MULTI-CRITERIA ASSESSMENT TO AUTOMATE WATER TREATMENT PLANTS USING THE ANALYTICAL HIERARCHY PROCESS

Claudio Macuada*, Rubén Alarcón, and Astrid Oddershede
Industrial Engineering Department,
University of Santiago of Chile,
Av. Ecuador 3769, Casilla 10233
Santiago, Chile.
Email: claudio.macuada@usach.cl, ruben.alarconh@usach.cl
astrid.oddershede@usach.cl

ABSTRACT

This paper presents a framework to assist the evaluation of water treatment (WT) plants and water waste treatment (WWT) plants to be automated at the Metropolitan Region in Chile. The different plants offer different attributes, related to production resources, feasibility and efficiency process. The aim is to determine the most suitable WT and WWT plants for incorporating an automated system during night shifts. The Analytical Hierarchy Process (AHP) is used to develop a new multicriteria decision model based upon expert judgments for identifying high-priority dimensions requirements for automating each treatment plant and its significant implications The study provides a basis for setting priorities and decision making s for incorporating an automated system to WT and WWT plants at any locality.

Keywords: AHP, Automation, water treatment plants, water waste plants.

1. Introduction

Nowadays, there is a main concern about WT plants production process and efficiency improvement of WWT plants. The need of cost-efficient and reliable treatment processes has significantly increased so as to meet the level of environmental regulations and national goals. Furthermore, as water treatment requirements are intensified the recognition of process automation at WWT plants has increased.

The water company in study has expectation in considering an automated wastewater system for their plants during night's shifts, in a preliminary stage. However, the plants differ in size, capacity, in human and production resources, feasibility and efficiency process. Though, the existence of diverse aspects, as image, capacity, functionality, and others, brings about a complex and conflicting problem situation that may influence the plant selection. Thus, the implementation of new technology competes, as well, for funding available involving challenging goals which could include tangible and/or intangible elements. Then, a multi-criteria decision making approach turns out to be appropriate to deal with multiple and conflicting objectives**.** The AHP developed by Thomas L. Saaty, (1998) is a versatile and proven decision support for multiple attribute decision-makings. It incorporates the subjective data enabling decision makers to organize and to evaluate the importance of the alternatives, objectives, and/or solutions.

In regard to previous related work, we may mention the following: Karimi et al., (2011) who used the fuzzy method and one of the many extensions of the AHP to select a process of wastewater treatment in Iran; Perez, Oddershede & Mena (2010), explored the feasibility to set up an appropriate domestic wastewater treatment system in an isolated small city at the south of Chile after a volcanic erup-

* Corresponding author

tion, Anagnostopoulos, Gratziou &Vavatsikos (2005) used AHP to evaluate various scenarios for a water treatment plant in Greece; Nakhaei & Taheriyoun (2005), considered various technologies for the application of wastewater treatment process through fuzzy AHP (FAHP) and gray relational analysis(GRA); Yingyuad (2005) used AHP to select a biogas production system by treatment of wastewater from tapioca starch in a Thailand region and Zeng et al., (2007), selected the optimal alternative wastewater treatment process through FAHP and GRA for a city in China. In a similar attempt, the purpose of the investigation is to develop a model for incorporating an automated system to WT and WWT plants for night shifts and to provide a basis for setting priorities at any locality.

Consequently, AHP is used to work on a new decision making model based upon expert judgments for identifying high-priority dimensions concerning the incorporation of automated system to WT and WWT plants. The paper is organized as follows. In the next section, the system description is presented. In section 3, the AHP application is described in detail. Section 4 releases results and information that is not currently available. An estimation of plant costs and expected benefits is provided at section 5. The result analysis is provided in section 6. Finally, in the section 7 the conclusions are presented.

2. System description

The study refers to development of a decision making model to support a Chilean company that must ensure the continued supply of water to more than 6 million people. The company is concerned about the significance of automating water treatment plants during night shifts, in view of the fact that, the general manager, deputy managers, heads of plants, supervisors, operators, and project engineers, would be affected by changing the mode of operation. In this sense, each of them had different viewpoint and expectations about the solution since from the company perspective would be a strategic decision for improving efficiency. On the other hand, have to relocate staff that currently operates during night shifts, to perform other responsibilities would add more value to the company.

These persons constituted a team of expert who participated in the categorization of the various plants according to pre-set criteria. In pursuing this task, each member of expert panel had to deal with prioritize the stated criteria knowing that some are in conflict with others. This fact is that some of the objectives to be achieved will benefit only at the expense of another.

The automation of the plants during night shifts can be a starting point for optimizing the whole operation, which is reflected in the following aspects:

- Lower costs for operators.
- Greater independence contingency (holidays, licenses, permits, etc.).
- Operation with PID controllers by linking the sensor systems and actuators by improving the operation of the plant in non-critical conditions.
- Can give step to automated operation 24 hours a day with only mobile monitoring and distance.
- Monitoring of plants requires staff with training in maintenance to overcome failures in the field and thus does not increase response times to problems. Then, it is required for training program that generates motivation in operational staff.
- Staff with greater operating range can operate different plants.

In this sense, some of the questions to be made are: How reliable are the plants today? What are the implications to automate plants in night shifts? What plants should be subject to this type of operation? What are the variables that can harm this intention? Does the results would be positive in terms of parameter of treatment quality by automating the plants in night shift?

For such effects, two groups of interest have been identified: the *area of potable water production* that captures and treats the raw water for later distribution as drinking water in technical and health conditions according to the national legislation; the *area of depuration of wastewater* that is responsible for processing these waters and complying with the requirements of quality which can be downloaded to a body receiver according to the regulations.

Within these two areas the plants are grouped according to their respective fields, where the expert team made their judgments based on their experience and knowledge. These judgments were incorporated and considered in the development of a model through the AHP to compare the criteria (Image, capacity, functionality, efficiency, reliability, availability, Unit) and assign a relative weight

3. AHP application

3.1 Problem situation structuring

The structuring is prepared in two main stages: the first stage is devoted to identify significant criteria that may impact the choice of production plants and water purification, which could eventually be automated in night shifts. The second stage corresponds to build a hierarchy structure incorporating critical categories in each level and their relationships. Once the basic structure is designed, the effort is focused on an evaluation process carried out with the team of expert that comprises managers, project engineers and members of the senior management, being twelve people who evaluated all the plants.

3.2 The hierarchy structure

The purpose is to structure a hierarchical model to reveal the operation plants (purification - production) that may be affected by the change in operation at night shift. Consequently a three level basic hierarchy model is designed to be evaluated. The levels and its nodes represent the decision factors that contribute to achieving the goal. The decision factors are based on a benchmarking with firms of similar relevance that operate in 24 hours shift system, related to the WT and WWT.

Figure 1, shows the hierarchy described above, being a faithful representation of the analysis undertaken. The levels of the hierarchical structure are as follows:

Level 0: Indicates the goal, the main aim is: "*Plant Automation at Night Shift*".
Level 1: Includes alternative approaches that will help determine the plants to be automated.
Level 2: Corresponds to the operation type, in this case are two separate processes (production and waste water purification) which implies that there will be an analysis for each process.
Level 3: Includes all the plants candidates to be automated during the night shift.

The criteria that were considered to meet the goal are:

- C**orporate image** refers to how the company is perceived. It is a generally accepted image of what a company "means" to their customers and the owners/shareholders.

- **Capacity** refers to the quantity of water treated in the plants during a certain period of time.

- **Functionality** refers to factors combination as, infrastructure, equipment, materials, services, human resources, technology (type of treatment), operation hours, communications and transportation that make operational the capacity and efficient in handling plants any time of the day during the 24hrs.

- **Efficiency** refers to the resources and infrastructure available to treat water at the lowest possible cost, measured by the unit cost of one cubic meter of water treated.

- **Reliability** expresses a degree of security that the system operates successfully for a certain period.

- **Availability** of the system is a measure expressed as a percentage indicating the time that an operating system works with respect to the total duration desirable for the different processes.

- **Dependency** is the functional disability of a productive system for the development of daily activities requiring help for their realization.

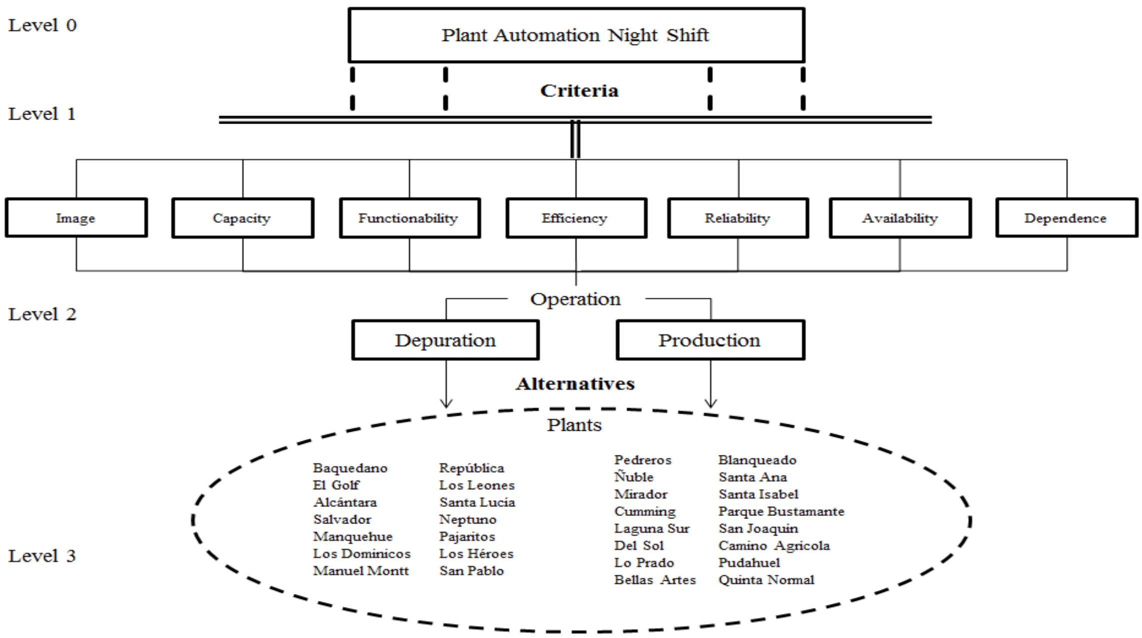

Figure 1. Hierarchy structure.

4. Priority results

The priority outcomes revealed that the corporate image is a determining factor for deciding the plant to be automated during night shift. The last column of table 1 indicates the global results for the global criteria for both types of treatment plants. For this particular case "*image*" obtained the highest priority (35.4%) followed by "*functionality*" (24.0%) and "*efficiency*" (15.9%).

From these results we can recognize that the main importance lies in the corporate image and in the plant functionality. This is consistent with the organization concern about building relationships of trust with their environment and ensures that the plants are 24 hours connected and will respond to the various requirements.

On the other hand, this outcome is directly related to the plants that have the greatest capacity for water treatment and more staff. There are areas where we must assure that any unexpected event might happen that may be view as an operation risk and have an effect on the environment.

In this sense, the plants candidates for automation in night shifts are those that have the lower weight in terms of image and functionality, as there is a lower risk of generating conflicts to the community in the event of any operational failure.

Table 1. Relative importance for plants and criteria.

Operation	Plant	Image	Capacity	Functionality	Efficiency	Reliability	Availability	Dependence	Local%	Global%	Criteria		Global Criteria
	Baquedano	12,00%	11,90%	13,50%	8,50%	7,80%	1,70%	7,14%	**10,60%**	**5,30%**	Image	35.4	
	El Golf	5,90%	5,40%	2,10%	4,80%	0,90%	3,60%	7,14%	**4,90%**	**2,40%**			
	Alcántara	7,70%	8,20%	6,70%	3,80%	4,30%	2,50%	7,14%	**6,70%**	**3,30%**	Capacity	10.4	**Image 35.4 %**
	Salvador	3,90%	3,40%	4,90%	1,60%	12,50%	9,60%	7,14%	**4,80%**	**2,40%**			
	Manquehue	1,60%	1,40%	6,20%	1,00%	15,80%	18,00%	7,14%	**4,50%**	**2,20%**	Functionality	24.0	
Depuration 50%	Los Dominicos	4,20%	8,20%	6,70%	2,80%	6,20%	2,50%	7,14%	**5,40%**	**2,80%**			
	Manuel Montt	4,10%	5,40%	6,70%	2,00%	5,80%	2,50%	7,14%	**5,00%**	**2,60%**	Efficiency	15.9	**Capacity 10.4%**
	República	12,00%	1,20%	6,70%	1,20%	15,80%	3,80%	7,14%	**7,80%**	**3,90%**			
	Los Leones	1,60%	2,40%	1,30%	5,60%	1,10%	11,40%	7,14%	**3,30%**	**1,60%**	Reliability	3.1	
	Santa Lucía	1,60%	2,40%	2,20%	13,70%	1,40%	17,80%	7,14%	**4,80%**	**2,40%**			
	Neptuno	9,30%	4,80%	2,10%	10,00%	2,40%	10,60%	7,14%	**7,00%**	**3,50%**	Availability	4.5	**Functionality 24.0%**
	Pajaritos	1,90%	1,90%	2,10%	1,70%	1,80%	11,40%	7,14%	**3,20%**	**1,60%**			
	Los Héroes	17,10%	20,60%	19,40%	19,10%	3,20%	2,30%	7,14%	**15,50%**	**7,70%**	Dependence	6.8	
	San Pablo	17,10%	22,80%	19,40%	24,20%	21,00%	2,30%	7,14%	**16,50%**	**8,30%**			
	Pedreros	15,50%	19,70%	11,30%	10,10%	11,90%	10,40%	10,70%	**12,90%**	**6,50%**			**Efficiency 15.9%**
	Ñuble	12,10%	13,40%	11,30%	10,10%	11,90%	10,40%	8,60%	**11,20%**	**5,60%**	Image	35.4	
	Mirador	7,00%	1,60%	5,00%	6,20%	4,20%	5,20%	6,10%	**5,70%**	**2,80%**			
	Cumming	8,80%	3,00%	13,00%	3,20%	8,70%	8,40%	7,00%	**8,30%**	**4,10%**	Capacity	10.4	
	Laguna Sur	3,30%	1,70%	5,50%	3,20%	3,80%	4,80%	5,40%	**4,00%**	**2,00%**			**Reliability 3.1%**
	Del Sol	7,80%	4,70%	8,30%	12,30%	8,90%	6,10%	7,40%	**8,40%**	**4,20%**	Functionality	24.0	
	Lo Prado	5,00%	4,00%	6,50%	6,10%	6,00%	5,40%	5,30%	**5,60%**	**2,80%**			
Production 50%	Bellas Artes	3,30%	2,50%	5,40%	5,90%	4,50%	5,40%	5,30%	**4,60%**	**2,40%**	Efficiency	15.9	
	Blanqueado	3,20%	1,60%	2,90%	4,50%	3,90%	3,20%	5,80%	**3,50%**	**1,70%**			**Availability 4.5%**
	Santa Ana	4,20%	4,00%	3,70%	5,90%	4,20%	5,40%	5,30%	**4,50%**	**2,30%**	Reliability	3.1	
	Santa Isabel	10,00%	19,00%	7,30%	5,90%	8,80%	10,00%	5,80%	**8,80%**	**4,40%**			
	Parque Bustamante	12,60%	19,00%	10,70%	5,90%	8,80%	10,00%	6,40%	**10,60%**	**5,40%**	Availability	4.5	
	San Joaquín	2,40%	2,30%	4,20%	5,90%	4,90%	5,80%	4,70%	**3,90%**	**1,90%**			**Dependence 6.8%**
	Camino Agrícola	1,40%	0,60%	1,60%	3,70%	2,50%	3,00%	5,70%	**2,40%**	**1,20%**	Dependence	6.8	
	Pudahuel	1,60%	1,40%	1,70%	4,80%	3,50%	3,40%	5,80%	**2,70%**	**1,30%**			
	Quinta Normal	1,80%	1,50%	1,60%	6,30%	3,50%	3,10%	4,70%	**2,90%**	**1,40%**			

The results obtained through the multicriterial method AHP is validated by the expert group, agreeing that in ***the depuration area,*** the candidate plants for automation are as seen in figure 2: "*Pajaritos"* (3.2 %), "*Los Leones* "(3.3 %), *"Manquehue"(*4.5 %), *"Salvador"(*4.8 %), and "*Santa Lucia"*(4.8 %).

While the ***in the production area***, exposed in figure 3, the candidate plants correspond to "*Camino Agricola* " (2.3 %), *"Pudahuel"(*2.7 %), *Quinta Normal(*2.9 %*), "Blanqueado"(3.5 %), "San Joaquin" (3.9 %), and "Laguna Sur"(4.0* %).

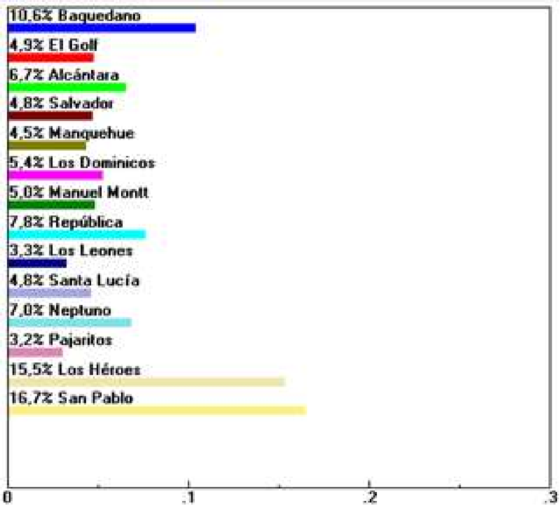

Figure 2. Depuration plants priority.

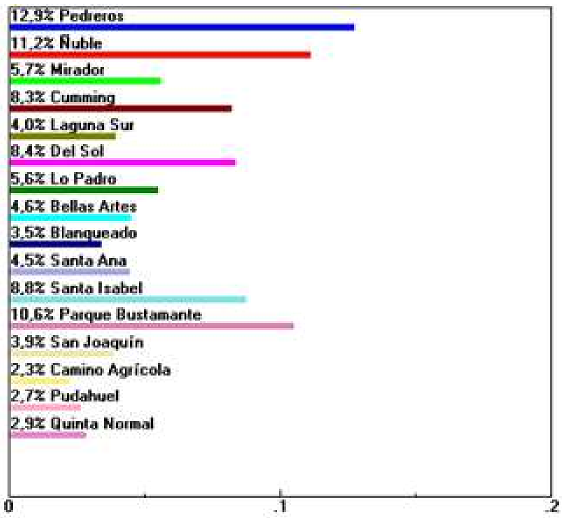

Figure 3. Production plants priority

From this, it is of interest to think about the different degree of importance assigned according to the company relevance criterion about which plants we have to have greater caution to automate the operation at night. This result could be implemented by decisions makers in order to a resource distribution such as the investment to automate the operation versus having staff that operate the plants.

5. Estimation of plant costs and benefits

In order to have an investment appreciation of the alternative treatment plants, an estimation of benefit cost (B/C) analysis is made. The reason B/C (Sullivan, Wicks & Luxhoj, 2004) is defined as the ratio of the equivalent value of the benefits to the equivalent value of the costs. (Equation 1)

$$B/C = \frac{PV(\text{benefits of the proposed project})}{PV(\text{total cost of the proposed project})} = \frac{PV(B)}{1 + PV(O\&M)} \qquad (1)$$

For the automation of WT and WWT plants, the table 2 summarizes the variables of "*investment*", *"cost of annual operation and maintenance*" and "*annual benefit*" to be considered:

Table 2. Cost and benefit variables

Investment	Annual Operation and Maintenance Cost	Annual Benefit
Online Equipment. - Position indicator. - Robustness SCADA System. - Sensors. - Alarms.	• Power. • Reagents. • Maintenance. • Waste. • Patents.	• Decreased inefficiency losses • Autonomy. • Environmental benefit. • Quality assurance. • Increased treatment capacity.

Given that a project is acceptable if the ratio B/C is greater than or equal to 1.0. Table 3: indicates the *depuration plants* that are acceptable to automate: "*Los Leones"* (8.9), *"Pajaritos"* (4.0), "*Santa Lucía* "(2.7), "*Manquehue"* (1.8), "*Salvador"* (1.7)," *Neptuno*" (1.1) y "*República"* (1.1). While for *water production plants* are as follows: "*Pudahuel"* (7.1), "*Quinta Normal*" (6.2), "*Blanqueado"* (5.3), "*Laguna Sur"* (1.6) y "*Camino Agrícola*" (1.6).

Table 3. Relationship B/C for depuration plants and production plants.

Depuration	**Plant**	**B/C**	**Production**	**Plant**	**B/C**
WWT	Baquedano	0.9	WT	Pedreros	0.9
	El Golf	0.6		Ñuble	0.8
	Alcántara	0.7		Mirador	0.4
	Salvador	1.7		Cumming	0.6
	Manquehue	1.8		Laguna Sur	1.6
	Los Dominicos	0.8		Del Sol	0.4
	Manuel Montt	0.8		Lo Prado	0.2
	República	1.1		Bellas Artes	0.2
	Los Leones	8.9		Blanqueado	5.3
	Santa Lucía	2.7		Santa Ana	0.9
	Neptuno	1.1		Santa Isabel	0.7
	Pajaritos	4.0		Parque Bustamante	0.9
	Los Héroes	0.2		San Joaquín	0.3
	San Pablo	0.2		Camino Agrícola	1.6
				Pudahuel	7.1
				Quinta Normal	6.2

6. Results analysis

In order to support the decision about which plant(s) is recommendable to automate during night shifts, we have considered B/C for the five most preferred treatment plants. Figure 4 shows the total relative weighting (blue) and benefit cost ratio (red) for both depuration and production plants, in terms of the dynamic sensitivity.

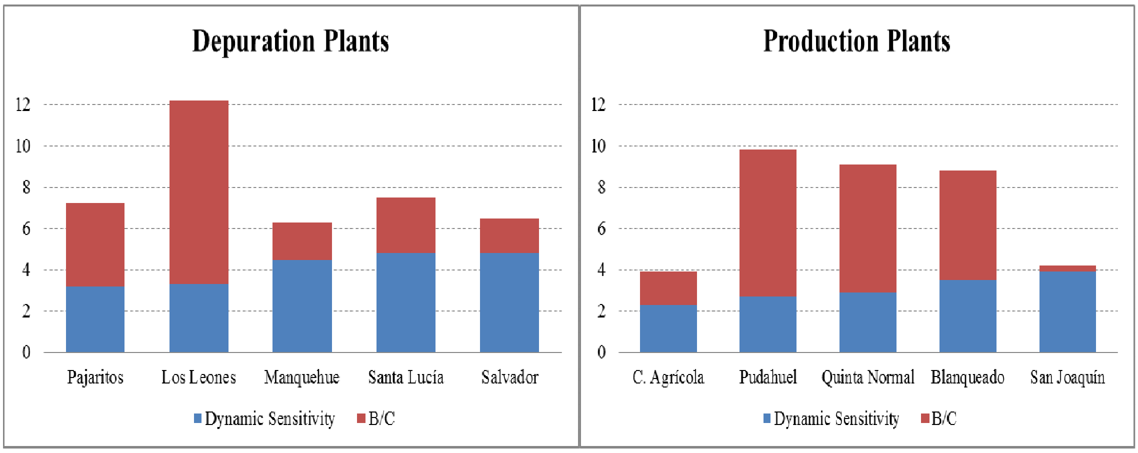

Figure 4. Relative Priority (blue) and B/C (red) for Depuration Plants (left) and Production Plants (right), in terms of the dynamic sensitivity.

For *depuration plants*, we can see that the treatment plant "*Los Leones*", in spite of obtaining the second place in terms of relative priority, fairly distant from the other plants is the best option. And for "*production plants*", the best option is "*Pudahuel*", followed by "*Quinta Normal*" and "*Blanqueado*".

7. Conclusions

In this study paper we have presented a real world situation problem for resource prioritization so as to make more efficient the operation of production and purification of water treatment through the Analytic Hierarchy Process. The methodology reflected to be a useful tool for structuring and managing this decision problem, allowing recognizing the issues that directly affects the selection of alternatives treatment plants and its impact.

Given the existence of different aspects and decisional variables to select those plants that would be able to dispense and or distribute personnel, the development of a decision model using AHP was advantageous because allowed a deep understanding about the priority requirements for automation of plants during night shifts, and through the process the relative importance of plants, to be automated is revealed.

Supporting the results delivered by the AHP method with the estimation of benefit and cost analysis consolidates the study. Both approaches showed that it is feasible to automate the resulting plants through the AHP.

The results of this study can be seen as base for companies that have operations in industrial processes requiring shift systems and evaluate tasks to be automated, seeking to improve the operation, and may allocate human resources to other responsibilities for adding value to offer better service to the community.

Acknowledgements

The authors would like to thank Dicyt and Industrial Engineering Department of University of Santiago of Chile for their support.

REFERENCES

Anagnostopoulos, K., Gratziou, M. y Vavatsikos, A. (2005). *Evaluation of wastewater facilities scenarios with the use of the AHP multicriteria method*. 9th International Conference on Environmental Science and Technology, Rhodes Island, Grecia.

Karimi, A., Mehrdadi, N., Hashemian, S., Nabi Bidhendi, G., & Tavakkoli Moghaddam, R. (2011). *Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods*. International Journal of Environment Science and Technology, Vol. 8, No. 2, pp. 267-280.

Nakhaei, M. & Taheriyoun, M. (2012). *Evaluation of Wastewater Treatment Technologies Applying Fuzzy Analytic Hierarchy Process and Gray Relational Analysis*. International Conference on Chemical, Civil and Environment engineering (ICCEE'2012), Dubai, UAE.

Pérez, A., Oddershede, A., y Mena, M. (2010). *Wastewater treatment system selection using the Analytical Hierarchy Process*. The Operations Research Society Annual Conference OR52, Egham, London, UK.

Saaty T. L. (1997). *Toma de Decisiones Para Líderes. El proceso jerárquico analítico. La toma de decisiones en un mundo complejo*. RWS Publications, USA.

Saaty, T. L. (1983). *Expert Choice*. Extracted from link http://expertchoice.com/ (December 10th 2012).

Saaty, T. L. (1998). *Método Analítico Jerárquico [AHP]: Principios Básicos. En Evaluación y Decisión Multicriterio. Reflexiones y Experiencias*. Santiago: Editorial Universidad de Santiago.

Sullivan, W., Wicks, E. & Luxhoj, J. (2004). *Ingeniería Económica de De Garmo*. México: Pearson.

Yingyuad, R. (2007). *Selection of biogas production system for tapioca starch wastewater by using Analytic Hierarchy Process*. Thesis for the Degree of Master of Science in Management Technology. University of Shinawatra, Bangkok, Tailand.

Zeng, G., Jiang, R., Guohe, H., Xu, M. & Jiambing, L. (2007). *Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis*. Journal of Environmental Management, vol. 82, no. 2, pp. 250-259.