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COMPARISON OF THE RELIABILITY OF PROGRAMMABLE LOGIC CONTROLLER AND ELECTROMAGNETIC RELAY CONTROL IN INDUSTRIAL PRODUCTION LINE

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ABSTRACT

This paper is aimed at determining the reliability of Industrial Production Line using Programmable Logic Controller. Production lines in the manufacturing sector are automated using Programmable Logic Controller module, which is programmed using programming software. The programming software used is the Siemens S7-200 while the programming language is the Ladder Programming language. Most manufacturing industries in Nigeria today still use relays for control purposes. The wirings from the control panel are so massive that any fault from the machine usually takes hours to trace and replace using the traditional electromagnetic relay. Alternative and better control methods use Programmable Logic Controller. Research articles on the reliability of PLC in a food production line are scarce. This paper is written to address this gap. The study uses the statistical analytical method, which provides useful and higher accuracy of the result as it allows high tolerance to uncertainties. The study determines the failure rate, the mean time between failures (MTBF), mean time to failure (MTTF), and availability as a means of determining the reliability of the network. Accordingly, the study showed that the mean availability of the Production line using PLC for three consecutive years is 84% while the reliability is 86%. Consequently, the use of PLC should be encouraged in industrial automation as the fault can be detected easily, thereby reducing downtime as compared to the use of electromagnetic relay in the control circuitry.

Keywords: *Programmable logic controller, availability, reliability, ladder programming language, relay logic.*

1. INTRODUCTION

Control Engineering has undergone several changes over time. For centuries, humans were the only means of controlling things [1]. Programmable Logic Controller (PLC) is a modern method of automating industrial processes. PLCs are advantageous over the normal computer as they were built for rugged industrial environment. PLCs consist of input modules or points, a central processing unit (CPU), and output modules or points. An input accepts a variety of digital or analogue signals from various field devices (sensors) and converts them into a logic signal that can be used by the CPU. This paper determines the reliability of food industrial processes using programmable logic controllers.

The literature on-field failure data of production lines are scarce. Among several researchers include the work of Alexey [2] who uses skip-lot sampling to ensure fewer or zero defective products are obtained in a given manufacturing enterprise. His work focuses on the method of selection from a group of produced items. Liberopoulos and Tsarouhas [3] presented a

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case study of speeding up a croissant production line by inserting an in-process buffer in the middle of the line to absorb some of the downtime, based on the simplifying assumption that the failure and repair times of the workstations of the lines have exponential distributions. The parameters of these distributions were computed based on ten months of actual production data. In another work, Inman [4] presented four weeks of actual production data from two automotive body-welding lines. He aimed to reveal the nature of randomness in realistic problems and to assess the validity of exponential and independence assumptions for service times, inter-arrival times, cycles between failures, and times to repair. Georg [5] presented in his methods of different steps in the deployment of programmable logic controllers. All the processes have one common problem: its limits are exceeded. The use of software in PLC programming can only eliminate this. According to Omer et al [6], the use of PLC increases the efficiency of a production line. Sadegh and Amir [7] enumerated the advantages of PLC over the traditional relay logic. Its economic advantage is its massive production of goods thereby lowering price. Mathematically, gamma distribution and Weibull distribution competes with each other in determining the reliability of a system. Weibull distribution can also be used to determine the failure rate.

According to Gurevich [8], data released by the relay protection unit of UES of Russia in a study carried out between the year 2000 to 2009, digital relay usage poses 89.6% correct operations with 10.4% incorrect operations, electromagnetic relay 93.53% correct operations with 6.47% incorrect operations and microelectronic relay 92.91% correct operations and7.07% incorrect operations. Electromechanical relays become problematic when there is a fault. Tracing the fault usually takes a longer time compared to digital relays, microprocessor-based relays or electronic relays used in a programmable logic controller. Therefore, the meantime to repair is usually larger for an electromechanical-based relay in a control panel of an industrial outfit.

According to H. Tavares et al [9], the key reliability parameters of an electronic relay is mean time between failures and mean time to repair. It is estimated that the failure rate of relay protected voltage equipment for underground cable is 0.00613 failures per year and 0.00333 failures per year for electronic digital relay operation. In this paper, the average failure rate per year for the programmable logic controller is 0.006959.

According to Edmund O.S et al [10], electromechanical relays due to ageing, high cost of maintenance and operational errors led to the use of microprocessor-based relays. Over 30% failure rate of electromechanical relays was as a result of malfunctioning. Other problems associated with an electromechanical relay were large spaced of an up to a room size occupied by them and few numbers of skilled personnel having the required technical know-how in electromechanical relay maintenance. These have led to the replacement with microprocessor-based relays. Microprocessor-based relay has more availability, cheaper to maintain and can test and monitor by itself.

In this paper, a detailed statistical analysis on a set of field failure data, covering three years, was obtained from a real automated food production line. An automated sausage food production line consists of several workstations or stages in series integrated into one system by a common transfer mechanism and a common control system. The movement of materials between stations is automated. There are six distinct stages in making sausage: kneading, forming, topping, baking, proofing, and wrapping. The programmable logic controller is used to implement these stages. Given the extensive length of the period covered, it is hoped that this paper will serve as a valid data source for food product manufacturers who wish to improve the output and operation of the production lines they manufacture and run, respectively. It can also be valuable to reliability and manufacturing systems analysts, who wish to model and analyze real manufacturing systems. This paper uses availability and reliability to determine the effectiveness, durability and quality of a production line.

2. METHODOLOGY

2.1 Materials

The following items are needed in a programmable logic controller (PLC).

(i) Programming device: A personal computer (PC), with STEP 7 Micro/WIN installed is used as a programming device with the S7-200.

(ii) Programming software: A software program S7-200 is required to tell the PLC what instructions it must follow. The S7-200 uses a Windows-based software program called STEP 7-Micro/WIN32.

(iii) Connector cables: A special cable referred to as a (Personal Computer /Point to Point Interface)

PC/PPI cable, is needed when a personal computer is used as a programming device. DIP switches on the PC/PPI cable are used to select an appropriate speed (baud rate) at which information is passed between the PLC and the computer.

(iv) Programming Language: Ladder Logic Diagram (LAD) is the programming language used with PLCs. The left vertical line of a ladder logic diagram in figure 2 represents the power portion. The output element or instruction represents the neutral or returns path of the circuit. The right vertical line, which represents the return path on a hard-wired control line diagram is omitted. Ladder logic diagrams are read from left-to-right, top-to-bottom. A network is any implemented circuit or system. A network may have several elements, but only one output coil. I0.0, I0.1 represents the inputs and Q0.0 represents the output relay or coil of a ladder logic diagram as shown in Figure 1.
These materials are available in the BIGI food production firm

2.2 Methods
Table 1 shows the workstations and machines of the BIGI production line. The parenthesis below the machine or workstation shows the processing time per BIGI.

2.3 Data Collection
Three years of data were collected from a BIGI food production Industry. Table 2, 3 and 4 shows the data collected for the first, second-year and third-year period. Table 5 also shows the overall data for the three years combined.

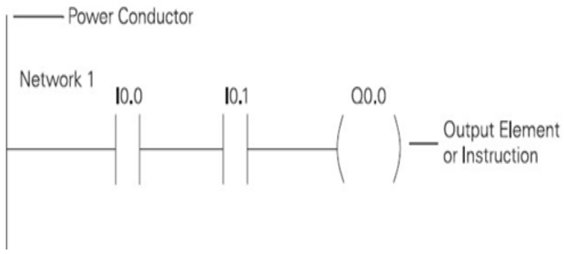

Figure 1: Ladder Logic Diagram

Table 1: The Workstations and machines of a Production line

Workstations		Machines		
WS.1	M.1.1	M.1.2	M.1.3	
Kneading	Flour silo	Mixer	Elevator-tipping device	
	(3 min)	(25 min)	(1 min)	
WS.2	M.2.1	M.2.2		
Forming	Lamination machine	BIGI machine		
	(30 min)	(5 min)		
WS.3	M.3.1			
Topping	Topping machine			
	(5 min)			
WS.4	M.4.1			
Baking	Baking oven			
	(2 min)			
WS.5	M.5.1	M.5.2	M.5.3	M.5.4
Proofing	Load zone	Transporter	Pan cooling unit	Unload zone
(50 min)				
WS.6	M.6.1	M.6.2	M.6.3	
Wrapping	Lifting machine	Wrapping machine	Carton machine	
(8 min)				
WS.7	M.7.1	M.7.2	M.7.3	M.7.4
Exogenous	Electric power	Water supply	Gas supply	Air supply

Table 2: Data for the first year

Month	A1	A2	A3	A4	A5	A6
January	0	1	0	1	1	0
February	1	1	0	0	1	1
March	0	0	1	1	1	1
April	1	1	0	1	1	1
May	0	0	0	1	1	1
June	1	1	1	1	1	0
July	0	1	1	0	1	1
August	1	1	0	1	1	1
September	1	1	1	1	1	1
October	1	0	0	0	0	1
November	1	1	0	0	1	1
December	1	1	1	1	1	1
Total	8	9	5	8	11	10

Table 3: Data for the second year

Month	A1	A2	A3	A4	A5	A6
January	1	1	1	1	1	1
February	1	1	1	1	1	0
March	1	1	1	0	1	1
April	1	1	0	1	1	1
May	1	0	0	1	1	1
June	1	1	1	0	0	0
July	1	0	0	0	1	1
August	1	1	1	1	1	1
September	0	0	0	0	0	0
October	0	1	0	1	0	1
November	1	0	1	1	1	1
December	1	0	1	0	1	0
Total	10	7	7	7	9	8

Table 4: Data for the third year

Month	A1	A2	A3	A4	A5	A6
January	1	1	0	1	1	0
February	0	1	1	1	1	1
March	0	1	1	1	1	0
April	1	1	1	0	1	1
May	1	1	1	1	1	1
June	0	0	1	1	1	1
July	1	1	1	1	0	0
August	1	0	1	1	0	1
September	1	1	1	1	1	1
October	1	0	0	0	0	1
November	1	1	1	1	1	1
December	1	1	1	1	1	0
Total	9	9	10	10	9	8

Table 5: Data summary for the three years

Year	A1	A2	A3	A4	A5	A6
First	8	9	5	8	11	10
Second	11	7	7	6	9	8
Third	9	9	10	10	9	8
Total	28	25	22	24	29	26

The mean time to repair (MTTR) is given by equation (1) as

$$MTTR = \frac{Td\ for\ each\ month}{number\ of\ failure} \tag{1}$$

where TD is total downtime, NF is the number of failures. The mean time before/between failures (MTBF) is given by equation (2)

$$MTBF = \frac{Tui\ for\ each\ month}{Number\ of\ failure} \tag{2}$$

where TUI is the uptime before failure. The reliability (RT) is given by equation (3)

$$RT = \frac{MTBF}{MTBF + MTTR} \tag{3}$$

The availability A is given by equation (4) as

$$A = \frac{TUI}{TUI + TD} \tag{4}$$

The Failure rate λ is given by equation (5) as

$$\lambda = \frac{Number\ of\ failures}{TUI\ \ for\ each\ month} \tag{5}$$

3. RESULTS AND DISCUSSION

The results of the three years and the overall mean period on the reliability assessment of PLC is presented in Tables 6, 7, 8 and 9.

Table 6: Results of computed parameters for the first year

Month	NF	TD	TUI	MTTR	MTBF
January	3.00	48.00	696.00	16.00	232.00
February	4.00	17.00	655.00	4.25	163.75
March	4.00	84.00	660.00	21.00	165.00
April	5.00	100.00	620.00	20.00	124.00
May	3.00	9.00	735.00	3.00	245.00
June	5.00	54.00	666.00	10.80	133.20
July	4.00	121.00	623.00	30.25	155.75
August	5.00	200.00	544.00	40.00	108.80
Sept.	6.00	310.00	410.00	51.70	68.30
October	2.00	70.00	674.00	35.00	337.00
Nov.	4.00	160.00	560.00	40.00	140.00
Dec.	6.00	206.00	538.00	34.30	89.66
Total	51.00	1379.00	7381.00	306.30	1962.46

i. Total number of failure alarms for the first year was 51
ii. Total Down Time (TD) for the first year was 1,379
iii. The total up times (TUI) before failures for the first year was; TUI = 7,381
iv. The mean time to repair MTTR for the first year was $MTTR = \frac{total\,TD}{no\,of\,failure} = \frac{1{,}379}{51} = 27.039$
v. The mean time before/between failures MTBF for the year was also ascertained using $MTBF = \frac{Total\,Tui}{no\,of\,failure} = \frac{7381}{51} = 144.725$
vi. The reliability is RT = $\frac{MTBF}{MTBF+MTTR} = \frac{1962.46}{1962.46+306.3} = \frac{1962.46}{2268.76} = 0.8649$
vii. The availability A = $\frac{TUI}{TUI+TD} = \frac{7381}{7381+1379} = \frac{7381}{8760} = 0.843$

Table 7: Results of computed parameters for the second year

Month	NF	TD	TUI	MTTR	MTBF
January	6.00	70.00	674.00	11.70	115.66
February	5.00	64.00	608.00	12.80	121.60
March	5.00	25.00	719.00	5.00	143.80
April	5.00	100.00	620.00	20.00	124.00
May	4.00	98.00	646.00	24.50	161.50
June	3.00	110.00	610.00	36.70	203.30
July	3.00	80.00	664.00	26.70	221.33
August	6.00	140.00	604.00	23.30	100.66
Sept.	0.00	0.00	720.00	0.00	0.00
October	3.00	96.00	648.00	23.00	216.00
Nov	5.00	164.00	556.00	32.80	111.20
Dec	3.00	190.00	554.00	63.30	176.66
Total	48.00	1137.00	7623.00	279.80	1700.37

i. Total number of failure alarms for the second year was 48
ii. Total Down Time (TD) for the second year was 1,137
iii. The total up times (TUI) before failures for the second year was; TUI = 7,623
iv. The mean time to repair MTTR for the second year was $MTTR = \frac{total\,TD}{no\,of\,failure} = \frac{1{,}137}{48} = 23.6875$
v. The mean time before/between failures MTBF for the year was also ascertained using $MTBF = \frac{Total\,TUI}{no\,of\,failure} = \frac{7{,}623}{48} = 158.8125$
vi. The reliability RT = $\frac{MTBF}{MTBF+MTTR} = \frac{1700.37}{279.8+1700.37} = \frac{1700.37}{1980.17} = 0.8586$
vii. The availability A = $\frac{TUI}{TUI+TD} = \frac{7623}{7623+1137} = \frac{7623}{8760} = 0.87$

Table 8: Results of computed parameters for the third year

Month	NF	TD	TUI	MTTR	MTBF
January	4.00	52.00	692.00	13.00	173.00
February	5.00	90.00	582.00	18.00	116.40
March	4.00	68.00	676.00	17.00	169.00
April	5.00	140.00	580.00	28.00	116.00
May	6.00	384.00	360.00	64.00	60.00
June	4.00	72.00	648.00	18.00	162.00
July	4.00	96.00	648.00	24.00	162.00
August	4.00	56.00	688.00	14.00	172.00
Sept.	6.00	240.00	480.00	40.00	80.00
October	2.00	30.00	714.00	15.00	357.00
Nov.	6.00	264.00	456.00	44.00	76.00
Dec.	5.00	145.00	599.00	29.00	119.80
Total	55.00	1637.00	7123.00	324.00	1763.20

i. Total number of failure alarms for the second year was 55
ii. Total Down Time (TD) for the second year was 1,637
iii. The total up times (TUI) before failures for the second year was; TUI = 7,123
iv. The mean time to repair MTTR for the second year was $MTTR = \frac{total\,TD}{no\,of\,failure} = \frac{1{,}637}{55} = 29.8$
v. The mean time before/between failures MTBF for the year was also ascertained using $MTBF = \frac{Total\,TUI}{no\,of\,failure} = \frac{7{,}123}{55} = 129.509$
vi. Computing the reliability of the PLC RT= $\frac{MTBF}{MTBF+MTTR} = \frac{1763.2}{1763.2+324} = \frac{1763.2}{2087.2} = 0.844$
vii. The availability A = $\frac{TUI}{TUI+TD} = \frac{7123}{7123+1637} = \frac{7123}{8760} = 0.81\ 3$

Table 9: Overall result of computed parameters for the 3 years

Year	NF	TD	TUI	MTTR	MTBF
First	51.00	1379.00	7381.00	306.30	1962.46
Second	48.00	1137.00	7623.00	279.80	1700.37
Third	55.00	1637.00	7123.00	324.00	1763.00
Total	154.00	4153.00	22127.00	910.10	5426.03

Overall number of failure alarms was 154

i. The overall Down Time (Td) was 4153

ii. The overall up times (Tui) before failures was; Tui = 22127

iii. The overall mean time to repair MTTR was $MTTR = \frac{total\ Td}{no\ of\ failure} = \frac{4153}{154} = 26.967$

iv. The overall mean time before/between failures MTBF was also ascertained using $MTBF = \frac{Total\ Tui}{no\ of\ failure} = \frac{22127}{154} = 143.681$

v. The reliability of the PLC is RT = $\frac{MTBF}{MTBF+MTTR}$ $= \frac{5426.03}{5426.03+910.1} = \frac{5426.03}{6302.25} = 0.8609$

Therefore, the overall reliability is 0.8609

vi. The total availability in three years is given as $A = \frac{22127}{22127+4153} = \frac{22127}{26280} = 0.8419$

4. DISCUSSIONS

The reliability of the Programmable Logic Controller was above 80% for the three years. For the first year, the least downtime was 9 hours for May where it also recorded the highest mean time before failure of 245hours. The lower the downtime, the higher the meantime before failure. The second-year has no downtime for September. The third-year has the greatest downtime of 384hours in May where it also has the least value of mean time before failure of 60hours.The greater the downtime, the smaller the meantime before failure.

5. CONCLUSIONS

The study shows that the mean availability of the production line using the Programmable Logic Controller was 84% while reliability was 86%. Since the key parameters of relay usage or protection are the meantime to repair and the mean time between failures, the average mean time to repair and mean time between failures using programmable logic controller are 303hours and 1808.67 hours. Electromagnetic relay has a higher mean time to repair as it takes longer time to detect the fault. Faults are detected faster by the PLC, which displays all faults on the computer monitor. The programmable logic controller which is made up of microprocessor-based relay has replaced electromagnetic relay due to reduced maintenance carried out on it; performs self-testing, monitoring and also provide event reporting. The use of PLC should be encouraged in industrial automation as the fault can be detected easily, thereby reducing downtime as compared to the use of electromagnetic relay in the control circuitry.

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