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Article

Modeling of the supply and consumption of the Huatusco Veracruz wáter network using SIMIO software

Modelación del abastecimiento y consumo de la red hídrica de Huatusco Veracruz con software SIMIO

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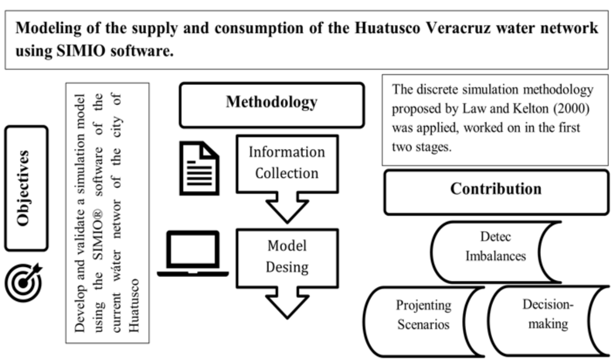
Abstract

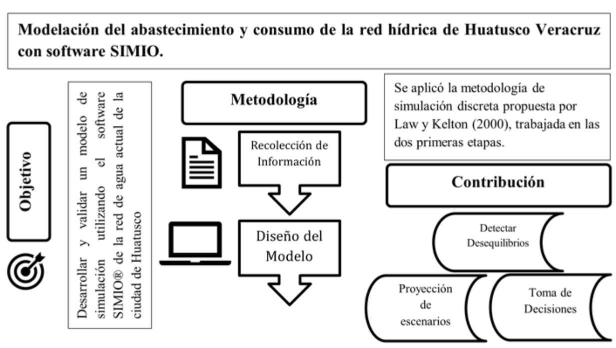
The main objective of this article is to develop and validate a simulation model using SIMIO® software for the current water network in the city of Huatusco, Veracruz, in order to analyze its consumption and distribution for different sectors: domestic, urban, commercial, industrial, residential, and social interest. To this end, the discrete simulation methodology implemented by Law and Kelton was used, which included the characterization of the infrastructure, the collection of historical consumption data, and the construction of a model representing the supply cycles, with the purpose of evaluating usage patterns. Once the model was simulated, it was validated against the real system using a paired t-test. The result of this work is a statistically validated model that can serve as a support tool for decision-making in the city's water management, facilitating the projection of future scenarios and the detection of possible imbalances in distribution.



Simulation, Water Network, Distribution

Resumen

El objetivo principal de este artículo es desarrollar y validar un modelo de simulación mediante el software SIMIO® de la red hídrica de la ciudad de Huatusco, Veracruz, para analizar su consumo y distribución de esta para sus diferentes sectores: domésticos, urbanos, comerciales, industriales, residenciales e interés social. Se empleó la metodología de simulación discreta implementada por Law y Kelton, que incluyo la caracterización de la infraestructura, la recopilación de datos históricos de consumo y la construcción de un modelo que representa los ciclos de suministro, para evaluar patrones de uso. Posteriormente, se procedió a validar el modelo contra el sistema real a partir de la prueba t-pareada. El resultado es un modelo validado estadísticamente el cual puede servir como una herramienta de apoyo para la toma de decisiones en la gestión hídrica de la ciudad, facilitando la proyección escenarios futuros y la detección de posibles desequilibrios en la distribución.



Simulation. Water Network, Distribution

Area: Advocacy and attention to national problems

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Introduction

Access to safe drinking water is a fundamental resource for human development, public health and economic development. Its management is a global and national priority, in Mexico, many cities currently face serious challenges in their water distribution network. At the national level, the National Water Program (PNH, 2024) identifies critical problems such as insufficient and inequitable access to water, with only 58% of the total population receiving this resource daily, which is due to inefficient use and losses in distribution networks that can reach up to 60% of the total volume and with a growing demand associated with population growth.(National Water Commission, 2020).

The problem to be solved in this work focuses specifically on the need to analyze and characterize the consumption and distribution of water in the water network of Huatusco, Veracruz, in order to improve the local management of the resource. Faced with this challenge, there is a need to use technical tools such as discrete simulation, which allows representing, analysing and projecting future scenarios of the behaviour of the city's water distribution network system.

In this context, simulation model technology has emerged as a tool of enormous importance, providing the basis for hydraulic calculation, planning, operation and management of distribution networks. The added value of simulation lies in its ability to analyze the complexity of the system under different conditions, including temporal variations, which allows various solution alternatives to be quickly evaluated, a crucial advantage for decision-making.

Unlike traditional analysis techniques that focus on designing new networks with theoretical parameters, simulation models for in-service distribution networks focus on the accurate estimation and calibration of modified parameters, such as actual demand, resulting in a deeper and more realistic understanding of system operation.(National Water Commission, 2014b) (National Water Commission, 2014a).

Water systems modeling encompasses a variety of approaches, depending on the objective. One can be the prediction of resources and adaptation to climate change: there are works focused on the projection of long-term water availability, analyzing supply and demand under the influence of climate change (Díaz León & Olarte Escobar, 2025). For example, in the Rimac River basin, the water balance is evaluated until 2050. These studies often employ advanced artificial intelligence (AI) methods, such as Recurrent Neural Networks (RNNs) or Bidirectional Neural Networks (BNNs) to predict hydrometeorological variables such as temperature, or Artificial Neural Networks (ANNs) to forecast monthly water availability. (Taboada Valenzuela, 2025)-

Another type of approach is the quantification of groundwater resources, these models focus on the dynamics of groundwater, using software such as MODFLOW6 to develop flow number models in aquifers, quantifying resources, reserves and the effect of artificial recharge using system dynamics as a method.(Giussepe Massone Grez, 2025)

This study is part of the operational simulation approach of the infrastructure. The main objective of this study was the development and validation of a simulation model using the SIMIO software, applying the discrete simulation methodology of the SIMIO® software. The simulation model focuses on representing the current supply cycles and evaluating the usage patterns of the different consumer sectors. Averill M. Law and W. David Kelton, (2000).

Having as the scope of this work a statistically validated model that represents the current situation of supply and consumption of the water network of the municipal capital of the city of Huatusco Veracruz, according to the number of intakes and average consumption of the different sectors identified, with which it can be constituted as a support tool for decision-making in the water management of the city. This would facilitate the projection of future scenarios and the detection of possible imbalances in water distribution.

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Methodology

The methodology applied to this simulation study was based on the one proposed by Law and Kelton (2000), this methodology is structured in three main stages: information, design and analysis, which in turn are divided into 10 steps.

Box 1

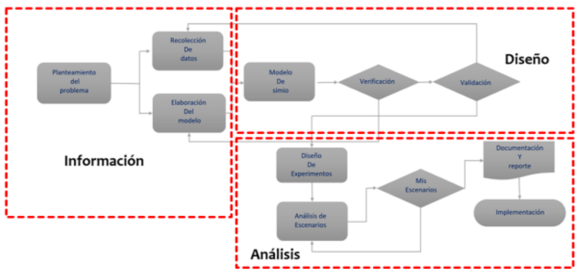

Figure 1
Methodology of Law and Kelton (2000)
Source: Own Elaboration

However, due to the complexity of the situation addressed, this work focused exclusively on the development of the first two stages. It is important to clarify that the third stage, corresponding to the Analysis, which includes the design of experiments, the evaluation of scenarios and the projection of improvements, is left as a line of work for the future. The following is the procedure followed:

1. Problem statement

What is sought in this first stage of the methodology is to clearly define all the sectors that the distribution network contemplates, as well as the various sources that feed it. The boxes, pumps and keys that make up the network were identified. The idea was to recognize the operation of the entire system so that with it we could know the data that needed to be collected. The operating hours of the parts that make up the water network were also studied, since they define the dynamics of supply to the different areas of the city. This information was essential to represent the real operating conditions within the simulation model.

2. Data collection

In this stage, operational and consumption data provided by the Municipal Commission of Drinking Water and Sanitation of the city of Huatusco (CMAS) were collected, which include volumes invoiced and distributed monthly in m^3.

The sectors were classified according to their type of use: Popular, Urban, Commercial, Low Commercial, Industrial, Residential and Social Interest, in order to characterize the different demand patterns. Subsequently, the data were organized and cleaned in an Excel table.

The statistical analysis consisted of two phases:

– First, a one-factor ANOVA was applied to the monthly consumption series of each sector, in order to identify significant variations between months (Gutiérrez Pulido & de la Vara Salazar, 2008)

– Secondly, goodness of fit tests were carried out (Kolmogorov-Smirnov, Anderson Draling and Chi-square), to contrast the data with theoretical distributions in order to have the behaviors of the different consumptions (Garcia Dunna *et al*., 2013)

3. Model development

Based on the structural and operational information collected, a conceptual diagram of the supply network was developed, where the sources of supply, pumps, boxes, tanks and consumption sectors were represented, as well as the connections between them. This diagram served as a base guide for the construction of the computational model in the SIMIO® software.

4. SIMIO® Model

The development of the simulation model in SIMIO® was continued based on the conceptual diagram of the supply network, using the objects of the flow library (Flow Library).

The entities, processes, routes and parameters corresponding to each consumption sector were created, seeking to faithfully reflect the dynamics of the real system. Adjustments were made in the flow rates and operating conditions based on the analyzed data, until a stable and coherent representation of the behavior of the water network was achieved.

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5. Model Verification

Once the model was implemented, the verification was carried out, which consisted of checking through the execution of multiple runs that the operating logic was correct and that the model behaved as expected. To this end, it was reviewed that:

– The operating hours of pumps and boxes will be adhered to according to the actual schedule.
– The flow paths and processes will behave according to the system topology.
– The consumption assigned to each sector coincided with the historical records.

The resulting model was successfully verified, guaranteeing its correct operation before statistical validation.

6. Model validation

Finally, the validation was carried out using a t-paired test, which allowed comparing the monthly consumption of the simulated model with the real data of the system, in order to determine if there were significant differences between the results. The hypothesis put forward was:

– H_0: There are no significant differences between the average monthly consumption of the real system and those of the simulated model.
– H_1: There are significant differences between the average monthly consumption of the real system and those of the simulated model.

The analysis is carried out with a confidence level of 95% to determine that the model is statistically representative and thus achieve the objective of the project stage.

Results

Step 1. Problem statement

In this stage, the necessary information was collected and organized for the construction of the simulation model of the water distribution network. The data was provided by the CMAS including network operational data, historical consumption records by sectors and distribution plans.

It is important to clarify that the city of Huatusco, Ver., is divided into supply sections according to the area that each part of the network supplies. Each section was assigned the type of consumption of each sector that is in the area.

Box 2

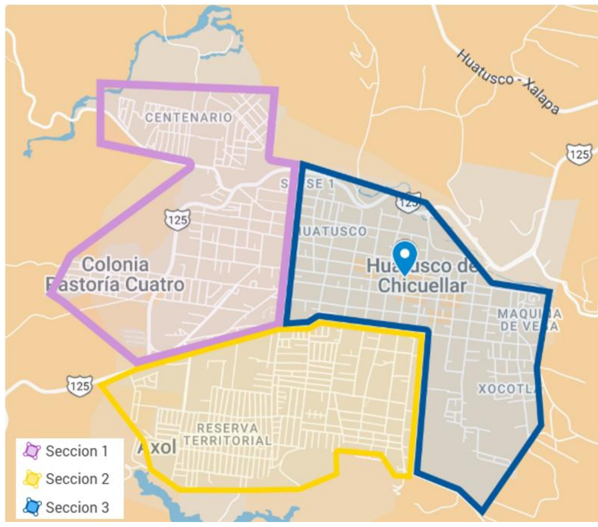

Figure 2
Sourcing Sections

Source: Own Elaboration

Likewise, the information related to the operating schedules of pumps and supply boxes was organized, which is essential to reproduce the real conditions of water distribution in the simulation model.

Box 3

Table 1
Hours of Operation

Receive from	Box	Timetable Open	Timetable Close	Send	Frequency
Axol 1 Sour Orange	Poplar grove	10:00 p.m.	07:00 p.m.	Lonas Garry	Daily
Poplar grove	Lonas Garry	3:00 a.m. 4:00 p.m.	8:00 a.m. 7:00 p.m.	Trejo	Every 3 days
Lonas Garry	Trejo	8:00 a.m.	11:00 a.m.	Section 3	Every 3 days
Axol 3	Reservation	10:00 p.m.	7:00 p.m.	Lonas Garry	Daily
Reservation	Lonas Garry	10:00 p.m.	5:50 a.m.	Trejo	Every 3 days
Reservation	Shepherding	5:30 a.m. 9:30 a.m.	8:30 a.m. 7:00 p.m.	Section 3	Every 3 days
Reservation	San Antonio	8:30 a.m.	9:00 a.m.	Section 3	Every 3 days
Axol 3	Reservation	-----	-----	Section 2	Daily
Axol 1 Sour Orange	Poplar grove	-----	-----	Section 1	Daily

Source: Own Elaboration

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Based on this information, the structural diagram of the supply network was developed, which represents the pumps, boxes and supply tanks, and the connections between them. This diagram forms the basis for the creation of the model in SIMIO.

Box 4

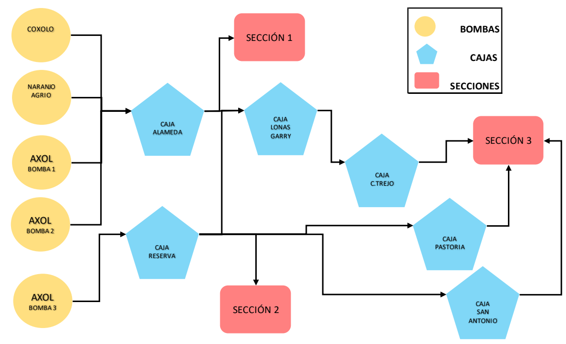

Figure 3
Structural diagram

Source: Own Elaboration

Step 2. Data collection

For this stage, monthly consumption samples were collected corresponding to each of the sectors into which the type of consumption of the supply network in the city is divided. To this end, the records provided by the CMAS were considered, which include the volumes invoiced and distributed monthly in m^3.

The data collected were organized in a matrix that made it possible to relate each sector of the city to its respective monthly volume of consumption. On the other hand, the data were subjected to a process of filtering and organization in order to guarantee its consistency.

In the first instance, a statistical analysis was carried out to identify patterns and significant variations in water demand by sector. For this, a one-factor ANOVA (Analysis of Variance) was applied to the corresponding monthly consumption records of each sector. The objective of this test was to contrast the null hypothesis of the same monthly averages against the alternative hypothesis that at least one month presents a significantly different consumption.

Table 2 presents the results obtained from the ANOVA, carried out for the different water consumption sectors.

Box 5

Table 2
One-factor ANOVA

Sector	*F*	*p-value*	Critical value for *F*
Popular	0.7896	0.6716	1.7341
Urban	0.8341	0.6237	1.7297
Commercial	0.0726	0.9999	1.7443
Low Commercial	0.5068	0.8698	1.8990
Residential	0.0531	0.9483	3.4028
Industrial	0.1660	0.9995	1.7906
Social Interest	0.096	0.9088	3.4028

Source: Own Elaboration

In this case, it can be observed that, in all the sectors analyzed, the calculated *F* values were lower than the F Critical Value and the *p-values* were greater than 0.05. With which we conclude that there are no statistically significant differences in monthly water consumption within each sector, that is, demand remains stable between months for all sectors.

Subsequently, goodness-of-fit tests were carried out (Kolmogorov-Smirnov, Anderson Draling and Chi-square), using the Stat::Fit and Minitab software. With the aim of contrasting the data series with known theoretical distributions. However, in all the cases evaluated, the statistical results indicated that the consumptions did not significantly fit any of the known theoretical distributions.

Faced with this situation, the construction of empirical probability distributions was chosen, based on the procedure offered by the SIMIO® software, which allows modeling random variables when they do not present an adjustment to theoretical distributions. These empirical distributions are constructed from the observed data. In this way, the probabilistic representation of the consumption variables was defined by empirical distributions, ensuring that the subsequent simulation is based on the real behavior of the historical data.

Step 3. Model development

In this phase, the simulation model was built in the SIMIO software, which is intended to represent the distribution and consumption network by sectors of the city, based on the information processed in the previous stages.

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The construction of the simulation model was carried out as follows:

Flow Library objects were selected and configured. Each of these objects will serve to represent some component of the water distribution system.

– FlowSource: represent the pumps of the aquifer supplies that feed the distribution network.

– Tank: they are used to represent the water storage and distribution boxes.

– FlowSink: represent the consumption of each type of sector, they serve to record the demand by monthly water volumes according to each type of sector.

– FlowNode: represent the faucets in the water distribution system, which are the ones that will define the path of the water.

– FlowConnector: these are the connectors of the objects, which represent the pipes of the water distribution network.

– ModelEntity: this is an entity which will represent what water is.

Step 4. SIMIO Model

Figure 4 presents the base simulation model implemented in the SIMIO® software, where the main components of the city's water distribution network are identified.

Box 6

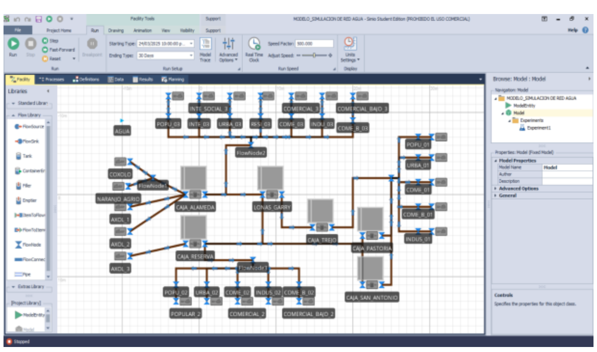

Figure 4

SIMIO® software model

Source: Own Elaboration

Step 5. Verification

The verification consists of checking the logic of the model, in which test runs were executed to observe that the simulation:

– Comply with the operating hours of pumps and boxes will operate on schedule.

– Confirm that the route and process logic adequately reproduce the operation of the distribution network.

– That the consumption assigned to each sector is representative of historical data.

With this, a base model was obtained verified in its operation.

Step 6. Validation

The validation of the model was carried out using the t-paired test, which is a hypothesis test that allows comparing a random sample of the real system against a random sample of the simulated model. In this case, the procedure consisted of comparing the sum of the consumptions of the sectors to have a total monthly consumption of the system between the real system and the simulated model. The table shows the values of twelve months of the city's monthly consumption. Likewise, it presents the values of the already simulated model for comparison.

Box 7

Table 3

T-paired test

	Data			
	Simulated	Real		
Races	Xi	Yj	Zj=Xi -Yj	$(Z_j - \bar{Z}10)^2$
1	208404.77	193248.68	15156.09	136909823.86
2	209289.86	205197.56	4092.31	405849.75
3	208013.29	190002.05	18011.23	211876757.50
4	208149.39	194822.24	13327.15	97454533.62
5	208434.33	214203.92	-5769.59	85097598.31
6	208647.08	204323.09	4324	754739.66
7	209154.03	195477.63	13676.40	104472032.09
8	208404.53	214901.86	-6497.33	99053588.21
9	209884.05	204211.52	5672.54	4916391.30
10	209011.30	210970.75	-1959.45	29318861.20
11	208924.46	225563.79	-16639.33	403791756.30
12	208751.86	210682.97	-1931.11	29102750.81
		Promedio=	3455.24	

Source: Own Elaboration

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A 95% confidence level was used for Z (=0.05), where Z_i=X j-Yj and the confidence interval was determined, resulting in being: (-3189.44, 10099.93), where it is observed that it includes zero, thus the result of the t-paired test showed that the simulated values do not differ statistically from those observed in reality. Therefore, H 0 cannot be rejected, concluding that the model adequately reproduces the behavior of the water distribution system and global consumption, which supports the statistical validity to be used in the experimentation and analysis of subsequent scenarios.

Conclusions

Taking into account the evidence presented in the work, we conclude that the development of the simulation model of the water network of the city of Huatusco, Veracruz, allowed to faithfully represent the current behavior of the distribution system, constituting a support tool for the water management of the municipality by facilitating the visualization and understanding of the operational dynamics of the network. Although the research focused exclusively on the first two stages of the discrete simulation methodology proposed by Law and Kelton, the results obtained provide a reliable and statistically validated representation of the current system.

Although the study was limited to these stages, the results achieved establish a solid basis for the analysis of future scenarios and the projection of strategies aimed at optimizing efficiency and equity in the distribution of the resource.

In future work, it is recommended to move towards the analysis stage by designing improvement scenarios that consider variations in water supply and demand, as well as evaluating the impact of preventive maintenance strategies, leak control and infrastructure expansion.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Rosas-Ramón, Alejandro: I carry out the collection of information, the development of the simulation model, the data analysis and the writing of the article.

Saavedra-Trujillo, Rigoberto: Contributes to the idea of the project, in the collection of information and the analysis of data.

Jiménez-Solís, Miguel Ángel: I carry out the design of the research and the analysis of the data, I review and participate in the writing of the article.

González-Sóbal, Martín: I contribute to the idea of the project, liaisons with the municipal authorities and the CMAS for the development of the project.

Availability of data and materials

The data were provided with the help and collaboration of CMAS. The SIMIO software was® used, a 3D modeling, simulation and animation tool of processes, using the discrete event technique, which allowed modeling, representing the different stages of water supply and consumption in the water network of the city of Huatusco, Veracruz.

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Abbreviations

ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
BRNN	Bidirectional Neural Networks
CMAS	Municipal Commission of Drinking Water and Sanitation
AI	Artificial intelligence
HNP	National Water Program
RNN	Recurrent neural networks

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Discussions

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