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DOI: <https://doi.org/10.61273/neyart.v3i1.100>

| Received: 03/15/2025 | Accepted: 05/20/2024 | Published: 06/29/2025

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Abstract: This research project consisted of the development and implementation of a computer system for remote monitoring and data acquisition on the operation of a wastewater treatment plant (WWTP) owned by the company CLARVI, located in Los Mochis, Sinaloa, Mexico, in order to take advantage of previously installed Industry 4.0 technology, but whose information could only be viewed on site, recorded manually, and not analyzed in any way. The purpose of this was to create a SCADA-type tool to aid in decision-making based on quantifiable information to improve overall equipment efficiency (OEE) in the plant's bioreactor. Over a period of five months, four water quality variables, WWTP downtime, water inflows to the supply network, and outflows after treatment were monitored using PLCs and specialized sensors. The information obtained was used to calculate the OEE percentage on a monthly basis as the system was implemented, and after carrying out activities based on the data analysis, the impact was observed. Finally, a very strong correlation was found between the OEE and the degree of implementation of the system. This research yielded very positive results with the use of this new tool, both qualitative and quantitative, but undoubtedly the most notable result was exceeding the 80% OEE proposed in the hypothesis to reach 93.56%, starting from an initial 12.94%.

Keywords: WWTP, CLARVI, Industry 4.0, SCADA, OEE, PLC.

Abstract: The present research work consisted in the development and implementation of a computer system for remote monitoring and data acquisition on the operation of a WWTP owned by the company CLARVI, located in Los Mochis, Sinaloa, Mexico, in order to properly take advantage of the industry 4.0 technology previously installed, whose information could only be viewed on site, whose registration was kept manually, and for which no type of analysis was carried out. The purpose of this was to create a SCADA-type tool that would aid in decision-making based on quantifiable information to improve the overall equipment efficiency (OEE) of the plant's bioreactor. During a period of five months, four water quality variables were monitored: WWTP shutdown times, water input flows to the supply network, and water output after treatment, through the use of PLCs and specialized sensors. With the information obtained, the percentage of OEE was calculated on a monthly basis as the system was implemented, and after carrying out activities based on the analysis of the data, the impact

was observed. Finally, a very strong degree of correlation was determined between the OEE and the degree of system implementation. In this research, very positive results were obtained with the use of this new tool, both qualitative and quantitative, but, without a doubt, it stands out to have exceeded the 80% OEE proposed in the hypothesis until reaching 93.56%, starting from an initial 12.94%.

Keywords: WWTP, CLARVI, Industry 4.0, SCADA, OEE, PLC.

INTRODUCTION

We often overlook the fact that "life originated in water and continues to depend on it" (Guerrero, 2006). What is not so obvious, from a productive, social, and demographic point of view, is that water resources "... are also indispensable for all production systems, which conditions the different aspects of social development" (Huaquisto & Chambilla, 2019). This development promotes growth and demographic concentration, greater demand, and water pollution. According to UN data, the world population will reach 8 billion by mid-November 2022 (UN-Habitat & WHO, 2021).

To alleviate the problems caused by this overpopulation in terms of environmental pollution from wastewater from urban developments and industry, prevent health problems (Calderón & Arteaga, 2019), and promote water reuse, WWTPs are being built. However, these facilities face various technical, organizational, social, and economic challenges (Martínez et al., 2016), for which some authors propose decentralization and smaller-scale construction as a solution (Lahera, 2010). For this to be practical and viable in the future, it will be necessary to have some form of real-time remote monitoring and control of several plants at once, which requires the implementation of a SCADA system.

Some of the challenges presented at CLARVI's "Zero Discharge" WWTP were: monitoring, which was carried out exclusively in person; the information generated was recorded manually in paper logs; and the data was not subjected to any subsequent analysis. The design, development, and implementation of a SCADA-type system sought to resolve the above situation, provide a tool to aid in decision-making regarding plant operation, and measure the impact of its implementation on overall equipment efficiency (OEE).

DEVELOPMENT

Software and hardware tools were used to develop this research project, including what could be considered conventional tools: servers, applications, programming languages, networks, protocols, etc., as well as industrial tools such as PLCs and specialized sensors (flow meters, pH meters, oximeters, conductivity meters, and suspended solids sensors). All of these were used together to design and implement the SCADA-type tool, through which the sampled information could be collected, stored, and analyzed, enabling the operator and/or supervisor to make the best decisions regarding plant operation based on quantifiable information.

Over an eight-month period from late March 2023 to early December of the same year, various activities were carried out, including: initial research and testing for software development; development of the various system modules; implementation, debugging, and improvements to the computer system; data sampling, storage, and interpretation; implementation of improvements and adoption of best practices.

An interdisciplinary team participated (directly and indirectly), involving different areas of the CLARVI company, including: Senior Management, Purchasing, Security, Maintenance, Innovation and Development, Marketing, Technical Services, Engineering, Production, and Systems. Thanks to this team, the objectives set were achieved and the expected numerical result was obtained, which was proposed as a minimum OEE of 80%.

Methodology.

This research consisted of six stages:

- (1) Research, development, and initial monitoring tests.
- (2) Monitoring of water entering the CLARVI internal network and treated water leaving the Zero Discharge WWTP.
- (3) Monitoring of PLC inputs, outputs, and quality variables at the WWTP.
- (4) Development of information analysis tools.
- (5) Periodic release of stages 2, 3, and 4 to the operator.
- (6) Implementation of improvements and adjustments until project completion.

To obtain OEE1—our benchmark measurement—it was necessary to complete the first three stages and a sampling period of one month. After the first measurement and having made progress in stage four, it was possible to gradually execute stages five and six to evaluate the impact of implementing the SCADA-type system on OEE month after month. The evaluation was proposed to be monthly to allow time for the execution of stage six, which basically consists of applying improvements and making adjustments based on the information obtained by the system.

Overall Equipment Effectiveness.

Overall Equipment Effectiveness (OEE) is a measurement method that promotes continuous improvement and consists of equipment availability, performance or productivity efficiency, and the quality rate achieved (Belohlavek, 2006). This would be the dependent variable for this work, and to determine each component variable, the following procedure was followed:

- **Productivity:** given by the percentage ratio between the volume of treated water and the volume of first-use water that entered the supply network. These volumes were obtained by sampling the effluent flow from the WWTP and the inflow of new water from the irrigation canal to the water treatment plant, respectively. The flows were stored in liters per second (L/sec) in the database, which, as samples were taken every second, facilitated their conversion to cubic meters.

$$\text{Productivity} = \text{Total output} / \text{potential output} \quad . \text{ Eq. (1)}$$

- **Availability.** - This variable is determined by the percentage ratio between the actual operating time of the WWTP and the scheduled operating time, which, theoretically, should be 24 hours a day, seven days a week, excluding only downtime caused by external power failures (or failures unrelated to the company) and scheduled maintenance shutdowns. In both cases, the times were stored in seconds.

$$\text{Availability} = \text{Available operating time} / \text{scheduled operating time} \quad . \text{ Eq. (2)}$$

- **Quality.** - To calculate this variable, four other variables were monitored: pH, suspended solids, conductivity, and dissolved oxygen. In each case, the first three had to be within their limits to be considered "acceptable," while for the last one, it was acceptable for it to exceed the limits as long as it did not exceed (for operational reasons) one hour for the limit.

upper limit and two for the lower limit. For a sample to be considered acceptable and not rejected, each of the four variables had to be acceptable; if any of them was not, the sample would be rejected. Monitoring was performed every second and the sample was evaluated automatically. The percentage ratio between accepted samples and total samples in a time interval was the quality indicator.

$$\text{Quality} = \text{Quality production} / \text{total production} \quad \text{Eq. (3)}$$

Integrating these three variables, we have:

$$\text{OEE} = \text{Availability} * \text{Performance} * \text{Quality} \quad \text{Ec. (4)}$$

Limits of quality variables.

It is possible to establish limits for two of the quality variables in a normative manner, specifically for pH and conductivity. The other two, being operational in nature, were obtained from specialized literature on the design and operation of wastewater treatment plants. Each of them is detailed below:

NOM-001-SEMARNAT-2021 (SEGOB, 2022a) - This is the Mexican regulation that "establishes the permissible limits for contaminants in wastewater discharges into receiving bodies owned by the nation." It establishes that the limit values for pH range from 6 to 9 units for all cases of receiving bodies. The permissible limits for the Zero Discharge WWTP were set at 6 to 8 pH units, which is within the limits established by the regulation.

NOM-127-SSA1-2021 (SEGOB, 2022b). - This standard from the Ministry of Health establishes the permissible limits for water quality for human use and consumption. In it, the chemical health specifications establish a maximum value of 1000 mg/L for total dissolved solids, which would be approximately 1428 $\mu\text{S}/\text{cm}$ of conductivity (Hanna Instruments, n.d.). The limits determined for the Zero Discharge WWTP range from 0 to 1500 $\mu\text{S}/\text{cm}$.

Operating Parameters. - For continuous aerobic processes, which are designed to remove organic matter, the dissolved oxygen range at which they must operate to remain constant is between 0.5 and 1.5 mg/L. However, higher levels of 2.0 mg/L are used when nitrification is desired (Ramalho, 2003). Based on this, limits of 1.5 to 2.5 mg/L were established.

Regarding the amount of suspended solids, the typical operating ranges for an extended aeration process are 0.05 to 0.1 kg of BOD per kg of SSVLM in aeration, and the following formula is used to calculate the food/microorganism (F/M) ratio for proper system operation, where Q is the influent or effluent flow in m³/day (Torrescano, 2009):³/day (Torrescano, 2009):

$$F/M = (BOD * Q) / (1000 * SSVLM) \quad \text{Eq. (5)}$$

If we solve for and assume that water with a BOD of 100 mg/L is already considered moderately polluted, that we have an average flow rate of 10 m³/day, and that the F/M ratio is greater than 0.1 kg of BOD per kg of SSVLM, we have:

$$SSVLM = (100 * 10) / (1000 * 0.1) = 10 \text{ kg}$$

Taking into account that SSVLM commonly represents between 70 and 80% of total suspended solids, we can say that:

$$SSTLM = 10 / 0.7 = 14.29 \text{ kg}$$

Homogenized in the 15 m³ capacity of the Zero Discharge WWTP tank, we have that the lower limit would be:

$$14.29 \text{ kg} / 15 \text{ m}^3 = 952.66 \text{ mg} / \text{L} \approx 1000 \text{ mg} / \text{L}$$

There is no upper limit for this variable.

The SCADA-type system.

The development of the tool was divided into three main tools shown in Figure 1, each of which has the following main functionality:

1. Obtaining flows (inlet and outlet) and water volumes, meters, time meters.
2. Obtaining quality variables and monitoring devices (status) of the WWTP.
3. Monitoring of quality variables and flows in real time, and analysis of information.

Figure 1. SCADA-type system modules.



The first of the applications has been slightly modified so that, when measuring inflow, it alerts if a certain consumption level is reached, and when monitoring outflow, it alerts if a certain time elapses without any flow being recorded.

In the second, you can see a small black button that actually controls the switching on and off of a dosing pump. However, as mentioned above, the plant is programmed to operate on a timer, and when it reaches its programmed time, any changes made with this button would be automatically overridden. This is why continuing with the control part was ruled out. This part of the development provides the same information that the operator would have when standing in front of the WWTP control panel.

As for the third tool, various graphs were developed for the analysis of monitored data, both in real time and for specific periods of time, which provides great visibility into plant operation, water consumption, treatment level, treatment quality, etc. In addition, this part of the development is where the causes of a particular failure or event are captured, as well as the confirmation of the start and end times of each of them. The following figure shows some of the graphs included in this section.

Figure 2. Graphs from the analysis application.



As established in stage 6 of the methodology, at a certain point, the system programming was also carried out, improved, adapted, and corrected during the execution of the research.

Percentage of SCADA implementation.

To quantify the independent variable, we decided to subdivide and evaluate each part of the IT development equally as we progressed through the branches. First, the development was divided into control and monitoring as if it were a complete SCADA system, as this was the initial intention. However, due to the way the plant's operation is programmed (by time), control was omitted and the project was limited to monitoring, which is why this part was assessed at 100%. This, in turn, was subdivided into data analysis and data acquisition, with each activity accounting for 50%. The latter included the execution of everything necessary to obtain the data, i.e., including hardware installation and/or software development. Subsequently, each activity was divided into the three component variables of OEE, with an approximate percentage of 16.66% each, to finally subdivide them into specific developments for each part and quantified in the same way, equally.

With the help of a schedule that recorded the most relevant activities of this research, it was easy to determine the monthly percentage implementation of the system during

the sampling period, which covered the months of July to November 2023. Table 1 below shows the results for this variable:

Table 1. Monthly implementation percentage of the SCADA system

Mes	% Implementación
Julio	54.16
Agosto	62.49
Septiembre	87.50
Octubre	91.66
Noviembre	100.00

Improvement activities.

Once the minimum necessary (in terms of IT development) had been obtained to quantify the initial OEE and following the proposed methodology, it was possible to gradually release sections of the software to the operator so that they could make decisions based on quantifiable and timely information. The most significant ones by component variable are listed below:

Productivity:

- Installation of analog flow meters in buildings.
- Implementation of alerts based on time and treatment levels.
- Detection, repair, and/or isolation of water leaks.
- Monitoring of weekly preventive maintenance.
- Installation of a buffer tank to release pressure on the WWTP membranes.
- Rationalization of new water entering the facilities by shutting down the water treatment plant outside working hours and implementation of a traffic light system to monitor compliance with this point.

Availability:

- Cell phone alerts via email in case of failures or events:
 - Permeate pump shutdown
 - Overload
- CCTV installation

- Training of paint shop personnel on the use of electrical power switches. Quality:
- Maintenance, calibration, and/or replacement of sensors.
- Development and implementation of a tool for real-time remote monitoring of quality variables.
- Periodic monitoring of the calibration of measuring instruments.
- Reconditioning of conductivity.
- Sharing of operating manual with sensor maintenance times with the operator.

Results

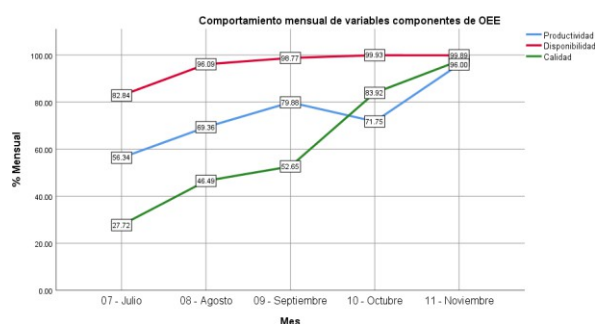
In summary, the monthly OEE results and those for each of its components, as the system was implemented and decisions were made based on information obtained by it—such as the above activities—were as follows:

Table 2. Monthly summary of OEE percentages.

Mes	Prod (%)	Disp (%)	Cal (%)	OEE (%)
Julio	56.34	82.84	27.72	12.94
Agosto	69.36	96.09	46.49	30.98
Septiembre	79.88	98.77	52.65	41.54
Octubre	71.75	99.93	83.92	60.17
Noviembre	96.00	99.89	97.57	93.56

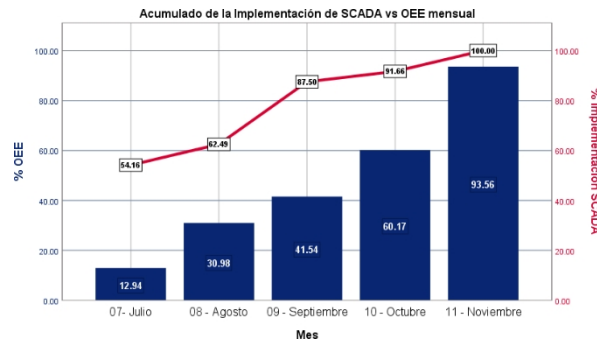
Represented graphically,

Figure 3. Monthly performance of OEE component variables



The following graph shows both the percentage of SCADA system implementation and the changes in OEE over time:

Figure 4. Cumulative SCADA implementation vs. monthly OEE.



The validity of this result was corroborated by calculating its degree of correlation using the Pearson method *Pearson method*, obtaining a strong positive correlation between the variables studied with a value of $p=0.908$.

Table 3. Degree of correlation between dependent and independent variables.

Correlaciones			
		% implementación SCADA	% OEE
% implementación SCADA	Correlación de Pearson	1	.908*
	Sig. (bilateral)		.033
	N	5	5
% OEE	Correlación de Pearson	.908*	1
	Sig. (bilateral)	.033	
	N	5	5

*. La correlación es significativa en el nivel 0,05 (bilateral).

DISCUSSION AND ANALYSIS OF RESULTS

Based on the results obtained, it can be said that each and every one of the proposed objectives, both specific and general, were successfully achieved. Some could be measured quantitatively, while others were reflected in the operation qualitatively.

The installed Industry 4.0 technology was successfully leveraged, going from 0% to 54.16% until reaching 100%, which represented the expected scope. First-use water consumption was reduced by 100 m³ per month and productivity was increased, which translates into an increase in recycled water consumption. Response time to failures was significantly reduced through cell phone alerts via email. Real-time remote monitoring and quality improvement became a reality. A database was created with thousands of records of both monitored variables and events, enabling information analysis. The system was designed and developed in such a way that

facilitates its adaptation/modification for future needs. There was a significant improvement in the ability to monitor the operation of the WWTP and the work of its operator. Finally, a tool was obtained that was not previously available (the system itself), which not only fulfilled the proposed goal of achieving 80% OEE, but also helped to exceed it by far, reaching 93.56%. At this point, it is important to mention that the SCADA-type system alone would not have changed the result, but this, together with the metrics used, provided visibility to focus efforts on addressing specific issues.

CONCLUSIONS

It is not easy to work on a project of this type in an applied and operational manner due to the economic implications involved. For this reason, many researchers resort to simulation, which is entirely valid and does not detract from their merit or credibility. An example of this type of work is that of Rajhans et al. (2020), whose approach is very similar to that of this study. Some other authors, such as Wu-Yang et al. (2020), use the same type of tools but direct their efforts in another direction, specifically toward improving energy efficiency, which gives rise to another very interesting study that could be put into practice if the opportunity arises.

Ultimately, all of this research seeks to resolve the problems presented by WWTPs so that they can comply with the three principles of sustainability for which they are built: environmental, social, and economic. However, it is also necessary for these infrastructure projects to be sustainable over time. The United Nations establishes this as its sixth goal in the list of "Sustainable Development Goals" (UN, 2016).

Finally, it remains to be said that there is always room for improvement. Studies such as these, even with favorable results, can be perfected and therefore present opportunities for improvement. We cannot sit idly by after obtaining the expected or desired results. Perseverance and consistency are required if sustainability is to be achieved in this regard.

FUTURE WORK

As future work, it is proposed to gradually eliminate time-based operation and adopt an automated system based on real-time monitoring of operating conditions, such as the status of devices, flows, levels, and quality variables. It would also facilitate the implementation of a

remote control for the WWTP, enabling remote operation in the event of contingencies and opening the door to further research. The scope could be extended to later stages of water treatment, such as purification and purification, evaluating the impact of a SCADA system on overall efficiency (OEE).

A second line of research could focus on the use of Industry 4.0 in a WWTP, conveniently directing efforts towards:

1. The study of applied energy efficiency improvements.
2. It is proposed to evaluate the impact on OEE of including remote control in the SCADA system, instead of using timers for WWTP operation.
3. Finally, it is suggested that a study be carried out on total productive maintenance (TPM), a variable directly related to OEE.

REFERENCES

- Belohlavek, P. (2006). *OEE Overall Equipment Effectiveness: A Unicist Approach*, (1^aEdition). Buenos Aires: Blue Eagle Group.
- Calderón, C. and Arteaga, V. (2019). *Factors determining the sustainability of the WWTP. Case study: Pucara WWTP in the municipality of Sacaba*. [Diploma thesis] Universidad Mayor de San Simón. Bolivia.
- Guerrero, M. (2006). *Water*. (5thedition). Mexico City: Fondo de Cultura Económica.
- Hanna Instruments (S.F). *Conductivity and dissolved*
<https://www.hannainst.es/blog/79/conductividad-y-solidos-disueltos>
- Huaquisto, S. and Chambilla, I. G. (2019). *Analysis of drinking water consumption in the town of Salcedo, Puno. Research and Development*, 19 (1), pp. 133-144.
http://www.scielo.org.bo/scielo.php?script=sci_arttext&pid=S2518-44312019000100010
- Lahera, V., (2010). *Sustainable infrastructure: Wastewater treatment plants*. Quivera. Journal de Territorial Studies , 12(2), pp. 58-69.
<https://www.redalyc.org/pdf/401/40115676004.pdf>

- Martínez-Austria, P. F., & Vargas-Hidalgo, A. (2016). *Adaptive dynamic model for water management in urban areas*. *Water Technology and Science*, 7(4), pp. 139-154.
<https://www.scielo.org.mx/pdf/tca/v7n4/2007-2422-tca-7-04-00139.pdf>
- UN (2016). *17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development*.
<https://www.un.org/es/impacto-acad%C3%A9mico/page/objetivos-de-desarrollo-sostenible>
- UN-Habitat and WHO (2021). *Progress in wastewater treatment. Global status and acceleration needs for SDG indicator 6.3.1. United Nations Human Settlements Program (UN-Habitat) and World Health Organization (WHO)*, pp. 3.
https://unhabitat.org/sites/default/files/2021/10/sdg6_indicator_report_631_progress-on-wastewater-treatment_2021_es.pdf
- Rajhans, A., More, S., Gambhir, S., & Deshmukh, V. (2020). *Research paper on wastewater treatment plant using PLC & SCADA*. *International Journal of Engineering Applied Sciences and Technology*, 4(12), pp. 651-657. <https://www.ijeast.com/papers/651-657,Tesma412,IJEAST.pdf>
- Ramalho, R. (2003). *Wastewater treatment*. (2ªEdition). Barcelona: Editorial Revertée. SEGOB (11 March 2022a). *NOM-001-SEMARNAT-2021*. Official Gazette Federación.
https://www.dof.gob.mx/nota_detalle.php?codigo=5645374&fecha=11/03/2022
- SEGOB (2 May May 2022b), *NOM-127-SSAI-2021*. Official Official of the
https://www.dof.gob.mx/nota_detalle.php?codigo=5650705&fecha=02/05/2022
- Torrescano, J. L. (2009). *Operating parameters in the activated sludge wastewater treatment process*. *Aquaforum*, 13(52), pp. 14-19.
http://seia.guanajuato.gob.mx/document/AquaForum/AF52/AF5204_ParametrosOperacion.pdf
- Wu-Yang, S., Ya-Yun, C., Lorensia, L. Jian-Gu, C., & Han-Yang, L. (2020). *Energy consumption analysis in wastewater treatment plants using simulation and SCADA system: Case study in northern Taiwan*. *Journal of Cleaner Production*, 276, 124248.
<https://www.sciencedirect.com/science/article/pii/S0959652620342931>

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