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Improving the Material Loading Process in a Ready-Mix Concrete Production Plant through Industry 4.0 Principles

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Abstract*– Urban and infrastructure development implies an increased demand for ready-mix concrete. Small companies producing ready-mix concrete must optimize their operations to improve productivity and meet demand. In this sense, our research applies the principles of Industry 4.0 to process monitoring, automation, and technical assistance to improve the productive efficiency of the material loading process in a ready-mix concrete plant. The methodology includes a literature review, field observation, and interviews with operating personnel. This information allowed the researcher to redesign the materials loading process, integrating monitoring technologies, such as the GPS Logger, to record operating times. In addition, a metal hopper was implemented to automate and facilitate the mixing of materials, and subsequently, employees were trained in the redesigned process using Industry 4.0 technologies. A 15-day pilot test validated the solution, demonstrating a reduction in cement loading time from 9 minutes and 59 seconds to 3 minutes and 33 seconds, with a 3.5% decrease in material waste. The total material loading time was reduced from 42 to 36 minutes per mixer, resulting in a 22% increase in daily production and a 42.6% improvement in operational efficiency. The economic evaluation confirmed the project's feasibility, with an NPV of S/. 23,020.73, a C/B ratio of 1.79 and an IRR of 22.22%, recovering the investment in only five months. These results demonstrate that the proposal optimizes processes and increases the company's competitiveness, paving the way for significant growth in daily production.

***Palabras clave*-- Process Improvement, Material Loading Process, Industry 4.0, Ready-Mix Concrete, Cost-Benefit Analysis.**

I. INTRODUCCIÓN

Globally, in recent years, Industry 4.0 or I4.0 has sought to integrate digital technology into SMEs simply and at an affordable cost for business development [1], [2]. To implement the principles of I4.0 in practice, the adoption and integration of technologies (sensors, actuators, equipment, or machines controlled by software) that allow monitoring and automating of operational processes and facilitating the exchange of information between different areas of companies [3], [4].

Incorporating these technologies has brought a series of changes in companies, modifying how they carry out their activities and processes [5]. For example, in Mexico, adopting I4.0 technologies in SMEs allows moving from models with only computer equipment and an internet connection to monitoring and automating processes (operational and production), reducing delay times and reducing waste from overproduction or overprocessing [1]. However, some authors still discuss adoption barriers due to social and cultural issues related to the perception that these solutions may reduce jobs. In addition, implementing I4.0 technologies requires an adequate alignment of organizational culture and production processes, which is not always easy to achieve [6], [7].

In the concrete sector, I4.0 promotes the application of sensors in production plants. These sensors allow real-time monitoring of critical variables, such as material quality and mixing time. They facilitate decision-making and the detection of failures in operation, thus reducing downtime and operating costs [8]. This technology improves efficiency and process optimization, translating into a more agile capacity to meet market demand and improve overall plant efficiency [9]. However, SMEs still face barriers to adopting Industry 4.0 principles and technologies, especially in Peru, where access to technology and know-how is limited [10].

In recent years, the construction sector's growth has generated a need to improve the efficiency of concrete production companies, with the primary objective of becoming more competitive [8]. Traditionally, SMEs in this sector operate with manual procedures and empirical processes, with only basic information systems. In this sense, SMEs record and process the data manually, leading to poor collection and analysis of their operations. This approach generates inefficiencies, cost overruns, and a high production rate of raw material waste [11]. Large companies that have adopted digital technologies and automation are intensifying the competition, worsening this situation., allowing them to optimize their processes and improve the quality of their products [12].

The ready-mix concrete industry is growing in Peru since ready-mix concrete is one of the most widely used materials in the construction industry, providing greater strength and durability to withstand various natural conditions [13], [14]. The SME in this study operates in Arequipa and produces and markets ready-mixed concrete. Its production process integrates a conventional loading subprocess, which involves loading the material from one point to another with a front-end loader, with the operators being the direct labor force during the process.

Over the past year, the company's sales have increased by 11%. However, this increase has revealed deficiencies in the production area, especially in the material loading sub-process, since the mixer is loaded sequentially, which limits production. In addition, the lack of information and control at each process stage generates greater raw material waste, causing overruns and economic losses.

This research aims to improve the efficiency of the loading subprocess of a ready-mix concrete production plant by implementing the principles of I4.0. The current conditions of the loading subprocess at the ready-mixed concrete production plant describe the critical factors affecting the materials' operation and handling. Based on this and the literature, the principles of Industry 4.0 applicable to monitoring the operational conditions of the loading subprocess are determined. The team redesigns the loading subprocess and performs a pilot test to evaluate how I4.0 technologies integrated into the new design reduce operating time. Finally, a cost-benefit analysis is performed regarding implementing the redesigned sub-process, considering the return on investment indicators.

II. THEORETICAL BACKGROUND

The concrete industry produces and distributes ready-mix concrete, a mixture of the following materials: cement, sand, crushed stone, admixture, and water [15]. This material is used in different stages and parts when constructing a building and should provide greater strength and durability to withstand the various natural conditions [4]. Ready-mixed concrete is the most widely used building material globally and is a massive product [15]. Over time, the concrete industry has altered its preparation by replacing the traditional mixing drum with the ready-mixed concrete industry. It is responsible for developing and designing mixtures, ensuring the quality of its product, and correct loading [16].

As a result, the production technologies of this construction material have reached a high level of development since its mechanization and automation in the plants responsible for producing ready-mix concrete [11]. According to Peruvian Technical Standard 399.144-212 [17], concrete is a mixture of materials (cement, water, admixtures, fine and coarse aggregate) dosed in defined proportions. According to their characteristics, admixtures can be added to concrete to improve its properties, including increased workability.

A. *Ready-mixed Concrete Production*

The following processes and activities describe the concrete production activity [13], [15], [17], [18]:

- **Loading and weighing of the materials:** during loading using a front-end loader, the raw material stored outside is extracted and poured into the plant's weigh hopper.
- **Transfer of materials:** Transferred the materials using a conveyor belt or screw conveyor that supplies all the materials to the mixer truck. Stored the materials in the hopper; from the control cabin, the operator manipulates the pneumatic solenoid valves to open and close the gates under the hopper so that the material falls by gravity to the belt.
- **Homogenization of materials:** The mixer truck is a vehicle that contributes as a ready-mix concrete transport unit and concrete mixer. Since the rear part has an oval rotating hopper that operates at a constant speed, its interior consists of helicoidal blades or paddles located on the sides that are responsible for receiving the materials that fall by gravity from the conveyor belt to the chute or nozzle of the rotating hopper of the mixer for homogenization, as well as facilitates the dispatch of concrete when reversing the direction of rotation of the blades or paddles.
- **Dosing:** During this subprocess, the personnel in charge of the area will focus on having a uniform and consistent mix according to the mix design or strength level requested.
- **Slump test:** This test measures the workability of ready-mix concrete in the plant and the field.
- **Specimen test:** The specimen test involves extracting a sample from the ready-mix concrete in the plant and on-site to determine its strength.
- **Dispatch:** All the technical information of the mix design is recorded, and the ready-mix concrete is transported to the job site by a mixer truck.

B. *Industrial Waste*

Waste is considered an inherent non-value-added activity contained in production processes. It is necessary to identify waste, to facilitate waste management, which can be categorized as follows [19], [20]:

- **Overproduction:** The production surplus is a relative measure; it is the difference between the quantity produced and the quantity demanded. Overproduction causes unnecessary inventories to exist.
- **Waiting:** Occurs when the operator or machinery is not performing an activity.
- **Inventory:** This includes all found materials, parts, materials, processed or finished products that are stagnant and waiting to be processed or sold.
- **Transportation:** Transportation depends mainly on the distribution in a plant. Poor distribution causes waste. To avoid this waste, actions that involve moving materials or tools to a specific location for handling are necessary.
- **Overprocessing:** These wastes are very difficult to identify because, unlike the other wastes, overprocessing is part of the process and contributes to the transformation of products that can be classified as valuable operations. This type of waste leads to an increase in production costs in a company.
- **Movements:** Workers should not perform these activities as part of the job, as they do not create value within production.
- **Defects:** These are the most common waste in the industry, as they are errors that must be corrected. Even workstations are created for defect correction.

C. *Principles of Industry 4.0*

The fourth industrial revolution, also called Industry 4.0 (I4.0), allows reaching a new level of digitization, control, and vertical and horizontal integration throughout the value chain of the product life cycle. Factories become "smart" to structure and modularly integrate sensors and actuators in production, allowing data and information to facilitate decision-making [21]. The authors Belman, Jimenez, and Hernandez [22], describe the fundamental principles of I4.0:

- **Interoperability:** The ability to communicate directly with all components allows optimized decision-making when working with real-time data generated by IoT devices.
- **Virtualization:** Intertwining the physical world with digitalization through software or a virtual simulation system. It allows us to work together to relate physical to digital.
- **Decentralization:** Implementing an intelligent product within the production area decreases human intervention and distributes data generation and processing throughout the operation and the company.
- **Real-time communication:** A computerized system must have real-time information about development. This will help decision-making and optimize the implementation of strategies, maintenance, and monitoring.

According to Hemann, Pentec, and Otón [23], the design principles help companies identify and implement I4.0 pilots:

- **Equipment monitoring:** Involves collecting information or data from all equipment and/or machines. It can also work in real-time to allow quick decision-making.
- **Intelligent supply chain—automated:** Automation involves implementing software to make processes more controlled and accurate and increase capacity.
- **Big data and analysis:** This is the collection of data from all systems in a base in order to know all the information and proceed to decision-making; for this, the cloud, autonomous robots, simulations, integration of H-V systems, IoT, cyber security, additive manufacturing, and AR are used, among others.

The present research applies the principle of equipment monitoring in real-time through a Global Positioning System (GPS) since it helps us understand the working hours and routes followed in the loading process, which is also called the loading of materials.

D. *Automation in the Ready-Mixed Concrete Industry*

Due to the increase of industries, technology has been constantly growing, and companies have opted to improve their processes through digitalization and automation to be more efficient and competitive in the market [9]. In Peru, technological changes related to automation are still in the background. However, the construction of skilled labor, the optimization of productivity, and the growth of new services contribute to new technologies in the industry [8].

The automation of processes is essential for companies to dominate the market; in the construction and concrete industry, the installation of a batching plant in the production of ready-mix concrete allows companies to work more efficiently, producing mixtures with the exact amounts of raw material with higher performance and high quality; its installation implies the reduction of machine hours and labor, generating savings for the company [4], [8].

In addition, in most of the concrete industry companies, their production area includes the implementation of a batcher, which involves the joint work of several pieces of equipment such as silos, hoppers, additive doser, vibrators, and scales, which is expected standard of the ready-mixed concrete production process is approximately 20 minutes. The entire process is controlled by linear and computerized software through a control panel programmed and supervised by a qualified person for its correct operation [24], [25].

III. METHODOLOGY

The first research stage analyzes the company's current situation to describe the ready-mix concrete production process. The second stage evaluates how the I4.0 principles can improve the loading process according to the literature's experiences. For this purpose, a GPS must monitor the time and routes followed since these data allow for measuring work times. The third stage contemplates the formal design of the loading process by implementing a hopper to improve the production of ready-mixed concrete. This stage includes designing, costing, and fabricating a metal hopper. We quantitatively evaluated the loading process design in the fourth stage using I4.0 principles and technology. For greater accuracy, captures are performed using the GPS Logger. Finally, in the fifth stage, an economic evaluation of the implementation of the hopper is carried out, which consists of preparing a cash flow, cost/benefit analysis, and internal rate of return.

This applied research seeks a practical solution to the problem of delay time and waste of materials in the loading process of a concrete company. Therefore, real information about the company is collected, considering its operation's particularities. This research adopts an explanatory scope and a mixed approach, as the researchers collect qualitative data through interviews and gather quantitative data on the operation times of the loading process using various instruments. Activities are developed under an experimental methodological design, with quasi-experimental tests, since pilot tests are carried out in the company's operation to evaluate the developed solution. The sample is selected by convenience, being the concrete production and commercialization company participating in the research. Researchers collected data to measure the problems of time and material waste, and they conducted pilot tests to evaluate the hopper and the design of the loading process.

IV. IMPLEMENTATION OF INDUSTRY 4.0 PRINCIPLES

The development begins with the collection of data through the techniques of non-participatory field observation, interviews with the personnel responsible, and the collection of some documents in order to first have a clear and, to some extent, formal vision of the ready-mix concrete production process, and then we describe the following information:

A. Concrete Production at the Plant

The primary data collected shows a steady increase in the demand for concrete in the city of Arequipa in recent months. In addition, they indicated that their maximum production capacity is 72 m^3, producing approximately 1,872 m^3 per month.

Part of this production limitation is because the loading process only allows transporting up to 8 m^3 of materials per trip, given the maximum capacity of the hopper. In addition, there are approximately nine trips per day. It was also reported that when orders exceed 72 m^3 per day, additional expenses (overtime or staff overtime) are incurred to cover the order, and even then, they do not always manage to provide adequate customer service.

B. The Company's Ready-mix Concrete Production Process

With the data obtained through field observation and interviews with the personnel responsible, we proceeded to formalize the operations of the ready-mix concrete process of the company under study, which includes seven main activities described below:

- **Intake of inputs and raw materials:** The plant assistant and the plant manager oversee the receipt of the inputs (cement, stone, sand, and admixture).
- **Loading of raw materials and inputs:** The heavy machinery operator, together with the plant assistant, enters the warehouse with all inputs, such as cement and raw materials, in a single hopper for weighing.
- **Transfer of inputs and raw materials to the mixer truck:** The plant manager, through a control panel, manipulates the electrical system of the plant by turning on and off the electric pumps, which are in charge of transferring the water and the required additive through hoses, as well as opening and closing the hopper gates causing the material to fall to the conveyor belt and thus everything goes in the direction of the chute of the mixer truck.
- **Homogenization or mixing of inputs and raw materials:** Once all the materials have been transferred to the mixer truck, the truck mixes them until they are homogeneous.
- **Dosing and quality control:** The quality technician is in charge of verifying that the mixture is homogeneous, in addition to dosing the water-cement ratio, and proceeds to quality control using the slump test and test tubes.
- **Registration of product and client information:** When the mixture conforms, the administrative assistant, on the order of the quality technician, proceeds to make the referral guide indicating the technical specifications of the mixture, the amount of m3 prepared, the information of the mixer truck, and the information of the operator who transports it to the construction site.
- **Dispatch:** After filling out the referral guide, the mixer truck proceeds to the location of the civil works (end customer) to be supplied.

The ready-mix concrete production process takes an average of 42 minutes. The loading (of stone, cement, and sand) takes the longest to produce, generating an overall time of 19 minutes for the loading process.

C. Raw Material Loading Process.

Based on the formalization of the company's production process, the cement loading operation has the most extended delay since it is carried out manually, as shown in Fig. 1.

Fig. 1 - Cement loading

In addition, cement transportation generates cement waste, as shown in Fig. 2. Since the material is spilled, A and B leave a trail from the warehouse to the hopper and vice versa.

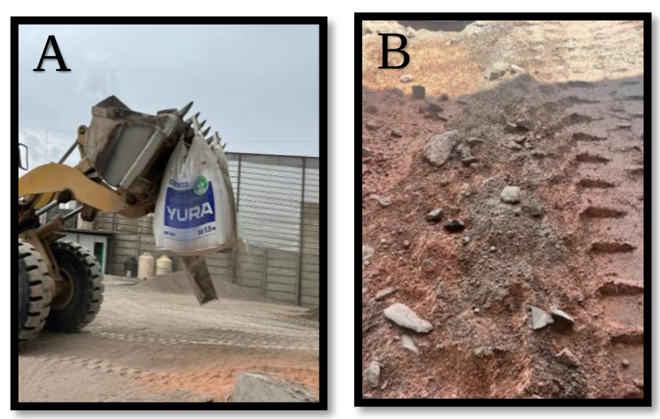

Fig. 2 - Waste generated during cement loading.

According to [26], the expected value of waste in the ready-mix concrete production process is 5%. If the company expects to meet its production goal of 100%, it should consider this percentage and, therefore, work with materials and inputs that correspond to 105%.

Table 1. Ready-mix concrete composition

Raw material or input	%
Cement (TN)	9.11
Stone (m^3)	46.10
Sand (m^3)	42.96
Additive TM12 (TN)	0.01
Additive 360 (TN)	0.03
Water (m^3)	6.79
Total	150

On the other hand, this operation took time to understand and corroborate the criticality of the loading process. For this purpose, an observation sheet was used to collect data for 15 days distributed over 1 month. Table 2 summarizes the average times calculated for raw materials and inputs loading operations.

Table 2. Loading process time recording

Material Loading Sub-Process (Average Time in Minutes)					
Day	Date	Stone	Cement	Sand	Total
1	18/12/2024	0:03:13	0:10:30	0:05:40	**0:19:22**
2	19/12/2024	0:03:03	0:10:05	0:06:17	**0:19:25**
3	20/12/2024	0:02:37	0:09:41	0:05:56	**0:18:14**
4	21/12/2024	0:03:23	0:09:56	0:05:42	**0:19:01**
5	26/12/2024	0:03:00	0:10:59	0:05:40	**0:19:39**
6	27/12/2024	0:02:31	0:09:35	0:05:19	**0:17:25**
7	28/12/2024	0:02:40	0:10:02	0:05:09	**0:17:51**
8	02/01/2025	0:03:20	0:10:43	0:06:18	**0:20:22**
9	03/01/2025	0:02:21	0:10:00	0:04:55	**0:17:16**
10	04/01/2025	0:02:45	0:09:54	0:05:23	**0:18:02**
11	08/01/2025	0:02:51	0:09:29	0:05:15	**0:17:35**
12	09/01/2025	0:02:45	0:10:17	0:05:33	**0:18:35**
13	10/01/2025	0:02:38	0:10:11	0:05:03	**0:17:52**
14	11/01/2025	0:02:30	0:08:50	0:05:00	**0:16:20**
15	15/01/2025	0:02:40	0:09:27	0:05:14	**0:17:21**
Global Average		**0:02:49**	**0:09:59**	**0:05:30**	**0:18:17**

The average time required to supply one mixer unit (stone, cement, and sand) is 18 minutes and 17 seconds. The material with the most extended delay is cement, with an average time of 9 minutes and 59 seconds. For greater precision in the analysis, the standard deviation of the data obtained was calculated to find the maximum and minimum limit of dispersion of the cement loading and the overall loading process, which is 32 seconds standard deviation of the cement loading (see Fig. 3) and 65 seconds standard deviation of the loading process (see Fig. 4).

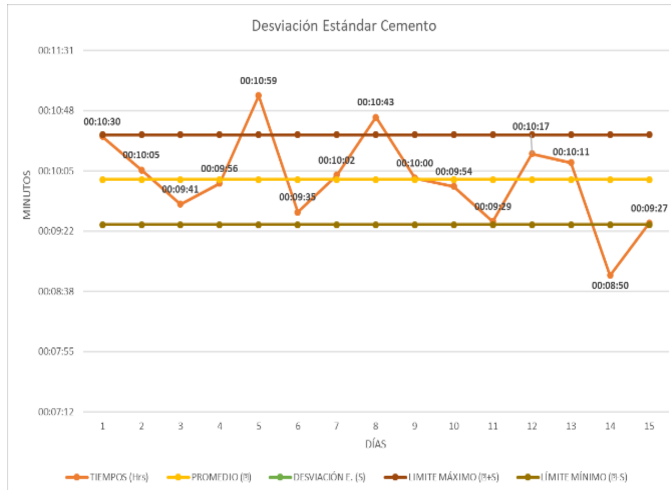

Fig. 3 - Standard deviation of cement loading.

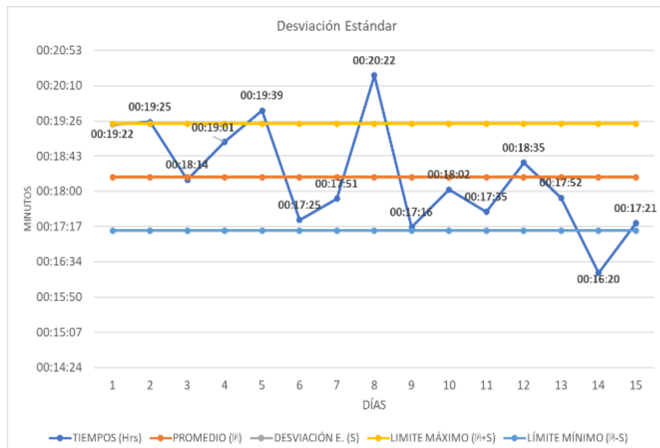

Fig. 4 - Standard deviation of loading process times.

D. Monitoring by "GPS Logger"

This research considers using a GPS device and application called "GPS Logger" to measure times and positions more accurately and cheaply. The GPS Logger must be installed on a mobile device (Android platform cell phone) that a person must operate. It is considered that the front loader operator can assume the responsibility of operating this device since the development of his activities would not be compromised. In addition, he executes the maneuvers and displacements to be monitored when carrying out the loading operations of the materials.

To facilitate the adoption of this technology, a procedure for the GPS Logger was developed and transferred through training for the operator. This procedure describes the step-by-step instructions for using the application and was applied in person with the employee in charge of operating the front loader. After this training, tests were carried out with the operator to corroborate the correct functioning of the application and data generation.

E. *Automation with the Implementation of a Hopper.*

We understand automation as implementing technology that reduces human or manual labor. In this sense, we have chosen to implement a new hopper in the production area since this implementation will allow us to reduce loading time and increase production capacity. Automation occurs because the new hopper allows the exclusive loading of cement, avoiding rows or bottlenecks, leaving the first one for loading stone and sand. The proposed hopper is used specifically to supply the cement to the mixer because the cement loading operation is the most time-consuming, as it is done manually, and it generates waste.

F. *Redefinition of the Material Loading Sub-process*

Implementing the new hopper for the cement loading operation changes the production process since the materials are unloaded differently. This saves time in the operation since two big bags of cement can be loaded independently of the other materials. The operational tests show that the ready-mix concrete production process has changed, so Fig. 5 shows the redefinition of the PDO of the ready-mix concrete production process, where the proposed change in the cement loading process can now be seen. This "operation 2" change estimates the time and material waste reduction.

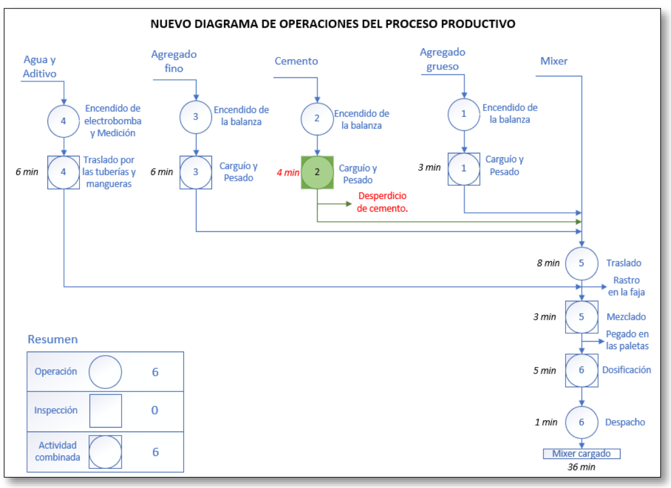

Fig. 5. Updated operations diagram

G. *Revaluation of Material Loading Operating Times.*

The start-up of the new loading process was evaluated over 15 days. These operational tests include activities where the front-end loader operator initiates and completes the GPS Logger data recording for each material loading. At the end of the working day, the operator sends the files with TXT, GPX, and KM extensions, where the GPS information, route times, and day annotations are recorded. Table 3 shows the averages in minutes for the 15 days that the material loading process times were reevaluated.

Table 3. Revaluation of the Material Loading Process

New Material Loading Sub-Process (Average Time in Minutes)					
Day	Date	Stone	Cement	Sand	Total
1	27/01/2025	0:02:34	0:03:40	0:04:21	**0:10:35**
2	28/01/2025	0:02:48	0:03:47	0:04:40	**0:11:15**
3	29/01/2025	0:03:12	0:04:30	0:04:21	**0:12:04**
4	30/01/2025	0:03:16	0:03:53	0:04:34	**0:11:43**
5	03/02/2025	0:01:21	0:00:00	0:04:22	**0:05:43**
6	04/02/2025	0:02:43	0:04:09	0:05:30	**0:12:22**
7	05/02/2025	0:02:28	0:03:42	0:05:16	**0:11:27**
8	06/02/2025	0:03:27	0:05:09	0:05:09	**0:12:40**
9	10/02/2025	0:03:37	0:03:00	0:05:45	**0:12:42**
10	11/02/2025	0:02:31	0:03:14	0:04:43	**0:10:47**
11	12/02/2025	0:04:45	0:04:01	0:05:13	**0:13:59**
12	13/02/2025	0:02:17	0:03:29	0:04:48	**0:10:53**
13	17/02/2025	0:03:33	0:03:39	0:05:01	**0:12:13**
14	18/02/2025	0:03:10	0:04:18	0:05:50	**0:13:18**
15	19/02/2025	0:02:41	0:03:48	0:05:34	**0:12:03**
Global Average		**0:02:58**	**0:03:33**	**0:05:00**	**0:11:35**

The average loading time of each material with the implemented hopper can be observed: cement, which takes an average of 03 minutes and 33 seconds; sand, which takes an average of 5 minutes; and stone, which takes an average of 2 minutes and 58 seconds. In addition, the average loading process time is 11 minutes and 35 seconds. Therefore, the new cement hopper reduced the loading time by 6 minutes.

H. *Efficiency of the New Material Loading Sub-Process*

To determine the efficiency of the loading process before and after the intervention with the developed proposal, it is necessary to consider the variations in loading time and productive capacity, for which the following formula is used to express the variation as a function of the intervention:

$$Variation\ (\%) = \frac{Variation\ after - Variation\ before}{Variation\ before} \times 100$$

In that sense, we can calculate the improvement in efficiency in terms of the loading time it takes to do it with one (before) and two hoppers (after).

$$Variation\ in\ Loading\ Time\ (\%) = \frac{36\text{ min} - 42\ min}{42\ min} \times 100$$

$$Variation\ in\ Loading\ Time\ (\%) = \frac{-6\text{ min}}{42\text{ min}} \times 100$$

$$Variation\ in\ Loading\ Time\ (\%) = -14.29$$

This indicates the loading time has been reduced by 14.29 % or 6 minutes per mixer. With this reduced time, it is possible to transport 11 mixers instead of 8 per day, which allows an increase in the ideal maximum production as calculated as follows:

$$Daily\ Production\ Variation\ (\%) = \frac{88\text{ m3/per day} - 72\text{ m3/per day}}{72\text{ m3/per day}} \times 100$$

$$Daily\ Production\ Variation\ (\%) = \frac{16\text{ m3/per day}}{72\text{ m3/per day}} \times 100$$

$$Daily\ Production\ Variation\ (\%) = 22.22$$

So, we interpret an increase of the ideal maximum daily production of 22% or 16 m^3. Calculating efficiency improvement, specifically operational efficiency, which refers to "the ability of an organization to optimize its processes and resources, achieving superior results at the lowest possible cost and time." From this, we can calculate operational efficiency, considering the decrease in operating time and the increase in production, through the following formula.

$$Operational\ Efficiency\ (\%) = (\frac{Final\ Production}{Initial\ Production} \times 100)\ /\ (\frac{Final\ Time}{Initial\ Time} \times 100)$$

By dividing the increase in production by the proportional increase in time, we obtain an index that reflects how the improvement in production is related to the reduction in time, where:

- If the efficiency index exceeds 100%, it indicates a net operational improvement.
- If the index equals to 100%, the production improvement and the time reduction are balanced.
- If the index is less than 100%, the improvement in production does not compensate for the reduction in time.

Applying this formula and considering this index to our results, we have:

$$Operational\ Efficiency\ (\%) = (\frac{88\text{ m3/per day}}{72\text{ m3/per day}} \times 100)\ /\ (\frac{36}{42} \times 100)$$

$$Operational\ Efficiency\ (\%) = 122.22\ /\ 85.71$$

$$Operational\ Efficiency\ (\%) = 1.426$$

Therefore, converting this index to percentage, we have 142.6 %, which is an improvement in operating efficiency equivalent to 42.6 %, which confirms and exceeds the hypothesis put forward four times.

I. Economic Evaluation

It is now time to describe the economic aspects related to the development of the proposal. For this purpose, we consider the total investment of the new metal hopper. Likewise, the costs and expenses involved in the company's operation are considered. With this, we calculated the NPV (Net Present Value), IRR (Internal Rate of Return), Cost Benefit, and IRR (Investment Recovery Period) indicators.

- **Net Present Value (NPV):** The NPV calculates the profitability of the investment where:
  - If the value is equal to 0 in the project, there will be no profit or loss; it is indifferent.
  - The project is not viable if the value is less than 0.
  - If the value exceeds zero, the project will be profitable.

The application has the following formula:

$$NPV = \sum_{t=1}^{n} \frac{Ft_t}{(1+i)^t} - CF_0$$

Where:

Ft_t: Cash flow
CF_0: Initial Investment
i: discount rate
t: period

$$NPV = \frac{185.17}{(1+10.46)^1} + \frac{5{,}207.78}{(1+10.46)^2} + \frac{11{,}025.67}{(1+10.46)^3} + \frac{12{,}611.20}{(1+10.46)^4} + \frac{-12{,}338.10}{(1+10.46)^5} + \frac{-14{,}586.55}{(1+10.46)^6} + \frac{9{,}704.25}{(1+10.46)^7} + \frac{15{,}407.47}{(1+10.46)^8} + \frac{16{,}674.85}{(1+10.46)^9} + \frac{33{,}404.37}{(1+10.46)^{10}} + \frac{695.20}{(1+10.46)^{11}} - 29{,}275.00$$

$$NPV = 168.00 + 4{,}268.00 + 8{,}181.00 + 8{,}471.00 - 7{,}503.00 - 8{,}030.00 + 4{,}836.00 + 6{,}952.00 + 6{,}811.00 + 12{,}352.00 + 233.00 - 29{,}275.00$$

$$NPV = 7.464.00$$

What can be interpreted from the NPV result is that the value is greater than 0, with S/ 7,464.00, which indicates that the project is profitable.

- **Internal rate of return (IRR):** The internal rate of return of economic cash flow is the rate of return on the investment.
  - The project will be indifferent if the IRR equals the discount rate.
  - The project will not be profitable if the IRR exceeds the discount rate.
  - The project will be profitable if the IRR exceeds the discount rate.

The IRR value is calculated based on the range of net profits from the beginning of the investment period to the last period. The internal rate of return was calculated at 36.88 %, which indicates that the project is profitable, exceeding the discount rate by three times.

- **Cost-Benefit (C/B):** The Cost-Benefit ratio is a financial tool that compares the cost of ready-mix concrete to the benefit it delivers.
  - If the cost-benefit is greater than 1, the project is advisable.
  - If the cost-benefit is equal to 1, the project is indifferent.
  - The project is NOT advisable if the cost-benefit is less than 1.

  The formula is as follows:

$$C/_B = \frac{NPV - CI}{|CI|}$$

Where:

CI: Total investment cost.
NPV: Net Present Value.
C⁄B: Cost-benefit.

$$C/_B = \frac{7{,}464.00 - (-29{,}275.00)}{|-29{,}275.00|}$$

$$C/_B = \frac{36{,}739.00}{|-29{,}275.00|}$$

$$C/_B = \frac{36{,}739.00}{29{,}275.00}$$

$$C/_B = 1{,}25$$

The result indicates that the company has a cost-benefit ratio of 1.25, meaning that the benefits outweigh the costs. Therefore, implementing the hopper should be beneficial.

- **Payback period:** The payback period for the company is important because it is an indicator that measures how long it will take to recover the total investment at its present value. As seen in Table 4, the recovery of the company's investment occurred in the fourth month; since the profit for the period is positive, the total investment in the new metal hopper has recovered, generating an additional profit of S/. 14,861.91 in the fourth month of demand for concrete in Arequipa. In addition, they indicated that their maximum production capacity is 72 m^3, producing approximately 1,872 m^3 per month.

Table 4 Payback period of the investment

Investment	Months	June	July	August	September
S/ - 12,338.10	Net Income	S/ - 14,586.55	S/ 9,704.25	S/ 15,407.47	S/ 16,674.85
Payback period		S/ - 26,924.65	S/ - 17,220.41	S/ - 1,812.94	S/ 14,861.91

CONCLUSION

Based on interviews and 15 days of field observation, the diagnostic phase revealed that the company lacks a formalized loading process and a systematic monitoring and data recording system. The lack of monitoring systems hindered the identification of inefficiencies, including an excessive average loading time of 18 minutes and a 3.5% material waste, which had gone unnoticed by the organization.

The literature review highlights that Industry 4.0 principles emphasize using technologies for efficient data acquisition and analysis. The company's lack of such mechanisms has limited its managerial capacity, making it challenging to detect deviations and implement corrective actions, negatively impacting operational efficiency and profitability.

The loading process was redesigned and formalized by integrating tools such as the Process Operation Diagram (POD), an automated metal hopper, and a GPS Logger monitoring system. Staff were trained over three days, and adopting the redesigned process was validated with no resistance from personnel or management.

A 15-day pilot test confirmed that the redesigned process reduced cement loading time from 9 to 3 minutes and the overall loading subprocess from 18 to 11 minutes. This reduced the total concrete production process time from 42 to 36 minutes per mixer, increasing daily output from 72 m^3 to 88 m^3 (+22%) and improving operational efficiency by 42.6%.

The economic evaluation demonstrated the project's feasibility: the Net Present Value (NPV) was S/. 23,020.73, the Internal Rate of Return (IRR) was 22.2%, and the Cost-Benefit Ratio was 1.79, with full investment recovery achieved within five months.

The general objective of improving the operational efficiency of the loading subprocess through integrating Industry 4.0 technologies was achieved. The implemented solution optimized time, increased productivity, and enhanced competitiveness, validating the research hypothesis and offering a replicable model for process modernization in small and medium-sized industrial enterprises.

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