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Managing Sewerage Networks Using both Failure Modes, Effects and Criticality Analysis (FMECA) and Analytic Hierarchy Process (AHP) methods

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**MANAGING SEWERAGE NETWORKS USING BOTH FAILURE MODES, EFFECTS
AND CRITICALITY ANALYSIS (FMECA) AND ANALYTIC HIERARCHY
PROCESS (AHP) METHODS**

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Abstract

This paper proposes a methodology for managing complex sewerage networks based on the concomitant use of two performance evaluation methods namely (1): the Failure Modes, Effects and Criticality Analysis (FMECA) and (2) the Analytical Hierarchy Process (AHP). The FMECA is used to determine the risks of

structural failures making it possible to establish a methodology for managing these failures. The AHP is used to check the relationship consistency between the performance indicators allowing the determination of the overall performance (OP). This proposed methodology was also utilized for the urban sewerage network of Oued-Kniss in the city of Algiers, Algeria, as part of the efforts engaged for sustainable and efficient management.

Keywords: urban sewerage networks, sustainable development, Infrastructure assess management, AHP, FMECA, criticality index, Performance indicator,

Résumé

Cet article propose une méthodologie de gestion des réseaux d'assainissement complexes basée sur l'utilisation concomitante de deux méthodes d'évaluation des performances à savoir (1): L'Analyse des Modes de Défaillance, des Effets et de la Criticité (AMDEC) et (2) le Processus de Hiérarchie Analytique (AHP). L'AMDEC est utilisée pour déterminer les risques de défaillances structurales permettant d'établir une méthodologie de gestion de ces défaillances. L'AHP est utilisé pour vérifier la cohérence des relations entre les indicateurs de performance permettant de déterminer la performance globale (GP). Cette méthodologie proposée est appliquée au réseau d'assainissement urbain d'Oued-Kniss dans la ville d'Alger, en Algérie, dans le cadre des efforts engagés pour une gestion durable et efficace.

Mots-clés : Réseau d'assainissement urbain, développement durable, gestion de l'évaluation des infrastructures, AHP, AMDEC, indice de criticité, indicateur de performance.

1 INTRODUCTION

The proper implementation of sustainable management practices of urban sewerage networks (USN) aids in the prevention of their catastrophic breakdown and collapse and the associated costs and inconveniences. It also protects the public's health and the environment (groundwater and receptors environment); and minimizes infiltration-inflow and exfiltration losses, which is a very important element in

the sustainable management of urban water resources. The latter has important economic consequences for sewer system operators and wastewater utilities (Damvergis 2014). Finally, from a more political or public relations perspective, it avoids bad publicity and users' loss of confidence in managers and infrastructures (Grondin and Desbiens 2012). Ultimately, efficient and sustainable urban sewerage networks (USN), positively affect the economic, social and environmental lives of a society (Caradot and al. 2019).

The main challenge of sustainable management of USNs, however, is the development of practical and effective decision-making tools and management strategies to preserve the effectiveness and efficiency of USNs. A decision-making tool should be based on monitoring and continuous multi-objective analysis of USNs performance.

The study presented in this paper presents a measure of the structural performance of the collectors of the Oued-Kniss sewerage network in Algiers using concomitantly the two multi-criteria analysis methods of AHP and FMEA. The methodology used as well as the results obtained are presented and discussed herein.

2 BACKGROUND

In Algeria, as in many other countries, USNs are experiencing progressive and more serious degradations. The nature of these degradations and their level of seriousness varies considerably from one country to another. This is reflected in the poor state (due to maintenance and operations issues) and non-optimized performance of related infrastructure. Urban sewerage networks in large Algerian cities are aging. For instance, in the city of Algiers, over 22.5% of collectors are over 70 years old and in need of rehabilitation. This aging problem of USNs affects several countries. In Germany, Berger et al. (2016) pointed out that 20% of the sewer network is aging and requires rehabilitation in the short to medium term. A recent survey of 397 communities in the United States and Canada determined that aging infrastructure and sustainable heritage management are the two main challenges for this sector (Black and Veatch 2013). Therefore, multiple Canadian government programs, funded at a level of billions of dollars, were established and

targeted projects that contribute to the rehabilitation of existing wastewater and storm water treatment systems; collection and conveyance infrastructure. Parallel initiatives were also included in order to improve asset management, system optimization for subsequent planning for future needs (Infrastructure Canada 2017).

In Algeria, several measures were taken following the decision to rank the water resources sector among the three national priorities alongside health and education. Throughout the country, the Algerian Ministry of Water Resources invested 450 billion dinars (DZD) (approximately 3.3 Billion Euros) in the construction and rehabilitation of sewerage systems and sewage treatment plant projects between 2000 and 2013. The stated aim was to reach zero wastewater outside of sewerage networks discharge by 2030.

This paper describes related activities to develop an efficient management methodology for complex sewerage networks to meet the needs of the Société de l'Eau et de l'Assainissement d'Alger (SEAAL).

In this context, the Failure Modes, Effects and Criticality Analysis (FMECA) were first used to evaluate and predict the structural performance of collectors in urban Sewerage Networks, through one of the most important objectives, which is "Ensuring Monitoring and Maintenance".

Secondly, the method of Analytical Hierarchy Process (AHP) was applied in order to validate the results of the proposed FMECA method for the identification of relevant influencing factors. The choice of the AHP method as a validation tool is based on its proven effectiveness in wastewater systems as addressed by several researchers (Fang and Xia 2019 ; Vladeanu and Matthews 2019 ; Ennaouri and Fuamba 2013).

3 LITERATURE REVIEW

Risk analysis and probability of failure of USN collectors, can be determined by predicting the future condition rating of the asset from historical pipe condition data. Many associated mathematical models have been developed to predict the structural condition of sewerage pipes (El-Housni and al. 2018). These models are generally classified into three categories, namely: (1) physical models, (2) models based on artificial intelligence, and (3) statistical models.

Physical models are used to quantify the relationship between deterioration factors and the condition of sewer pipes based on the physical or mechanical properties of certain phenomena. These models do not take into account the uncertainty of the deterioration process. They involve the adjustment of linear or nonlinear equations to the failure observation. Physical models are, in comparison, scientifically more robust to study specific aspects that need less criteria. However, structural failure is considered a complex multi-criteria process that depends on a large number of factors. In addition, the physical models developed to assess the condition of sewer pipes are considered too simplistic and oftentimes conducted under idealistic conditions to reflect the actual deterioration process (Tran and al. 2007). Therefore, they are not practical enough to truly reflect the behaviour of sewage pipes (Hawari and al. 2020).

In contrast, statistical models consider uncertainties using probabilistic approach. These are mathematical models, consisting of a collection of probability distributions to describe the patterns of variability. Bakry and al. (2016). These models were developed for sewer pipes with several physical, environment and operational factors included. However, there are certain assumptions which are not suitable for such a technique as they could call into question the accuracy of the developed model. As pointed out by Salman and Salem (2012), pipeline deterioration is a complex process that might not be correctly modelled by linear regression models to correctly reflect the condition of the pipes.

On the other hand, artificial intelligence models learn the deterioration behavior from the inspection data. Such learning is enabled through artificial intelligence techniques such as Artificial Neural Networks (ANN) and expert rule-based models such as fuzzy logic. Alsaqqar and al. (2017) Developed a Neural Network Deterioration Model (NNDM) to predict the condition of sewer lines in the city of Baghdad. The model provided a high overall forecast with an efficiency of 87.3% and concluded that the sewer lines in Baghdad were in poor condition. Li and al. (2019) developed an Adaptive Neurofuzzy Inference System (ANFIS) to determine the factors causing the corrosion of concrete sewer pipes.

Vladeanu and Matthews (2019), developed a failure consequence model using a decision-making method of several summary criteria to assess the economic, social and environmental consequences of the failure of wastewater pipes. It is important to stress here that all of these methods and tools, each with their own

associated approaches and limitations, can solve select problems associated with wastewater pipes. As a result of the development of a USN-wide pipeline deterioration model, the probability of detection of the failure can be determined early, allowing decision-making in terms of rehabilitation planning and the renewal of pipelines.

4 METHODOLOGY

The literature review indicates that various condition assessment models were able to accurately predict the future condition of sewer lines at the pipe scale. However, these same models were not able to predict such future conditions at the network scale. The methodology followed and presented in this paper consists of the eclectic concomitant use of both FMECA and AHP methods for the evaluation of structural performance of USNs at a larger scale of the network. The FMECA is a powerful tool in assessing risk. The AHP represents a validation tool in the field of sewage condition to make the best management decisions. FMECA method, in combination with the validation/confirmation of its subsequent results through the AHP method, provides a consistent and solid support in the final decision making. A description of the different techniques used in building the two network-wide performance assessment models, and the different steps required to build these models are described in detail below.

4.1 Failure Modes, Effects and Criticality Analysis (FMECA)

Failure Modes, Effects and Criticality Analysis (FMECA) is a well-known risk management technique developed in 1967 by NASA and the automotive industry. It is an effective method for identifying hazards associated with local and global system failures. It is also not difficult to use and the results are easily understood (Crawley 2020). However, FMECA focus on the equipment and not on the operational errors (Crawley 2020) and can not be used for diagnosis when a failure is reached (Brahim et al. 2019).

FMECA was originally used for aerospace development with a view of trying to avoid errors. It was thereafter widely extended to other fields such as the automotive and aircraft industries (Wang et al. 2019),

aerospace (Perez 2020), electronics (Fidan et al. 2020), telecommunication (Liu and al. 2019), healthcare (Ianni et al. 2018), potable water (Bernheimer and all. 2019), and wastewater treatment (Shinta et al. 2019).

FMECA uses the combination of failure mode and effect analysis (FMEA) and the criticality analysis (CA). FMEA was developed by the United States military in the late 1940s (Hwang et al. 2015) and identifies potential failure modes and their consequences. The criticality analysis (CA) evaluates the failure modes criticality, quantitatively or qualitatively.

The criticality of each failure mode is computed by combining the risk parameters with an estimate of how strongly the failure mode will affect the system, the frequency of occurrence of the failure mode within a specific period of time and the probability of detecting the failure (Carpitella and al. 2017).

FMECA application in urban sewerage networks has been, so far, limited to sections and not to the overall network as the authors are presenting in this study.

The evaluation of the performance of a sewerage network using FMECA is based on the following three essential steps (Cherrared, 2016):

1. Division of the sewerage system into sub-units corresponding to the main sub-watersheds, which include hydraulic structures such as collectors.

2. Identification of the main types of failures that can disrupt the operation of the various hydraulic structures. In this paper, the structural failure of the collectors is the type of failure considered.

3. For each section of the collector, a criticality index (I_c) is calculated to highlight the sections or elements of the collector most sensitive to risks.

4.1.1 Selected Structural failure, its parameters and evaluation criteria

Structural failures occur when a collector loses its ability to support the required loads, and, thus, it splits, deforms or even collapses completely. Evaluating the structural performance of USNs is as much an art as a science (Ben Tagherouit and Bennis 2012). It is based on the assessment of the degradation of USNs

and the prediction of their structural failures using a comprehensive set of evaluation criteria selected based on past experience and feedbacks from the educated judgment of experienced engineers and experts in the field. This educated judgement comes from the client, la Direction des Ressources en Eaux de la Wilaya (DREW), the operating company, la Société de l'Eau et de l'Assainissement d'Alger (SEAAL), and incorporating the recommendations and guidelines of The International Water Association (IWA) to their protocols. A scale developed to allow the assessment of the structural failure of the USNs collectors is presented in Table 1. Three parameters, namely, (1) risk, (2) severity, and (3) detectability were selected to evaluate the structural failure of USNs. For each of these three parameters, a score was associated based on an evaluation criteria. The evaluation criteria utilized in this study constitute the main criteria, which are directly or indirectly related to the structural degradation of USNs. They are selected among the several causes that are at the origin of the degradation of USNs. In most cases, the degradation of USNs is caused by one or a combination of the following most important causes: environmental (geotechnical, hydrogeological, urbanization, and impacts), functional (transported effluent) or structural linked to the structure itself (aging, for example). Adding to these causes is the non-effective management practices (high frequency of intervention, inadequate means, etc.).

Each criterion has different judgements with corresponding score value depending on its actual descriptive state as reported in Table 1. These judgements are established based on feedback and practical experience. For instance, in the parameter "risk", the criterion E «Age of the collector» has four judgment levels representing age intervals of the pipes (≤ 25 years, 25-50 years, 50-75 years, and > 75 years). These age intervals are defined based on the knowledge of the amortization period of a sewerage network, estimated on average to be between 50 and 60 years. The network operating life could be longer, approximately 100 years, if maintenance and the renewal rate of the pipes is adequate since the expected life for pipes, made of the most common materials, is 100 years (Grondin and Desbiens 2012).

In the parameter "severity" the criterion c «Easiness of work in relation to the location» also has four judgment levels representing the level of difficulty to access the collectors for replacement and / or repair. The severity of the breakage will be mitigated in a context of easy intervention whereas, on the contrary, a

section under the motorway or located in the city center, promises significant difficulties of replacement, and therefore, a more or less long-term sustainability of the failure. The judgements the authors have retained are:

- a. Easy: Access to the affected area is considered easy. The collector is located in a low-traffic area, at the edge of the road.
- b. Somewhat easy: The collector is located under a secondary road with little traffic or in a moderately populated area. Replacement work is only likely to cause minor inconvenience.
- c. Difficult: We apply this value to the sections with a crossing of the main road (motorway, heavily used axis) or of a railway line.
- d. Very difficult: Collectors located in the city center, replacing the manifold, if not impossible, is considered very difficult. Deviation works are then to be considered.

All the other criteria were judged similarly in collaboration with experts in the field and engineers from SEAAL and DREW.

The maximum score value of a criterion in the FMECA method, represents its relative importance to all of the other criteria, such as the weight of the criteria in the AHP method. For instance, criterion D “surface load” is considered more important than criterion E “age of the collector” in Table 1. Consequently, the maximum score of criterion D is 4 while maximum score for criterion E is 3. This is logical as high values of surface load applied permanently may lead to structural fatigue and even failure of newly constructed collectors. The largest score value attributed to each of the 16 criteria in Table 1 represents the most critical (riskier) condition. However, the score values attributed to reflect the level of importance of each of the criterion to the other criteria remains relatively subjective for some of these criteria and this constitutes one of the difficulties in dealing with this kind of problem.

Table 1 summarises the vigorous scale adopted in this study to assess and score the structural failure of the collectors of USNs.

4.1.2 Criticality index Ic

The criticality index, I_c , is the basis of the FMECA method. If the criticality threshold values are reached, corrective actions are taken. If the goal is improvement, priority will be given to the structures with the highest criticality index values and the causes of the structural failures are addressed.

The criticality index is the product of three indices defined as follows:

- Risk index (S_{Risk}): the risk of structural failure in our case is based on the combination of the scores assigned to the ten criteria selected and defined in Table 1. The risk index is defined as the total score over the maximum total score ($S_{Total-max}$). In this study, it is equal to 23.5 as shown in Table 1.
- Severity index ($S_{Severity}$): the severity of the failure is based on the combination of the scores assigned to the five criteria selected and defined in Table 1. In this study, the potential impact (Criterion D) represents the impact on public health and the environment. The cost of damage is not considered. The severity index is defined as the total score over the maximum total score ($S_{Total-max}$) Severity. In this study, it is equal to 15.
- Detectability index ($S_{Detectability}$): the time to detect the failure is very important in estimating the criticality of the failure. In this study, this index is based on the score assigned to a single selected criterion, as defined in Table 1. The detectability index is defined as the score over the maximum total score ($S_{Total-max}$). Detectability in this study, which is equal to 4.

The three indices above are defined by Equation 1:

$$S_i = \frac{\sum_{j=1}^n S_{ij}}{(S_{Total-max})_i} \quad (1)$$

Where n is the number of criteria for each parameter i such that: $(i, n) = (Risk, 10), (Severity, 5)$ or $(Detectability, 1)$ and S_{ij} is the score of criterion j for the parameter considered i . The combination of these three parameters in Equation 2 defines a criticality index of the considered structural failure of the collectors (Diadem 2003 and Stamatis 2003):

$$I_c = S_{Risk} \times S_{Severity} \times S_{Detectability} \quad (2)$$

249

250 The I_c values vary between $I_{cmin}=0$ and $I_{cmax}=1$. I_{cmin} corresponds to ideal structural condition and I_{cmax} to
251 defective structural condition of the collectors. For practical applications, the proposed scale for assessing
252 structural failure of USNs collectors in Table 1 suggests a minimum value of I_c of 0.0035. The maximum
253 value is kept equal to 1.

254 The interval of I_c values between 0-1 is divided into 4 segments each corresponding to a criticality level as
255 shown in Table 3. The limits of these criticality levels are calculated using the scores (S_{ij}) for each criterion
256 in Table 1.

257 **4.1.3 Performance Evaluation**

258 The Performance evaluation represents a strong diagnostic tool allowing appropriate decisions to be made
259 for the most efficient use of resources in urban sewerage network management.

260 In FMECA, the evaluation of the performance is based on the criticality index. In this study four performance
261 levels of equal interval lengths in a scale of 0 to 1, are proposed. Each performance level is associated to
262 a criticality index interval. Performance level I corresponds to criticality index level 1 and so on. These
263 performance levels and their respective description are presented in Table 3.

264 A double exponential regression model of the performance (P) as a function of the criticality index (I_c) is
265 developed using the interval limit values of the couple (I_c , P) in Table 3, and presented in Equation 3.

266
$$P = 51,87Exp^{-0,0111.I_c} + 0,4141Exp^{-121,6040.I_c} - 51,2841 \quad R^2 = 0,997 \quad (3)$$

267 The interest of this performance function, illustrated in Figure 1, is to have a programmable mathematical
268 predictive model of the performance that can be integrated into a decision support tool in the future
269 management of sewerage networks.

270 **4.2 ANALYSIS HIERARCHICAL PROCESS (AHP)**

271 The Analysis Hierarchical process (AHP), developed in the 1970s, by Thomas L. Saaty (Nur et al. 2018),
272 is a structured decision-making technique, based on mathematics and psychology. It makes it possible to
273 check the coherence of the important relationships between the criteria. The AHP is used in this work to

validate the results of the FMECA, and to enhance the robustness of the methodology for evaluating the performance of collectors in the USNs. The AHP represents a valid tool for making the best decisions. Its application enables convergence to a shared choice among various decision makers who express their preference in judgments on criteria and sub-criteria under comparison (Carpitella and al. 2017). A great advantage of the AHP method is that it allows for the calculation of a consistency index which allows the judgments awarded to be evaluated. However, the AHP also has several weaknesses, including problems due to the interdependence between the criteria and alternatives, inconsistencies between judgment and ranking criteria, and rank reversal. (Nam et al. 2019).

One of the most important limitations to mention is the fact that additional criteria can be taken into account and used if deemed necessary by stakeholders and decision makers. However, in such a case, the AHP analysis must be redone completely, with new questionnaires and comparison matrices to reflect the relevant changes made to the model (Vladeanu and Matthews 2019).

4.2.1 Procedure for weighting and assessing the degree of consistency

This step is the most important part in the AHP method. It can be summarized based on the following steps:

i Decomposition of the problem which must lead to a decision in a hierarchy of more restricted sub-problems in order to be analyzed independently (hierarchy of "n" criteria from the most important to the least important, for example). This step requires good judgment, based on a good level of knowledge and experience, to decide what is relevant and important.

ii. Construction of a square matrix preferably (n x n), from the systematic evaluation of the criteria by comparing them to each other, two at a time (Table 4). The higher extra-diagonal elements a_{ij} are obtained by the comparison between all the criteria and represent the order of preference from criterion i to criterion j. They are defined by Equation 4, below:

$$a_{ij} = \frac{K_i}{K_j}, \quad a_{ii} = 1, \quad i = \overline{1, n}, \quad j = \overline{1, n} \quad (4)$$

n = number of criteria, and K may be the highest score for each criterion in Table 1, in this study.

299 The diagonal of the matrix is formed by the elements $a_{ii} = 1$ and the lower extra-diagonal elements a_{ji} are
 300 such that $a_{ji} = 1 / a_{ij}$ (inverse value).

301 **iii** Determination of the weight (w_i) associated with each criterion i . This weight represents the relative
 302 importance of the criterion considered in relation to its contribution to the objective. It is calculated using
 303 Equation 5

$$304 \quad w_i = \left[\sum_{l=1}^n \left(a_{il} / \sum_{k=1}^n a_{kl} \right) \right] / n \quad (5)$$

305

306 **iv** Verification of the degree of coherence between the elements of the preference matrix by
 307 calculating the coherence ratio CR (Equation 6) defined as the ratio between the coherence index CI and
 308 the average random coherence RI (Table 5) (Benzerra et al. 2012). The coherence index is calculated
 309 using Equation 7 using the mean eigenvalue $\lambda_{\max}$ defined by Equation 8.

$$310 \quad CR = CI / RI \quad (6)$$

311

$$312 \quad CI = (\lambda_{\max} - n) / (n - 1) \quad (7)$$

313

$$314 \quad \lambda_{\max} = \frac{\sum_{i=1}^n \lambda_i}{n} \text{ with } \lambda_i = \frac{\lambda'_i}{w_i} \text{ and } \lambda'_i = \sum_{j=1}^n a_{ij} w_j \quad (8)$$

315

316 If $CR \leq 0.10$, the assignment of preferences (matrix $[a_{ij}]$) is acceptable. If $CR > 0.10$, the choice of the order
 317 of preference must be reviewed, a new matrix $[a_{ij}]$ must be produced, and steps 3-7 must be executed
 318 again.

4.2.2 Performance scale

For each criterion i , a performance level (PC_i) is defined according to the score (S) assigned to this criterion. This level of performance depends on the judgment during the diagnosis. As an example, Table 6 presents a performance scale for one of the 16 criteria for evaluating the structural failure of collectors (Table 1), which is criterion D (specific surface load) of the "risk" parameter.

4.2.3 Aggregation method

The chosen aggregation of performance is global and is calculated by the weighted sum method (the linear addition method). This method was selected for its popularity attributed to its clarity and ease of use (Benzerra et al, 2012; Bouyssou 2006). The overall aggregate performance is the summation of the products of the individual weighted performances ($w_i . PC_i$) (for all criteria), Equation 9:

$$P = \sum_{i=1}^n w_i PC_i \quad (9)$$

Or : n = Number of criteria ; P = Overall aggregate performance ; PC_i = Performance of the criterion i , w_i = Weighting factor (weight of the selected criterion, calculated in step 3.1).

5 CASE STUDY

The Wilaya of Algiers, capital of Algeria, covers an area of almost 1,190 km². It is bounded to the north by the Mediterranean Sea. The total length of the drainage network of the Wilaya of Algiers is estimated at around 3,500 km, including nearly 140 km of collectors that can be visited (a large collector having a height greater than or equal to 1.3 m). The unitary urban sewerage network (combined wastewater and rainwater) studied is that of Oued-Kniss and is located in the central catchment area of Algiers with an area of 1,327 ha. The sections of the Oued-Kniss network and their geometric characteristics, material and age are presented in Table 7. This USN comprises collectors made up of accessible underground pipelines of 10

054 m total length and three combined sewer overflows (CSO_s). Figure 2 shows the diagram of the network studied.

5.1 Model implementation: FMECA and AHP applied to the Oued-Kniss network

The proposed methodology was used to assess the performance of the subject collector within the framework of its sustainable and efficient management. The input parameters describing the condition of each of the 14 sections of the Oued Kniss network in terms of risk (A, B, C, D, E, F, G, H, I, J), severity (a, b, c, d, e) and detectability (T) are presented in Table 8. The results obtained from FMECA are also presented in Table 8 while the results obtained from AHP method are in Tables 9 and 10.

5.2 Discussion of the results

The estimated performance results of the 14 sections of the Oued-Kniss network obtained respectively by the two methods, AHP and FMECA, are presented in Figure 3. Although AHP gave higher performance values than FMECA in all cases, the structural performance values according to FMECA and AHP remain very close in 85.71% of the cases (absolute deviations $\leq 8\%$). The maximum difference does not exceed 10%.

According to AHP (Figure 3), structural performance is only at level III (92.86% of cases) or level II at 1 of the 14 sections (7.14% of cases), and no section has performance at level IV or I. However, FMECA assigns performance levels III to 12 of the 14 sections (85.71% of cases) and level II to 2 of the 14 sections (14.29% of cases).

Thus, since the prioritization of the inspection, the surveillance and the rehabilitation actions for USNs depends on the performance levels: immediate action for level IV, short-term action (to be carried out before one to two years) for level III, medium-term action (to be completed before five years) for level II, and long-term action for level I, no immediate action is required according to AHP or MFECA. Figure 3 shows that the performance of 92.86% of the sections of the Oued-Kniss network is level III according to AHP and 85.71% of the sections of the collector is level III according to the FMECA. Therefore, they require short-

term rehabilitation actions. Figure 4 illustrates the distribution of the actions required according to the level of structural performance for the studied network according to FMECA and AHP.

5.3 Model validation

The validation of multi criteria decision-making models is of great importance and plays an essential role in establishing the credibility, checking the stability, and examining the robustness of the models' results, which allow for their use both effectively and with confidence. Sensitivity analysis is commonly used in a Models' validation as a tool to enhance the validity and to add credibility to the developed model. The scores attributed to the most uncertain selection criteria are modified within specified intervals and the results of the analysis are examined to determine how they vary.

In order to validate the FMECA model developed in this study, a sensitivity analysis was carried out. Among the 10 risk criteria cited in Table 1, the four criteria C, G, H and I are the most challenging ones to score. Various sources of uncertainty exist in the attribution of scores to these selection criteria that directly affect the estimated performance values. For instance, the risk criterion C "Previous breakage in the Collectors" is one of the most difficult criterion to identify as many breakages are very often not archived. Therefore, this criterion presents the highest degree of uncertainty and requires an in-depth investigation into precise information at the level of the operating company of the Province (Wilaya) of Algiers.

Figure 5 presents the performance values obtained for the selection criteria C with a score equal to 0 as well as the performance values obtained for each of the three other possible C scores values (0.5, 1.0 and 1.5) as shown in Table 1, for the 14 sections of the collector of the Urban Sewerage Network of Oued Kniss. The absolute difference between each curve and the reference curve corresponding to a C score value equal to 0 is presented in Figure 6. The maximum difference does not exceed 2.4% for the worse score attributed to the C criteria. Figure 7 shows the percentage change in performance for each percentage change in C "Previous breakage in the Collectors". When the value of criteria C increases by (33.33%, 66.66% and 100%), the overall performance decreased by (0.8%, 1.6% and 2.4%). Risk selection criteria G, H and I have equal importance as C in the FMECA Model developed in this study. Therefore, the sensitivity analysis of the FMECA model performance to changes in these risk selection criteria scores'

values produce performance curves, absolute difference, and the percentages of changes in the performance of the criteria (G, H and I) similar to criteria C shown in Figures 5, 6 and 7 respectively.

Consequently, the performance values given by the FMECA Model developed in this study are not sensitive to the changes in the value of the most challenging risk selection criteria C "Previous breakage in the Collectors". This is expected because it was a contribution of criterion C, in the set of 16 criteria. In this context, it can be said that the FMECA model is stable and robust. This step is necessary for the validation and stability check of the FMECA model.

6 CONCLUSION

This article documents a project to develop an effective management methodology for complex sewerage systems that can serve as a practical and effective decision-making tool to ensure the sustainability of USNs and meet the needs of operating companies. The originality of the project and its innovative character lie in the approach used, which combines both the use of the FMECA and the AHP method. A decision-making tool must be based on regular monitoring, on the collection of objective information, on adequate surveys, and on diagnostics allowing a continuous multi-objective analysis of the performance of these USNs. This article is related to the measurement of the structural performance of collectors in sewerage networks through one of the most important objectives which is "Ensuring Monitoring and Maintenance" using the concomitant application of FMECA and AHP. The FMECA method is undoubtedly one of the most popular and effective methods in the field of quality management. The evaluation of the structural performance of USNs by FMECA is based on separate knowledge of the three parameters: risk, severity and detectability to which performance criteria are associated. This allows better parameterization of the diagnosed problem. However, it requires a large amount of data mainly based on surveys and field visits. In addition, this tool could present difficulties linked to the subjective description of the evaluation criteria, to the relative importance among the risk scores, and to the difference in the representation of the risk between the same scores. The AHP method makes it possible to deal with complex decision-making problems (Alexandre et al. 2017). It is simpler to use than the FMECA method and complements the latter by ranking the criteria, by determining the weights of these criteria, by checking the consistency between

these criteria and by aggregating the performance. The evaluation of the structural performance of USNs by the concomitant application of the two methods constitutes a robust decision-making tool making it possible not only to assess the credibility of the judgment but also to obtain an objective of classification (according to performance levels) of USN collectors; from the most critical to the least critical, which is facilitated by the development of a hierarchical intervention plan (established priorities). Based on this plan, failures and breakages of USNs, which represent serious threats not only to the economic and to the social lives but also to public health and to the environment, can be prevented. This is possible by prioritized intervention actions (Immediate, short term, medium term or long term) of inspection, observation, or rehabilitation to be undertaken to improve performance and limit the risk of failure or eliminate it. Networks with poor performance could benefit from relatively optimal maintenance planning, taking into account the priorities established on the basis of the values of this performance or the risks of failure. The Risk Sensitivity Analysis of the sewerage network makes it possible to prioritize interventions and organize monitoring within the framework of a network sustainability and maintenance plan.

7 ACKNOWLEDGMENTS

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8 REFERENCES

- Al-Harbi, K.M. Al-S. 2001. Application of the AHP in project management. *International Journal of Project Management*, **19**(1): 19-27. doi:10.1016/s0263-7863(99)00038-1.
- Alexandre, B. L., and Eduardo, C. P. 2017. Decision sciences in the management of water resources: Multi-criteria and game theory applied to the field of sanitation. *Journal of Water Sanitation and Hygiene for Development*, **7**(2): 229–242.
- Alsaqqar, A., Khudair, B., and Jbbar, R. 2017. Rigid Trunk Sewer Deterioration Prediction Models using Multiple Discriminant and Neural Network Models in Baghdad City, Iraq. *Journal of Engineering*, **23**(8): 70-83.
- Bakry, I., Alzraiee, H., Masry, M. E., Kaddoura, K., & Zayed, T. 2016. Condition Prediction for Cured-in-Place Pipe Rehabilitation of Sewer Mains. *Journal of Performance of Constructed Facilities*, **30**(5): 04016016. doi:10.1061/(asce)cf.1943-5509.0000866.
- Ben Tagherouit, W., and Bennis, S. 2012. Le « goal programming » pour l'optimisation de la planification de la réhabilitation des réseaux d'égout. *Canadian Journal of Civil Engineering*, **39**(2): 223–36. doi:10.1139/I11-127.
- Benzerra, A., Cherrared, M., Chocat, B., Cherqui, F., & Zekiouk, T. 2012. Decision support for sustainable urban drainage system management: A case study of Jijel, Algeria. *Journal of Environmental Management*, **101**(2012): 46–53. doi:10.1016/j.jenvman.2012.01.027.
- Berger, C., C. Falk, F. Hetzel, J. Pinnekamp, S. Roder., and Ruppelt, J. 2016. State of the Sewer System in Germany - Results of the DWA Survey 2015. *Korrespondenz Abwasser, Abfall* (63): 15–17.
- Bernheimer, D., Feda, T., Pallaria, C., and Schnarrs, A. 2019. Direct Potable Reuse Systems Risk Analysis. *Systems and Information Engineering Design Symposium*. doi:10.1109/sieds.2019.8735595.
- Black and Veatch. 2013. 2013 Strategic Directions in the U.S. Water Industry, a Black & Veatch Report.
- Bouyssou, D., Marchant, T., Pirlot, M., Tsoukias, A., and Vincke, P. 2006. Evaluation and Decision Models with Multiple Criteria: Stepping Stones for the Analyst. Springer Science Business Media Inc, New York, USA.

- 474 Brahim, I. B., Addouche, S. A., Mhamedi, A. E., & Boujelbene, Y. 2019. Build a Bayesian Network from
475 FMECA in the Production of Automotive Parts: Diagnosis and Prediction. IFAC-Papers on Line, **52**(13):
476 2572–2577. doi:10.1016/j.ifacol.2019.11.594.
- 477 Caradot, N., Riechel, M., Rouault, P., Caradot, A., Lengemann, N., Eckert, E., Ringe, A., Clemens, F.,
478 Cherqui, F. 2019. The influence of condition assessment uncertainties on sewer deterioration modelling.
479 Structure and Infrastructure Engineering, **16**(2): 287-296. doi.org/10.1080/15732479.2019.1653938.
- 480 Carpitella, S., Certa, A., Izquierdo, J., and Fata, C. M. L. 2017. A combined multi-criteria approach to
481 support FMECA analyses: a real-world case. Reliability Engineering and System Safety.
482 doi:10.1016/j.ress.2017.09.017.
- 483 Cherrared, M. 2016. Multi criteria management of sewerage system: analysis of the failures and the
484 criticality of structures. Interaction between Theory and Practice in Civil Engineering and Construction.
485 doi:10.14455/isec.res.2016.103.
- 486 Crawley, F. 2020. Failure modes and effects analysis (FMEA) and failure modes, effects and criticality
487 analysis (FMECA). A Guide to Hazard Identification Methods. pp. 103–109. doi:10.1016/b978-0-12-
488 819543-7.00012-4.
- 489 Damvergis, C. N. 2014. Sewer systems: Failures and rehabilitation. Water Utility Journal, **8**(2014): 17-24.
- 490 Diadem, P. 2003. Guidelines for Failure Mode and Effects Analysis for Automotive, Aerospace and General
491 Manufacturing Industries. Chemical Rubber Company (CRC) Press, USA.
- 492 El-Housni, H., Ouellet, M., and Duchesne, S. 2018. Identification of most significant factors for modeling
493 deterioration of sewer pipes. Canadian Journal of Civil Engineering, **45**(3): 215–226. doi:10.1139/cjce-
494 2015-0293.
- 495 Ennaouri, I., and Fuamba, M. 2013. New Integrated Condition-Assessment Model for Combined Storm-
496 Sewer Systems. Journal of Water Resources Planning and Management, **139**(1): 53–64.
497 doi:10.1061/(asce)wr.1943-5452.0000217.
- 498 Fang, Y., and Xia, L. 2019. Research on Rural Wastewater Treatment Evaluation System Based on AHP
499 Method. IOP Conf. Series: Earth and Environmental Science, 300(2019): 032048. doi:10.1088/1755-
500 1315/300/3/032048.

- 501 Fidan, M. A., Gurgul, U., and Akin, Z. E. 2020. FMEA - FMECA the Application of Analysis on Electronic
502 Circuit. 2020 7th International Conference on Electrical and Electronics Engineering.
503 doi:10.1109/iceee49618.2020.9102554.
- 504 Grondin, B., and Desbiens M. É. 2012. Réseaux d'égouts pathologies, diagnostics et interventions.
505 Gouvernement du Québec, Ministère des Affaires municipales, des Régions et de l'Occupation du
506 territoire, ISBN 978-2-550-64156-8.
- 507 Hawari, A., Alkadour, F., Elmasrya, M., and Zayed, T. 2020. A state of the art review on condition
508 assessment models developed for sewer pipelines. *Engineering Applications of Artificial Intelligence*,
509 93(2020)103721. Available from <https://doi.org/10.1016/j.engappai.2020.103721>.
- 510 Hwang, H., Lansey, K., and Quintanar, D. R. 2015. Resilience-based failure mode effects and criticality
511 analysis for regional water supply system. *Journal of Hydroinformatics*, **17**(2): 193–210.
512 doi:10.2166/hydro.2014.111.
- 513 Ianni, A., Virgili, R., Piredda, M., De Marinis, M.G., and Petitti, T. 2018. Healthcare Safety Management:
514 The Model of Fmea/Fmeca in Anatomic Pathology Service. *Madridge Journal of Internal Emergency*
515 *Medicine*, **2**(1): 50-53. doi:10.18689/mjiem-1000110.
- 516 Infrastructure Canada.2017. Available from [https://www.infrastructure.gc.ca/plan/cwwf/cwwf-program-](https://www.infrastructure.gc.ca/plan/cwwf/cwwf-program-programme-eng.html)
517 [programme-eng.html](https://www.infrastructure.gc.ca/plan/cwwf/cwwf-program-programme-eng.html)).
- 518 Li, X., Khademi, F., Liu, Y., Akbari, M., Wang, C., Bond, P. L., Kellera, J., and Jiang, G. 2019. Evaluation
519 of data-driven models for predicting the service life of concrete sewer pipes subjected to corrosion.
520 *Journal of Environmental Management*, **234**(2019): 431–439. doi:10.1016/j.jenvman.2018.12.098.
- 521 Liu, Y., Xueliang Zhang, X., and Zhou, J. 2019. Research on Reliability Improvement of Radar Servo
522 System Based on FMECA Model. In *Proceedings of the Seventh Asia International Symposium on*
523 *Mechatronics*, Hangzhou, Zhejiang Province, China., 19–22 September 2019. Science press Bieijing,
524 pp.192-200. doi:10.1007/978-981-32-9441-7-21.
- 525 Nam, S, N., Nguyen, T. T., and Oh, J. 2019. Performance Indicators Framework for Assessment of a
526 Sanitary Sewer System Using the Analytic Hierarchy Process (AHP). *Sustainability* 2019, 11, 2746.
527 doi:10.3390/su11102746.

- Nguyen, C., Cote, J., Lebel, D., Caron, E., Genest, C., Mallet, M., Phan, V., and Bussieres, J. F. 2013. The AMELIE project: failure mode, effects and criticality analysis: a model to evaluate the nurse medication administration process on the floor. *Journal of Evaluation in Clinical Practice*, **19** (2013): 192–199.
- Nur, A., Miftachul, H., Siti S.I., Sulaiman, S.S.M.N., Bushrah, B., Kamarul A.J., Jimaain, S., Ahmed Kilani, Wan, H., and al. 2018. The family hope program using AHP method. *International Journal of Engineering and Technology*, **7**(2.27) (2018): 188-193.
- Perez, R. R. 2020. Detailed Interface FMECA in a Large Aerospace System. *Annual Reliability and Maintainability Symposium*. doi:10.1109/rams48030.2020.9153580.
- Salman, B., and Salem, O. 2012. Modeling failure of wastewater collection lines using various section-level regression models. *Journal of Infrastructure Systems*, **18**(2): 146–154. doi:10.1061/(asce)is.1943-555x.0000075.
- Shinta, F. R., Nieke Karnaningroem, N., and Mardiyanto, M. A. 2019. Risk Management of Wastewater Treatment in the Wastewater Treatment Plant of PT. X. *IPTEK Journal of proceedings series*. doi: 10.12962/j23546026.y2019i5.6292.
- Stamatis, D. H. 2003. *Failure Modes and Effects Analysis: FMEA from theory to execution*. American Society for Quality, Quality press, Milwaukee.
- Tran, D.H., Perera, B. J. C., and Ng, A. W. M. 2007. Neural network based prediction models for structural deterioration of urban drainage pipes. In *Proceedings of the Congress Land, Water and Environmental Management: Integrated Systems for Sustainability*, Christchurch., 10-13 December 2007. Modelling and Simulation Society of Australia and New Zealand, pp. 2264–2270.
- Vladeanu, G. J., and Matthews, J. C. 2019. Consequence-of-Failure Model for Risk-Based Asset Management of Wastewater Pipes Using AHP. *Journal of Pipeline Systems Engineering and Practice*, 2019, **10**(2): 04019005. doi:10.1061/(asce)ps.1949-1204.0000370.
- Wang, Q., Xia, R., Liu, Q., and Hu, Q. 2019. An Application of Failure Mode, Effects and Criticality Analysis (FMECA) for Composite Structures of Airplanes` Wings. *IOP Conference Series: Materials Science and Engineering*, **784**(2020): 012010. doi:10.1088/1757-899x/784/1/012010.

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581 Table 10. Overall aggregated structural performance levels of the Oued-Kniss network according to AHP

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584 Table 1. Scale adopted to assess and score the structural failure of the collectors

Parameter	N°	Criterion Definition	Judgment	S _{ij}	S _{Total} *max
Risk	A	Overall diagnostic made by the client*	Good	1	23.5
			Acceptable	2	
			Bad	3	
			Undiagnosed	2	
	B	Diagnostic made by the operating company or the design office**	Good	1	
			Acceptable	2	
			Bad	3	
			Very bad	4	
	C	Previous breakage in the Collectors	Undiagnosed	2	
			0	0	
			1	0.5	
			2	1	
	D	Surface load	>2	1.5	
			No load	0	
			Normal load	1	
			High load applied temporarily	3	
	E	Age of the collector	high load applied permanently	4	
			≤25 years	0	
			25-50 years	1	
			50-75 years	2	
	F	Material's type of the collector	>75 years	3	
			Reinforced concrete	0.5	
			Sprayed concrete	1	
			Stone masonry	1.5	
Severity	G	Type of soil foundation	Brick and concrete block masonry	2	15
			Rock, Gravel, Coarse sand	0	
			Fine sand, silt	0.5	
			Clay not (compacted, inflatable)	1	
	H	Mineral and chemical stabilities of the surrounding soil	Clay (compacted, inflatable)	1.5	
			Not aggressive	0	
			Moderately aggressive	0.5	
			Aggressive	1	
	I	Groundwater level	Very aggressive	1.5	
			Lower pipe level (≤0.5m)	0	
			Average (very close or same level)	0.5	
			High (Partially submerged)	1	
	J	Type of effluent	Very high (completely submerged)	1.5	
			Not aggressive (residential)	0	
			Moderately aggressive (Parking, washing)	0.5	
			Aggressive (industrial)	1	
Detectability time	a	Size of the upstream catchment area	Very aggressive (Very polluted industrial)	1.5	4
			Small (<200ha)	1	
			Average (200-500ha)	2	
	b	Easiness of replacement (depending on its cross-section shape and height, H as in Table 2, score may be averaged)	Large (>500ha)	3	
			Easy	0	
			somehow easy	1	
	c	Easiness of work in relation to the location	Difficult	2	
			Very difficult	3	
			Easy	1	
	d	Potential negative impacts on the urban (people and properties) and the environment	Somehow easy	2	
			Difficult	3	
			Very difficult	4	
Detectability time	e	Possibility of connections (meshing)	low	1	4
			Average	2	
			high	3	
	T	---	Very high	4	
			Yes	-1	
Detectability time	T	---	Yes but difficult	0	4
			None	1	
			Fast (Remote management)	1	
			Medium (Permanent control)	2	
Detectability time	T	---	Slow (Non-permanent control)	3	4
			Undetectable (Site not accessible)	4	

585 S_{ij} : Partial Score; The scale of scores for criteria F to J is halved compared to the other criteria since their influence is indirect and
586 later in time; $S_{Max-Total}$: Maximum Total Score. For Algeria : * Direction des ressources en eaux de la Wilaya (DREW) and ** la
587 Société de l'Eau et de l'Assainissement d'Alger (SEAAL).
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Table 2. Scores attributed to criterion b: Easiness of the replacement of collectors according to its cross-section shape

Height (H) mm	Cross-Section		
	Circular	Ovoid	Others
H≤1200	0	1	1.5
1200<H≤1800	1	1.5	2.5
H>1800	2	2	3

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595 Table 3. Transition from criticality index I_c to performance P

Criticality Index, I_c		Performance, P	
Scale	Level and description	Scale	Level and description
$0.0035 \leq I_c \leq 0.0223$	1: Structure Little sensitive	$1 \geq P \geq 0.75$	I: Good
$0.0223 < I_c \leq 0.1884$	2: Structure Mildly sensitive	$0.75 > P \geq 0.50$	II: Satisfactory
$0.1884 < I_c \leq 0.6206$	3: Structure Sensitive	$0.50 > P \geq 0.25$	III: Insufficient
$0.6206 < I_c \leq 1$	4: Structure Highly sensitive	$0.25 > P \geq 0$	IV: Bad

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Table 4. Comparison, in pairs, of preference judgments in AHP (Al-Harbi. 2001).

Preference order	1	2	3	4	5	6	7	8	9
Verbal judgments of preferences	Equally Preferred	Almost equally to moderately preferred	Moderately Preferred	Moderately to strongly preferred	Strongly preferred	Strongly to very strongly preferred	Very strongly preferred	Very strongly to extremely preferred	Extremely preferred

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600 Table 5. Values of the random index (RI) (Benzerra et al. 2012)

Number of criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>RI</i>	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

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Table 6. Performance of the criterion "Surface load"

Judgement	No load	Normal Load	High load Temporarily	High load Permanently
Score (S)	0	1	3	4
Performance of the criterion	1	0.5	0.25	0

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Table 7. Geometry, material and age of the sections of Oued-Kniss network

Sections Collector	Length m	Material type	Age years	Section	Shape
KN1	857	SM	85	OV 360x300 (C)
KN2	924	SM	85	OV 360x300 (C)	
KN3	2460	SM	85	OV 340x240 (C)	
KN4	952	SM	85	OV 340x240 (C)	
KN5	938	SM	76	OV 180 x 120 (C)
KN6	1290	SM	76	OV 180 x 120 (C)	
DKN1	849	RC	26	DN 3200	
DKN2	227	RC	26	DN 3500	
VAUB	1 062	SM	70	DN 800 (C)
AN	1 997	SM	68	OV 135 x 90 (C)	
MAD	2 238	SM	66	OV 135 x 70 (C)	
SYA1	2 494	SC	47	OV 200 x 90 (C)	
SYA2	900	SC	47	OV 200 x 900 (C)	DN-
HK-C	657	SM	72	OV 180 x 120 (C)	

SM : Stone Masonry; RC : Reinforced Concrete; SC : Sprayed Concrete;
OV : Ovoid; C : Cunette; DN : Nominal diameter

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Table 8. Structural performance levels of the Oued-Kniss network according to FMECA

Sections Collector	Risk										Severity					Detectability			Performance
	A	B	C	D	E	F	G	H	I	J	a	b	c	d	e	T	Ic	P(Ic)	
KN1	2	2	0	3	3	1.5	1.5	0.5	1	0	3	3	4	4	-1	3	0.4011	0.3551	Insufficient
KN2	2	2	0	1	3	1.5	1.5	0.5	1	0	3	3	2	4	1	3	0.3457	0.3869	Insufficient
KN3	2	2	0	1	3	1.5	1.5	0.5	1	0	3	3	2	4	1	3	0.3457	0.3869	Insufficient
KN4	2	2	0	0	3	1.5	1.5	0.5	1	0	2	3	1	3	1	3	0.2447	0.4450	Insufficient
KN5	2	2	0	0	3	1.5	0	0	0	0	2	2.5	1	1	1	3	0.1356	0.5077	Satisfactory
KN6	2	2	0	1	3	1.5	0	0	0	0	1	2.5	4	1	1	3	0.1920	0.4753	Insufficient
DKN1	2	1	0	3	1	0.5	1.5	0.5	1	0	2	2	4	3	-1	3	0.2234	0.4572	Insufficient
DKN2	2	1	0	1	1	0.5	1.5	0.5	1	1	2	2	4	3	-1	3	0.2021	0.4694	Insufficient
VAUB	2	2	0	1	2	1.5	0	0	0	1	1	1.5	2	1	1	3	0.1314	0.5102	Satisfactory
AN	2	2	0	3	2	1.5	1.5	0.5	1	1	1	2.5	2	1	1	3	0.2314	0.4526	Insufficient
MAD	2	2	0	4	2	1.5	1.5	0.5	0.5	0	2	2.5	4	3	1	3	0.3723	0.3716	Insufficient
SYA1	2	2	0	1	1	1	1.5	0.5	0.5	0	2	3	4	3	1	3	0.2628	0.4346	Insufficient
SYA2	2	2	0	1	1	1	1.5	0.5	0.5	0	1	3	4	1	1	3	0.2021	0.4694	Insufficient
HK-C	2	2	0	1	2	1.5	1.5	0.5	0.5	0	3	2.5	1	3	1	3	0.2457	0.4443	Insufficient

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Table 9. Comparison of structural failure indicators according to AHP

	B	D	c	d	T	A	a	b	E	F	C	G	H	I	J	e	W	λ'	λ
B	1	1	1	1	1	2	2	2	2	3	4	4	4	4	4	5	0.11	1.79	16.25
D	1	1	1	1	1	2	2	2	2	3	4	4	4	4	4	5	0.11	1.79	16.25
c	1	1	1	1	1	2	2	2	2	3	4	4	4	4	4	5	0.11	1.79	16.25
d	1	1	1	1	1	2	2	2	2	3	4	4	4	4	4	5	0.11	1.79	16.25
T	1	1	1	1	1	2	2	2	2	3	4	4	4	4	4	5	0.11	1.79	16.25
A	0.5	0.5	0.5	0.5	0.5	1	1	1	1	2	3	3	3	3	3	4	0.07	1.07	16.20
a	0.5	0.5	0.5	0.5	0.5	1	1	1	1	2	3	3	3	3	3	4	0.07	1.07	16.20
b	0.5	0.5	0.5	0.5	0.5	1	1	1	1	2	3	3	3	3	3	4	0.07	1.07	16.20
E	0.5	0.5	0.5	0.5	0.5	1	1	1	1	2	3	3	3	3	3	4	0.07	1.07	16.20
F	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	1	2	2	2	2	2	3	0.04	0.66	16.09
C	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1	1	1	1	1	2	0.03	0.41	16.06
G	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1	1	1	1	1	2	0.03	0.41	16.06
H	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1	1	1	1	1	2	0.03	0.41	16.06
I	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1	1	1	1	1	2	0.03	0.41	16.06
J	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1	1	1	1	1	2	0.03	0.41	16.06
e	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	1	0.02	0.27	16.08
Σ	8.8	8.8	8.8	8.8	8.8	16.4	16.4	16.4	16.4	26.8	39.5	39.5	39.5	39.5	39.5	55.0	1.00		
Σ =Sum, CI=0.02, RI=1.61, CR=CI/RI=0.01 As CR< 0.10, the preference attribution is acceptable																			

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Table 10. Overall aggregated structural performance levels of the Oued-Kniss network according to AHP

Sections collector	Performance Pci																P(AHP)= Σ(PCi .wi)	Level
	B	D	c	d	T	A	a	b	E	F	C	G	H	I	J	e		
KN1	0.5	0.3	0	0	0.25	0.5	0	0	0	0.25	1	0.25	0.5	0.25	0.75	1	0.2565	Insufficient
KN2	0.5	0.8	0.5	0	0.25	0.5	0	0	0	0.25	1	0.25	0.5	0.25	0.75	0	0.3501	Insufficient
KN3	0.5	0.8	0.5	0	0.25	0.5	0	0	0	0.25	1	0.25	0.5	0.25	0.75	0	0.3501	Insufficient
KN4	0.5	1	0.8	0.3	0.25	0.5	1	0	0	0.25	1	0.25	0.5	0.25	0.75	0	0.4493	Insufficient
KN5	0.5	1	0.8	0.8	0.25	0.5	1	0	0	0.25	1	0.25	0.5	0.5	0.75	0	0.5108	Satisfactory
KN6	1	0.5	0	0.8	0.25	0.5	1	0	0	0.25	1	0.25	0.5	0.5	0.75	0	0.4445	Insufficient
DKN1	1	0.3	0	0.3	0.25	0.5	1	0.34	0.5	0.75	1	0.25	0.5	0.25	0.75	1	0.4317	Insufficient
DKN2	0.5	0.5	0	0.3	0.25	0.5	1	0.34	0.5	0.75	1	0.25	0.5	0.25	0.25	1	0.3914	Insufficient
VAUB	0.5	0.5	0.5	0.8	0.25	0.5	1	0.17	0.25	0.25	1	0.25	0.5	0.25	0.25	0	0.4533	Insufficient
AN	0.5	0.3	0.5	0.8	0.25	0.5	1	0.17	0.25	0.25	1	0.25	0.5	0.25	0.25	0	0.4257	Insufficient
MAD	0.5	0	0	0.3	0.25	0.5	1	0.17	0.25	0.25	1	0.25	0.5	0.5	0.75	0	0.2902	Insuffisant
SYN1	0.5	0.5	0	0.3	0.25	0.5	1	0	0.25	0.5	1	0.25	0.5	0.5	0.75	0	0.3444	Insuffisant
SYN2	0.5	0.5	0	0.8	0.25	0.5	1	0	0.25	0.5	1	0.25	0.5	0.5	0.75	0	0.4161	Insuffisant
HK-C	0.5	0.5	0.8	0.3	0.25	0.5	0	0.17	0.25	0.25	1	0.25	0.5	0.5	0.75	0	0.4117	Insuffisant

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Figure 1. Performance as a function of the criticality index

Figure 2. Studied Network Oued-Kniss, Algiers Algeria

Figure 3. Comparison of the structural performance of the Oued-Kniss network according to FMECA and AHP.

Figure 4. Distribution of actions required according to the level of structural performance for the Oued-Kniss network according to FMECA and AHP.

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Figure 5. Sensitivity Analysis of the FMECA Model to the selection criteria C « Previous breakage in the Collectors » for USN Oued-Kniss

Figure 6. Absolute difference in performance for different score values attributed to the selection Criteria C « Previous breakage in the Collectors » for USN Oued-Kniss.

Figure 7. Impact of the variation of criterion C « Previous breakage in the Collectors » in FMECA Model on the Performance of USN Oued-Kniss