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Application of simulation as an improvement proposal for the street sweeping process of a municipality in the High Mountains region

Aplicación de la simulación como propuesta de mejora para el proceso de barrido de calles de un Municipio de la región de las Altas Montañas

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Abstract

The following research is carried out in order to develop a sweeping model that allows efficiencies in the workforce of the Municipality of Orizaba, reducing the time of sweeping the routes and taking advantage of the resources available, facilitating decision-making for the relevant authorities through simulation. The project was carried out in three stages, contemplating the analysis of the initial information, which allowed us to study the scanning process, identifying the activities that are carried out and how they are carried out, the next stage consisted in the construction of the simulation model through SIMIO which allowed observing the behavior of the data collected, finally in the stage 3 that is currently being developed, an alternative is proposed to improve the scanning process, which will be implemented as a pilot test, as well as contributing to the design of a manual that allows standardizing this process.

Sweep process, Simulation, Sustainable Awareness

Resumen

La siguiente investigación se realiza con el fin de desarrollar un modelo de barrido que permita eficientar la mano de obra del Municipio de Orizaba, logrando disminuir el tiempo de barrido en las rutas y aprovechar los recursos que se tienen disponibles, facilitando la toma de decisiones para las autoridades correspondientes, a través de la simulación. El proyecto se realizó en tres etapas, contemplando el análisis de la información inicial, la cual permitió estudiar el proceso de barrido, identificando las actividades que se realizan y como se llevan a cabo, la siguiente etapa consistió en la construcción del modelo de simulación a través de SIMIO lo cual permitió observar el comportamiento de los datos recolectados, finalmente en la etapa 3 que actualmente se desarrolla, se propone una alternativa de mejora al proceso de barrido, la cual se implementará como prueba piloto, así mismo, se contribuirá con el diseño de un manual que permita estandarizar dicho proceso.

Barrido, Simulación, Conciencia Sustentable

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Objectives

General Objective

To design a simulation model of the sweeping service through the SIMIO application, in order to improve sweeping times, reducing operating costs and resources required by the Public Cleaning Department of the Municipality of Orizaba.

Specific Objectives

– Perform an initial diagnosis to identify the current state of the routes, through a study of times and movements of the sweeping process, considering the resources used and operating costs.

– Design the real model of the sweeping process in the SIMIO Simulation software, analyzing the variables of time, distance and working personnel.

– Build the simulation model with the sweeping process improvement alternative.

– Implement the pilot test of the simulation model alternative oriented to time reduction.

– Create the sweeping process manual to standardize times and activities.

Metodology

The research work was carried out based on the sweeping process carried out on routes 7 and 8 established by the Department of Public Cleanliness and Ecology during the 2022-2025 administration. Carrying out the analysis of the form of sweeping called "aircraft wing", which has been used in previous administrations to carry out manual sweeping of public roads, green areas, sidewalks, roads and parks.

The methodology is based on the one proposed by Law and Kelton (2000) which indicates the method that should follow the simulation process through the scientific method.

Stage 1 Analysis of initial information.

Stage 2 Simulation evaluation of the scanning process.

Stage 3 Pilot test of alternative scanning process improvement.

Contribution

Apply the simulation in order to model a real system of the street sweeping process, which presents to the Goverment Authorities a proposal for improvement, by minimizing the scanning times, contributing to better management of available resources

Introduction

Currently, the contamination and mismanagement of MSW represents a serious problem worldwide, since the lack of an adequate collection system can have serious consequences for public health. That is why several countries have sought to generate new ways to encourage the population to create an awareness of recycling and seek to generate less waste. Mexico is one of the countries with the most pollution problems in the streets, due to the lack of an environmental culture.

This represents an area of opportunity for the authorities to create programs that promote environmental awareness among citizens. Orizaba is a municipality that has worked to promote sustainable awareness, implementing actions and programs aimed at caring for the environment (Osenguenda R. 2021). The sweeping and public cleaning program, allows offering the inhabitants of the Municipality to transit through the streets without pollutants, providing clean recreational spaces, where children can play freely. (UV Orizaba, 2018)

These programs make the quality of life of the inhabitants better, by favoring services focused on the conservation, restoration and use of ecosystems and natural resources available. Therefore, this project seeks to offer a sweeping alternative that allows the efficient use of the resources available for such activity. In this way, the Public Administration of the City Council will be able to better manage the resources favoring the promotion of a sustainable culture in the citizens.

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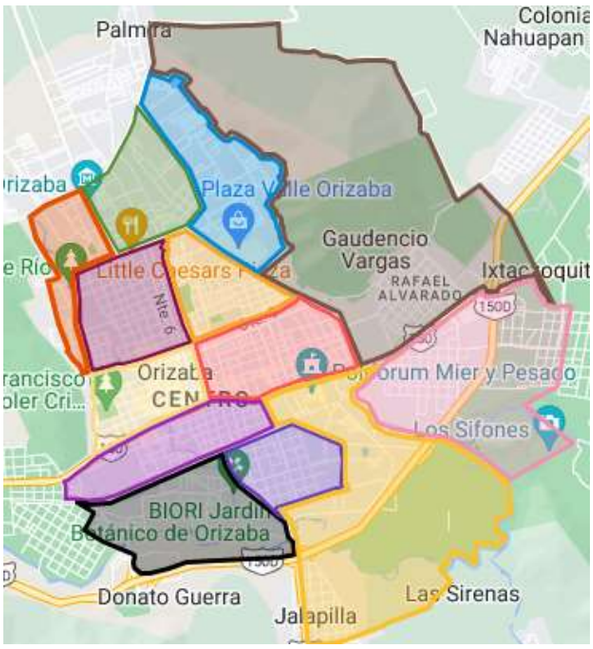

Figure 1 Sweeping routes Municipality of Orizaba

The municipality of Orizaba is divided into 13 routes, in which the sweeping process is carried out manually, with a staff of 54 employees and 4 supervisors, in two different shifts, morning and evening, working in the following schedules; the morning shift from 4 am to 1 pm and in the evening from 1 pm to 8 pm.

Methodology to be developed

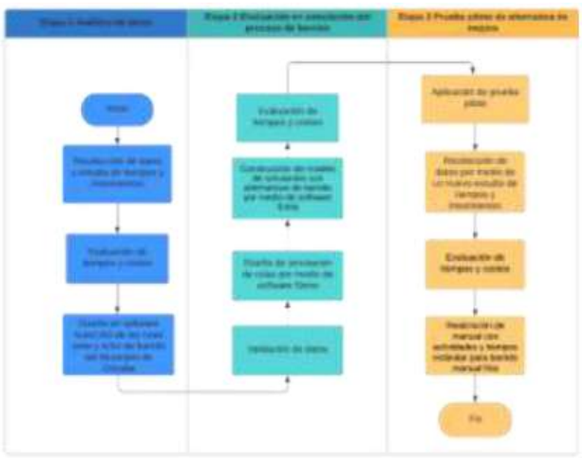

Figure 2 Methodology
Source: Prepared by the authors

Stage 1 Analysis of initial information

Data collection and time and motion study:

Within the first stage, the following activities were carried out; starting with data collection that was carried out by means of a study of times and movements of routes 7 and 8, which allowed for a more in-depth analysis of the activities that are carried out within the manual sweeping process. The main objective of the time and motion study is to eliminate or improve unnecessary tasks that can directly and indirectly affect the productivity and quality of the process (Salvendy G. 2001). Since this tool allows to analyze the processes, breaking them down to determine which are the activities, tasks or specific steps to complete the final process (Render B. 2009).

Time and cost evaluation: Subsequently, an evaluation of the costs that were provided by the Department of Public Cleaning was performed, to analyze the economic shrinkage that the process currently has, this table can be seen in Figure 4 Economic shrinkage.

Design in AutoCAD Software of the sweeping routes 7 and 8 of the Municipality of Orizaba:

The design of the streets of the Municipality of Orizaba was performed in DWG format, using the AutoCAD program, this software allows creating 2D and 3D models, having a higher precision to work with the plans more accurately (Seys S. 2019). This software is compatible with SIMIO software, and allows exporting the plan, generating the layout to be used as a basis for the design. The plan covers sweeping routes 7 and 8, starting from the exit point, which is located at 440 Poniente 10 Street, Lourdes, in the Municipality of Orizaba, and considers the streets Oriente 9, Oriente 7, Oriente 5, Oriente 3, Colón Street, Oriente 2 and Oriente 4.

Stage 2 Evaluation in simulation of the sweeping process

Data validation:

By means of MINITAB software, which is a statistical tool with a user-friendly interface that is focused on data analysis and process improvement based on the implementation of quality control tools and SIX SIGMA (Minitab).

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Therefore, the data analysis of the time and movement study was carried out considering the time variable in relation to the distance, in order to analyze the probability distribution to which this variable adjusts. In the first instance, descriptive statistics data were obtained, with a total of 265 data, a minimum of 0.317 minutes and a maximum of 15.083 minutes, which corresponds to the time it takes operators to sweep one linear meter of the routes.

Estadísticas

Variable	N	N*	Media	Error estándar de la media	Desv.Est.	Mínimo	Q1	Mediana	Q3	Máximo
Tiempo total	265	0	4.208	0.158	2.574	0.317	2.492	3.717	5.367	15.083

Figure 3 Descriptive statistics
Source: Own Elaboration

An individual distribution identification test was applied, which includes a Chi-square test and the Anderson Darling test, which determines the distribution to which the data best fit, which can be observed in the probability graph, in the time variable. Therefore, when analyzing the goodness-of-fit test, it is concluded that it resembles a normal distribution.

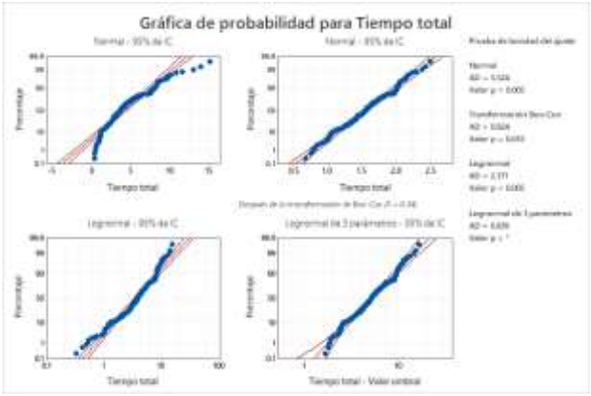

Figure 4 Distribution identification test
Source: Prepared by the authors

According to the value of the Anderson-Darling (AD) normality test that can be observed in the graph, with a total of 5.524, it is greater than the significance level of .005 having the following hypothesis; $P > \alpha$: Therefore, it is concluded that there is sufficient evidence to say that the data follow a normal distribution.

Design of route simulation by means of SIMIO software:

The construction of the simulation model was based on SIMIO, which is a software for modeling, simulation and 3D animation of process flows that allows modeling the behavior of logistic, industrial and service systems, that is, of a real or imaginary system, which in this case is the sweeping process of the established routes (Simio). The basis used for this model was the AutoCAD layout, which recreates the path followed by the operators, comparing it with the real times obtained in the study of times and movements.

Construction of the simulation model with the sweeping alternative:

In this section, the sweeping alternative is proposed, which seeks to reduce the time that the workers spend during the street sweeping route. The next step to be carried out in conjunction with the Department of Public Cleaning will be to implement the pilot test in order to validate the model.

Results

By means of the study of times and movements, the results shown in Table 1 were obtained. The minimum total travel time is 8 hours and 25 minutes, while the maximum time is 9 hours and 21 minutes. This table allowed a more in-depth analysis to establish the dead and effective times.

Calles	Tiempo de recorrido	Demoras	Tiempo de ocio	Tiempo efectivo	Distancia
Oriente 9	8:25:12	1:08:28	38.28	7:16:44	7783.66
Oriente 7	8:55:49	01:25:44	55.44	7:30:05	9000.63
Oriente 5	8:53:14	0:40:14	10.14	8:13:00	6238.1
Oriente 3	9:21:00	01:12:22	42.22	8:08:38	8273.09
Colón	8:38:45	01:06:40	36.4	7:32:05	7832.66
Oriente 2	9:07:25	01:01:43	31.43	8:05:42	7803.87
Oriente 4	9:04:09	0:57:30	27.3	8:06:39	12132.44
Promedio	8:55:05	1:04:40	34.46	7:50:25	8437.78

Table 1 Travel time of the streets
Source: Own Elaboration

Based on the analysis of times and movements, a process flow diagram was obtained, which can be seen in Figure 5. This diagram shows the activities performed by the operator from the time he arrives at the base work area until he finishes the manual sweeping of the route assigned to him.

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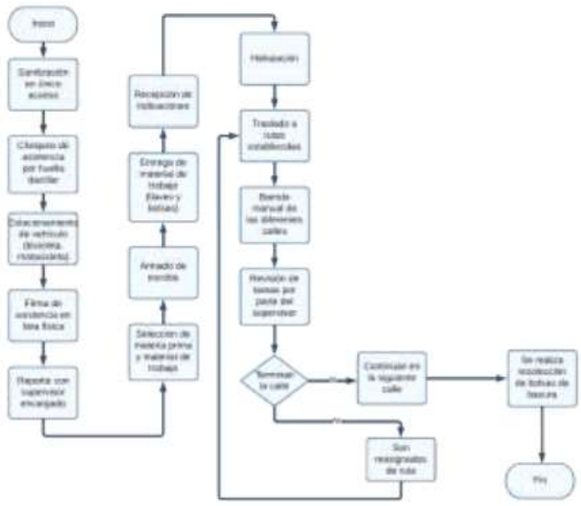

Figure 5 Sweeping process diagram
Source: Own Elaboration

Looking at Table 2, an analysis of idle time versus effective time was established, and it was found that there is a monthly economic loss of $5,441.70 pesos, which is equivalent to the salary of an average operator. This indicates that there is an economic loss in the manual sweeping process, which is an area of opportunity for improvement.

Calles	Tiempo de recorrido	Demoras	Tiempo de ocio	Tiempo efectivo	Distancia	Demoras en minutos	Costo por demoras	Merma económica
Oriente 9	8:25.12	1:08.28	36.28	7:16.44	7785.66	68.28	$ 64.18	$ 35.98
Oriente 7	8:55.49	01:25.44	55.44	7:30.05	9030.63	85.44	$ 80.31	$ 52.11
Oriente 5	8:53.14	0:48.14	10.14	8:13.00	6238.1	48.14	$ 37.73	$ 9.93
Oriente 3	9:21.00	01:12.22	42.22	8:08.38	8273.09	72.22	$ 67.89	$ 39.69
Costa	8:36.46	01:06.40	36.4	7:32.05	7832.66	66.4	$ 62.42	$ 34.22
Oriente 2	9:07.26	01:01.43	31.43	8:05.42	7803.67	61.43	$ 57.74	$ 29.54
Oriente 4	9:04.09	0:57.30	27.3	8:06.39	12132.44	57.3	$ 53.86	$ 25.66
Promedio	8:55.05	1:04.40	34.46	7:50.25	8437.79	64.46	$ 60.59	$ 32.39
						Total	$ 424.14	$ 226.74
						Mensual	$ 10,179.30	$ 5,441.70
							Anual	$ 65,300.37

Table 2 Economic loss
Source: Own elaboration

Figure 6 shows the sweeping model, which was developed using SIMIO software, where areas of opportunity were found, which allowed the development of a new sweeping alternative.

Figure 6 Sweep program layout
Source: Own Elaboration

To perform the validation of the runs that were run in the SIMIO program, the N¨B Test was developed, which allows to know the optimal number of runs so that the data are closer to the real ones. Using the following parameters:

			Var=	4.539220988			
			α=	0.1			
			β=	0.7			
Corridas	Valor de t		√var/i			Comprobación	
i= 6	2.015048373	x	0.869791257	=	1.752671458	≤ β : 0.7	NO
i= 7	1.943180281	x	0.805270229	=	1.564785229	≤ β : 0.7	NO
i= 8	1.894578605	x	0.753261325	=	1.42711279	≤ β : 0.7	NO
i= 9	1.859548038	x	0.710181588	=	1.320616778	≤ β : 0.7	NO
i= 10	1.833112933	x	0.673737411	=	1.235036761	≤ β : 0.7	NO
i= 11	1.812461123	x	0.642383416	=	1.164294968	≤ β : 0.7	NO
i= 12	1.795884819	x	0.615035296	=	1.104532552	≤ β : 0.7	NO
i= 13	1.782287556	x	0.590906799	=	1.053165835	≤ β : 0.7	NO
i= 14	1.770933396	x	0.569412039	=	1.008390797	≤ β : 0.7	NO
i= 15	1.761310136	x	0.550104292	=	0.968904266	≤ β : 0.7	NO
i= 16	1.753050356	x	0.532636191	=	0.933738064	≤ β : 0.7	NO
i= 17	1.745883676	x	0.516733006	=	0.90215572	≤ β : 0.7	NO
i= 18	1.739606726	x	0.502174217	=	0.873585645	≤ β : 0.7	NO
i= 19	1.734063607	x	0.48878049	=	0.84757646	≤ β : 0.7	NO
i= 20	1.729132812	x	0.476404292	=	0.823766293	≤ β : 0.7	NO
i= 21	1.724718243	x	0.464922983	=	0.801861151	≤ β : 0.7	NO
i= 22	1.720742903	x	0.45423367	=	0.781619363	≤ β : 0.7	NO
i= 23	1.717144374	x	0.444249293	=	0.762840174	≤ β : 0.7	NO
i= 24	1.713871528	x	0.434895629	=	0.745355235	≤ β : 0.7	NO
i= 25	1.71088208	x	0.426108953	=	0.729022171	≤ β : 0.7	NO
i= 26	1.708140761	x	0.417834205	=	0.713719636	≤ β : 0.7	NO
i= 27	1.70561792	x	0.410023531	=	0.699343482	≤ β : 0.7	i es el número óptimo de corridas

Table 3 Number of optimal runs
Source: Own Elaboration

Based on these results, it was found that the number of runs that allows the model to have statistical validity is 27, as shown in Table 3.

Based on the analysis carried out jointly with the experts (who carry out the sweeping process), a sweeping alternative was developed by means of the SIMIO software, which can be seen in Figure 9.

Figure 7 Alternative layout of swept form
Source: Own Elaboration

In order to develop the proposal, a graphic analysis was made on different alternative ways, based on this, the simulation model was developed, which can be seen in Figure 9, based on the data obtained through the simulation, the estimated sweeping time applying this model is 7 hours 35 minutes 18 seconds. Having a shorter process time compared to the sweeping time with the current form.

Compared to the sweeping time of 8 hours 25 minutes 12 seconds for the current sweeping time on East 9th Street, there is a total reduction of 1 hour, 9 minutes and 54 seconds.

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Calles	Tiempo de recorrido	Demoras	Tiempo de ocio	Tiempo efectivo	Distancia	Demoras en minutos	Merma económica
Oriente 9 Forma actual	08:25:12	01:08:28	38.28	07:16:44	7783.66	68.28	$35.98
Oriente 9 forma alterna	07:35:18	01:08:28	38.28	06:34:22	8627.09	35	$32.90

Table 4 Cost comparison
Source: Own Elaboration

Based on table 4 of cost comparison, we can see that there is a decrease in the cost per delay, having an economic loss of $32.00 pesos, compared to the economic loss of the way they currently perform, with a cost of $35.98 pesos. This will lead us to have a monthly saving of $789.60 pesos, being the monthly salary of an operator.

Future work

Future work is based on the application of the pilot test with the proposed alternative, during which the time study will be carried out to validate the model, also considering the costs, in order to evaluate the results obtained and compare them with the "airplane wing" sweeping method currently used. For this pilot test we will work together with the sweeping personnel of the public cleaning coordination of the Municipality of Orizaba.

Another of the objectives is that based on the new modifications that have been carried out in the sweeping process, a manual will be created, where work instructions will be developed, as well as procedures and technical references that will allow both operators and supervisors to develop the sweeping process in a better way.

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Conclusions

The application of the time and motion study allowed the development of the process diagram, identifying the activities that are performed in the sweeping process. Likewise, through the simulation, it was possible to model the real system, analyzing the variables that intervene with the purpose of standardizing the times, favoring the use of resources (labor and inputs). The realization of the simulation model in the alternative way, allowed to achieve the initial objective of the project, which is to reduce the time and resources required to perform the sweeping process, allowing to focus on new projects that allow to continue with the work of the Municipality of Orizaba, seeking to promote a sustainable awareness in the population.

The use of SIMIO software in its academic version allows modeling complex systems where different factors are integrated, managing to recreate the process being studied, through capturing and describing the system, simulating it and at the end it is possible to obtain a 3D animation that allows the user to understand it in a better way. (Simio, 2022).

The contribution of this research project is aligned with the National Strategic Program in Socioecological Systems and Sustainability (Pronaces-SSyS), because it is oriented to the proposal of an alternative that allows minimizing costs in terms of labor associated with shifts and schedules of workers, as well as the resources used in the sweeping process, favorably impacting the public cleaning service and thus the authorities can visualize and exercise new projects for the benefit of the environment favoring sustainable awareness in citizenship.

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