World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:3, No:4, 2009

A Condition Rating System for Wastewater Treatment Plants Infrastructures

Altayeb Qasem, Tarek Zayed, and Zhi Chen

***Abstract*—**Statistics Canada stated that the wastewater treatment facilities in most provinces are aging and passes 63% of their useful life in 2007 the highest ratio among public infrastructure assets. Currently, there is no standard condition rating system for wastewater treatment plants that give a specific rating index that describe the physical integrity of different infrastructure elements in the treatment plant and its environmental performance. The main objective of this study is to develop a condition-rating index for wastewater treatment plants mainly activated sludge systems. The proposed WWTP CRI, is based on dividing the treatment plant into its three treatment phases; primary phase, secondary phase and the tertiary phase. The condition-rating index will reflect the infrastructures state for each phase, mainly tanks, pipes, blowers and pumps.

***Keywords*—**Condition rating index, Wastewater treatment plants, AHP- MUAT.

I. Introduction

WASTEWATER treatment plants (WWTP) main function is to protect the human health and the environment from excessive overloading with different kinds of pollutants. Wastewater treatment plants are considered one of the major infrastructure assets on both the federal and municipal levels. Unfortunately, many studies showed that the US and Canada's infrastructures are deteriorating and are approaching their projected service life [12]. A recent study conducted by statistics Canada (2008) reported that average age of Canada's wastewater treatment facilities has been increasing steadily since the 1970s. Wastewater treatment facilities exceeded 63% of their service life by the end of the year 2007 on the national scale. This is the highest percentage among other public infrastructures assets (roads, bridges, water supply systems, wastewater treatment facilities and sewer systems) as shown in Fig. 1. The report also stated that the average age of wastewater treatment facilities increased from 17.4 years in 2001 to 17.8 years in 2007. This aging is lead by Price Edward Island followed by Quebec where the average age went from 16.9 years in 2001 to 19.1 years in 2007 [8]. In the U.S. the ACSE (2005) developed an infrastructure report card, this report card was developed by a panel of 24 of leading civil engineers whom analyzed hundreds of studies, reports and other sources and surveyed more than 2,000 engineers to determine what the state of different infrastructure facilities nationwide is. A grade was given to each facility. Grades were assigned based on condition capacity, and funding versus need, following a traditional grading scale. The report shows that the wastewater sector grade had dropped from grade [C] in 1988 to [D-] in 2005. This shows the need for urgent actions to maintain the functionality of these facilities.

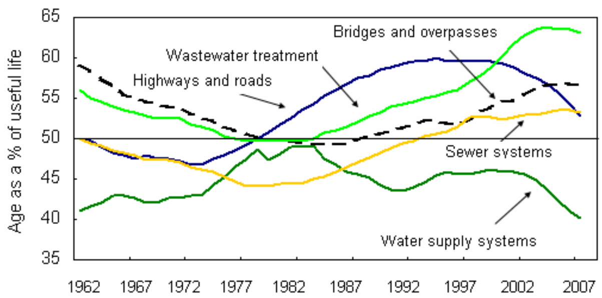

Fig. 1 Infrastructures Remaining service Life (Statistics Canada, 2008)

The main objectives of this study are; (1) to provide a review of current practices used to evaluate wastewater treatment plants, and (2) to develop a new methodology for wastewater treatment plants condition rating index. A well-structured condition rating system for a wastewater treatment plant, which reflect the physical integrity and treatment efficiency of each phase in the treatment plant,this is a key factor in asset management and decision-making processes. It can provide sufficient information on the treatment plants physical integrity and treatment efficiency. This condition rating system can be used to evaluate characterize and prioritize different maintenance rehabilitation and replacement (MR&R) plans for wastewater treatment facilities.

II. Infrastructures Deterioration and Condition Assessment

Infrastructure deterioration can be a resultant of the interaction of many factors that affect the infrastructure itself. Many studies categorized theses factors into physical, environmental and operation factors [2], [3], [4], [7] and [11]. These factors are and their interactions are responsible for the deterioration rate of various infrastructure facilities. The same categorization is adopted in this study by classifying the factors affecting the WWTP infrastructures. Tanks, pipes, pumps and blowers are considered in this study. Condition rating (CR) models require a lot of data which can be obtained from municipalities' historical data and operational or can be achieved by other expert dependent techniques.

Knowing the state and condition of different infrastructure facilities is necessary for municipal engineers to plan for future MR&R plans. The condition of different infrastructure facilities can be determined by either applying direct destructive and non-destructive inspection techniques. However, it is not economically feasible to have direct inspection of all facilities. To be economically feasible condition rating models (CR) can be used to evaluate the state of various infrastructures. A CR models can be used as a pre-investigation tool that gives a reliable infrastructure condition assessment before applying further measures, or it can be used to as prioritization tool to apply detailed inspection over the most needed infrastructure facilities.

III. WWTP CR Model Development

Wastewater treatment plants are designed to treat wastewater before release it to the environment after subjecting it to many treatment processes. Typically, wastewater treatment is divided into three phases, primary, secondary and tertiary treatment, each treatment phase is responsible for specific pollutants removal. In addition, each phase has its own infrastructures elements that are needed to perform the required treatment in each phase. The infrastructure elements considered in this study are tanks, pipes, pumps and blowers. This study is based on a typical activated sludge system and its treatment phase that are shown in Fig. 2. The proposed WWTP CRI is designed to measure the treatment performance and the infrastructure performance of each treatment phase.

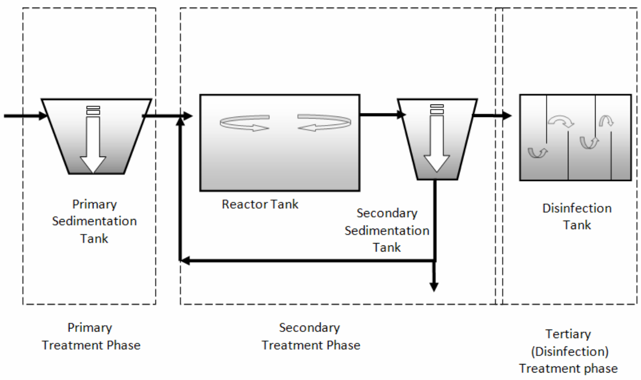

Fig. 2 Wastewater Treatment Phases

The condition assessment scale adopted in this study is a [1 – 10] scale, where 10 mean excellent 1 means critical. This scale can be adjusted according to a desired treatment level. This CR value is associated with specific MR&R action for both operational and infrastructure units.

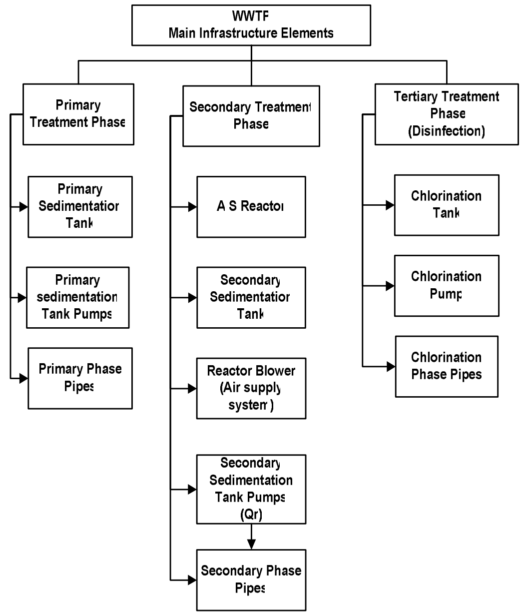

Fig. 3 WWTP Infrastructure Elements Based on Treatment Phase

IV. WWTP Infrastructure CR

The second part of this study is to develop a methodology to evaluate the condition rating of the infrastructure facilities of WWTPs based on the hierarchy shown in Fig. 3. Typically, WWTP are different is unique and has its own facilities and its own specific infrastructures. Tanks, pipes, pumps and blowers are the main elements in any WWTP and there condition can directly affect the WWTP performance. As mentioned, the WWTP is divided into three treatment phases shown in Fig. 2. The proposed infrastructure condition-rating model for WWTPs infrastructures is based on evaluating the CR of those infrastructure elements in each treatment phase. This approach is justified because wastewater characteristics varies from phase to phase and therefore it is expected to have different impact on the infrastructures of each phase.

There are many factors affecting the deterioration of each infrastructure, it is impossible to consider all factors contributing to the infrastructure deterioration study [13]. Therefore, the proposed condition rating model is this current study is considering only some of the major factors that affect the infrastructure guided by pervious studies of [3], [11] and others. The WWTP infrastructure physical, operational and environmental factors considered in the study are shown in Fig. 4 and Fig. 5 respectively.

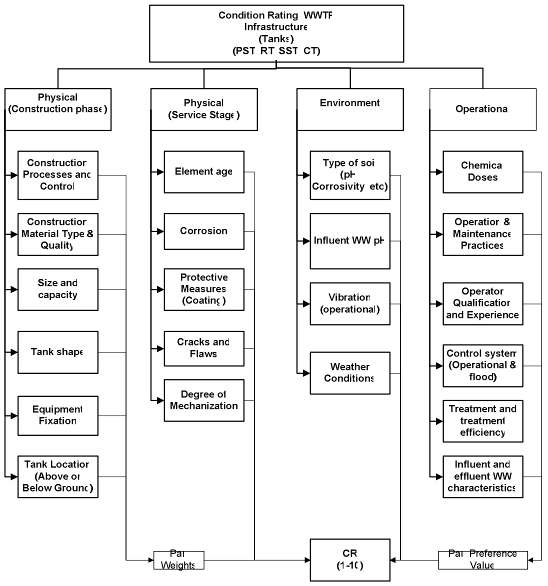

Fig. 4 Hierarchal Factors Affecting WWTP Tanks Deterioration

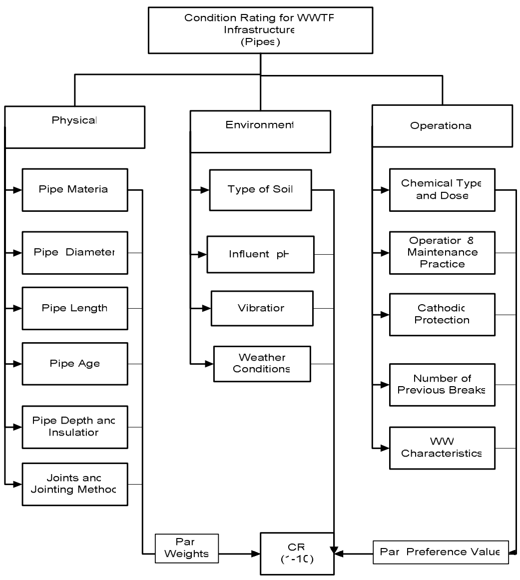

Fig. 5 (a)

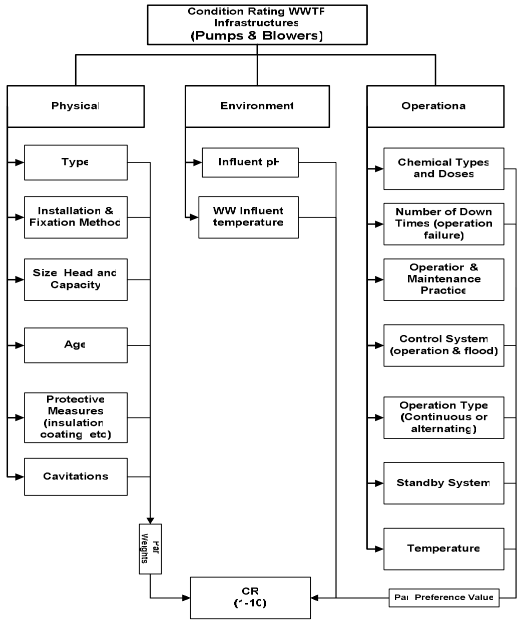

Fig. 5 (b)

Fig. 5 (a) Hierarchal Factors Affecting WWTP Pumps & blowers Deterioration (b) Hierarchal Factors Affecting WWTP Pipes

V. MODEL DEVELOPMENT DATA

To develop the CRI for the WWTP infrastructure elements requires a lot of data. This data is of all types, historical, physical operational and environmental. After performing some contacts with some major WWTP most of the required data were not available due to many different reasons Fortunately, most of the contacted WWTPs have good treatment records, however these records are done to check the compliance with permits and they are not standardized on all plants.

In order to overcome this problem an expert subjective system is adopted in this study based on Saaty's, (1991) analytical hierarchy process (AHP) approach will be used. Eigen Vector method (EV) is used to estimate the weight of each factor and sub factor. The AHP combined with the multi attribute utility theory (MAUT) approach is used to develop the CR.

VI. THE ANALYTICAL HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) is defined as a general theory of measurement [9]. The AHP is one of the decision models in which it is used to evaluate different decision alternatives by introducing qualitative factors the need to be evaluated. The AHP can be applied for different application since it can deal with qualitative and quantitative factors (Saaty, 1980).

The AHP is considered a powerful too to determine the relative importance of different models parameters when quantitative data is not available or difficult to obtain. The ability of AHP to give relative importance of different parameters can be related to different preference level of its alternative to give an overall ranking for the alternatives with their preferences [5].

The AHP consist of hierarchical structure, which presents the relationships of the objective, criteria, and sub objectives. The hierarchal structure adopted in this study are shown in Figs. 5 and 6.

After developing the hierarchy AHP method is used to find the weights (Importance) of each factor affecting the CR of this facility. In other words the AHP with be used to find the weights of the physical, environmental and operational factors by developing the pair-wise comparison matrix. This matrix is then send to experts (sanitary engineers, contractors, consultants and WWTP operators) on a form of questionnaire. Experts are required to fill a number from (1 to 9) based on Saaty scale shown in Table I. The higher the number reflect higher importance of the factor. The AHP will be applied for both main factors (level 2 in the hierarchy) and sub-factors (level 3 in the hierarchy).

The AHP multi criteria decision problem approach is based on analyzing the pair-wise matrix based on considered criteria.

- The matrix must be a square matrix (n x n) for the criteria and sub criteria.
- The matrix must be transverse matrix in which $a_{ij} = 1/a_{ji}$ and all diagonal elements in the matrix $a_{ii} = 1$, this type of matrix is called reciprocal matrix.
- The matrix will be based Saaty's (1-9) qualitative importance scale

  The matrix consistency must be checked before further analysis. The consistency index is checked used equation. The more CI is close to zero the more the matrix is consistence (1).

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

where

$\lambda_{\max}$ is the Maximum EV value for the matrix n

n is the matrix size

The Consistency ration is then calculated using Equation2. C.R acceptable values are within 10 % (C.R. <0.1) Saaty (1980).

$$C.R = C.I / R.I \quad (2)$$

where

C.I. is the consistency Index

R.I is the Random consistency index.

In multi-criteria decision analysis, which is the case in our research, requires the application of relative decomposition procedure, in which each sub-criteria is weighted against its main criteria to get the overall weight decomposition. This is shown in equation 3.

$$W_{ij} = w_i . v_{ij} \quad (3)$$

where:

W_{ij} Sub factor decomposition wt

w_i relative weight of criteria *i*

v_{ij} weight of sub-factor j within the i factor

The pair-wise comparison matrix will be analyzed to get the weight for each factor (wi) and sub factors(vij). Pair wise matrixes must be check against consistency and if it does not satisfy all the tests the results are discarded .After verification of priority weights (Wi) for all matrices that are consistent. Experts are required to assign a condition rating for the preference attributes of each sub factors of are required to assign the $Pv_{(ij)}$ for each sub-factor using a scale from 1 to 10, the $Pv_{(ij)}$ value will be used to calculate the CR using Equation 3.

VII. Factors Preference Value

Preference values (Pv) are numbers representing the preferred values for the different factors affecting the WWTP infrastructures. This is done by assigning a Pv for each sub-factor using a scale from (1 to 10). Pv values and the Eigen-vector weights are then used to calculate the condition rating (CR_{INF}) for each infrastructure facility in each phase using Equation 5. adopted from [5] .

$$CR_{INF} = \sum_{i=1}^{n} \sum_{j=1}^{m} w_i . v_{ij} . Pv_{ij} \quad (4)$$

where

CR_{INF} the condition rating of certain infrastructure element

w_i relative weight of criteria i

v_{ij} weight of sub-factor j within the i factor

Pv_{ij} sub factor preference value

VIII. WWTP Infrastructure CR

The condition rating of the whole treatment plant can be evaluated by defining specific weights for each infrastructure facility in each treatment phase. This is applied using Equation 6.

$$CR_{WWTP} = \sum_{l}^{p} \varpi_l \sum_{k=1}^{o} \theta_{kl} \sum_{i=1}^{n} \sum_{j=1}^{m} w_i . v_{ij} . Pv_{ij} \quad (5)$$

where

CR_{WWTP} the condition rating of the whole wastewater treatment plant infrastructures

ϖ_l the weight of each treatment phase

θ_{kl} the weight of each infrastructure element in each treatment phase

IX. DISCUSSION AND CONCLUSION

The methodology adopted in this research is based on evaluating the treatment performance of the wastewater treatment plants and its infrastructures. This means that the specific environmental standards govern the CR developments interims of permit compliance towards different pollutants removals and their concentrations. This research is assuming standard activated sludge performance only and not including sludge handling and processing in addition, it is only focusing of the BOD removal. The proposed CR model is flexible and can account for these, factors if the required data is available for it.

Evaluating the CR model for the wastewater treatment infrastructure methodology is based on the AHP-MAUT to overcome the unavailability problems of the infrastructure performance.

The proposed CR methodology adopted in this research is based on simple functionality factors that can be easily achieved and therefore can specify specific immediate remediation actions. The proposed CR methodology can also indicate whether WWTP infrastructure have the capacity to accommodate the required remediation actions.

The proposed CR methodology in this research can be the backbone of a decision support system for wastewater treatment plants maintenance and rehabilitation plans.

In witch, the developed CRI can be used concurrently with WWTP maintenance rehabilitation and maintenance plans in which MR&R action are stated based on the CR to achieve the desired serviceability level. Fig. 6 illustrate this concept.

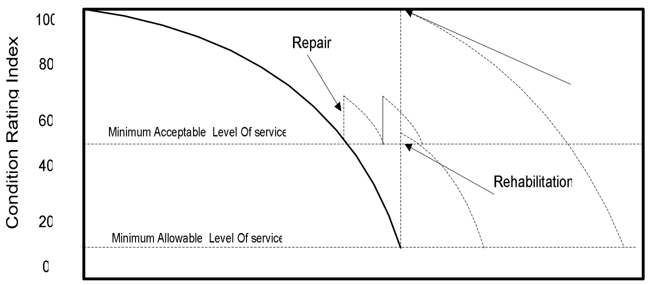

Fig. 6 CRI and MR&R Relationship

This research shows that the development of a condition rating system for wastewater treatment plant is doable, however it is challenged by the unavailability of data required for different elements in the treatment plant such as historical maintenance and upgrading records.

REFERENCES

[1] ACSE, (2005). “Report Card for American Infrastructures”, available on http://www.asce.org/reportcard/2005/index.cfm, surfed on April 2004.

[2] Al Barqawi H., (2006). “Condition rating models for underground infrastructure: Sustainable water mains”. M.A.Sc., Concordia University, Montréal, Canada.

[3] Al-Barqawi, H., Zayed T., 2006. “Condition Rating Model for Underground Infrastructure Sustainable Water Mains”. ASCE, Journal of Performance of Constructed Facilities, Vol. 20, No. 2, pp. 126-135.

[4] Best practice, (2003). “Best Practices for Utility-Based Data”- A best practice by National Guide to sustainable Municipal Infrastructure, Issue No 1.0, NRC Infra-guide publication.

[5] Elmisalami, T., E., (2001). “Developing a multi-attribute utility model for selecting information technologies in the construction industry”. Ph.D. theses, Iowa State University.

[6] Keeney L., Raiffa H., (1993). “Decisions with multiple objectives: preferences and value tradeoffs”. Cambridge University Press.

[7] Kleiner, Y. and Rajani, B. (2001). “comprehensive Review of structural deterioration of water mains: Physically based Models”. NRCC-43722. Urban Water, Vol. 3. pp. 151 -164.

[8] Mychèle G., Valérie G. and Donald O. (2008). ”Age of Public Infrastructure -A Provincial Perspective-, Statistics Canada Report – No. 11-621-MIE2008067.

[9] Saaty, T.,(1991). “Decision Making with Dependence and Feedback: The Analytic Network Process”. Pittsburgh, PA, RWS Publications.

[10] Statistics Canada (2008), “The age of public infrastructure”, available on http://www.statcan.gc.ca/daily-quotidien/080213/dq080213a-eng.htm

[11] Urhaman F., (2007). “Integrated condition assessment models for sustainable sewer pipelines”. M.A.Sc., Concordia University Montreal Canada.

[12] Vanier, D.J., and Rahman, S. (2004). MIIP Report: “Survey on Municipal Infrastructure Assets”, <http://irc.nrc-cnrc.gc.ca/pubs/fulltext/b5123.2/b5123.2.pdf>.

[13] Zayed, T. and Halpin, D., (2005). “Pile Construction Productivity Assessment.” ASCE Journal of Construction Engineering and Management, Vol. 131 (6), June 1, pp.705– 714.