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Journal Industrial Engineering

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Knowledge Area

The works must be unpublished and refer to topics of Production systems design, product quality management, operations research, computer simulation, supply chains, quality certification, hydrometeorology and other topics related to Engineering and Technology.

Content Presentation

As the first article, we present, *Reduction of unproductive times in auto parts company by applying the time and motion methodology*, by BAHENA-MEDINA, Lilia Araceli, GÓMEZ-VICARIO, Miguel Ángel, PÉREZ-ESPAÑA, Nohema and ACOSTA-FLORES, Norma Karina, with adscription in the Universidad Politécnica del Estado de Morelos, as second article we present, *The implementation of augmented reality as a support instrument in the training of predictive maintenance*, by RAMÍREZ-ULLOA, Sergio, FAUSTO-LEPE, Gabriela Margarita, BARRON-BALDERAS, Juan Jose and TORRES-NAVARRO, Joel, with adscription in the Universidad Tecnológica de Jalisco, as third article we present, *Maintenance management system for a fleet of official vehicles in a higher education institution*, by FORNÉS-RIVERA, René Daniel, CANO-CARRASCO, Adolfo, LÓPEZ-FIGUEROA, Julio César and ARMENTA-RAMOS, Juan Israel, with adscription in the Instituto Tecnológico de Sonora, as fourth article we present, *Graphical user interface for a PLC programming implemented in an ARM Cortex-M4 microcontrolle*, by EUSEBIO-GRANDE, Raúl, IBARRA-BONILLA, Mariana Natalia, AMARO-BALANZAR, Jovanni and SÁNCHEZ-TEXIS, Fernando, with adscription in the Instituto Tecnológico Superior de Atlixco.

Content

Article
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Reduction of unproductive times in auto parts company by applying the time and motion methodology

Reducción de tiempos improductivos en una empresa de autopartes aplicando la metodología de tiempos y movimientos

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Abstract

A study of times and movements was developed to reduce unproductive travel times in an assembly line of an auto parts company. The tools used for the study were three: time analysis by elements (ten samples were filmed for each method and the videos were analyzed breaking down the cycle into elements); flow process diagram, to identify each of the activities and the spaghetti diagram that shows the actual flow with measures and trajectories. A proposal for the redistribution of materials was created taking into account the principle of the minimum distance traveled, the collaborators were trained on the modifications in both methods (one piece at a time and several pieces at a time); subsequently, a pilot test was run to verify the feasibility of the proposal. Both the distance and the time were reduced between 20 to 30% for the two methods analyzed.

Time and motion study, Cycle time, Spaghetti diagram

Resumen

Se desarrolló un estudio de tiempos y movimientos para reducir tiempos improductivos de recorrido en una línea de ensamble de una empresa de autopartes. Las herramientas utilizadas para el estudio fueron tres: análisis de tiempos por elementos (se filmaron diez muestras por cada método y se analizaron los videos descomponiendo el ciclo en elementos); diagrama de proceso de flujo, para identificar cada una de las actividades y el diagrama de espaguetti que muestra el flujo real con medidas y trayectorias. Se creó una propuesta de redistribución de materiales tomando en cuenta el principio de la mínima distancia recorrida, se capacitó a las colaboradoras sobre las modificaciones en ambos métodos (una pieza a la vez y varias piezas a la vez); posteriormente, se corrió una prueba piloto para verificar la factibilidad de la propuesta. Tanto la distancia como el tiempo se redujeron entre un 20 a 30% para los dos métodos analizados.

Estudio de tiempos y movimientos, tiempo ciclo, diagrama de spaguetti

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Introduction

Information from the 2019 Economic Census indicates that the manufacturing sector in Mexico in 2018[1] was the most important in terms of total gross production, generating 48.2% of the national total. SMEs accounted for 97.9% of the sector's total economic units, 27.6% of total employed personnel and generated 5.9% of total gross production. Given their impact on the national economy, researchers such as Palomo[2] document that SMEs dedicated to manufacturing lack training, techniques, tools, quality management systems, a culture of innovation and technological development that would allow them to remain and/or survive in the face of the demand and quality standards required by transnationals.

The products produced in these companies have high percentages of waste and/or reprocessing, which is reflected in high production costs, a greater number of customer complaints, a decrease in competitiveness, and, in addition to this, does not allow them to access other market sectors and position their products.

In this sense, work measurement as part of industrial engineering is one of the areas that has several support tools for process optimisation.

Authors such as Kanawaty [3] and Baines [4], agree that work measurement provides a means of measuring the time spent in carrying out an operation or series of operations, in such a way that it separates effective times from those that are not.

Guha and Verma [5] mention that there is a close relationship between time study and motion study, both of which are work measurement techniques used by industrial engineers to improve performance or operational efficiency. Motion surveying is concerned with the reduction of work content, waste and posture difficulties that lead to worker fatigue and aims to establish the best possible way of performing the work; whereas time surveying is concerned with investigating and reducing any non-value added activities associated with the work and establishing the standard time for an operation. Therefore, by using time and motion studies, it is possible to reduce waste and increase the efficiency and productivity of an organisation.

Moreover, proper space utilisation is an important source of cost reduction; proper layout of work areas reduces unnecessary movements and waste of time and energy.[3] Chandra et al.

Chandra et al. document in a time and motion study, conducted in the erection of steel structures in the construction industry, an increase in efficiency of 37.95%, and a reduction of idle time by 40.24% (after two weeks of implementation).[6] Su and Quiliche describe in a study of time and motion in the erection of steel structures in the construction industry an increase in efficiency of 37.95%, and a reduction of idle time by 40.24% (after two weeks of implementation).

Su and Quiliche describe in the time and motion study for a fishing industry, the reduction of standard operating times by 40.18%, as well as the increase of raw material productivity by 7.8%.[7] In the same study, Su and Quiliche describe the reduction of standard operating times by 40.18%, as well as the increase of raw material productivity by 7.8%.

Quintero and Omaña evidenced the optimisation of the supply chain in the creation of an oncology centre through the analysis and evaluation of the time and movements with the PERT - CPM technique, minimising the time from 52 to 39.10 weeks (24.79%).[8] Andrade-del Rio et al.

Andrade-del Rio et al. showed an increase in production of 5.49% as a result of a time and motion study in an industry that manufactures footwear, thus proving that the use of production management techniques increases productivity and efficiency in production processes.[9] Something similar occurs in a review article, in which Ankur and Darshak document the application of the work study tool in 10 different companies, in which a reduction in process time ranging from 5 to 20% was observed.[10] In this project, a study of time and motion was developed using the PERT - CPM technique.

In the present project, a time and motion study was developed to reduce unproductive travel times in an auto parts company.

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In one of the assembly lines of the VR model, excessive travel times were observed in the movements of the employees within the operation.

The tools used for the study were three: time analysis by elements [11, 12], process flow diagram to identify each of the activities [13, 14] and the spaghetti diagram [15, 16, 17], which is represented by the real flow with measurements and trajectories made by the collaborator. For the time analysis, ten samples were filmed (five for each method), it is worth mentioning that two methods were used: one piece at a time (UPV) and several pieces at a time (VPV) and the videos were analysed by decomposing the cycle into elements.

Subsequently, a proposal for redistribution of materials was created taking into account the principle of minimum distance travelled, which consists of placing the materials so that the distance is minimal, the pilot test was carried out taking into account restrictions and space factors, the results were analysed using the same three tools and the information was compared.

The objective of the project was to reduce unproductive travel times by at least 20% in the assembly line by studying times and movements and relocation of materials.

Development

For the development of this project it was necessary to determine the sequence of each of the activities that the employees carry out and to identify the problem of the distances travelled that affect their production time.

The company works with the UPV method, which consists of taking the parts one at a time so as not to damage them, however, this is complicated for the employees, causing delays in their activities, which is why they carry out their operations using VPV so as not to fall behind in the sequences.

It is worth mentioning that the programmed production per shift is 250 sequences and the real production is 238. This is why the walking time is an important factor that affects their cycle time and the delivery of sequences to the customer.

Five-time samples were taken by both methods (UPV and VPV) to get an approximation of the percentage of cycle time spent walking the parts (see Table 1).

UPV					
Model	VR				
Samples	30.23 s	32.26 s	41.16 s	28.07 s	46.13 s
Average	35.57 s				
T. Cycle	1.24 min				
Percentage in C.T.	42%				

VPV					
Model	VR				
Samples	30.59 s	30.97 s	24.44 s	32.85 s	29.86 s
Average	29.74 s				
T. Cycle	1.24 min				
Percentage in C.T.	35%				

Table 1: Average walking time of both methods and the percentage it represents in the cycle time of the VR model.

The following areas of opportunity for improvement were identified for the distribution of materials:

- Performing combined activities.
- Box racking takes up too much space.
- Unoccupied space on the shelves of the Cover
- Retractor and Cover RR of collaborator 1 right side.
- The space taken up by the water waste box.
- The space taken up by the foam box and cleaning equipment.

Methodology

To develop the time and motion study it was necessary to break down the operation into the different activities called "elements" to observe in detail if repetitive activities do not add value, ten samples were taken (videos of the two methods in which they make the operation) that were recorded to subsequently obtain accumulated operations and averages of each element.

Flow of taking VPV, VR LD model:

The following tables show the summaries of the time analysis by elements for each contributor; the average times for each activity are shown with their total average cycle time (see Table 2 and 3).

Summary of time analysis by elements VR LD VPV flow model		
Activity		Average time (s)
1	Takes box from rack	1.40
2	Walks and puts box on table	2.50
3	Walk around part	2.80
4	Takes part VRLD01	2.45
5	Cleaning and inspection	1.05
6	Walks to table	1.95
7	Places part in box	1.85
8	Walk around part	5.10
9	Takes part VRLD02	1.80
10	Cleaning and inspection	2.00
11	Walks part	2.30
12	Takes part VRLD03	1.89
13	Walk around part	2.40
14	Takes part VRLD04	2.00
15	Walk to table	4.70
16	Cleaning and inspection	7.40
17	Places in box	4.50
18	Waiting time	2.10
19	Walks to computer	2.90
20	Scan	3.10
	TOTAL average cycle time (s):	56.19

Table 2 Summary of the time analysis by elements, average times of the VPV method, employee LD

Summary of time analysis by elements VR LI VPV flow model		
Activity		Average time (s)
1	Walk by part	5.20
2	Take part VRLI01	2.35
3	Walk by part	1.75
4	Take part VRLI02	1.00
5	Walk through part	1.25
6	Take part VRLI03	1.15
7	Walk around part	2.10
8	Takes part VRLI04	1.80
9	Walk to table	3.40
10	Cleaning, inspection	15.70
11	Places parts in box	7.35
12	Waiting time	6.10
13	Walks to computer equipment	1.00
14	Detaches and attaches label	1.00
15	Walks to desk	0.90
16	Takes box	1.00
17	Walks to dolie	2.80
18	Deposits box in dolie	1.60
	TOTAL average cycle time (s):	57.45

Table 3 Summary of the time analysis by elements, average times of the VPV method, collaborator LI

Subsequently, process flow diagrams of the activities with their times and distances were made to identify operations, displacements, delays, etc. for each method and collaborator. The observed distances were measured with the help of a flexometer from the position of the table where they start the operation to the location of each material (Annexes 1- 4). Table 4 shows the summary of actual times and distances for the VPV method for both collaborators.

VR	
VPV method	
CURRENT DISTRIBUTION	
LD	LI
Cycle time: 56.19 s	Cycle time: 57.45 s
Distance travelled: 27.78 m	Distance travelled: 18.81 m
Travel time: 24.65 s	Travel time: 18.4 s
Target 20% reduction in travel time	
20% = 4.93 s	20% = 3.68 s

Table 4 Summary of times and distances for the VPV method for both collaborators

Subsequently, with the results obtained for both the average cycle time and the distance travelled in metres, the travel time was obtained by adding the seconds in which the flowchart indicates that the operator walks.

A layout of the current situation was designed in AutoCAD software and the spaghetti diagrams were drawn up on this.

This diagram shows this extracted information together with its walking flow represented by curved lines (see Figure 1).

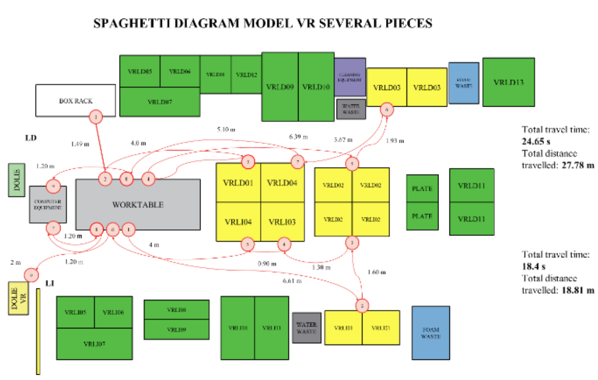

Figure 1 Spaghetti diagram of the VR model, VPV flow of both collaborators

UPV flow of VR model:

The following table shows the time summaries with the averages of the activities performed with the UPV flow of the VR model (see Table 5 and 6).

Summary of time analysis by elements Model VR LD flow UPV		
Activity		Average time (s)
1	Takes box from rack	1.80
2	Walks and puts box on table	2.00
3	Walk around part	5.60
4	Takes part VRLD02	1.30
5	Walks to table	5.20
6	Cleaning and inspection	3.20
7	Places in box	2.20
8	Walk around part	5.70
9	Takes part VRLD03	1.60
10	Cleaning and inspection	3.90
11	Walk to table	6.50
12	Place in box	1.05
13	Walk around part VRLD04	4.45
14	Takes part	1.00
15	Cleaning and inspection	2.06
16	Walks to table	8.60
17	Place in box	1.05
18	Walk around part VRLD01	2.10
19	Takes part	1.45
20	Cleaning and inspection	2.25
21	Walk to table	3.60
22	Places in box	1.00
23	Walks to computer equipment	1.10
24	Scans	6.80
	TOTAL average cycle time (min):	1.26

Table 5 Summary of the time analysis by elements, average times of the UPV method, collaborator LD.

Summary of time analysis by elements VR LI UPV flow model		
	Activity	Average time (s)
1	Walk by part	4.40
2	Take part VRLI01	1.00
3	Walk to table	4.80
4	Cleaning and inspection	3.10
5	Places in box	1.00
6	Walk around part	5.55
7	Takes part VRLI02	0.85
8	Walk to table	4.90
9	Cleaning and inspection	3.55
10	Places in box	1.85
11	Walks by part	3.70
12	Takes part VRLI03	1.10
13	Walk to table	3.70
14	Cleaning and inspection	2.90
15	Place in box	1.25
16	Walks by part	2.90
17	Takes part VRLI04	1.22
18	Walk to table	3.00
19	Cleaning and inspection	2.90
20	Place in box	1.20
21	Waiting time	12.20
22	Walks to computer equipment	1.60
23	Detaches and places sequence in box	1.25
24	Walks to desk	1.50
25	Takes box	1.00
26	Walks to dolie	3.00
27	Deposits box in dolie	1.00
	TOTAL average cycle time (min):	1.27

Table 6 Summary of the time analysis by elements, average times of the UPV method, collaborator LI.

Table 7 shows the summary of current times and distances for the UPV method, for both collaborators.

VR UPV Method	
CURRENT DISTRIBUTION	
LD	LI
Cycle time: 1.26 min	Cycle time: 1.27 min
Distance travelled: 47.29 m	Distance travelled: 48.6 m
Travel time: 40.75 s	Travel time: 39.05 s
Target 20% reduction in travel time	
20% = 8.15 s	20% = 7.81 s

Table 7 Summary of times and distances for the UPV method for both collaborators

The following spaghetti diagram representing the route flow, tracing the trajectories with curved lines, can be observed (see Figure 2)

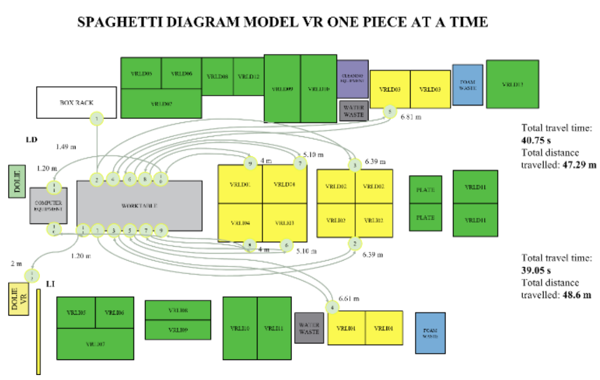

Figure 2 Spaghetti diagram of the VR model path, UPV flow. It shows the path of both collaborators

Proposed relocation of materials:

Having obtained the results of times for each of the models, collaborators and methods, the proposal for the relocation of materials was made, the areas of opportunity previously described were taken into account and the materials with the highest consumption for each model were identified, with the help of the materials area, which provided the necessary information. The following table shows the LD and LI materials ordered by model, from highest to lowest consumption with their standard pack and their existence in the line (see Table 8).

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Side	Name	Quantity	On-line
LI	VRLI04	6	12 boxes
LD	VRLD01	6	12 boxes
LI	VRLI03	8	12 boxes
LD	VRLD04	8	12 boxes
LI	VRLI02	22	2 containers
LD	VRLD02	22	2 containers
LI	VRLI01	21	2 containers
LD	VRLD03	21	2 containers

Table 8 Order of materials from highest to lowest consumption with their standard pack and the quantity on the line

The following layout proposal was made in the AutoCAD software, the most consumable materials were arranged and brought closer together, thus contemplating the following restrictions that would affect the test results:

- The box rack was proposed to be rotated 90° to the right to save space; the current layout is like this because another model's dollie is placed in that area.

- The rack containing very low consumption parts was changed from standard pack to container.

- The container for the larger and heavier material was placed at the end of the assembly area, leaving a 67 cm aisle.

- The worktable is 2.85 m long, and it was not possible to move it during the test, so it is necessary to adjust the length by two thirds.

The foam waste containers are set up in the lay-out because the VRLD02 and VRLI02 material arrives with a protective foam packaging on each piece; therefore, the container is changed 3 or 4 times per shift, so it is not possible to relocate it.

Once all of the above points had been taken into account, the final proposal was created in which the materials were arranged according to their frequency of consumption (see Figure 3).

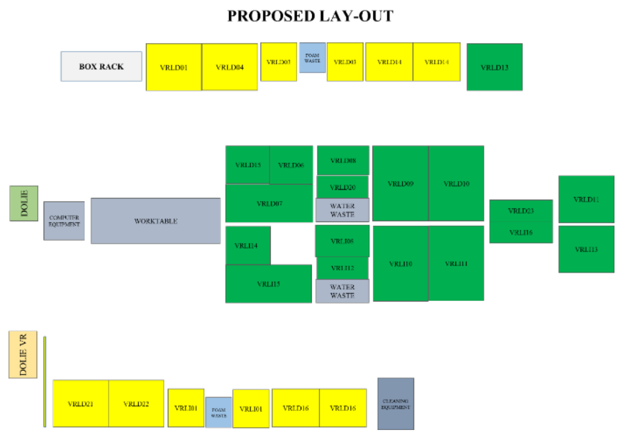

Figure 3 Lay-out proposal

Based on the new distribution of materials proposed for the pilot test, the collaborators were trained in relation to the new distribution of racks, and once they were located in their work area, the test was carried out.

Three samples were taken for each of the methods of the model, then the distances for the new distribution were measured and finally the flow diagrams of operations and spaghetti were drawn up.

Flow of taking VPV, VR model:

With the samples taken, the analysis of times by elements was carried out by taking out their accumulated and the averages of each activity in seconds; collaborator 1 LD (see Table 9), collaborator 2 LI (see Table 10).

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TIME ANALYSIS BY ELEMENTS						
Line or process:		Sequencing line A			Date:	
Operation:		Indoor sequencing LD model VR			Number of observations: 3	
Model VR VPV		REMARKS			TOTAL cs	PROM seg
	Description of the element	1	2	3		
1	Takes box from rack	0.01	0.43	0.85	0.03	1.00
		0.01	0.01	0.01		
2	Walks and puts box on table	0.03	0.455	0.88	0.075	2.50
		0.02	0.025	0.03		
3	Walk around part	0.1	0.515	0.95	0.2	6.67
		0.07	0.06	0.07		
4	Takes part VRD02	0.11	0.53	0.96	0.035	1.17
		0.01	0.015	0.01		
5	Walk around part	0.13	0.55	0.97	0.05	1.67
		0.02	0.02	0.01		
6	Takes part VRD03	0.14	0.56	0.98	0.03	1.00
		0.01	0.01	0.01		
7	Walks through part	0.16	0.58	1	0.06	2.00
		0.02	0.02	0.02		
8	Take part VRD04	0.17	0.59	1.01	0.03	1.00
		0.01	0.01	0.01		
9	Walk around part	0.18	0.6	1.02	0.03	1.00
		0.01	0.01	0.01		
10	Take part VRD01	0.185	0.61	1.03	0.025	0.83
		0.005	0.01	0.01		
11	Walk to table	0.21	0.63	1.05	0.065	2.17
		0.025	0.02	0.02		
12	Cleaning and inspection	0.31	0.72	1.13	0.27	9.00
		0.1	0.09	0.08		
13	Place in box	0.35	0.77	1.17	0.13	4.33
		0.04	0.05	0.04		
14	Walks to computer equipment	0.36	0.78	1.19	0.04	1.33
		0.01	0.01	0.02		
15	Scans	0.42	0.84	1.23	0.16	5.33
		0.06	0.06	0.04		
Total cycle time		0.42	0.42	0.39	1.23	41

Table 9 Results of the time analysis by elements of the collaborator 1 LD of the VR model, method several pieces at a time

Time analysis by elements						
Line or process:		Sequencing line A			Date:	
Operation:		Indoor sequencing LI model VR			Number of observations: 3	
Model VR VPV		Remarks			Total cs	Prom seg
	Item description	1	2	3		
1	Walk by part	0.04	0.515	0.945	0.125	4.17
		0.04	0.045	0.04		
2	Take part VRLI02	0.05	0.52	0.955	0.025	0.83
		0.01	0.005	0.01		
3	Walk by part	0.06	0.525	0.965	0.025	0.83
		0.01	0.005	0.01		
4	Take part VRLI01	0.07	0.535	0.975	0.03	1.00
		0.01	0.01	0.01		
5	Walk through part	0.09	0.555	0.995	0.06	2.00
		0.02	0.02	0.02		
6	Take part VRLI03	0.1	0.565	1.015	0.04	1.33
		0.01	0.01	0.02		
7	Walk around part	0.11	0.575	1.025	0.03	1.00
		0.01	0.01	0.01		
8	Takes part VRLI04	0.12	0.585	1.035	0.03	1.00
		0.01	0.01	0.01		
9	Walk to table	0.135	0.605	1.055	0.055	1.83
		0.015	0.02	0.02		
10	Cleaning, inspection	0.255	0.715	1.14	0.315	10.50
		0.12	0.11	0.085		
11	Places parts in box	0.31	0.755	1.18	0.135	4.50
		0.055	0.04	0.04		
12	Waiting time	0.39	0.835	1.26	0.24	8.00
		0.08	0.08	0.08		
13	Walks to computer equipment	0.4	0.845	1.27	0.03	1.00
		0.01	0.01	0.01		
14	Detaches and attaches label	0.42	0.855	1.29	0.05	1.67
		0.02	0.01	0.02		
15	Walks to desk	0.43	0.865	1.3	0.03	1.00
		0.01	0.01	0.01		
16	Takes box	0.44	0.875	1.31	0.03	1.00
		0.01	0.01	0.01		
17	Walks to dolie	0.46	0.895	1.33	0.06	2.00
		0.02	0.02	0.02		
18	Deposits box in dolie	0.47	0.905	1.34	0.03	1.00
		0.01	0.01	0.01		
Total cycle time		0.47	0.435	0.435	1.34	45

Table 10 Results of the time analysis by elements of the collaborator 2 LI of the VR model, method several pieces at a time

The flow charts of collaborator 1 LD (see Annex 5) and collaborator 2 LI (see Annex 6) are shown with the proposed activities and the times obtained from the test (see Table 11).

Proposed distribution	
LD	LI
Cycle time: 41 s	Cycle time: 44.66 s
Distance travelled: 17.62 m	Distance travelled: 18.37 m
Travel time: 17.34 s	Travel time: 13.83 s
The distance travelled was reduced:	
36.57% = **10.16 m**	2.33% = **0.44 m**
Travel time was reduced:	
29.65%=**7.31 s**	24.83% = **4.57 s**

Table 11 Proposed distribution for the VPV method

With the times and distances obtained, a spaghetti diagram was created showing their route when taking their material (see Figure 4).

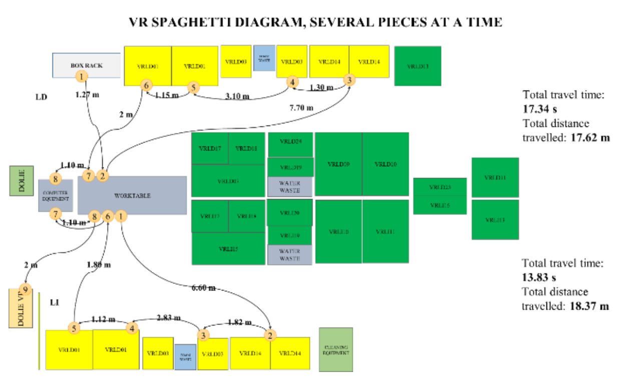

Figure 4 Spaghetti diagram of the VR model, method several pieces at a time

Flow of taking one piece at a time, model VR:

The following tables represent the time analysis by elements with their cumulative and averages for each activity in seconds, contributor 1 LD (see Table 12), contributor 2 LI (see Table 13).

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Time analysis by elements						
Line or process:		Sequencing line A			Date:	
Operation:		Indoor sequencing LD model VR			Number of observations: 3	
Model VR UPV		Remarks			Total cs	.Prom seg
	Item description	1	2	3		
1	Takes box from rack	0.005	0.61	1.265	0.02	0.67
		0.005	0.01	0.005		
2	Walks and puts box on table	0.02	0.63	1.28	0.05	1.67
		0.015	0.02	0.015		
3	Walk around part	0.08	0.68	1.33	0.16	5.33
		0.06	0.05	0.05		
4	Takes part VRD02	0.09	0.69	1.34	0.03	1.00
		0.01	0.01	0.01		
5	Walks to table	0.135	0.74	1.39	0.145	4.83
		0.045	0.05	0.05		
6	Cleaning and inspection	0.205	0.78	1.44	0.16	5.33
		0.07	0.04	0.05		
7	Places in box	0.215	0.795	1.46	0.045	1.50
		0.01	0.015	0.02		
8	Walk around part	0.265	0.84	1.5	0.135	4.50
		0.05	0.045	0.04		
9	Takes part VRD03	0.275	0.85	1.51	0.03	1.00
		0.01	0.01	0.01		
10	Cleaning and inspection	0.315	0.89	1.55	0.12	4.00
		0.04	0.04	0.04		
11	Walk to table	0.345	0.925	1.58	0.095	3.17
		0.03	0.035	0.03		
12	Place in box	0.355	0.935	1.59	0.03	1.00
		0.01	0.01	0.01		
13	Walk around part VRD04	0.375	0.945	1.61	0.05	1.67
		0.02	0.01	0.02		
14	Takes part	0.385	0.955	1.62	0.03	1.00
		0.01	0.01	0.01		
15	Cleaning and inspection	0.405	0.975	1.64	0.06	2.00
		0.02	0.02	0.02		
16	Walk to table	0.435	1.005	1.67	0.09	3.00
		0.03	0.03	0.03		
17	Place in box	0.445	1.025	1.68	0.04	1.33
		0.01	0.02	0.01		
18	Walk around part VRD01	0.46	1.04	1.695	0.045	1.50
		0.015	0.015	0.015		
19	Takes part	0.465	1.055	1.705	0.03	1.00
		0.005	0.015	0.01		
20	Cleaning and inspection	0.5	1.155	1.72	0.15	5.00
		0.035	0.1	0.015		
21	Walk to table	0.525	1.18	1.745	0.075	2.50
		0.025	0.025	0.025		
22	Places in box	0.535	1.195	1.755	0.035	1.17
		0.01	0.015	0.01		
23	Walks to computer equipment	0.545	1.205	1.765	0.03	1.00
		0.01	0.01	0.01		
24	Scans	0.6	1.26	1.81	0.155	5.17
		0.055	0.055	0.045		
Total cycle time		0.6	0.66	0.55	1.81	1.01

Table 12 Results of the time analysis by elements of collaborator 1 LD of the VR model, one piece at a time method

Time analysis by elements						
Line or process:		Sequencing line A			Date:	
Operation:		Indoor sequencing LI model VR			Number of observations: 3	
Model VR UPV		Remarks			Total cs	Prom seg
	Item description	1	2	3		
1	Walk by part	0.06	0.64	1.17	0.175	5.83
		0.06	0.06	0.055		
2	Take part VRLI01	0.065	0.645	1.175	0.015	0.50
		0.005	0.005	0.005		
3	Walk to table	0.115	0.69	1.225	0.145	4.83
		0.05	0.045	0.05		
4	Cleaning and inspection	0.145	0.72	1.255	0.09	3.00
		0.03	0.03	0.03		
5	Places in box	0.155	0.73	1.265	0.03	1.00
		0.01	0.01	0.01		
6	Walk around part	0.195	0.77	1.305	0.12	4.00
		0.04	0.04	0.04		
7	Takes part VRLI02	0.2	0.775	1.31	0.015	0.50
		0.005	0.005	0.005		
8	Walk to table	0.23	0.805	1.34	0.09	3.00
		0.03	0.03	0.03		
9	Cleaning and inspection	0.25	0.83	1.36	0.065	2.17
		0.02	0.025	0.02		
10	Places in box	0.26	0.84	1.37	0.03	1.00
		0.01	0.01	0.01		
11	Walks by part	0.27	0.86	1.38	0.04	1.33
		0.01	0.02	0.01		
12	Takes part VRLI03	0.28	0.865	1.385	0.02	0.67
		0.01	0.005	0.005		
13	Walk to table	0.3	0.89	1.405	0.065	0.17
		0.02	0.025	0.02		
14	Cleaning and inspection	0.315	0.91	1.42	0.05	1.67
		0.15	0.02	0.015		
15	Place in box	0.32	0.92	1.43	0.025	0.83
		0.005	0.01	0.01		
16	Walk around part	0.34	0.94	1.45	0.06	2.00
		0.02	0.02	0.02		
17	Takes part VRLI04	0.35	0.95	1.46	0.03	1.00
		0.01	0.01	0.01		
18	Walk table	0.365	0.97	1.475	0.05	1.67
		0.015	0.02	0.015		
19	Cleaning and inspection	0.39	0.985	1.495	0.06	2.00
		0.025	0.015	0.02		
20	Places in box	0.4	0.995	1.505	0.03	1.00
		0.01	0.01	0.01		
21	Waiting time	0.48	0.995	1.555	0.013	4.33
		0.08	0	0.05		
22	Walks to computer equipment	0.49	1.01	1.565	0.035	1.17
		0.01	0.015	0.01		
23	Detaches and places sequence in box	0.51	1.035	1.59	0.07	2.33
		0.02	0.025	0.025		
24	Walks table	0.52	1.045	1.6	0.03	1.00
		0.01	0.01	0.01		
25	Takes box	0.54	1.065	1.62	0.06	2.00
		0.02	0.02	0.02		
26	Walks to dolie	0.57	1.095	1.65	0.09	3.00
		0.03	0.03	0.03		
27	Deposits box in dolie	0.58	1.115	1.66	0.04	1.33
		0.01	0.02	0.01		
Total cycle time		0.58	0.535	0.545	1.66	0.55

Table 13 Results of the time analysis by elements of contributor 2 LI of the VR model, one piece at a time method

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The flow charts of contributor 1 LD (see annex 7) and contributor 2 LI (see annex 8) are shown with the proposed activities and the times obtained from the test (see Table 14).

Proposed distribution	
LD	**LI**
Cycle time: 1.01 min	Cycle time: 55.33 s
Distance travelled: 39.27 m	Distance travelled: 34.9 m
Travel time: 29.17 s	Travel time: 30 s
The distance travelled was reduced:	
16.95% = **8.02 m**	28.18% = **13.70 m**
Travel time was reduced:	
28.41%=**11.58 s**	23.17% = **9.05 s**

Table 14 Proposed distribution for the UPV method

With the measured times and distances, a spaghetti diagram was created showing their route when taking their material (see Figure 5).

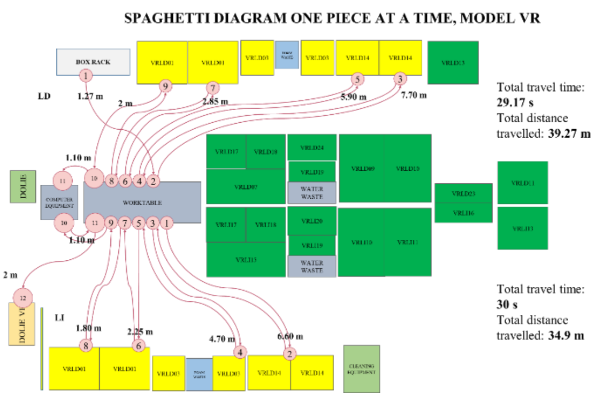

Figure 5 Spaghetti diagram of the VR model, one piece at a time method

Results

As part of the diagnostic stage, five runs were carried out to take the walking times performed by the collaborators in both methods (UPV and VPV) and on both sides (LD and LI), it was identified that the distance travelled by the UPV method on the right side is 47.29 m, and 48.6 m on the left side; while for the VPV method it is 27.78 m and 18.81 m on the right and left side respectively. When implementing the improvements in terms of material relocation, it was observed that the results of distance reduction for the VR model had a positive impact on time reduction. The new distribution of materials, racks and containers allowed a reduction of up to 13 m in the distances travelled by the collaborators in the UPV method and a reduction in time of 8 to 9 s; while for the VPV method the reductions in distances were up to 10 m and in time ranged from 4 to 7 s. (See figure 6).

VR		VR	
UPV Method		**VPV Method**	
CURRENT DISTRIBUTION		CURRENT DISTRIBUTION	
RH	LH	RH	LH
Cycle time: **1.26 min**	Cycle time: **1.27 min**	Cycle time: **56.19 s**	Cycle time: **57.45 s**
Distance travelled: **47.29 m**	Distance travelled: **48.6 m**	Distance travelled: **27.78 m**	Distance travelled: **18.81 m**
Travel time: **40.75 s**	Travel time: **39.05 s**	Travel time: **24.65 s**	Travel time: **18.4 s**
Target 20% reduction in travel time		Target 20% reduction in travel time	
20% = 8.15 s	20% = 7.81 s	20% = 4.93 s	20% = 3.68 s
PROPOSED DISTRIBUTION		PROPOSED DISTRIBUTION	
RH	LH	RH	LH
Cycle time: **1.01 min**	Cycle time: **55.33 s**	Cycle time: **41 s**	Cycle time: **44.66 s**
Distance travelled: **39.27 m**	Distance travelled: **34.9 m**	Distance travelled: **17.62 m**	Distance travelled: **18.37 m**
Travel time: **29.17 s**	Travel time: **30 s**	Travel time: **17.34 s**	Travel time: **13.83 s**
The distance travelled was reduced:		The distance travelled was reduced:	
16.95% = **8.02 m**	28.18% = **13.70 m**	36.57% = **10.16 m**	2.33% = **0.44 m**
Travel time was reduced:		Travel time was reduced:	
28.41%=**11.58 s**	23.17% = **9.05 s**	29.65%=**7.31 s**	24.83% = **4.57 s**

Figure 6 Comparative table of time and distance reduction results of the two methods, VR model

Annexes

Ubicación: Área de producción		Resumen						
DIAGRAMA DE FLUJO DE PROCESO								
Actividad: Secuenciado de pilares A LD		**Actividad**	**Actual**			**Propuesto**	**Ahorros**	
Fecha: 10 de Octubre del 2018		Operación	11					
Colaborador: LD		Transporte	5					
Analista:		Demora	1					
Marque el método y tipo apropiados: Método: ● Actual ☐ Propuesto Tipo: ● Obrero ☐ Material		Inspección	3					
		Almacenaje	0					
		Tiempo (seg)	59.19					
Comentarios:		Distancia (m)	27.78					
Descripción de la actividad:		Símbolo (Operación)	(Transporte)	(Demora)	(Inspección)	(Almacenaje)	**Tiempo (seg)**	**Distancia (m)**
1	Toma caja de rack	●					1.40	
2	Camina y pone caja en mesa		●				2.50	1.49
3	Camina por parte	●					2.80	4
4	Toma parte VRD01	●					2.45	
5	Limpieza e inspección				●		1.05	
6	Camina a la mesa		●				1.95	4
7	Coloca parte en caja	●					1.85	
8	Camina por parte	●					5.10	6.39
9	Toma parte VRD02	●					1.80	
10	Limpieza e inspección				●		2.00	
11	Camina por parte		●				2.30	1.93
12	Toma parte VRD03	●					1.89	
13	Camina por parte		●				2.40	3.67
14	Toma parte VRD04	●					2.00	
15	Camina a la mesa		●				4.70	5.10
16	Limpieza e inspección				●		7.40	
17	Coloca en caja	●					4.50	
18	Tiempo de espera			●			2.10	
19	Camina al equipo de cómputo	●					2.90	1.20
20	Escanea	●					3.10	
TOTAL:		11	5	1	3		56.19	27.78

Annex 1: Process flow diagram of partner 1 LD, VPV flow.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LI modelo VR	Actividad	Actual	Propuesto	Ahorros
Fecha: 10 de Octubre del 2018	Operación	11		
Colaborador: LI	Transporte	5		
Analista:	Demora	1		
Marque el método y tipo apropiados: Método: ■Actual □Propuesto Tipo: ■Obrero □Material	Inspección	1		
	Almacenaje	0		
	Tiempo (seg)	57.45		
Comentarios:	Distancia (m)	18.81		

Descripción de la actividad:		Símbolo ○	⇨	D	□	▽	Tiempo (seg)	Distancia (m)
1	Camina por parte	●					5.20	6.61
2	Toma parte VRLI01	●					2.35	
3	Camina por parte		●				1.75	1.60
4	Toma parte VRLI02	●					1.00	
5	Camina por parte		●				1.25	1.30
6	Toma parte VRLI03	●					1.15	
7	Camina por parte		●				2.10	0.90
8	Toma parte VRLI04	●					1.80	
9	Camina a mesa		●				3.40	4
10	Limpieza, inspección				●		15.70	
11	Coloca partes en caja	●					7.35	
12	Tiempo de espera			●			6.10	
13	Camina a equipo de cómputo	●					1.00	1.20
14	Desprende y coloca secuencia a caja	●					1.00	
15	Camina a mesa	●					0.90	1.20
16	Toma caja	●					1.00	
17	Camina a dolie		●				2.80	2
18	Deposita caja en dolie	●					1.60	
TOTAL		11	5	1	1	0	57.45	18.81

Annex 2: Process flow diagram of contributor 2 LI, VPV flow.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LD modelo VR	Actividad	Actual	Propuesto	Ahorros
Fecha: de Octubre del 2018	Operación	15		
Colaborador: LD	Transporte	5		
Analista:	Demora	0		
Marque el método y tipo apropiados: Método: ■Actual □Propuesto Tipo: ■Obrero □Material	Inspección	4		
	Almacenaje	0		
	Tiempo (min)	1.26		
Comentarios:	Distancia (m)	47.29		

Descripción de la actividad:		Símbolo ○	⇨	D	□	▽	Tiempo (seg)	Distancia (m)
1	Toma caja de rack	●					1.80	
2	Camina y pone caja en mesa		●				2.00	1.49
3	Camina por parte	●					5.60	6.39
4	Toma parte VRD02	●					1.30	
5	Camina a mesa		●				5.20	6.39
6	Limpieza e inspección				●		3.20	
7	Coloca en caja	●					2.20	
8	Camina por parte	●					5.70	
9	Toma parte VRD03	●					1.60	6.81
10	Limpieza e inspección				●		3.90	
11	Camina a la mesa		●				6.50	6.81
12	Coloca en caja	●					1.05	
13	Camina por parte	●					4.45	5.10
14	Toma parte VRD04	●					1.00	
15	Limpieza e inspección				●		2.06	
16	Camina a mesa		●				8.60	5.10
17	Coloca en caja	●					1.05	
18	Camina por parte VRD01	●					2.10	4
19	Toma parte	●					1.45	
20	Limpieza e inspección				●		2.25	
21	Camina a mesa		●				3.60	4
22	Coloca en caja	●					1.00	
23	Camina a equipo de cómputo	●					1.10	1.20
24	Escanea	●					6.80	
TOTAL:		15	5	0	4	0	1.26 min	47.29

Annex 3: Process flow diagram of collaborator 1 LD, UPV method.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LI	Actividad	Actual	Propuesto	Ahorros
Fecha: 10 de Octubre del 2018	Operación	17		
Colaborador: LI	Transporte	5		
Analista:	Demora	1		
Marque el método y tipo apropiados: Método: ■Actual □Propuesto Tipo: ■Obrero □Material	Inspección	4		
	Almacenaje	0		
	Tiempo (min)	1.27		
Comentarios:	Distancia (m)	48.6		

Descripción de la actividad:		Símbolo ○	⇨	D	□	▽	Tiempo (seg)	Distancia (m)
1	Camina por parte	●					4.40	6.39
2	Toma parte VRLI01	●					1.00	
3	Camina a mesa		●				4.80	6.39
4	Limpieza e inspección				●		3.10	
5	Coloca en caja	●					1.00	
6	Camina por parte	●					5.55	6.61
7	Toma parte VRLI02	●					0.85	
8	Camina a la mesa		●				4.90	6.61
9	Limpieza e inspección				●		3.55	
10	Coloca en caja	●					1.85	
11	Camina por parte	●					3.70	5.10
12	Toma parte VRLI03	●					1.10	
13	Camina a mesa		●				3.70	5.10
14	Limpieza e inspección				●		2.90	
15	Coloca en caja	●					1.25	
16	Camina por parte	●					2.90	4
17	Toma parte VRLI04	●					1.22	
18	Camina a mesa		●				3.00	4
19	Limpieza e inspección				●		2.90	
20	Coloca en caja	●					1.20	
21	Tiempo de espera			●			12.20	
22	Camina al equipo de cómputo	●					1.60	1.20
23	Desprende y coloca secuencia a caja	●					1.25	
24	Camina a mesa	●					1.50	1.20
25	Toma caja	●					1.00	
26	Camina a dolie		●				3.00	2
27	Deposita caja en dolie	●					1.00	
TOTAL:		17	5	1	4	0	1.27 min	48.6

Annex 4: Process flow diagram of the UPV method of collaborator 2 LI.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LD modelo VR	Actividad	Actual	Propuesto	Ahorros
Fecha: 25 de Noviembre del 2018	Operación		9	2
Colaborador: LD	Transporte		5	0
Analista:	Demora		0	1
Marque el método y tipo apropiados: Método: □Actual ■Propuesto Tipo: ■Obrero □Material	Combinada		1	2
	Almacenaje		0	0
	Tiempo (seg)		41	15.19
Comentarios:	Distancia (m)		17.62	10.16

Descripción de la actividad:		Símbolo ○	⇨	D	□	▽	Tiempo (seg)	Distancia (m)
1	Toma caja de rack	●					1.00	
2	Camina y pone caja en mesa		●				2.50	1.27
3	Camina por parte	●					6.67	7.70
4	Toma parte VRD02	●					1.17	
5	Camina por parte		●				1.67	1.30
6	Toma parte VRD03	●					1.00	
7	Camina por parte		●				2.00	3.10
8	Toma parte VRD04	●					1.00	
9	Camina por parte		●				1.00	1.15
10	Toma parte VRD01	●					0.83	
11	Camina a la mesa		●				2.17	2
12	Limpieza e inspección				●		9.00	
13	Coloca en caja	●					4.33	
14	Camina al equipo de cómputo	●					1.33	1.10
15	Escanea	●					5.33	
TOTAL:		9	5	0	1	0	41	17.62

Annex 5: Process flow diagram of collaborator 1 LD, VPV method.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LI modelo VR	**Actividad**	**Actual**	**Propuesto**	**Ahorros**
Fecha: 10 de Octubre del 2018	Operación		11	0
Colaborador: LI	Transporte		5	0
Analista:	Demora		1	0
Marque el método y tipo apropiados:	Combinada		1	0
Método: ☐ Actual ◉ Propuesto	Almacenaje		0	0
Tipo: ◉ Obrero ☐ Material	Tiempo (seg)		44.66	12.79
Comentarios:	Distancia (m)		18.37	0.44

Descripción de la actividad:		Símbolo ●	⇨	D	□	▼	Tiempo (seg)	Distancia (m)
1	Camina por parte	●					4.17	6.60
2	Toma parte VRLI02	●					0.83	
3	Camina por parte		●				0.83	1.82
4	Toma parte VRLI01	●					1.00	
5	Camina por parte		●				2.00	2.83
6	Toma parte VRLI03	●					1.33	
7	Camina por parte		●				1.00	1.12
8	Toma parte VRLI04	●					1.00	
9	Camina a mesa		●				1.83	1.80
10	Limpieza e inspección				●		10.50	
11	Coloca partes en caja	●					4.50	
12	Tiempo de espera			●			8.00	
13	Camina a equipo de cómputo	●					1.00	1.10
14	Desprende y coloca secuencia a caja	●					1.67	
15	Camina a mesa	●					1.00	1.10
16	Toma caja	●					1.00	
17	Camina a dolie		●				2.00	2
18	Deposita caja en dolie	●					1.00	
TOTAL		11	5	1	1	0	44.66	18.37

Annex 6: Process flow diagram of contributor 2 LI, VPV method.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LD modelo VR	**Actividad**	**Actual**	**Propuesto**	**Ahorros**
Fecha: 25 de Noviembre del 2018	Operación		15	0
Colaborador: LD	Transporte		5	0
Analista:	Demora		0	0
Marque el método y tipo apropiados:	Combinada		4	0
Método: ☐ Actual ◉ Propuesto	Almacenaje		0	0
Tipo: ◉ Obrero ☐ Material	Tiempo (min)		1.01	25 seg
Comentarios:	Distancia (m)		39.27	8.02

Descripción de la actividad:		Símbolo ●	⇨	D	□	▼	Tiempo (seg)	Distancia (m)
1	Toma caja de rack	●					0.67	
2	Camina y pone caja en mesa		●				1.67	1.27
3	Camina por parte	●					5.33	7.70
4	Toma parte VRD02	●					1.00	
5	Camina a mesa		●				4.83	7.70
6	Limpieza e inspección				●		5.33	
7	Coloca en caja	●					1.50	
8	Camina por parte	●					4.50	5.90
9	Toma parte VRD03	●					1.00	
10	Limpieza e inspección				●		4.00	
11	Camina a la mesa		●				3.17	5.90
12	Coloca en caja	●					1.00	
13	Camina por parte	●					1.67	2.85
14	Toma parte VRD04	●					1.00	
15	Limpieza e inspección				●		2.00	
16	Camina a mesa		●				3.00	2.85
17	Coloca en caja	●					1.33	
18	Camina por parte	●					1.50	2
19	Toma parte VRD01	●					1.00	
20	Limpieza e inspección				●		5.00	
21	Camina a mesa		●				2.50	2
22	Coloca en caja	●					1.17	
23	Camina a equipo de cómputo	●					1.00	1.10
24	Escanea	●					5.17	
TOTAL		15	5	0	4	0	1.01 min	39.27

Annex 7: Process flow diagram of partner 1 LD, VPV method.

Ubicación: Área de producción	Resumen			
Actividad: Secuenciado de pilares A LI	**Actividad**	**Actual**	**Propuesto**	**Ahorros**
Fecha: 25 de Noviembre del 2018	Operación		17	0
Colaborador: LI	Transporte		5	0
Analista:	Demora		1	0
Marque el método y tipo apropiados:	Combinada		4	0
Método: ☐ Actual ◉ Propuesto	Almacenaje		0	0
Tipo: ◉ Obrero ☐ Material	Tiempo (seg)		55.33	20.87
Comentarios:	Distancia (m)		34.9	13.70

Descripción de la actividad:		Símbolo ●	⇨	D	□	▼	Tiempo (seg)	Distancia (m)
1	Camina por parte	●					5.83	6.60
2	Toma parte VRLI02	●					0.50	
3	Camina a mesa		●				4.83	6.60
4	Limpieza e inspección				●		3.00	
5	Coloca en caja	●					1.00	
6	Camina por parte	●					4.00	4.70
7	Toma parte VRLI01	●					0.50	
8	Camina a la mesa		●				3.00	4.70
9	Limpieza e inspección				●		2.17	
10	Coloca en caja	●					1.00	
11	Camina por parte	●					1.33	2.25
12	Toma parte VRLI03	●					0.67	
13	Camina a mesa		●				2.17	2.25
14	Limpieza e inspección				●		1.67	
15	Coloca en caja	●					0.83	
16	Camina por parte	●					2.00	1.80
17	Toma parte VRLI04	●					1.00	
18	Camina a mesa		●				1.67	1.80
19	Limpieza e inspección				●		2.00	
20	Coloca en caja	●					1.00	
21	Tiempo de espera			●			4.33	
22	Camina al equipo de cómputo	●					1.17	1.10
23	Desprende y coloca secuencia a caja	●					2.33	
24	Camina a mesa	●					1.00	1.10
25	Toma caja	●					2.00	
26	Camina a dolie		●				3.00	2
27	Deposita caja en dolie	●					1.33	
TOTAL:		17	5	1	4	0	55.33	34.9

Annex 8: Process flow diagram of contributor 2 LI, UPV method.

Acknowledgements

To the Polytechnic University of the State of Morelos and to the auto parts company for the facilities granted for the realisation of this project.

Conclusions

At the beginning of the project, an inadequate distribution of materials was identified in the assembly area, with the most consumed materials being further away than those of lower consumption. This problem was addressed with a study of times and movements with the help of an analysis of times by elements, which served as support to visualise the time of each activity carried out, the delays and distances involved.

It was possible to carry out the pilot test in spite of space restrictions that did not allow all the necessary adjustments to be made.

The proposed objective was achieved as it was possible to reduce by more than 20% the time and distance travelled for the realisation of the VR model for both methods.

It is worth mentioning that this distribution remained fixed on the line and it is preferable to take into account the space of the work table, and also to train both collaborators as there is still a difference in the operating times of each one.

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The implementation of augmented reality as a support instrument in the training of predictive maintenance

La implementación de la realidad aumentada como un instrumento de apoyo en el adiestramiento del mantenimiento predictivo

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Abstract

Augmented Reality is an emerging technology, the use of which can complement the perception and interaction with the real world and allows the student to be in a real environment augmented with additional information generated by the computer. This technology is gradually being introduced into new areas of application such as, among others, the training of industrial process operators, marketing, virtual tours, among others. The academic world is not on the fringes of these initiatives and has also begun to introduce Augmented Reality technology in some of its disciplines. However, the knowledge and applicability of this technology in teaching is minimal; Among other reasons, it is due to the very nature and state of development of said technology, as well as its scarce presence in the daily spheres of society. The development of initiatives in the use of this technology in education and its dissemination will contribute to its extension in the teaching community and especially in helping the understanding of various topics where it is sometimes not possible to have expensive materials for students of maintenance races

Augmented reality, Education, Predictive maintenance

Resumen

La Realidad Aumentada es una tecnología emergente, cuyo uso puede complementar la percepción e interacción con el mundo real y permite al estudiante estar en un entorno real aumentado con información adicional generada por la computadora. Esta tecnología está poco a poco introduciéndose en nuevas áreas de aplicación como son entre otras el entrenamiento de operarios de procesos industriales, marketing, recorridos virtuales entre otras. El mundo académico no está al margen de estas iniciativas y también ha empezado a introducir la tecnología de la Realidad Aumentada en algunas de sus disciplinas. Sin embargo, el conocimiento y la aplicabilidad de esta tecnología en la docencia es mínima; entre otros motivos se debe a la propia naturaleza y estado de desarrollo de dicha tecnología, así como también a su escasa presencia en los ámbitos cotidianos de la sociedad. El desarrollo de iniciativas en la utilización de esta tecnología en la educación y su divulgación contribuirán a su extensión en la comunidad docente y sobre todo en la ayuda de la comprensión de diversos temas donde a veces no es posible contar con materiales costosos para los alumnos de las carreras de mantenimiento.

Realidad aumentada, Educación, Mantenimiento predictivo

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Introduction

In these times, the technological and economic changes that are taking place generate uncertainty in recent graduates as they doubt their ability to get a job, as industries increasingly require an infinite number of skills in the area of maintenance, to achieve the optimal functioning of the production areas.

With this precedent, it is of great importance to link the industry with the academy before the stay, so that employers can be up to date with the scope, applications and potential of the students. Taking the above into account, this research contributes scientifically and academically with the aim of documenting and providing didactics to involve students in the subject of Industry 4.0, seeking the enrichment of new professional competences.

Likewise, it was also possible to provide tools for analysing projects for their feasibility and application in industry, as the subject of Augmented Reality had never been addressed at the Technological University of Jalisco as a support tool for maintenance, which presented an opportunity to contribute to knowledge with the learning and teaching of new professional competences, both for students and teachers.

Hence the intention to use the topic of augmented reality as a subject focused on the development of applications in the area of predictive maintenance, taking advantage of the example of some companies that already use it in their inspection processes.

Literature review

The integration of emerging technologies in industry has been one of the most recurrent lines of research in the last 10 years, and some of the contributions of the state that are related to the continuous evolution of these technologies stand out (Furth, 2011; Villalustre, 2016). In recent years, university education systems have brought about a series of alternatives and proposals for education using the Internet as a great communication tool and trying to displace face-to-face classes (Sevillano and Vázquez-Cano, 2015).

Similarly, the challenge for universities, in this framework, consists of the search for new educational alternatives around professional competences rather than around traditional subjects in such a way as to stimulate the development of didactic proposals that involve collaborative work for the promotion of valuable learning and the successive increase in the teaching activity of the use of emerging technologies that combine different approaches that are more creative and collaborative (Bressler and Bodzin, 2013; Vázquez-Cano et al., 2015; Álvarez-Marín et al., 2017).

In this sense, the educational and technological reality within the university goes hand in hand with the incorporation of new tools that bring students closer, in a simple way, to the curricular content. One of the technologies that is currently gaining momentum and importance is Augmented Reality, which has been making headway, especially in higher education (Chang, et al., 2013; Cuendet, et al., 2013; Cabero and García, 2016; Barroso and Gallego-Pérez, 2017). Nowadays, emerging technologies such as Augmented Reality (AR) are becoming more popular (Kipper and Rampolla, 2012; Moreno-Martínez and Leiva-Olivencia, 2017); this technology is estimated to have a training horizon in schools of 3 to 5 years (Johnson et al., 2013). Also, it can be observed that in the latest "EduTrend" report carried out by the Observatory of the Tecnológico de Monterrey (Tecnológico de Monterrey, 2015), it is placed as a technology with an adoption time in the centres of the Tecnológico de Monterrey of between one and two years. Augmented Reality (AR), according to Cabero and García (2016) and Barroso, et al. (2016), is a technology that allows the combination of digital information and physical information in real time through various technological supports such as, for example, tablets or smartphones, to generate a new and beneficial educational scenario.

On the other hand, Fombona et al. (2012) and Neven et al. (2011) define augmented reality as a tool that allows images of reality to be enlarged, based on their capture by the camera of a PC or smartphone that adds virtual elements for the construction of a mixed reality with computer objects.

Cabero and García (2016), for their part, mention the most significant properties: being a mixed reality, integrated in real time, possessing a diversity of layers of digital information, which is interactive and which, through its use, enriches or alters the information. Augmented Reality therefore offers countless educational possibilities and immense potential to enhance learning and teaching (Bacca et al., 2014; Prendes, 2015). In addition, it provides students with access to rich, varied and meaningful multimedia content, providing them with a relevant context with which they can interact immediately (Cabero and García, 2016). As mentioned by Di Serio et al. (2013) augmented reality systems are distinguished by three basic properties: a) combining real and virtual objects in a real environment, b) aligning real and virtual objects with each other, and c) executing them interactively and in real time. From a technological point of view, Cabero and Barroso (2016), adding to the proposals of various authors, mention the different resources and technological devices required for the production and observation of augmented reality objects, specifically the authors point out the following: 1) An element that captures the image of the reality that the users are seeing (computer screen, a telephone, or a video console); 2) A device to project the mixture of real images with the synthesised images (the three mentioned above can be used); 3) A processing element or several processing elements that are necessary for the production and observation of augmented reality objects; 3) A processing element or several that work together whose function is to interpret the real world information received by the user, generate the virtual information that each specific service needs and mix it in an appropriate way (computers, mobile phones or video game consoles); 4) A specific type of software for the production of the programme; 5) An augmented reality activator or markers that can be QR codes, physical objects, GPS....); and 6) A content server where the virtual information that we want to incorporate into reality is located". Augmented Reality requires contextualised studies in training processes that allow us to identify its advantages and limitations; a technology whose functionality and practicality has been focused on by various researchers (Prendes, 2015; Garay et al., 2017).

Methodology

By implementing the use of Augmented Reality as a didactic resource in University education for predictive maintenance applications with 2nd term students it will serve to strengthen professional competencies, position the brand and strengthen the sense of relevance in both teachers and students at UTJ.

Hence, this research is proposed as an exploratory study whose main objective is to raise awareness of augmented reality as an option for developing competences in university education. To this end, a methodological conception based on virtual collaborative research-action by the student was taken into account as an alternative for encouraging their own generic and specific competences in the Higher Education Area (Pool-Cibrian and Martínez-Guerrero, 2013). This methodological idea is based on fostering the responsibility of team or collaborative work. The experiences provided by Millis and Rhem (2010) show that collaborative or team work is a strategy that contributes to enhancing and promoting learning by allowing different points of view and opinions to be valued, which helps to improve one's own perspective and facilitates exchange, as it stimulates and guides learning to successfully address communicative situations between peers. Quantitative approaches are not able to describe cognitive abilities in virtual learning environments. Usual statistical techniques lead to a perception of structures, which means that their results are always distributions (univariate or multivariate) of individual attributes. Therefore, we opted for a methodology with a qualitative approach that allows us to analyse in greater depth the functionality, limitations and possibilities of the didactic use of augmented reality by students who have used it in training processes.

The qualitative analysis was based on a coding and categorisation process structured in two stages: the descriptive stage and the interpretative stage. The procedure was organised in three phases: 1) Phase 1: "Segmentation and identification of units of meaning and grouping into descriptive categories". 2) Phase 2: "Construction of a system of emerging thematic nuclei" and 3) Phase 3: "Identification of qualitative domains (sequential and transversal analysis of the categories)".

The participant sample consisted of 24 students from the Technological University of Jalisco with the following characteristics: corresponding to the second semester of the mechatronics degree in the flexible manufacturing area. The questionnaire "Didactic use of Augmented Reality as a tool for predictive maintenance" was designed (The link is: https://docs.google.com/forms/d/e/1FAIpQLSelA55_O2pPbPRFj2w8JbOs7X20S5JIiT6gwX5TMP6jW9485g/viewform).

The design of the questionnaire was based on the theoretical considerations made by Barroso and Gallego-Pérez (2017) and was reviewed by expert judgement in order to delimit the main possibilities of Augmented Reality applied in training contexts applied to predictive maintenance in Higher Education. The main objective of the questionnaire was to gather the opinion of the students according to descriptive and evaluative aspects of the different applications of Augmented Reality as a tool to facilitate predictive maintenance within University Education.

Results

The objective pursued in this research is to present a project model for the development of predictive maintenance applications using augmented reality as a strategy to develop new professional skills, and at the same time to position the brand and sense of belonging of the participants involved towards the Universidad Tecnológica de Jalisco.

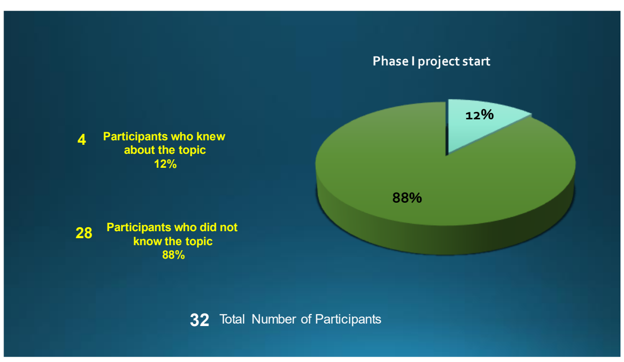

Figure 1 Start of the project
Source: Own elaboration

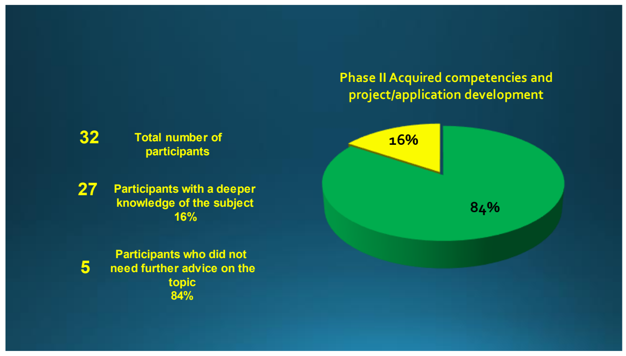

Figure 2 Phase II Competences acquired and project development / application
Source: Own elaboration

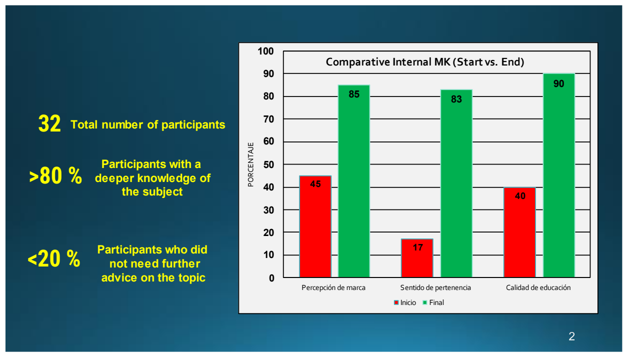

Figure 3 Comparison of start vs. end
Source: Own elaboration

Discussion

I consider that the main objective was achieved by increasing the level of acquired competences in the participants, as well as increasing the level of brand perception and brand belonging, with respect to the general population of the university.

As a result, it can be mentioned that the present research made its contributions and benefits, leaving the precedent of taking advantage of unit 3 of visualisation of the subject of electrical circuits, the development of projects with emerging technologies, applicable to these times of change such as industry 4.0.

By innovating educational programmes with emerging technologies, students increase their sense of perception, belonging and branding towards the university.

Figure 4 UTJ AR logo developed in class
Source: Own elaboration

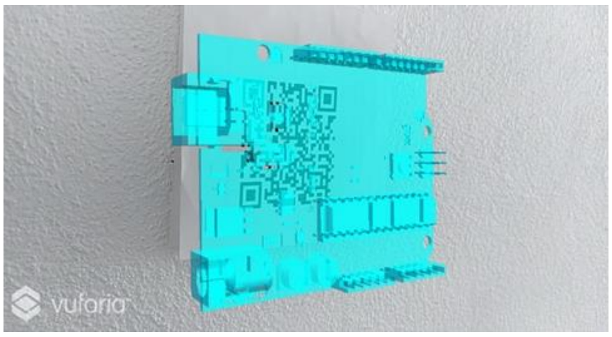

Figure 5 Arduino AR board developed in class
Source: Own elaboration by the students themselves

And as a new way of positioning the Technological University of Jalisco within the state's higher education ecosystem, using the subject of drones with a dual purpose. Development of professional skills and a sense of belonging to the UTJ.

Conclusions

Although this research contributes new content that should be considered for incorporation into teaching - such as increasing competences or motivation, it is necessary to increase studies on the incorporation of this technology in the educational field. This is due to the fact that the vast majority of the research that has been carried out focuses on less specific actions, so it is necessary to give a more specific approach to the use of augmented reality as a tool for teaching predictive maintenance. On the other hand, the results that can be seen in other research, allow us to appreciate the panorama that Augmented Reality technology can be incorporated into university teaching to facilitate the acquisition of skills by students, hence it is due to a number of aspects, among which we could highlight: the interactive and participatory context that it creates for students, as well as the levels of satisfaction; and, on the other hand, the motivation and acceptance that this technology awakens in the students.

Finally, it is necessary to emphasise that, if this technology is to be incorporated into training, it is necessary for universities to have the appropriate equipment to carry it out.

As an anecdote it is worth mentioning that one as a teacher is the guide of the students, since experience has shown that the students can produce excellent works in a self-taught way, it is only a question of motivation.

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Maintenance management system for a fleet of official vehicles in a higher education institution

Sistema de administración de mantenimiento a flotilla de vehículos oficiales en una institución de educación superior

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Abstract

This investigation is developed in a Higher Education Institution (IES), being the loan process of official vehicles of the fleet of the Technological Institute of Sonora (ITSON), administered by the Headquarters of the Department of General Services and Maintenance (JDSGyM), which presents difficulties as the vehicles are not in optimal operating conditions in the provision of the transfer service between the different campuses, as well as departures to regional and international events of a cultural, sports, academic and research nature; as a result of mechanical and electrical failures, which are detected by the user already in the corresponding commission, putting their integrity and safety at risk; addressing this need through the Reliability Centered Maintenance (RCM) tool. The objective was to formulate a proposal for maintenance activities, through the RCM methodology, to have a relevant preventive maintenance program. The procedure was: Evaluate the object under study; collect data; identify actual and potential failures; proposal of a preventive maintenance program; design training protocol and delivery of results. These were: a pertinent preventive maintenance program (database) and a training program. This achieving the objective of this investigation.

Program, Maintenance, Fleet

Resumen

Esta investigación se desarrolla en una Institución de Educación Superior (IES), siendo el proceso de préstamo de vehículos oficiales de la flotilla del Instituto Tecnológico de Sonora (ITSON), administrada por la Jefatura del Departamento de Servicios Generales y Mantenimiento (JDSGyM), el que presenta dificultades al no encontrarse en condiciones óptimas de funcionamiento los vehículos en la prestación del servicio de traslado entre los diferentes campus, así como salidas a eventos regionales e internacionales de carácter cultural, deportivo, académico e investigación; a consecuencia de fallas mecánicas y eléctricas, las cuales son detectadas por el usuario ya en la comisión correspondiente, poniendo en riesgo su integridad y seguridad; abordando esta necesidad a través de la herramienta Mantenimiento Centrado en Confiablidad (RCM). El objetivo consistió en realizar una propuesta de actividades de mantenimiento, a través de la metodología RCM, para contar con un programa de mantenimiento preventivo pertinente. El procedimiento fue: Evaluar el objeto bajo estudio; recolectar datos; identificar fallos ocurridos y potenciales; propuesta de un programa de mantenimiento preventivo; diseñar protocolo de capacitación y entrega de resultados. Los mismos fueron: un programa de mantenimiento preventivo pertinente (base de datos) y un programa de capacitación. Logrando así el objetivo de esta investigación.

Programa, Mantenimiento, Flotilla

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Introduction

Nowadays, maintenance operations are focused on carrying out studies on equipment and processes prone to failure, applying statistical techniques, measurement methodologies, economic management of procedures, among others, which allow for planning tasks and resources to prevent failures or production stoppages from occurring (Leyva, 2018). In this way, the aim is to reduce maintenance and prevent halthing production in the company as much as possible, which cause substantial losses of resources (Chanta, 2017).

Maintenance is the set of operations and required upkeeps to ensure that facilities, buildings, industries, among others, can continue to function properly (Real Academia Española, [RAE], 2021). Bermúdez-Puente (2019); and Fernández (2018) consider that the common factor in the maintenance objective is to ensure the longest possible service life of production plants and machinery, aiming for maximum availability, profitability, productivity and operational safety. According to Bermúdez-Puente (2019) and Gutiérrez y Valencia (2020); maintenance is classified into: Corrective Maintenance: repair or replacement of equipment after it has already failed; Preventive Maintenance: consisting of refurbishing or replacing components of a piece of equipment or the equipment as a whole; Predictive Maintenance: consisting of carrying out inspections at regular time intervals and taking action to prevent failures and their consequences, including inspections with instruments or with human senses; Detective Maintenance: the regular inspection of the internal functions of the equipment to check if they are failing and repair them if necessary; Upgrade Maintenance: is the modification or redesign of the original condition of the equipment or its installation method; Total Productive Maintenance (TPM) is defined as the removal of production losses due to the condition of equipment, or, in other words, keeping equipment ready to produce products of the expected quality at its maximum capacity, without unscheduled downtime.

Reliability Centered Maintenance (RCM), is a methodology to elaborate maintenance plans that include all types of strategies (preventive, predictive, fault finding, etc.) expressed by Tambra-Sanchez (2021). In the same order of ideas it is a process for determining what needs to be done to ensure that any equipment continues to do what its users want it to do, in its current operational context (Moubray, 2021 and Melendres-Quispe, 2019).

In any industry it is essential to know the performance for which indicators are variables that attempt to measure, quantitatively or qualitatively, events occurring within the company in order to support actions. Some of the main attributes of a good indicator are availability, simplicity, specificity and reliability (Silva-Astudillo, 2019). According to Quintana (2020), they are a quantitative, observable and verifiable expression that allows describing characteristics, behaviors or phenomena of reality. In the words of López and Valdiviezo (2017), indicators empower to optimally evaluate the performance of the maintenance management system and plan activities in line with the goals and objectives outlined by the department, which are; Reliability: ability of an asset to perform a required function; Maintainability: which will allow for prediction, evaluation and improvement of decisions; and Availability: ability of the equipment to operate under stable conditions. In the opinion of López (2019), costs are the set of resources sacrificed or lost to achieve a specific good, being for Suárez (2019), a consideration that is provided in order to receive a product or service. In turn, for IMG (2020), maintenance costs represent a high proportion of total production costs.

For Muyulema et al. (2020) and Aguirre (2018), they are the unavoidable expenses to maintain a production line; whereas Torres (2017) argues that the decrease in the budget limits the amount of investments programmed to maintain the company at its optimal level; affecting its productivity; which is defined by López (2018) and Vásquez (2018) as the relationship between the amount of goods and services produced and the amount of resources used in manufacturing, which serves to evaluate the performance of workshops, machines, work equipment and employees.

The above is supported by the efficient use of the fleet defined by Nissan Business & Fleet (2022) as a group of vehicles operated under a single business; in turn, according to Todo Seguros (2022), a fleet is a set of specific vehicles or of different types, from cars, trailers, pick-ups, motorcycles and trucks, which are part of the assets of a company in order to carry out an activity according to its line of business. For the efficient use of a fleet, it is necessary that it be managed through databases, which are very useful tools for managing large files and facilitating information retrieval (IONOS Digital Guide, 2019). They are an essential part of information systems: they enable to store, modify, process and interconnect the information necessary for the proper functioning of software, applications and programs designed to run on computers, servers or mobile applications (Arcidiacono, 2021 and OMS, 2021). The aforementioned is associated with continuous improvement being for ISO 9001 (2015), a process that seeks to improve the products, services and processes of an organization through a general attitude, which forms the basis for ensuring stabilization and continuous detection of errors or areas of opportunity. As stated by Leyva (2018), it is to carry out activities and constant changes that are applied to improve products or processes in order to seek total quality and customer satisfaction or stakeholders. Taking into account Evans and Lindsay (2020), process improvement is an important business strategy in the markets because customer loyalty is based on the value delivered, this is created through business processes. These changes should be a proactive management task which should be considered as an opportunity and not simply as a reaction to problems and threats from competitors.

The object of the study is the institutional vehicle fleet as part of the general services offered by the JDSGyM, which is the lease of these vehicles. The fleet consists of 150 units: 61 pick-ups, 51 sedans, 19 vans and 1 motorcycle, 13 trucks, 3 minibuses, 1 wagon and 1 bus. These vehicles are assigned to different areas of the six ITSON campuses with different locations, two in Ciudad Obregón, two in Navojoa, one in Guaymas and one in Empalme, in the state of Sonora, Mexico.

The use of the vehicles is for institutional purposes such as regular transportation services between the different campuses, as well as trips to regional and international cultural, sports, academic and research events. The units have mechanical and electrical failures detected by the user during commissions which affects arrival and departure times and endangering the safety and integrity of the personnel occupying such vehicles because of not being in optimal operating conditions and not having adequate control of the different preventive maintenance services that each unit should have (ITSON, 2021). Finally, the institution wishes to minimize unforeseen events resulting from not planning preventive maintenance of official vehicles. Therefore, it was necessary to improve the preventive maintenance program through the RCM methodology, in order to have a relevant maintenance program.

Methodology to be developed

The object of study was the institutional vehicle fleet. The methodology developed was the adaptation of the study of Naula and Tapia (2019), implementation of the Reliability Centered Maintenance methodology.

The procedure was: 1) to evaluate the object under study; 2) to collect data; 3) to identify occurrences and potential failures; 4) to propose a preventive maintenance program; 5) to design a training protocol; and 6) to deliver results.

Results

The result obtained is presented. It contains large tables, which due to their size, only a part will be presented.

Describing the area under study

A list of data families was made for each vehicle, including purchase invoice, insurance policy, list of claims, brand, model, type of vehicle, type of engine, fuel consumption, maintenance history, description of activities performed, maintenance cost history, criteria for scheduling maintenance and maintenance projections.

Data collection

This stage started with the evaluation of the object of study. For this purpose, a form was designed using the Google Forms platform, which has the function of collecting yet unknown information by filling in the fields indicated in the tool. In order to improve the accuracy of the collection, a space was assigned for attaching an image of each element requested in the form. The format presented in Table 1 was also prepared in order to calculate the percentage known, which is 37.5% (the calculation is made by dividing the number of known entries by the total number), which indicates that 62.5% of the data is unknown. This information is necessary to complement the database and indicate the possible potential source of the required data.

No. of entries	No. Lista	Family	Source			
			Current Database	Form	Invoices	Internet
1	1	Brand				
2	2	Model				
3	3	Serial No.				
4	4.1	Vehicle type				
5	4.2	Number of windows (tinted)				
6	5	Tire code				
7	6	Battery type				
8	7.1	Engine type				
9	7.2	Fuel consumption				
10	8	Fuel type				
11	9	Type and size of windshield wipers				
12	10	Capacity				
13	11	Transmission type				
14	12	Drive type				
15	13	Color				
16	16	Mileage capture				

Table 1 ITSON fleet data identification

The checked boxes in the "Current Database" column will come from the organization's current database; the checked boxes in the "Forms" column will come from the Google Forms form designed for fleet data collection; the boxes marked in the column "Invoices" will be extracted from the invoice of each vehicle; the checked boxes in the column "Internet" will be obtained through research on the Internet.

Identifying past and potential failures

After collecting the pertinent data and supported by the interview with the fleet inspector, a list of recurring failures and their possible causes was created (see Table 2).

Recurring faults	Possible causes
Puncture Low tire pressure	Visual inspection of each tire is recommended / Lack of movement.
Premature tire wear Vehicle does not start Air conditioning is not working Engine overheating	Alignment and balancing Required Battery, alternator and starter Compressor, condenser, fan Leaks, lack of refrigerant, thermostat failure

Table 2 List of failures (only a few)

This list of recurring faults and possible causes serves as a support resource to know which are the possible failures or breakdowns that could present each of the vehicles and that should be taken into account in periodic reviews by the user.

Proposal of a preventive maintenance program

After the identification of recurrent failures and their possible causes, the preventive maintenance program was developed with its four main buttons or books with the support of Microsoft Excel software, see Figure 1, which shows: (a) front page, which directs the user to enter the Maintenance program, which at the client's request, users and passwords could be created to manage its use, see Figure 1; (b) main menu, which describes in general terms each vehicle (truck, sedan, pick-up, bus, motorcycle), see Figure 2; (c) complete fleet summary; directs to the summary of each unit showing the economic number of the unit, last registration date, registered mileage, and the direct link to the maintenance plan of each unit; and (d) segmented database, shows: economic number of the vehicle, description/occupants, serial number, vehicle type, area of assignment, asset number, caretaker and license plate.

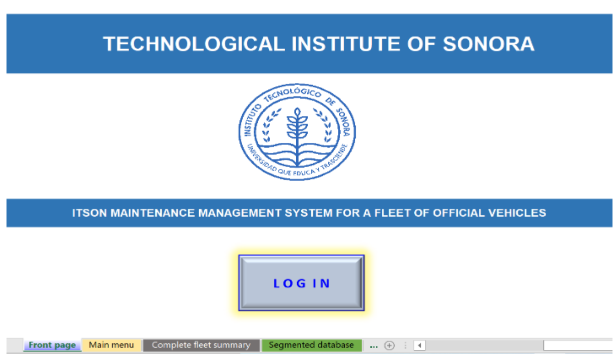

Figure 1 Preventive maintenance program

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Figure 2 shows the main menu, which is very visually appealing and user-friendly.

Figure 2 Vehicles main menu

The maintenance program is designed with a traffic light system that allows easy identification of the maintenance status of each vehicle, since a frequency of attention is established for each specific type of service.

Designing a training protocol

With information obtained from the fleet inspector, a training protocol was designed to provide all members of the JDSGyM and fleet users with the knowledge to perform the prelease inspection themselves, the information on preventive maintenance of each vehicle, the frequency of inspections, the detection of failures, and the criteria for sending the vehicle for expert review. The training protocol is a document consisting of the elements: (a) company activity, (b) justification; (c) scope; (d) program purposes; (e) general and specific training process objective; (f) goals; (g) strategies; (h) types of training (inductive, preventive, corrective, for career development); (i) training modalities (training, updating, specialization, improvement and complementation); (j) training levels (basic, intermediate and advanced); (k) actions to be developed; (l) frequency; (m) duration; and (n) material resources.

Delivery of results

The results presented are (a) preventive maintenance program (Excel database, which includes the list of customer requirements, requirements checklist, critical data collection form and list of recurrent failures); and (b) user training protocol.

Conclusions

To ensure that the vehicles that make up the fleet are in optimal operating conditions, that the lease process is not interrupted and that there are no inconveniences for users during a trip, errand or commission, a training protocol and a database containing the preventive maintenance program were developed thanks to the support of the project's stakeholders and academic contributors. Likewise, the percentage of known data was increased from 37.5% to 100% through the timely feeding of the database. In the short and medium term, the impact would be the timely performance of preventive maintenance. In the long term, a considerable amount of information will be stored, generating a robust data analysis system for the maintenance of the fleet for subsequent studies, thus fulfilling the objective of this research.

Recommendations

Continue with the preventive maintenance protocol for the fleet. When replacing components, ensure that they meet and/or exceed the specifications of the original parts. Create awareness among users (through the training protocol) about periodic inspections, preventive care, defensive driving and timely reporting of failures.

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Graphical user interface for a PLC programming implemented in an ARM Cortex-M4 microcontroller

Interfaz para la programación gráfica de un PLC implementado en un microcontrolador ARM Cortex-M4

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Abstract

This paper presents the design of a Programmable Logic Controller (PLC) using an ARM Cortex-M4 microcontroller, model STM32F407, which allows integrating the OS-Micropython operating system. To controlling the PLC hardware, the development of a graphical or visual type-programming interface is presented that is easy to use for the operator and incorporates power control functions, such as control of digital inputs/outputs, analog channels readings, timers and counters. The interface communicates with the PLC microcontroller through the UART serial protocol. The firmware microcontroller and the graphical interface were programmed in Python language. Two validation tests for the interface are presented, that probe the correct performance. This work is part of one of the stages of development of a clay sifter- lump-breaker-type machine, which will be operated by ceramic producers in the Cohuecan region in the state of Puebla, Mexico, where it is expected to automate the pottery process and influence the economic reactivation of the region.

Interface, PLC, ARM microcontroller, Python

Resumen

El presente trabajo presenta el diseño de un controlador lógico programable (PLC) utilizando un microcontrolador ARM Cortex-M4, modelo STM32F407, el cual permite integrar el sistema operativo OS-Micropython. Para controlar el hardware del PLC se presenta el desarrollo de una interfaz para programación tipo gráfica o visual que sea de fácil uso para el operador e incorpore funciones de control de potencia, tales como control de entradas y salidas digitales, lectura de canales analógicos, temporizadores y contadores. La interfaz se comunica con el microcontrolador del PLC a través del protocolo UART. El firmware del microcontrolador y la interfaz gráfica se programaron en lenguaje Python. Se presentan dos pruebas de validación de la interfaz que comprueban el correcto desempeño. Este trabajo forma parte de una de las etapas de desarrollo de una máquina tipo desterronador-cernidor de arcilla, la cual será operada por los productores de cerámica de la región de Cohuecan en el estado de Puebla, en México, en donde se espera automatizar el proceso de alfarería de la comunidad e incidir en la reactivación económica de la región.

Interfaz, PLC, Microcontrolador ARM, Python

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Introduction

The Programmable Logic Controllers (PLC) represent a key piece in industrial automation systems. Nowadays it is common to find automated processes not only in large scale industries, but also small companies are beginning to look for solutions based on automation to improve their production processes. The PLC main function is to execute control processes and sequences of industrial machinery. The basic elements of a PLC are the memory, the Central Processing Unit (CPU), Input and Output modules, Power Supply and Programming device. For decades, the PLC architecture has not changed (Goldschmidt, 2018), the controller hardware is considered a typical embedded system and the software is an operating system with standardized communication protocols (Mellado & Nuñez, 2022). Additionally, the high cost of acquiring a commercial PLC makes it unattractive or unprofitable to implement in small industries. For this reason, it is important to develop alternative solutions for the design of PLC devices. Some solutions have proposed the use of microcontrollers (Sanver, et al., 2018; Asif, et al., 2016; Rida, et al., 2014), including those found on development boards such as the PLC-Arduino, There is also OpenPLC (OpenPLC, 2022), which has support for Raspberry cards (Andrei, et al., 2020), Arduino (Cohenour, 2018), among others. These last two are OpenSource-type projects, however, in Mexico these types of projects are under development and obtaining the cards is not always easy. Despite the progress reported, today it is still very difficult to find qualified personnel capable of programming and implementing an automated system based on microcontrollers, mainly because of the programming and electronics involved. For this reason, this work proposes the design of a PLC based on an ARM microcontroller, which is considered high performance and allows the OS-Micropython operating system integration that allows programming in Python language. The Python language uses functions with a very clean, simple and compact syntax, which is why it is very easy to learn and very suitable for introducing yourself to systems programming; besides that it is easy to combine with other compiled languages, such as C and C++, which are also widely used languages (Langtangen, 2011).

Then, to facilitate programming, an interface for graphical or visual programming of the PLC is proposed, which is developed in Python language. This in order to be used by people with general automation knowledge, without the need to be programming experts.

The paper organization is as follows: Section 2 describes the general architecture of this propose. Section 3 presents the description of the PLC hardware and section 4 presents the description of the graphical user interface for programming of the PLC. Section 5 presents the preliminary results. Conclusions and work in progress are presented in section 6.

System general description

The proposed system is divided into two main stages, the first corresponds to the graphical programming interface, which is developed in Python language and the second corresponds to the PLC electronic board, which is implemented with an ARM Cortex-M4 microcontroller, model STM32F407. The electronic board has input and output modules implemented with power circuits ready to be used with independent power supplies. The communication between the electronic board and the interface is carried out through the UART interface.

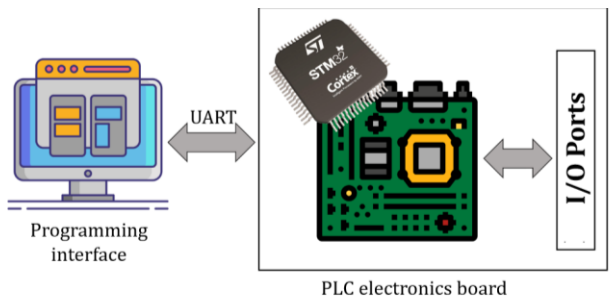

Figure 1 PLC proposal block diagram
Source: Own elaboration

PLC Hardware Description

The PLC proposed design consists of 14 optically isolated digital inputs to receive 12 or 24 VDC signals, 8 independent relay outputs with normally open (NO) and normally closed (NC) operating modes, an expansion port of 16 pins with power supply at 3.3 V that will allow the addition of expansion boards designed for future applications, such as analog-digital converters. The PLC offers a voltage output of 12 VDC at 20W, allowing industrial sensors to be connected directly to the board.

The system can be programmed via an on-board USB port with a micro-USB connector. The relay outputs can work with direct current voltages at 24 VDC, or alternating current at 127-220 VAC. The digital outputs are designed to work with industrial contactors that are ultimately responsible for driving high current loads. An indicator LED is integrated to display the status of each of the inputs and outputs.

ARM microcontroller

The PLC is implemented in an ARM Cortex-M4 microcontroller, model STM32F407 from the ST Microelectronics manufacturer. The microcontroller internal architecture includes a CPU with 100 kB RAM memory, 1 MB Flash memory dedicated to program memory. This microcontroller is considered high-performance because it includes multiple peripherals that are useful for the implementation of the PLC, such as: RS-232 or RS-485 serial communication ports, analog inputs with an analog-digital converter (ADC) with resolution of 12-bit and USB port with a factory integrated Bootloader or on-site programming mode.

Power Digital inputs

The circuit of each of the 14 digital inputs is presented in Figure 2. As can be seen, the input circuit to the optocoupler U5, model PC81713NIPOX, consists of a resistor R4 in series with the status indicator LED, D3. R4 is responsible for limiting the current flowing through the circuit. The output circuit consists of a resistor R6 connected in series to the internal transistor. The output is connected from the collector terminal (4) to the digital terminal of the microcontroller C0. This configuration was designed as an inverted logic, so that in the presence of 12 V at the input, the PLC will detect a logic 0 state. All inputs share a common node or GND, however, this node is isolated from the common node of the microcontroller and the rest of the electronics. The GND node is offered as a screw terminal, this allows the user to use an external source to power the outputs.

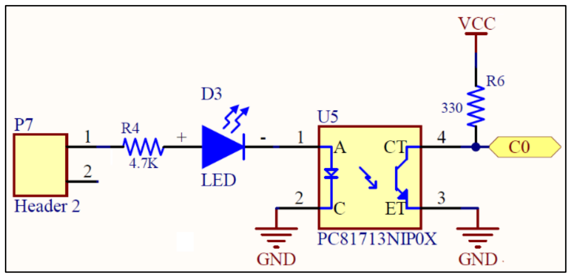

Figure 2 Digital input circuit
Source: Own elaboration

Power Digital outputs

Relay outputs require optical isolation between the microcontroller and the power elements. The circuit of each of the 8 outputs is shown in Figure 3. Terminal D0 corresponds to a microcontroller output pin to which indicator LED D17 and the internal LED of the PC81713NIPOX optocoupler are connected in series. The output circuit uses a 12 VDC source and consists of a series circuit of resistors R40, R41 and transistor (C-E), where the emitter terminal (3) is connected to the base of an external transistor Q1, model MMBT3904LT1G, operating in switch mode. The Collector-Emitter circuit of Q1 is a series circuit of the 12 VDC source and a reverse connected diode D25 for protection of Q1 during the switching process. Also D25 is connected in parallel to the coil of relay K1. The common terminal of each relay is independent, this feature makes the outputs more versatile, because they allow the user to connect different voltage loads to each output.

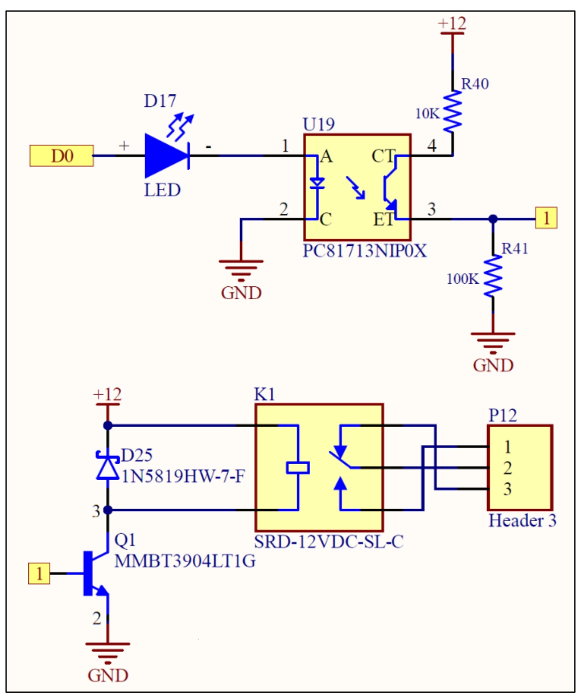

Figure 3 Digital output circuit
Source: Own elaboration

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Power supply

The PLC internal circuitry is powered by two independent sources of 12 VDC at 20W. Each source is a compact integrated module encapsulated in a protective plastic that allows direct connection to 127-220 VAC. Although the sources have protection against overcurrent and short circuit; at the input of both sources, a fuse protection circuit was implemented, which protects against short circuits, a shunt capacitor-transformer filter circuit that protects against voltage transients or harmonics, and finally, a varistor that protects against voltage spikes. One of the supplies is used to power the microcontroller and the relays. The microcontroller has its own 3.3 VDC switched DC-DC supply. This supply draws power from the main 12 VDC supply mentioned above. The second source is intended as a power supply integrated to the PLC. This source will allow the user to directly power the industrial sensors that are connected to the board, through a screw terminal.

PLC programming interface description.

In addition to the capabilities of the PLC hardware, it is important in a design to consider the means by which the hardware will be controlled. Therefore, most commercial PLC manufacturers implement their own user interface through which programming is carried out. Some of the most common languages are: ladder diagram, Grafcet and blocks. In this work, a graphic or visual programming is proposed so that anyone with general knowledge of automation is able to use it in automation processes. The operation of the interface is divided into two main parts, the programming of the firmware in the microcontroller and the programming of the user interface in the computer. Both systems are programmed in a Python language and the logic is described below.

ARM microcontroller firmware

The microcontroller firmware programming was developed in MicroPython language, implementing functions for the control of digital inputs and outputs, timers, counters, logic functions and analog inputs. Communication with the microcontroller and the programming interface is carried out via UART.

Figure 4 shows a microcontroller programming logic flowchart. The first step is to configure the serial communication with the computer, through a COM port, later it receives the configurations made by the user from the computer interface, to finally execute the functions corresponding to the configuration by the user.

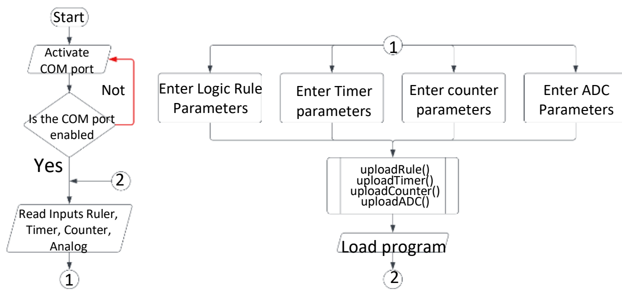

Figure 4 Microcontroller firmware logic flowchart
Source: Own elaboration

Programming interface

The interface with which the PLC is programmed is developed in Python language using the Tkinter library. It is designed as a block-based graphical interface for easy and simple use. Among the configurations available in the programming interface are the following: digital inputs and outputs, timers, counters, logic rules and analog inputs. Figure 5 shows a very general operation flow diagram of the user interface, which is executed from a personal computer (PC).

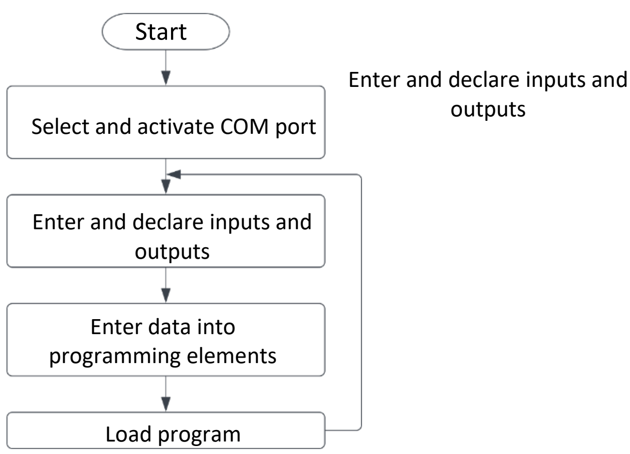

Figure 5 Flowchart of the user interface logic
Source: Own elaboration

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Results

The proposed work is in progress, then the preliminary results obtained during the development were obtained using a commercial development board that incorporates the same STM32F407 microcontroller (Intesc, 2022) are described below. Figure 6 is a full view of the graphical user interface. It consists of 6 main block parts: 1) Serial communication configuration. 2) Program output terminal. 3) Reading of analog channels. 4) Logic functions 5) Timers and 6) Counters. It should be noted that these functions can be configured by the user according to their needs.

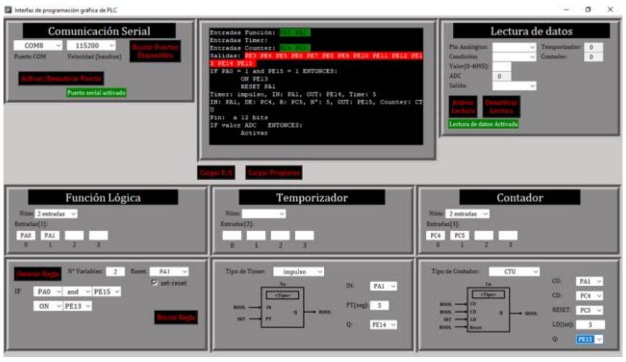

Figure 6 Graphical user interface for PLC programming
Source: Own elaboration

To verify the operation, two practices are described below, one of a small automation process and the second on the reading of an analog signal.

Test 1

Below is a small example of automation of a process which consists of the following steps:

A conveyor belt (represented by a green LED) moves some containers.

1. When the sensor S1 (represented by button 1) detects the container, the conveyor stops.

2. Cylinder A1 extends (represented by a white LED) to open a gate for 5 seconds and fill the container positioned below with some material.

3. Subsequently, an internal counter will be increased to repeat this action 5 more times.

4. There are also two other buttons, one for Start and another for Reset.

Figure 7 shows the configurations for the PLC to execute the actions required by the previously described process. Mainly it is possible to appreciate the configuration of logic functions of AND type, the impulse timer and an ascending counter.

Figure 8 shows the PLC connection diagram and its different components.

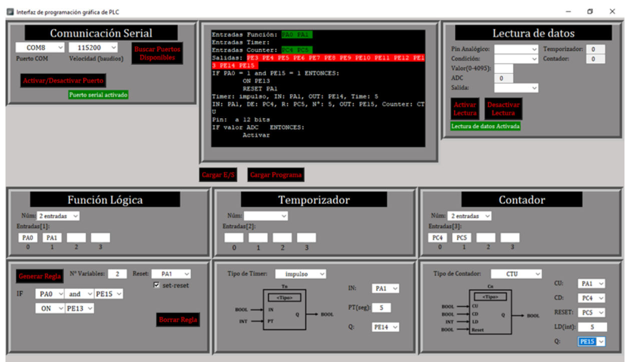

Figure 7 PLC programming for test 1
Source: Own elaboration

The counter and timer values will start at 0 and the only led on will be red, indicating that the counter is not equal to 5. Figure 9 shows the implementation and programming of the counter.

Figure 10 shows the result after pressing the start button, the green led turns on, which represents the motor of the conveyor belt. Figure 11 shows the indicators when the conveyor has been turned off.

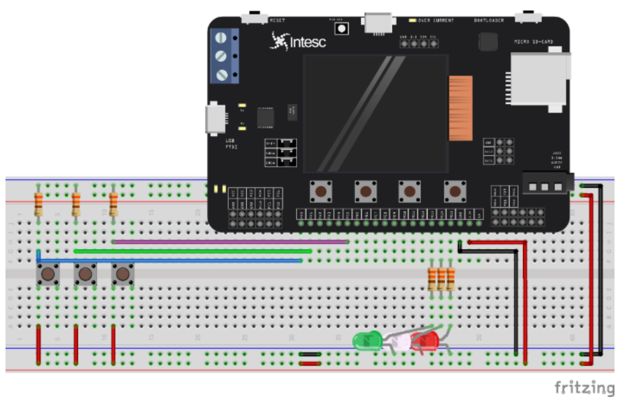

Figure 8 Electrical connections for test 1
Source: Own elaboration

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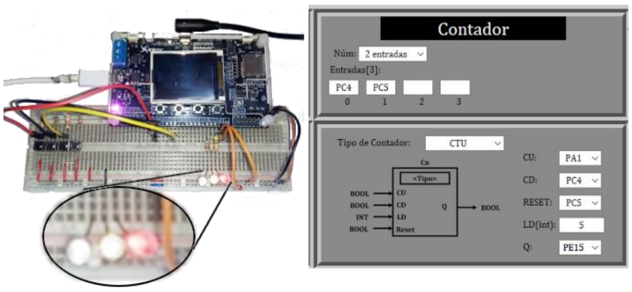

a) b)

Figure 9 a) Electrical connections implementation. The red led on indicating that the counter is not equal to 5. b) Counter configuration
Source: Own elaboration

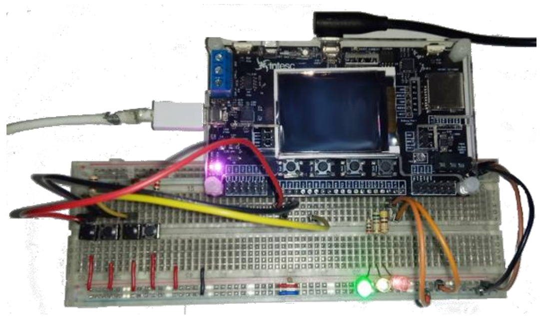

Figure 10 The green led on indicating that the conveyor belt is moving
Source: Own elaboration

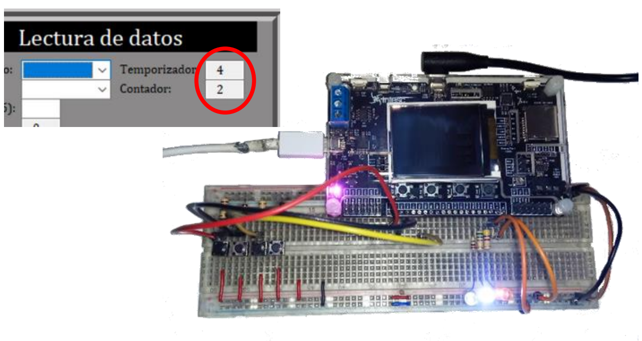

Figure 11 Time and counter indicator on the interface and white led on indicating that cylinder "A" is on, the green led is off indicating that the band is off
Source: Own elaboration

Test 2

Test 2 consists of evaluating the operation of the analog inputs, for this, in Figure 12 we show a connection circuit which consists of an analog potentiometer and a led.

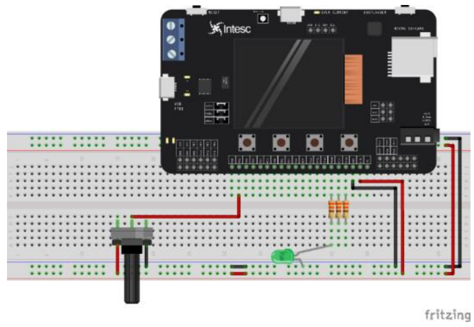

Figure 12 Connection of the potentiometer to the PLC and led
Source: Own elaboration

Figure 13 shows the configuration and visualization of the data of the analog channels. The analog pin section is the name or address of the physical pin of the microcontroller, the condition is the conditional element for some action to happen, the value section (0-4095) is the minimum and maximum value that can be read, remember that the ADC of the microcontroller is 12 bits, ADC in the current reading and finally the output is the digital pin that will be activated or deactivated depending on whether the rule that we have programmed is fulfilled or not.

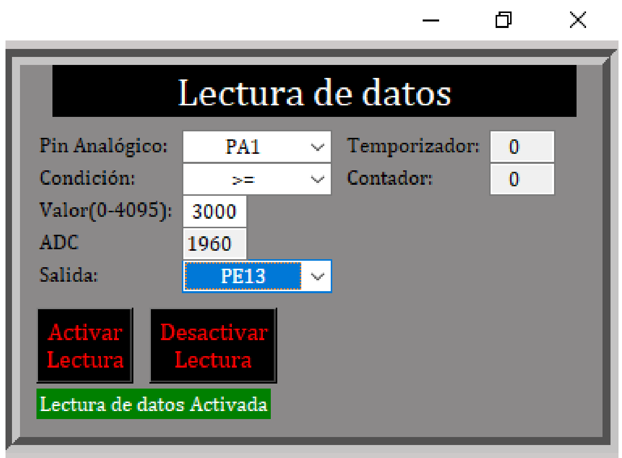

Figure 13 Interface for configuration and display of analog channels
Source: Own elaboration

Figure 14 shows the result obtained when the analog reading is below 3000, a condition that we established for the LED to turn on.

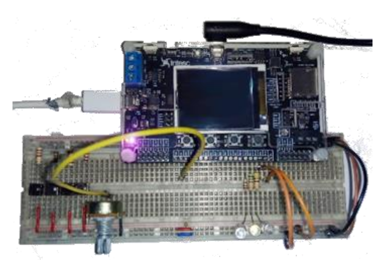

Figure 14 Physical connection of the potentiometer to the PLC and led
Source: Own elaboration

Figure 15 shows the operation of the PLC and its programming by turning on the LED when the potentiometer exceeds the programmed level.

Figure 15 The green led turns on when the potentiometer exceeds the programmed level
Source: Own elaboration

Conclusions

The electronic design proposal for a PLC using an ARM microcontroller with a graphical programming interface was presented. This work is part of one of the design stages of a development project for an industrial-type machine to sift clay, in which a three-phase Power motor will be used and will be operated by ceramic producers in the Cohuecan region in the state of Puebla, in Mexico. For this reason, a graphic control interface was proposed for easy operation and the PLC has relay power outputs that can work with direct current voltages at 24 VDC, or alternating current at 127-220 VAC.

The PLC printed circuit board is in the manufacturing process, so only the performance of the graphical interface was validated, which through two tests could verify its proper functioning.

Future work is to finalize the PLC and perform tests with high power elements.

Acknowledgment

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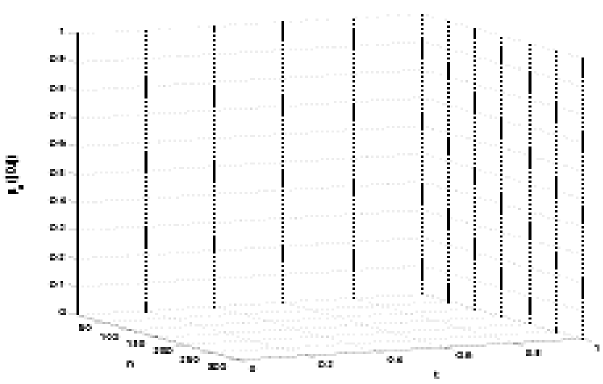

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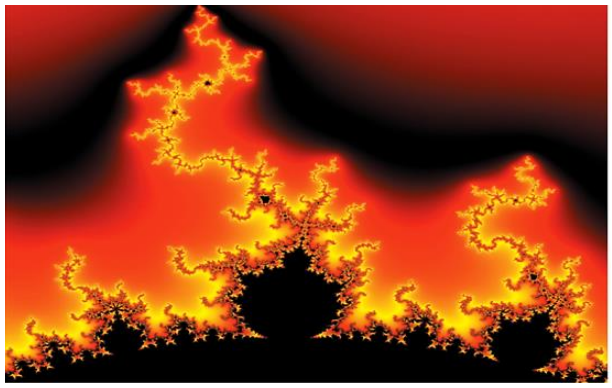

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