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Statistical Analysis of Time Collection Tools for Simulation of Industrial Systems

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Abstract **-** This research focuses on statistically analyzing the results of time collection tools for use in simulating industrial systems, employed in a Honduran banking institution. The adaptability of the instruments to changes in simulated industrial systems is evaluated, validating time reduction strategies through piloting and data triangulation.
The methodology included time measurements using manual timing, Excel, and a microcontroller (ESP). Through piloting with the tools, improvements were identified prior to official data collection. As part of the results, it was found after the final data collection that the majority of the bank's clients opt for multiple services. In conclusion, it is essential to define the activities to be analyzed beforehand to avoid unnecessary data collection.
After collecting the data, a statistical analysis was conducted to examine the properties of the tools used. Through tests comparing variances and means, as well as ANOVA to examine multiple samples, it was concluded that the tools perform similarly in data collection. Therefore, the selection of any of the three tools is left to the user's discretion.
The statistical analysis and data simulation provided by the banking institution revealed certain peculiarities of the system used. During equality tests, an approximate delay of two minutes was noted in the banking system's time records. Additionally, the simulation indicated that the average time within the system increases by 3.89% when considering the use of the ticket machine compared to not using it.

Keywords**:** microcontroller (ESP), FlexSim, time between arrivals, processing times, banking institution.

1. Introduction

This article addresses the fundamental issue related to efficient management of waiting times in the banking sector, a highly complex task with direct consequences on customer satisfaction and positioned as a critical challenge for organizations. In this context, the focus is on evaluating the use of Methods Engineering tools and their impact on the effective recording of times required for simulation models, applicable to the Honduran banking sector, using Industrial Systems Simulation.

The need to improve accuracy in processing time recording is particularly relevant in the banking field, where high margins of error significantly hinder researchers' work in conducting simulations. The presence of considerable inaccuracies directly impacts strategic decisions and solutions proposed by professionals involved in this field. To address this complex task, the development of an innovative tool [1] that utilizes a microcontroller is proposed to obtain information in field measurements [2]. This tool is designed to simplify the data collection process, allowing greater efficiency and accuracy in obtaining relevant information.

The implementation of this solution not only aims to improve the quality of collected data but also to free humans from repetitive and tedious tasks, allowing them to focus on more analytical and strategic aspects of their roles [3]. Several studies have addressed the issue of time management in different contexts, including specific cases in Honduras, Colombia, and Ecuador. Various studies have addressed time management in Honduras, highlighting the application of similar tools to tackle this issue.

On the other hand, other studies focused on using Microsoft Excel for time recording in specific areas such as accounting and claims. Subsequently, this information was integrated with quality tools aiming to reduce waste in the system, demonstrating the versatility and usefulness of accessible tools like Excel in process optimization [4]. In another Honduran context, FlexSim was used to analyze response times in the national emergency system 911. The implementation of this

technology aimed to improve service quality, thus avoiding the inefficient use of resources. This case underscores the pressing need to adopt advanced technologies to optimize information processing in critical sectors [5].

In the Colombian context, process automation has been implemented in textile areas using microprocessors. These devices store accurate data on the times required for each activity, thus offering valuable information contributing to more efficient operations management [6]. On the other hand, the issue of waiting times at a transport terminal has been addressed, where significantly elevated waits were identified, even exceeding the actual duration of the journey. To tackle this challenge, various data collection formats were implemented, and a detailed simulation of waiting times was carried out. This approach allowed for effectively identifying and addressing the problem, aiming to optimize efficiency and user experience at the transport terminal [7].

In the Ecuadorian context, time management has been addressed through specific studies focused on the trucking process at a beverage distribution center. In this case, digital clocks and formats designed to record times associated with each phase of the process were used [8]. In the development of this study, various tools were employed, including the use of Microsoft Excel for data recording, along with a digital clock. Additionally, printed formats were used in conjunction with a manual stopwatch, where data were recorded for later tabulation in Excel and subsequent analysis. Furthermore, a microprocessor was implemented to automate this task, allowing data recording with the simple press of a button.

Through these tools, data such as time between arrivals were collected, recorded from the moment the user started using the ticket machine at the bank under study until obtaining their printed ticket. Regarding processing times, the start was recorded upon reaching the cashier, and the final time was considered the moment they left [9]. After conducting a statistical analysis to compare all the tools used, a simulation of the bank's current situation was carried out, as certain information that simulation can provide is not available in its system. To conduct the simulation, data provided by the entity were considered, including processing times and additional information from which arrival times and waiting times can be calculated. This article is structured into sections covering methodology, results, conclusions, and recommendations. Specifically, the conclusions of the article are found in section 4.

2. Methodology

2.1. Type of Research

The research is based on a quantitative approach, useful for describing, explaining, and predicting the studied phenomena by identifying relationships among its elements [10]. The aim is to validate and ensure the reliability of the results, emphasizing the importance of establishing comparisons and precedents. Tools from Methods Engineering were used to gather data, which were statistically analyzed through Experimental Design. This process allowed for the assessment of the capabilities of the measurement instruments, facilitating the creation of an accurate simulation in the research development.

The research was conducted under a correlational approach with the purpose of determining whether the Methods Engineering tools used were statistically equal or if there was any variation among them. Making these comparisons was essential to establish statistical relationships between the tools, defining a control variable and thus ensuring a more comprehensive and accurate assessment of their performance.

2.2. Research Variables

2.2.1Independent Variables

The independent variable is the type of data collection tool. It is considered an independent variable as it encompasses the various types of tools used in the study to identify their characteristics and differences.

2.2.2 Dependent Variables

As the dependent variable, we have the Effective Time Record. This is the outcome of the time collection using different tools and how much they differ when compared with a control variable. The control variable used was the times provided by the ticketing system.

2.3. Applied Techniques and Instruments

This section is divided into two subsections: techniques and instruments used in methods engineering, and techniques techniques used in simulation of industrial systems.

For methods engineering, the following instruments were used: digital stopwatch, digital clock, physical data collection sheet, digital data collection form, and computer-assisted stopwatch (ESP). The techniques employed in methods engineering are job analysis and time and motion study. For simulation of industrial systems, the techniques used include manual recording with printed format, statistical analysis, and FlexSim.

2.4. Population and Sample

2.4.1Population:

The main office of the banking institution under study.

2.4.2 Sampling:

The sampling employed in this study adopts a non-probabilistic approach, specifically convenience sampling. To conduct the analysis, specific conditions have been defined that must be met; the main condition is that the branches under study must have an implemented ticket system. Secondly, the importance of examining branches that fail to reach 80% of the goals established by the bank was identified. In this context, it was identified that a single branch fails to meet this goal, becoming the focus of evaluation for the study.

This research has been carried out with this type of sampling since it is an available case to which access is obtained [10]. The choice of the banking institution with the points aligns with the research purpose in order to employ data collection tools for later comparative analysis among them using the information provided by the specific banking institution.

2.4.2 Sample:

The study sample consists of the 8 cashier booths operating within the main office of the banking institution under study.

2.5. Validation Methodology

The research was divided into various phases, each requiring a validation process. After data collection and statistical analysis, a validation process was conducted to define the effectiveness of the different time measurement tools. Through piloting, criteria were established, and tools were developed according to the situation studied in the established banking institution. These results were then compared with the times provided by the bank, which were recorded through the implementation of a ticket system. These times served as a reference point and basis for validating the authenticity of the collected data.

Subsequently, various simulations were created in FlexSim, with variations in distributions. The validation of these simulations was carried out through triangulation, where experts in Industrial Systems Simulation analyzed and evaluated the work done. They confirmed that the model was functional and closely resembled reality as much as possible. Once the model was validated, the improvements identified during the research process were implemented.

3. Results

3.1 Measurement of Processing Times and Time Between Arrivals at the Banking Institution Under Study

In the context of time measurement, it is crucial to highlight the criteria used to record them. In the case of processing times, the moment a person arrives at the counter and begins to be served is considered the initial time, while the moment they leave is taken as the final time. Regarding the use of the machine, the start is recorded when the person begins to use it, and the moment they take their printed ticket is established as the end. Out of the 2202 observations made, 1144 correspond to processing at the counters, while the remaining ones are related to the use of the machine and the time between arrivals. These 1144 observations are distributed as follows:

- Excel: 446
- Manual Data Entry: 370
- ESP: 328

Based on this data, the percentages of clients using multiple cashiers are calculated as follows:
- Excel: 86%
- Manual Data Entry: 88%
- ESP: 82%

Likewise, the total percentages of clients using customer service cashiers are determined as:
- Excel: 13%
- Manual Data Entry: 11%
- ESP: 18%

It is relevant to note that the remaining 1% in all groups corresponds to counter 11, designated for tax payment. Thanks to these observations, the flow within the bank was identified, showing that counters 3, 4, and 5 serve 73% of the clients, while the remaining 27% is distributed among the other counters.

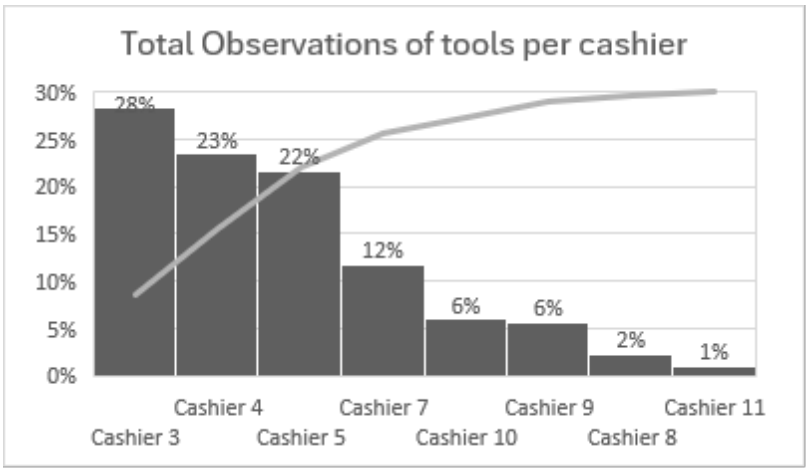

Figure 1: Total Observations of tools per cashier

3.2 Comparative Analysis of Data Collection Tools: Efficiency in Time Collection

3.2.1 Time between Arrivals

The data from the bank's ticket system, coinciding with the measurement times conducted for this analysis regarding the time between arrivals, were considered. It was decided to use the Minitab tool to statistically analyze the collected data, as has been done in other research studies [11], thanks to its capability to perform various statistical tests. The variance test in Minitab was applied to determine the equality of variances between both samples: the tool to be analyzed and the data extracted from the bank. This test required both critical values to exceed the significance level to not reject the null hypothesis, indicating that the variance between means is statistically equal.

Subsequently, a test of equality of means was conducted, considering a significance level of 0.05. The null hypothesis, which posits that the means are equal, is rejected when the p-value is less than the pre-established significance level. By rejecting it, it is concluded that the means between both samples differ statistically. The results of the equality of means tests are shown in Table 1 below.

Table 1: Summary of Results - Tests of Equality of Means (arrival times).

	Excel a. Ticket System	**Manual Recording a. Ticket System**	**ESP a. Ticket System**
Is the null hypothesis rejected?	Yes	No	Yes
Estimation of the difference with a 95% confidence interval	(0.081, 1.875)	(-0.216, 1.897)	(0.065, 2.337)

All null hypotheses were rejected, except for the one related to manual registration versus the ticket system. The means of all tools with rejected null hypotheses differ statistically from the ticket system employed by the bank. Studying the estimation of the difference, minimal changes are observed, suggesting that the ticket system is delayed by one or two minutes, recording an activity two minutes after its start or conclusion, as observed. The delay in the system may cause confusion among analysts, which in turn could lead to high margins of error and, consequently, the formulation of incongruent solutions.

3.2.2 Machine Usage Time

3.2.2.1 Criteria for taking initial and final times.

Measurements specifically taken to analyze the usage time of the ticket machine were employed, defining the initial time as the moment when the customer began using the machine and the final time as the instant when they took their printed ticket. Since this information was not available in the bank's ticket system, a variance test was conducted in Minitab to assess the equality of variances between the tools used. It was established as a condition that both critical values must exceed the significance level to not reject the null hypothesis, thus indicating that the variance between the means is statistically equal.

3.2.2.2 Equality Tests

After this procedure, a test of equality of means was conducted with a significance level of 0.05. The null hypothesis, which states that the means are equal, is rejected if the p-value is less than the established significance level. By rejecting it, it is concluded that there is a statistically significant difference between the means of both samples. The results of the equality tests are shown below in Table 2.

Table 2: Summary of Results- Tests of Equality of Means (machine usage time).

	Excel a. Ticket System	**Manual Recording a. Ticket System**	**ESP a. Ticket System**
Is the null hypothesis rejected?	No	No	No
Estimation of the difference with a 95% confidence interval	(-0.0373, 0.0885)	(-0.0723, 0.0256)	(-0.0865, 0.0799)

For the purpose of summarizing, a summary table has been created with the results of the equality of means tests [12]. According to the data shown in Table 3, the results of the equality tests conducted indicate that the samples collected for all tools on the observed days are statistically equal. This means that there is no significant difference between the means of both samples. It is observed that the times might vary slightly, but they do not reach a value high enough to have a significant impact on the study. Using any of the three tools, in this case for machine usage time, will have the same effect on the collected data.

3.2.3 Processing Times

3.2.3.1 Operational Cashiers

All data related to processing times at the various active cashier boxes within the bank were analyzed. It is important to note that transaction start times were considered when the person approached the cashier box. Similarly, regarding the end time, it was measured when the customer left, using the three available tools: Excel, Manual Registration, and ESP.

To conduct the analysis of variance (ANOVA), all measurements were grouped by cashier box, differentiating between each tool. Finally, the data from all days were grouped to compare them with the measured information provided by the ticket system. During the ANOVA analysis, cashier box 11 was excluded because, as established in Minitab, it did not meet the minimum requirement of 15 observations; only 6 observations were recorded on all days data were collected.

The conditions considered when analyzing an ANOVA [13] are as follows:

• The null hypothesis states that the sample means are statistically equal, using a significance level of 0.05 for hypothesis testing.

• If the obtained p-value is less than the established significance level (0.05), the null hypothesis is rejected, allowing to conclude that the samples are not statistically equivalent.

• To corroborate the comparison result, confidence intervals at 95% can be considered. If the interval includes the value 0, it is interpreted that there is no statistically significant difference between the samples.

The following values will be observed in Table 3 and Table 4.

Table 3: Summary of ANOVA Results (processing time cashiers 3-7).

	Cashier 3	**Cashier 4**	**Cashier 5**	**Cashier 7**
EX - Tickets	0.75	0.971	0.817	0.736
MR- Tickets	0.869	1	0.912	0.995
ESP- Tickets	0.903	0.999	0.439	0.781
MR - EX	0.705	0.967	0.998	0.92
ESP - EX	0.707	0.975	0.28	0.999
ESP - MR	1	1	0.308	0.947

Table 4: Summary of ANOVA Results (processing time cashiers 8-10).

	Cashier 8	Cashier 9	Cashier 10
EX - Tickets	0.856	0.14	0.87
MR- Tickets	0.999	0.999	0.943
ESP- Tickets	0.654	0.998	0.906
MR - EX	0.9	0.469	0.662
ESP - EX	1	0.315	1
ESP - MR	0.707	1	0.707

The results presented in Table 3 and Table 4 indicate that, adopting a significance level of 0.05, none of the null hypotheses are rejected in the comparisons of both the tools used and the data provided by the bank. This suggests that the data collected with the tools and the data provided by the bank for the observed active cashier boxes are considered statistically equal.

3.3 Simulation Model

A simulation of the current situation of the bank was carried out, utilizing all the information provided by the entity, which details aspects such as customer types, processing times, and scheduled and unscheduled downtime for cashiers. The analysis began by examining the processing times of the cashier stations and verifying consistency across days using the Minitab tool. Subsequently, the day with the highest amount of data was selected to be inputted into Experfit, where a table with all relevant distributions was generated.

Different customer types and their paths within the bank were identified, along with distributions corresponding to downtimes. Additionally, the machine usage time, a crucial data point for the simulation, was analyzed and inputted into Experfit for distribution. Finally, the bank layout was designed, prioritizing service to elderly customers at all cashier stations. The results of the simulation are shown below in Figure 2.

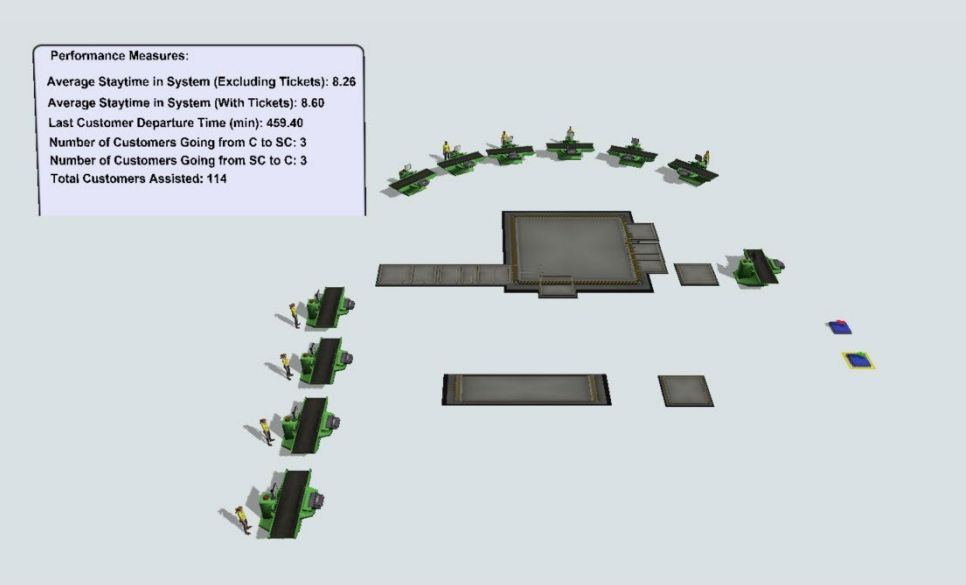

Figure 2: Simulation Model

This simulation aims to replicate reality with the objective of experimenting and obtaining various results by hypothetically changing the model [14]. As seen in Illustration 4, the average times in the system vary by 4% depending on whether the machine is used or not. At first glance, there may not be much difference, however, these differences should be considered when establishing goals. Regarding the departure time of the last customer, which was 459.40 minutes, this indicates that the customer left the bank premises at 4:39:24 P.M., even though the bank closes at 4:00:00 P.M.

After completing the simulation, a model validation process was carried out to ensure that the simulation results were statistically consistent with real bank data. Hypothesis tests of means were conducted, with a significance level of 0.05, using data from experimenter scenario 1, which underwent 25 repetitions. Validation focused on the number of clients served daily at tellers 3 and 9, and the time of departure of the last client, as these data are more reliant on the simulator's operation rather than directly inputted data (distributions). Once the model was statistically validated, it underwent expert triangulation, where each expert meticulously reviewed all aspects of the simulation, including connections, distributions, priorities, customer types, etc. At the end of the meeting, all three advisors confirmed its correct functioning. This approach enhances result reliability by providing a more comprehensive view supported by multiple sources [15].

4. Conclusion

4.1 During the measurements, it was evident that when conducting the same measurements with different tools, it is essential to define beforehand the activities that will be analyzed to avoid unnecessary data collection. Regarding the measurement of processing times in the boxes, establishing the start and end of the studied action prevented discrepancies among the collected data, ensuring the coherence of the data obtained by different researchers.

4.2 All the tools used showed differences with the ticket system, ranging from 0 to 2.3 minutes, suggesting that the system of the bank entity under study records activity with a delay within those values. Using any of the 3 tools will have the same effect on the collected data. It is important to avoid incorrect information combinations in the samples of each of the tools used when statistically analyzing the data to minimize the impact of this delay discrepancy on the study.

4.3 The validation of the model provides solid scientific support for decisions regarding wait time management in the bank, ensuring that future solutions are based on concrete evidence. The piloting allowed for precise data collection, facilitating a deep understanding of the situation within the bank and enabling necessary criteria adjustments accordingly. This ensures that any idea within the bank is supported by the created simulation model, thus avoiding unnecessary resource expenditure.

4.4 This study has created an innovative tool that can statistically match the effectiveness of conventional tools such as Manual Data Entry and Excel. The design of this tool makes it easy for the data collector to perform their task quickly and ensures the accuracy of the data. It eliminates the possibility of losing data due to manual input, as it simply requires pressing a button to record the information.

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