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Basheer Najemaldeen Shaheed
Department Al-Najaf, Technical Engineering College, Iraq

Nasir Hussein Selman
Technical University ATU Najaf, Iraq

Corresponding Author:
Basheer Najemaldeen Shaheed
Department Al-Najaf, Technical Engineering College, Iraq

Developing the control system for the old industrial machines using PLC and IIOT

Basheer Najemaldeen Shaheed and Nasir Hussein Selman

Abstract
In fact, modernizing old machines by making them automated is a cost-effective way to increase productivity and reduce risks in industries. The need for manual labor is reduced by adding advanced industrial-generation technologies to make the machines more sophisticated. In this paper, an automatic control and remote monitoring system is designed and implemented for an old steel plate cutting machine based on a programmable logic controller (PLC) and human-machine interface (HMI). The use of the encoder helps to determine the length of the steel plate to be cut and sends a signal to the PLC. Integration of the HMI module with the Internet for remote control and data storage helps increase efficiency and reduce human error. Practical test results showed that the developed system significantly improved productivity, achieving higher levels of accuracy, safety, and cost-effectiveness in production processes.

Keywords: IOT, IIOT, Industry 4.0, PLC, HMI, VFD

1. Introduction
Internet of Things (IoT) is a term used to describe a network of smart devices that are linked to one another through the Internet. We can reliably monitor and precisely control any device through this system. Thanks to the basic structure of IoT systems make use of a large number of smart devices that are able to acquire, process, transmit, and receive data from one another. According to predictions, by 2025, there will be an estimated 30 billion active network-connected gadgets [1-3]. The Industrial Internet of Things (IIoT) technology was developed in conjunction with intelligent control systems that analyze the collected data and optimize the ongoing industrial processes in order to increase execution speed and decrease associated costs [4, 5]. The fact that IIoT systems may result in a major increase in the efficiency, throughput, and reaction time of operations inside these businesses is one of the most significant factors driving the rapid emergence of IIoT systems in diverse industries [6, 7]. Nevertheless, it also presents challenges concerning data security, privacy, interoperability, and workforce preparedness [8]. In recent years, some research has dealt with using IOT in developing industries [9-14]. Konstantinos Mykoniatis [9] proposed designing a real-time condition monitoring and maintenance management system for low-voltage industrial motors using IoT. The device monitors the temperature and vibration frequency level of industrial motors. It transmits the data wirelessly to a logging station and sends push notifications whenever one of these parameters is exceeded the limits. Through monitoring, the system increased the operational effectiveness of production. K. Friansa [10] created a smart microgrid system based on the IoT for monitoring the operation of the battery. To get battery parameters, like the voltage, current, and temperature, the IoT uses digital communication TCP/IP with JSON format as data gathering. These data may be seen on a computer or a mobile device via an HMI. J. Możaryn [11] proposed a fault isolation and remote monitoring system with the help of IIoT technology for controlling the water level in a network of three linked tanks. The unknown input observer method has been implemented in the fault detection and isolation module on the PLC controller to isolate simulated sensor and actuator failures. IIOT remote system was used for monitoring and damage detection of the system components. M. Q. Tran [12] proposed a novel IoT architecture that secures online monitoring of the state of induction motors by using machine learning algorithms. The newly IoT architecture technique offers reliable motor problem diagnosis in industrial settings owing to vibration. Additionally, the developed IoT system has minimal latency to detect motor defects and cyberattacks and display them on the IoT platform's primary dashboard. N. D. Jayanto [13] suggested a virtual lab desktop system that allows users to

connect to the lab computer's hardware from any location at a predetermined time. This program includes web-based HTML and VNC (Virtual Network Computing) protocols to connect to the lab computer and access simulations of PLC, HMI, and hydraulic. The test results demonstrate that each portion functions properly when the lab computer is accessed from any location. M. K. Gupta [14] proposed designing a control panel with relays, SMPS, PLC, and HMI to provide for simple system access and control. Where switches and the HMI may both be used to control appliances. This project conforms with green building and electricity conservation initiatives, which may reduce energy waste. Motivated by the efforts of the above researchers, this paper focuses on the development of an old steel plate-cutting machine that was installed early in the factory. Besides adding PLC and HMI to the updating control system, advanced remote monitoring technologies such as the Industrial Internet of Things were used. Thus, the old system was transferred to the fourth generation of the industry, while saving the cost needed to purchase an advanced machine. This paper is organized as follows. Section 2 discusses the description of the machine to be developed, and section 3 introduces the requirements for the developed machine. Section 4 describes software of the system, while sections 5 and 6 present the practical results and conclusions, respectively.

2. Description of the machine to be developed

The machine consists of a group of mechanical parts lined up in a longitudinal line, as shown in Figure 1. The first part is the steel roll coil that starts to rotate when the plate is pulled by three phase induction motor. The next stage is the leveling roller that is installed to make the plate flat. Then the steel sheet passes through the hydraulic cutting to be cut. The machine is operated manually at least by three operators.

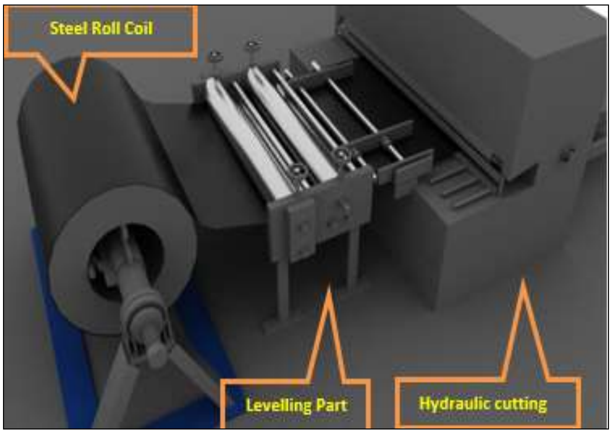

Fig 1: Construction of the Machine to be developed

3. Requirements for the developed machine

The necessary parts required for developing the system and converting it from a manual system to automatic control and remote control were considered after studying and analyzing how the old system worked and its productivity and reliability. Industrial automation system requirements are shown in the block diagram of Figure 2. The following sections describe these requirements.

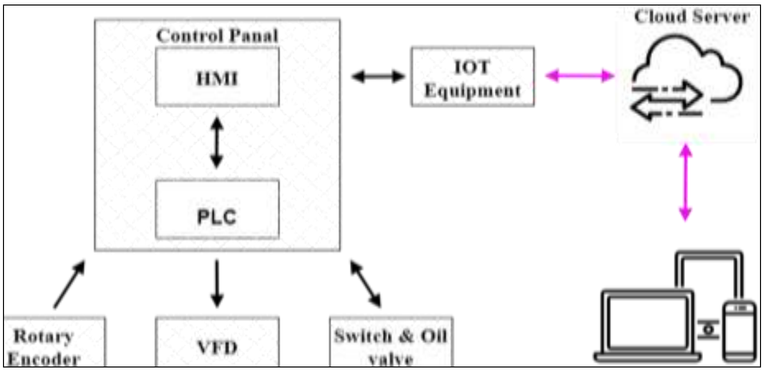

Fig 2: Block diagram of industrial automation system requirements

3.1 Programmable logic controller (PLC)

The intersection of IIoT and IoT has profound PLC is a control module used to automate processes in industrial applications [15]. The DVP12SE11R series from the Delta brand was utilized as the control of the machine used in this work. The specifications of the PLC are provided in Table 1. The DELTA PLC has its own programming language implemented in WPL software 2.5.1 [16]. The ladder diagram (LAD) approach is the one employed in programming [17]. The PLC receives the signals from the sensors (Encoder and limit switch signals), then processes them according to the program steps of the system. After that, sends the required action to the VFD and motors.

Table 1: Delta PLC specification

Model	Operating voltage	Max. frequency	Input/Output ports	Comm ports
DVP12SE11R	24 VDC	100 kHz	8 input/4 output digital	1 Ethernet, 2 RS-485, 1 RS-232

3.2 HMI

HMI stands for Human Machine Interface, a technology that allows humans to interact with machines, such as computers, robots, and industrial equipment, in a more intuitive and natural way [18, 19]. HMI is used for system monitoring, operation, and remote control. DOP Soft version 1.00.11 was used to create HMI software demos. DOP-107DV supports various monitoring and control services, including VNC (Virtual Network Computing), eServer, SMPT, etc. A VNC client (or viewer) is used here to remotely control the machine. All steel plate length data is also stored by eServer for future reference. Figure 3 shows the HMI.

Fig 3: Human Machine Interface (HMI)

3.3 A variable frequency drive (VFD)

VFD is a piece of technology that regulates the speed of an AC motor by altering the frequency of the electricity that is supplied to the motor. VFDs can also provide additional features, such as soft starting, overcurrent protection, and fault diagnostics [20, 21]. Here, a VFD was utilized to control the leveling motor speed. The leveling motor starts off rotating at a given speed, but before the plate reaches the desired length, the motor starts to slow down and eventually stops. The VFD specifications are displayed in Table 2.

Table 2: VFD specifications

Rated power (KW)	Rated voltage (V)	Rated current (A)	Frequency (Hz)
5.5	380	13	0-400

3.4 Encoder

A rotary encoder is an electro-mechanical device that converts the angular position or rotation of a shaft into an electronic signal that can be used by a digital system such as a microcontroller or a computer [22-24]. In this study, a rotary encoder from the Autonics brand was used to measure the length of the steel plate. When the encoder wheel rotates with the steel plate, it produces pulses that are sent to the PLC. Figure 5 gives a picture of the encoder used in this design. Specifications of the encoder are given in Table 3.

Fig 4: Rotary encoder

Table 3: Specification of the rotary encoder

Model	Shaft external diameter	Pulse number per revolution	Phase type	Voltage
E50S8	8 mm	500	3:A, B, Z	12-24 V DC

3.5 Requirements of IIOT

Remote HMI access refers to the ability of HMI to access and interact from a remote location over the network connection [25]. Delta HMI allows remote access for controlling, monitoring, and data collection on a Local Area Network (LAN) via VNC Viewer. Remote access from anywhere at any time via Virtual Private Networks (VPN) can be used to connect the HMI to the device's system.

3.5.1 Radmin VPN

It is software that allows you to create a secure connection between two or more computers over the internet [26]. Radmin VPN allows to set up of a secure connection between an HMI and a remote computer over the internet as if they were connected to a LAN. Thus, creating a tunnel between the two ends of the connection as shown in Figure 5.

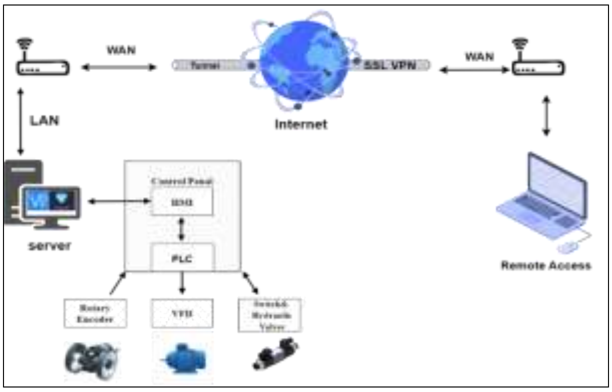

Fig 5: System with required IoT parts

3.5.2 Wireless router

It is required in a computer network to route data packets from one network to another [27]. A wireless router can be used with an HMI to connect to industrial equipment or automation systems with the internet. Figure 6 shows the Wireless router TP-Link-TL-WR845n chosen to be used in the cutting plate steel machine.

Fig 6: Wireless router

4. Software of the System

Figure 7 shows the flowchart of the system's operation. The following parts have been programmed according to that scheme.

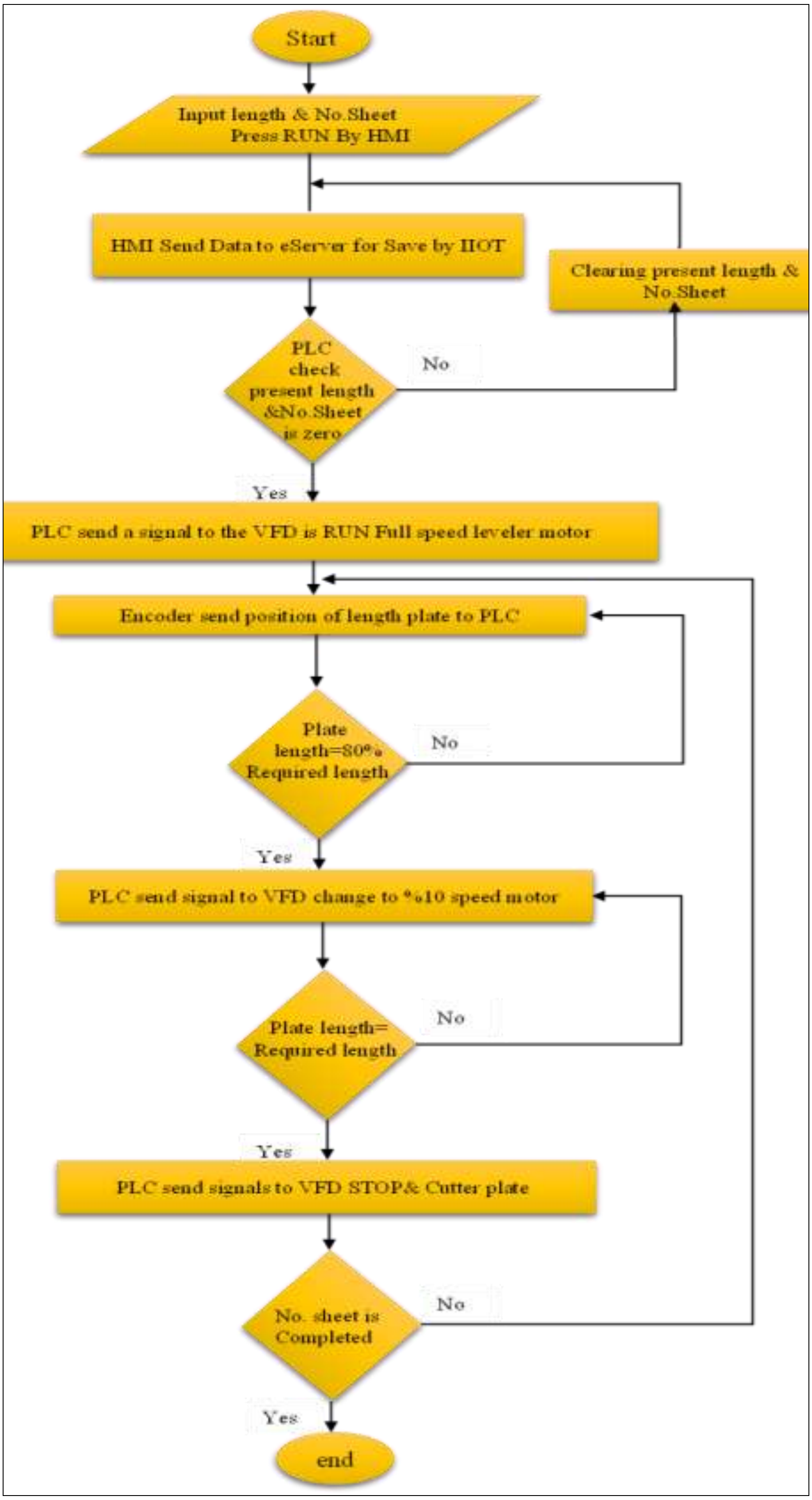

Fig 7: Flowchart of the system

4.1 Programming of PLC

Programming PLCs is based on the most common approach using ladder diagrams. The ladder diagram for the cut-length plate machine is designed using WPL Soft, software for Delta PLCs. The ladder diagram consists of several rungs that represent different functions and operations of the machine. The ladder diagram starts with inputting the starting signals from the HMI, encoder sensor, and switch. The PLC processes it according to the program, and then the PLC gives signals to the VFD and oil valves to control the speed of the leveling motor and cut the length of the plate. A computer can run the designing LAD and validate it. Figure 8 depicts a screenshot of a section of the ladder diagram logic program.

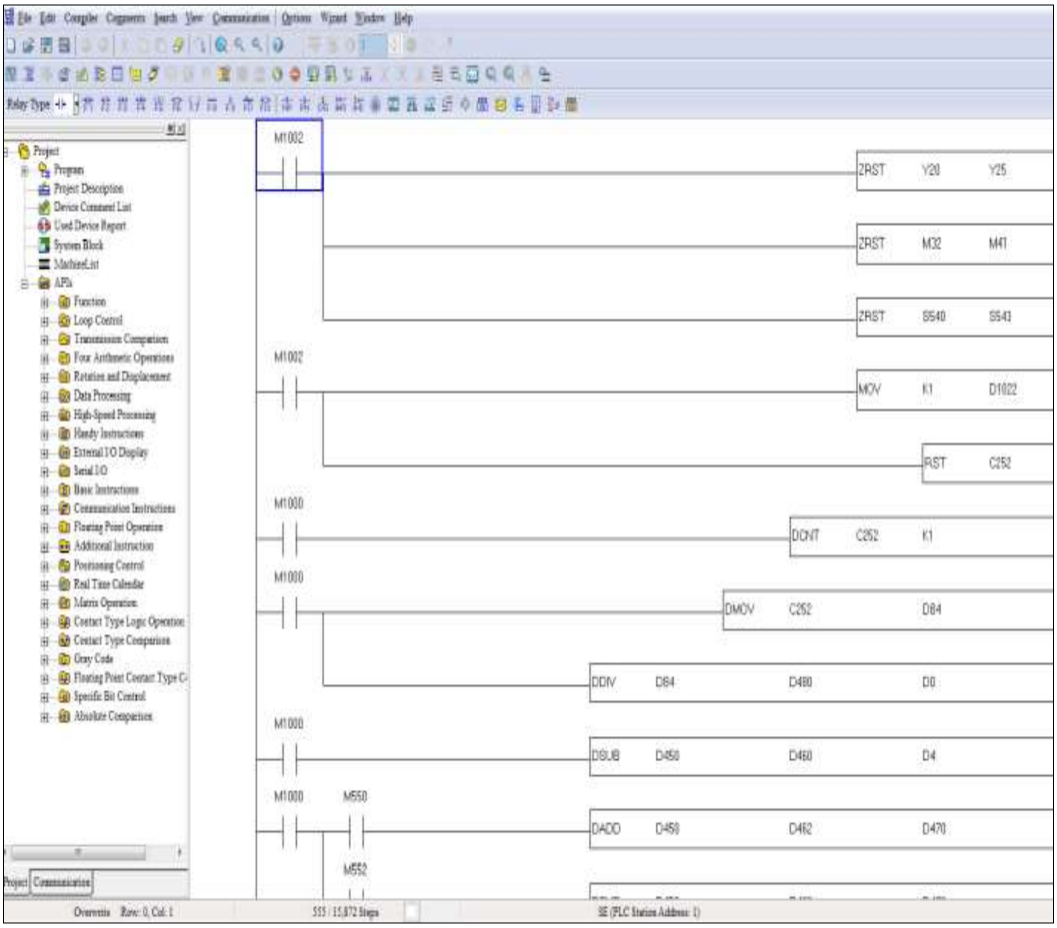

Fig 8: Screenshot of a section of the ladder diagram logic program

4.2 Programming of HMI (HMI Screen Design)

In this design, the DOPSoft 4.00.16 is used to program the screen of the HMI that provides easy access and control of the system. The programming of the HMI included icons to screen elements: data display, buttons, and input data. A screen element of the HMI and a PLC address are connected by icons. Figure 9 gives the Screenshot of the program DOPSoft for HMI. Where use HMI to enter and display the following data:

a) Input distance: the necessary length of the steel plate in (mm),
b) No. sheet: indicates the amount of steel plate needed,
c) present distance: It describes the instantaneous length in (mm) of the steel plate as it travels through the cutting press,
d) present Sheet: Provides the finished steel plate that has been cut,
e) cleared (CLR): button for clearing the data display,
f) RUN: Run the machine automatically,
g) Reverse (REV) and Forward (FWD) rotate of leveling motor.

Fig 9: HMI input and display data

5. Results and discussion

The automation control system for the cut-length plate machine integrated with IIOT has been effectively developed. The hardware elements of the smart control system prototype are built using components and materials that adhere to industrial standards, including PLC, HMI, relays, MCB, terminal blocks, push buttons, switches, and cables. The main control system board and control desk panel are depicted in Figures 10 and 11 respectively.

Fig 10: Main control board

Fig 11: Control desk panel

Testing the Effectiveness of Remote Access in Monitoring and Controlling involved conducting the HMI access via the Internet using a VNC viewer on a laptop or phone. The HMI is connected to the Internet wirelessly through a router, with a secure communication tunnel created using Radmin VPN between the client/user and the HMI. This allows for remote monitoring and control of the machine from a mobile or laptop as if the user were physically in front of the machine's HMI screen, as depicted in Figure 12. The HMI data is saved on the local computer by eServer and presented in an Excel file, where A column are date, B column are length of plate steel in mm and C column are number of plate steel, as illustrated in Figure 13.

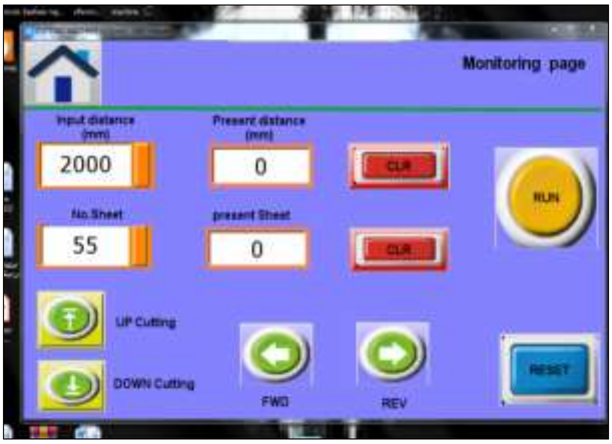

Fig 12: Remote access of HMI

C	B	A
400	2400	02/18/2023
400	2400	02/18/2023
400	2400	02/18/2023
10	2000	02/18/2023
10	2000	02/18/2023
10	2000	02/18/2023
1	2000	02/18/2023
1	2000	02/18/2023
1	2000	02/18/2023
1	2000	02/18/2023
1	2000	02/18/2023

Fig 13: Screenshot of file Excel

The control system program underwent multiple practice tests and modifications to achieve the ultimate automation process for the machine for the control used to cut the steel plate with satisfactory accuracy. The result of the test shown in Table 4 illustrates the changes in productivity pre and post-system renewal. It is evident that the rise in the production of plates is inversely correlated with the length of the plate. Specifically, when the plate length is 1 meter, productivity increased from 150 plates per hour to 190 plates per hour, whereas when a plate length of 7 meters, the increase was from 30 plates per hour to 43 plates per hour. The variance in productivity growth is attributed to stopping that occurs after each plate is produced.

Table 4: Before and after of productivity

Sample Length(cm)	System development	
	Before	After
100	150	190
200	120	162
300	80	113
400	50	82
500	40	66
600	35	54
700	30	43

Figure 14 presents a comparison of the daily production cost before and after development, which amounts to $90/day and $28/day respectively. The data clearly indicates a substantial reduction in the total cost, with the post-development cost being less than one-third of the pre-development cost.

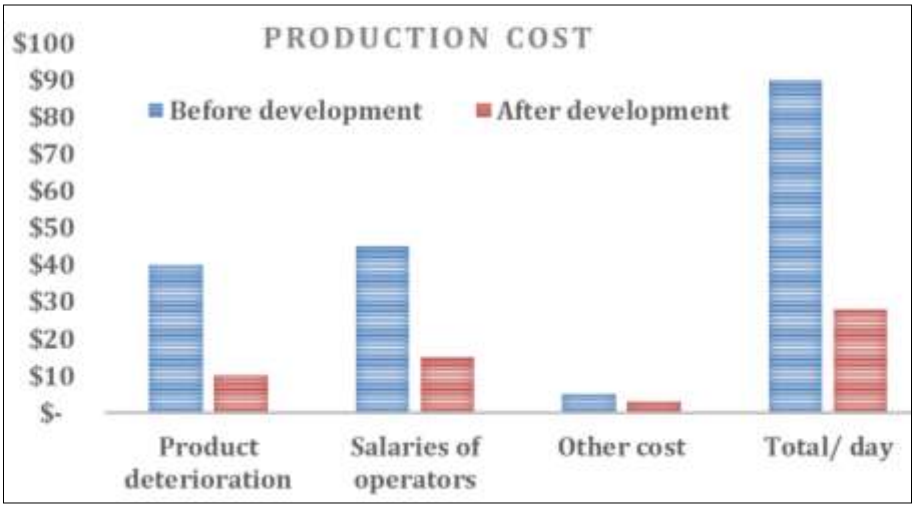

Fig 14: Average production cost

6. Conclusion

A remote monitoring and automatic control system based on a PLC and HMI have been successfully designed and implemented to improve the operation of an old steel plate cutting machine in the plate production plant. The PLC receives a signal from the encoder, which senses the position of the plate length, which in turn slows down the motor gradually by sending a signal to the VFD. The plate-cutting process is then completed until it reaches the required length. The operator can input the panel length and quantity via the HMI interface. Also, Delta HMI allows remote monitoring only locally and data storage by both VNC and eServer. Therefore, VPN technology was used to monitor and record data remotely, anywhere in the world. The system succeeded in achieving two improvements. The first is developing towards Industry 3.0 by introducing computer technology and automation. Second is the transformation to Industry 4.0 and advanced monitoring and remote technologies such as the Industrial Internet of Things. The system showed its ability to increase production capacity, improve safety, and reduce labor costs. The successful implementation of this system is an example of how new technologies can use to improve old machines and increase their efficiency and how this improvement saves the capital that is needed to purchase a new machine.

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