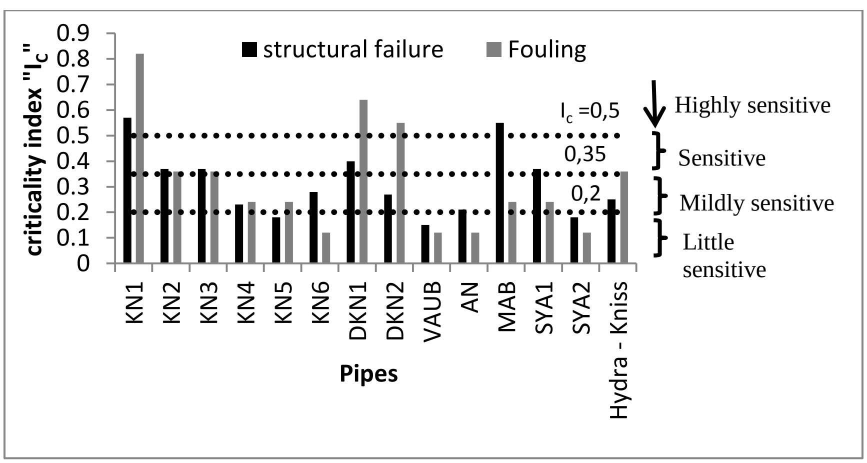

Figure 2. Criticality index and performance classes.

They are located in densely populated areas where the necessary interventions after a collector collapse would be very difficult to achieve. Important factors of increased criticality are also the presence of high loads (passage under building, under railway tracks or high traffic road), the age of the collector or the fact that collapses of the structure have already been occurred in the past. About the fouling risk, the more sensitive pipes are those located in the areas with low slopes, which undergo an downstream hydraulic influence (tide level, threshold of downstream discharge, pumping station), which receive waters containing sands from wadis and of course those whose the silting up has already been observed in the past. The criticality index is also obviously influenced by the upstream catchment size.

Rehabilitation actions of pipes were proposed according to the nature of failures.

5 CONCLUSION

The used methodology has allowed us to establish a credible performance scale of the principal works of sewerage system of Algiers. However it requires an important quantity of data essentially based on surveys and field visits.

The structures whose index of criticality is high can enjoy a relatively optimum maintenance schedule taking into account the priorities established on the basis of performance values or of evaluated failure risk. The Analysis of sensitivities to the risks of the sewerage system allows, as part of sustainability plane and network maintenance, to prioritize interventions and to organize monitoring.

The classic FMEA is a risk assessment tool that allows establishing priorities for intervention. Thus, it allows to reduce and to eliminate the risks of failure. However, this tool could present difficulties such as subjective description of the evaluation criteria, the relative importance among the risk scores, the difference in the representation of risk among the same scores, and the shared knowledge between members of the team of FMEA. We could improve this aspect by using a method less subjective (Kwai-Sang *et al.* 2009, Pillay and Wang 2003, Rajiv *et al.* 2007) like the fuzzy theory (Yeh 2007).

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