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# DEFECT REDUCTION OF AUTOMATIC FARE COLLECTION SYSTEM FOR A NEW MRT MONORAIL LINE USING DMAIC

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**ABSTRACT**

The objective of this research is to examine and address issues related to the quality of the automatic fare collection system for the new Mass Rapid Transit (MRT) line and to decrease maintenance time to meet the key performance indicator (KPI) set by the Mass Rapid Transit Authority (MRTA). A total of 1,497 work orders were collected from a survey conducted between June and August 2023. The study utilizes the DMAIC methodology and identifies the primary issue as "Note Module Faulty" commands on the Ticket Vending Machine (TVM), particularly for cash transactions where banknotes become stuck in the banknote acceptor (BNA) section, resulting in transaction failures. After conducting a root cause analysis, it was determined that the problem stemmed from the inadequate design of the banknote acceptor for the new polymer banknotes, Biaxially Oriented Polypropylene (BOPP) film. Following the resolution of the problem, it was noted that the daily influx of work orders follows an exponential decay trend, represented by the equation Yt = 3.525x(0.97803t), and the maintenance time has decreased from 62 minutes per work order to 9.27 minutes per work order.

**Keywords:** automatic fare collection system, banknote acceptor, quality problem solving, DMAIC.

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## 1. INTRODUCTION

In the current situation, the new monorail train line project was officially opened for service in the midyear of 2023. When it is officially open for service, the project would enter the Defect Liability Period (DLP) during which the company must guarantee the quality of the equipment and systems delivered to the stakeholders responsible for the concession [1].

During the warranty period, the process for addressing defects after delivery will commence when the station master identifies an issue with the software or hardware system. The station master would then notify the maintenance team, who would in turn report the problem to the company in the form of a work order. Work orders that have a significant impact on service would be discussed in a meeting to find a solution. From June 3, 2023, to August 10, 2023, a total of 1,479 orders were received, with 32 being brought to the meeting. The order that had the most impact on service was the Note Module Faulty order on a single ticket vending machine (TVM), due to its high frequency and average maintenance time of 62 minutes per order, which exceeds the Key Performance Indicator (KPI) of the Mass Rapid Transit Authority (MRTA) set at 30 minutes per order. Urgent action is required to address this situation.

The work order that had the greatest impact on service was the Note Module Faulty and the work order on the TVM equipment. By using DMAIC and other quality improvement methodologies to find the cause of the problem [2-4], it was found that the banknote receiving section, Banknote acceptor (BNA), inside the equipment, was not suitable for receiving. The new type of banknote is made from Biaxially Oriented Polypropylene material, BOPP, due to the above reasons. One idea to solve the problem is to change the shape, size, and materials inside the BNA device based on joint consideration by the company and the contractor. To be able to support new banknote formats and result in no waste in operations.

## 2. LITERATURE REVIEWS

### 2.1 DMAIC Methodology

Statistical analysis tools play a crucial role in driving the process improvement mechanism. Motorola and other companies have discovered through their Six Sigma projects that problems and their potential for problems can be eliminated by effectively utilizing various statistical analysis techniques and tools available in the DMAIC process [5-7]. Each tool has its distinct characteristics for identifying the root causes of problems. Furthermore, the level of complexity of the analysis tool may indicate the level of improvement that can be achieved. All tools are chosen based on their suitability for solving problems and enhancing the process, and they are organized in a logical order according to the DMAIC process. This facilitates analytical thinking, ensures consistency in the process improvement mechanism, establishes a clear pattern, and encourages employees in the organization to use data and statistics in a disciplined manner to make decisions and solve problems. To increase the efficiency of the work process according to the concept of Six Sigma, which emphasizes the importance of measurement and analysis to adjust various operations [8-9]. The goal of this approach is to improve work by designing the 5 steps of the DMAIC approach to be interconnected and have a cumulative impact over time with the following steps [10-14]:

a) Define phase involves identifying the problem and what is necessary to solve the problem successfully.

b) Measure phase is to determine the efficiency of the current process. Use a data collection plan to track and monitor performance while making changes.

c) Analyze phase is the step of studying such data and using the information to identify the root cause of the problem

d) Improve phase is the process of finding a solution that will be applied and measured including testing and mistake prevention

e) Control phase is the step that creates a control plan to assess the impact of the change and creates a response plan to act in case performance starts to decline again.

**2.2 Wastes in Operations**

Eliminating wastes (7 Wastes) plays a crucial role in the Lean Manufacturing framework [15-16]. This system focuses on eradicating losses and enhancing quality in operations to boost the efficiency of tasks or activities. The drawbacks of having 7 Wastes include extended production lead time, poor product quality, and increased costs [17]. The production process frequently encounters different types of losses, leading to decreased efficiency and effectiveness. Consequently, numerous strategies are being explored to minimize these wastes [18-20].

a) Over production. The act of producing goods in quantities that exceed the current demand or producing them in advance has been a long-standing practice. This stems from the notion that each step in the production process should yield as much output as possible to minimize the cost per unit, without taking into account the accumulation of work in process (WIP) and the resulting inflexibility in the production process.

b) Inventory. The practice of purchasing materials in large quantities to ensure a constant supply for production or to take advantage of bulk discounts often leads to an excess of inventory that surpasses the actual demand. Managing and maintaining this surplus is a burden.

c) Transportation. Transportation, as an activity, does not contribute value to materials. Therefore, it is essential to control and minimize the distance of transportation to only what is necessary.

d) Motion. Inefficient working postures, like reaching for objects far away or bending over to lift heavy items from the floor, lead to physical exhaustion and work delays.

e) Over Processing. Operations arise from unnecessary repetitive tasks in the production process that do not contribute value to the final product, such as quality inspections that do not enhance accuracy or product quality. These non-value-adding tasks should be integrated into the production process.

f) Delay. Waiting happens when machines or employees halt operations due to factors like raw material shortages, machine breakdowns, unbalanced production processes, or changes in production models.

g) Defect. The production of defective items may require rework to meet customer specifications or result in waste production, leading to losses.

## 3. METHODOLOGY

**3.1 Problem Definition and Current Conditions (Define and Measure Phases)**

Throughout this research, the investigator meticulously documented work orders for further examination. Over three months, from 3 June to 10 August 2023, the daily influx of work orders was carefully tracked and summarized. This data is visually represented in Figure-1.

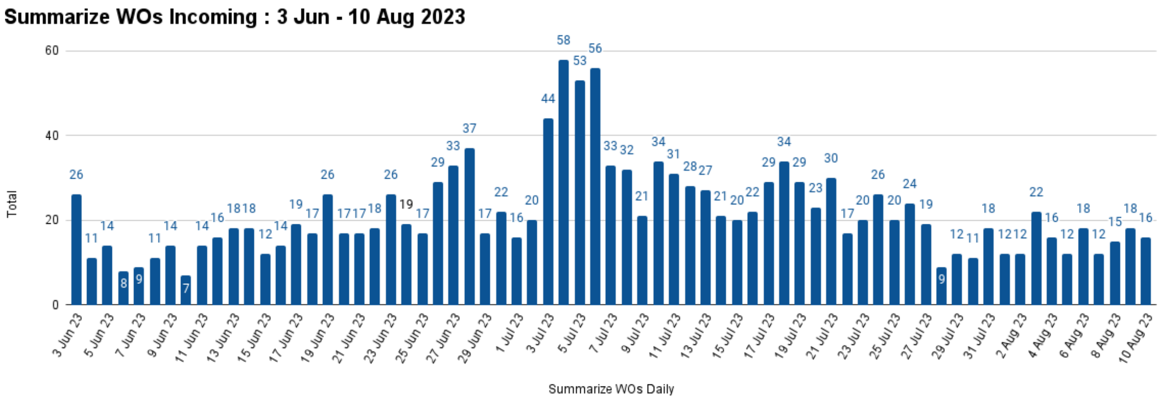


**Figure-1.** Daily work orders from June to August 2023.

During the analysis of work orders related to equipment affecting passenger service, a total of 1,497 work orders were recorded and tracked. The study specifically focused on five pieces of equipment: one-way ticket vending machine (TVM), automatic gate equipment (GAT), point of sale (POS) machines, station computer control (SCS), and walk-through metal detectors (WTMD). Among these, the TVM device received the highest number of work orders daily, totaling 424. Following this, the GAT equipment and POS equipment each had 276 work orders, SCS equipment had 128 work orders, and WTMD equipment had 11 work orders. The study aimed to identify the equipment most affected by work orders and analyze the total maintenance time as well as the average repair time. The maintenance time for each work order was summarized in Table-1 for further analysis.

**Table-1.** Number of work orders and repair time.

| Work Orders | No. | Total time (mins) | Average time (mins) |
|---|---|---|---|
| Note Module Faulty | 106 | 6572 | 62 |
| KYC Not Sync | 75 | 3675 | 49 |
| Thin Card Cannot Be Insert | 42 | 2226 | 53 |
| Hang | 44 | 1364 | 31 |
| Walk Through Are Skew | 2 | 136 | 68 |

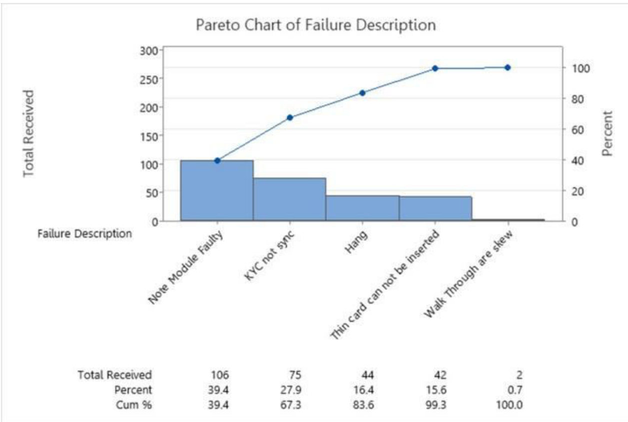


**Figure-2.** Pareto of a number of work orders.

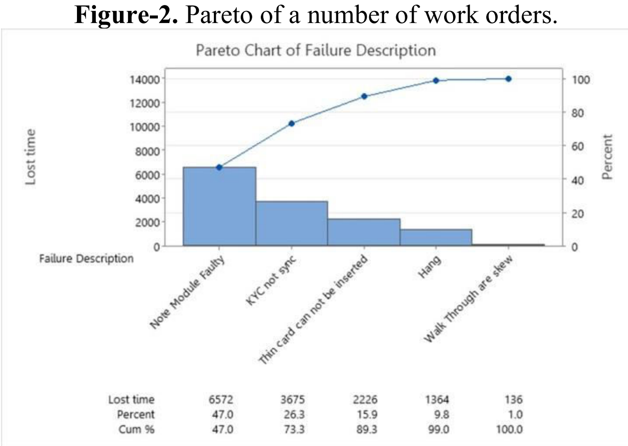


**Figure-3.** Pareto of time to repair.

### 3.2 Root Cause Analysis (Analyze Phase)

The researcher conducted data analysis on the volume of work orders to determine which work orders have the most substantial impact on passenger service at the station. By utilizing "number of work orders received" and "total repair time" as the basis for the diagram, Pareto Diagrams were developed. The outcomes are depicted in Figure-2 and Figure-3.

To establish the correlation between causes and effects and devise efficient solutions, it is imperative to conduct a thorough analysis of each work order. The researcher examined the impact of each task and subsequently constructed a cause-and-effect diagram, along with a Priority Matrix to highlight the significance of each cause. The evaluation criteria focused on the complexity and simplicity of resolving the issue, the time required for resolution, and the extent of problem coverage. This analysis is illustrated in Figure-4 and Figure-5.

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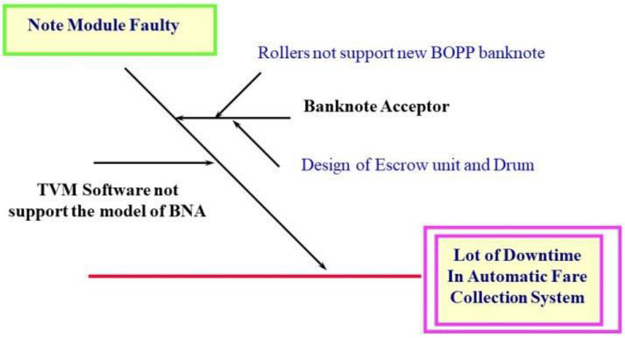


**Figure-4.** Cause and effect diagram.

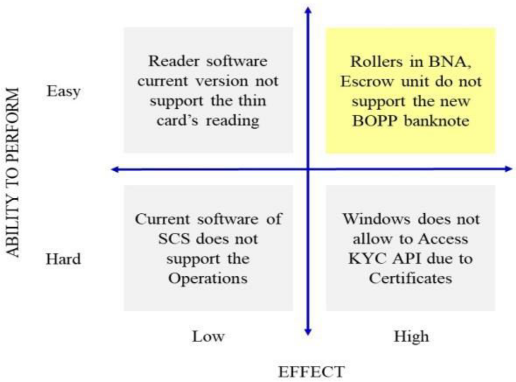


**Figure-5.** A priority matrix.

After analyzing the priority matrix to determine the significance of each factor, it is evident that addressing the Note Module Faulty work order issue by modifying the design elements such as shape, dimensions, and materials to create an updated BNA model is a viable solution. This adjustment can be implemented during the project timeline and proves to be beneficial in resolving issues that impact passenger service at the station with optimal effectiveness. A prevalent issue with this BNA model is the occurrence of bank notes getting stuck, leading to temporary downtime of the ticket vending machine (TVM) as depicted in Figures 6 and 7.

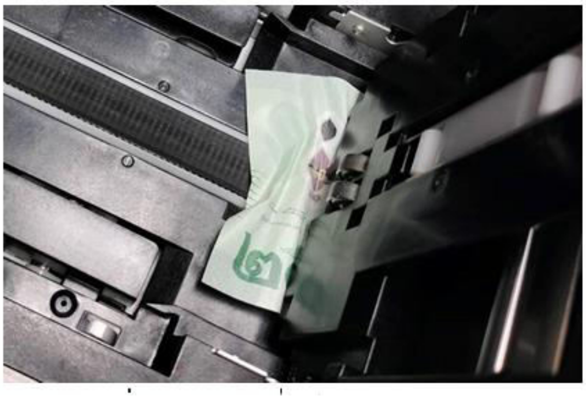

**Figure-6.** A stuck BOPP banknote in BNA.


**Figure-7.** TVM temporary downtime.

### 3.3 Finding Solutions (Improve Phase)

From summarizing the results using the Pareto diagrams including the priority matrix. The analysis indicates that the work order requiring the most attention is the Note Module Faulty work order. The details of the necessary improvements for Engineering changes are as follows:

a) Modifications to the Deposit Unit area to avoid issues with the Entrance Shutter malfunctioning and the rollers wearing out. The changes involve three parts: Solenoid Assy, Shutter, and the banknote separating rollers. The location of these parts is presented in Figure 8 below.

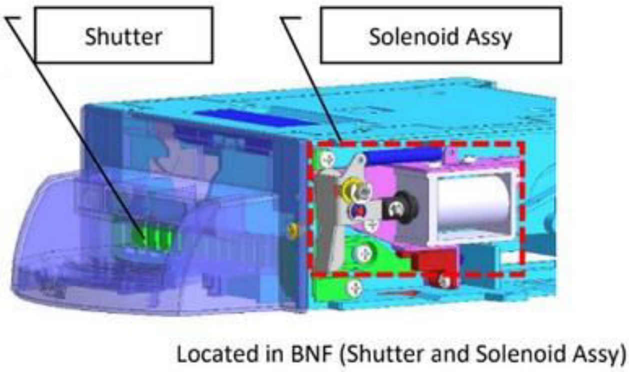


**Figure-8.** Deposition unit.

In the solenoid Assy, another bearing is added to reduce the friction between metal parts, and the shape and thickness of some metal parts have to be reduced and fit to the new bearing as shown in the new solenoid assy in Figure-9.

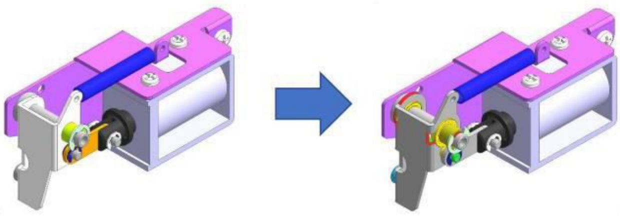

**Figure-9.** Design before and after solenoid assy.

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At the banknote separating rollers in Figure-10, the material of feed rollers is changed from Silicone (hardness 70') to polyurethane rubber (hardness 80') to improve wearing-out resistance. Furthermore, the material of reduction rollers is also changed from HNBR (hardness 55') to polyurethane (hardness 80') as depicted in Figure-11.

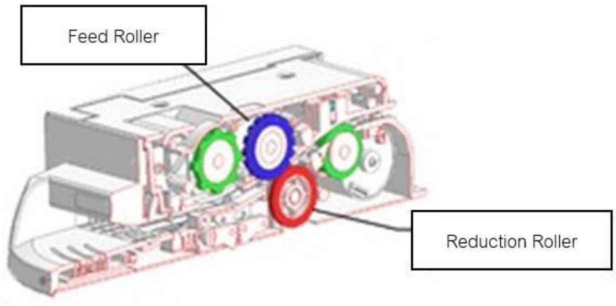


**Figure-10.** Location of separating rollers.

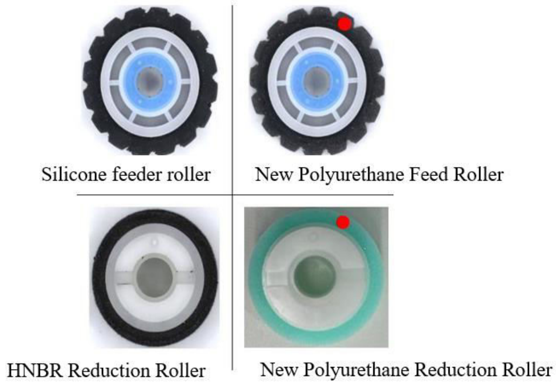


**Figure-11.** New type of banknote separating rollers.

b) Modifying the Escrow Area (ESC) in Figure-12 to minimize banknote jamming during ejection from the Escrow Drum and to address the removal of the RC-R.

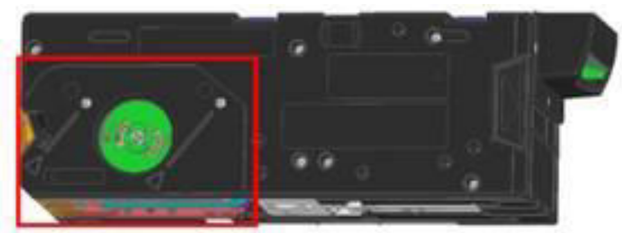

**Figure-12.** Escrow unit and drum.

c) Adjusting the Validation Unit (VAL) area to prevent the expansion of the transport roller within the validation unit. The material of the transport roller has been switched from EPDM to silicone to enhance friction. Additionally, the material of the idle roller has been changed from polyurethane to fluorine rubber. The roller design has been altered to decrease contact points and increase pulling pressure, as illustrated in Figure-13.

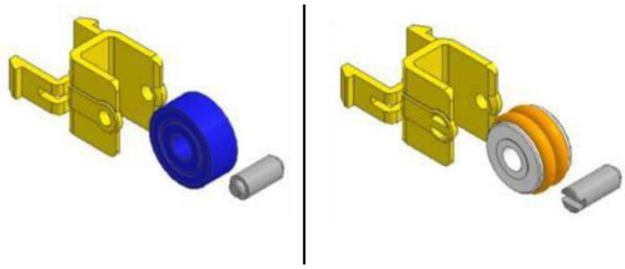

**Figure-13.** Before and a new idle roller.

### 3.4 Implementation Steps (Control Phase)

Fundamental troubleshooting recommendations were shared with the CR Committee and a decision has been made to move forward with the new design solutions. A pilot test will be conducted on all eight stations, such as YL04, YL07, YL10, YL13, YL14, YL16, YL17, and YL23, from September 11 to September 15, 2023. Following this, the testing phase will run from September 16 to September 29, 2023, lasting a total of 2 weeks.

## 4. RESULTS

The results of the improvement indicate that following the completion of the BNA equipment model change in eight stations, there were a total of 20 work orders entered into the system for Note Module Faulty during the trial period lasting 32 days. The project's objective is to eliminate any work orders related to Note Module Faulty from being entered into the system, a goal that has not yet been accomplished. It was identified that the primary reason for the continued influx of work orders into the system is twofold:

a) The implementation plan for the installation of the new BNA model across all TVM equipment has not been fully executed in all stations within the control plan period. Consequently, work orders are still being generated from TVM stations or equipment that have not yet been upgraded to the new BNA model.

b) Following the installation of a new BNA model in a TVM device, a subsequent software update of the TVM device is necessary to ensure hardware and software compatibility, as well as the accurate export of maintenance reports.

Upon analyzing the trend of work orders entering the system and the maintenance period, it was observed that the number of work orders is decreasing. This decline is evident through the linear equation:

$$Y_t = 4.449 - 0.0662t \quad (1)$$

and the growth curve model

$$Y_t = 3.525 \times (0.97803^t) \quad (2)$$

Additionally, the maintenance repair time has decreased from 62 minutes per work order to 9.27 minutes per work order, falling below the success index of the Mass Rapid Transit Authority (MRTA). The S-Curve

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trend model also indicates a decreasing trend with the equation:

$$Yt = 10^4 / (95.3497+2.09638 \times (1.04544^t)) \quad (3)$$

as well as the growth curve model with the equation

$$Yt = 300.489 \times (0.97869^t) \quad (4)$$

The trend analysis plots of these results are presented in Figures 14, 15, 16, and 17.

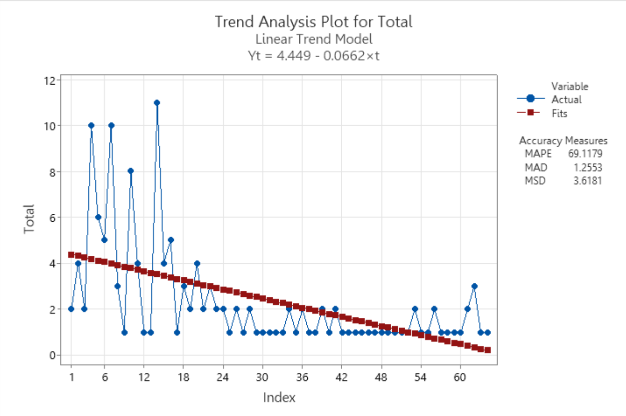


**Figure-14.** Trend Analysis Plot for the number of work order in the linear model.

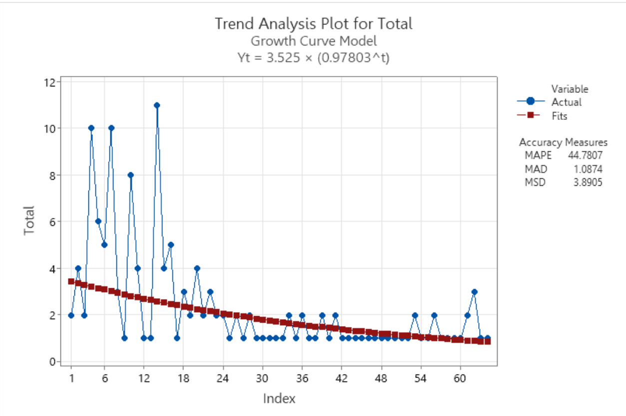


**Figure-15.** Trend Analysis Plot for the number of work order in the growth curve model.

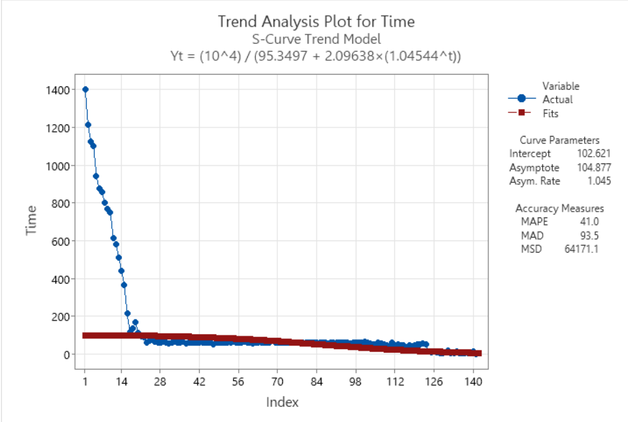


**Figure-16.** Trend Analysis Plot for repair time in the S-curve model.

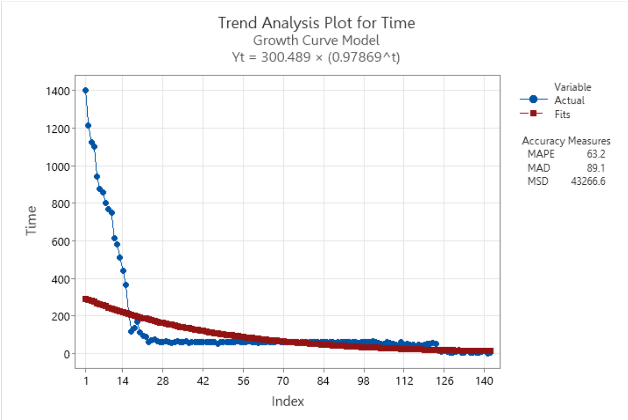


**Figure-17.** Trend Analysis Plot for repair time in the growth curve mode.

## 5. CONCLUSIONS

The initiative focusing on the quality management of the Automatic Fare Collection System for the new MRT monorial line is aimed at addressing the persistent issue of Note Module Faulty on the single-ticket vending machine (TVM) within the Automatic Fare Collection System (AFC). The goal is to minimize the maintenance duration to align with the performance standards set by the Mass Rapid Transit Authority (MRTA). The process commences with an examination of the workflow involved in handling work orders, starting from the problem report by the Quality Assurance Center to the resolution and closure of the work order. The analysis of work processes during the warranty period, encompassing the delivery, documentation, and monitoring of work orders from June 3 to August 10, 2023, will be conducted. The data obtained would be scrutinized to identify the key issues impacting passenger service using DMAIC and tools such as the Pareto Diagram, the Cause and Effect Diagram, and the Priority Matrix. These tools did help establish the correlation between cause and effect, facilitating the identification of efficient problem-solving methods that prioritize the quality of services. By evaluating the significance of each case based on factors like complexity, time consumption, problem coverage, and direct impact on passengers, it is evident that modifying the design, dimensions, and materials of the entire banknote acceptor (BNA) model offers the most effective solution to rectify the Note Module Faulty issue. The investigation revealed that the underlying cause of the "Note Module Faulty" problem lies in the unsuitability of the banknote acceptor (BNA) for the new banknotes composed of biaxially oriented polypropylene (BOPP) polymers. Consequently, the banknote acceptor (BNA) model will be modified accordingly. The TVM's deposit unit (BNA), escrow unit (ESC), and validation unit (VAL) area have been modified in terms of shape, size, and material. The problem-solving process, following the guidelines, resulted in a decrease in the number of work orders, as indicated by the linear equation $Y_t = 4.449\text{-}0.0662t$, or according to the growth curve model with the equation $Y_t = 3.525 \times (0.97803^t)$. Additionally, the maintenance repair time per order decreased from 62 minutes to 9.27 minutes after improvement.

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