PLC Based Monitoring and Prediction: A Case Study of Injection Molding

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Abstract

One of the domains of the fourth industrial revolution is condition monitoring and predictive maintenance. The most optimal use of machinery can be ensured by precisely predicting the remaining useful lifespan of mechanical parts. In injection molding machines, screw damage affects not just productivity but also very high economical loss due to its high time to repair or change. This paper describes a PLC-based live data-driven method to monitor the screw and heaters state and predict the breakthrough moment of the screw, by observing the total consumed current is taken by the heater zone within the molding process. The consumed current is obtained from solid-state relay sent to PLC analog input module through current transform and current transducer. A mismatch between consumed current and set current in the PLC analog input module indicates one or more heaters are not in functioning state, the screw can be damaged and PLC digital output module stops its signal to shut the motor of the machine instantly. After implementing the method results in the permanent solution of screw breakage due to heater damage. The graphs of the heater zone consumed current versus time provide the heaters are functioning properly or not by abnormalities of current consumption values.

Keywords
Programmable Logic Controller, Predictive maintenance, Reciprocating screw, Injection molding, and Injection heaters

1. Introduction
The concepts of condition monitoring and predictive maintenance have gotten a lot of attention in the industry during the last few years. Before that preventive maintenance (PM) was on main focus but over maintenance and maintenance cost has significantly increased in PM. Then condition monitoring and predictive maintenance (PdM) came with the concept of maximizing component useful life and uptime and machine downtime. By assessing the actual state of machine elements or even anticipating their probable time of failure, unexpected downtime can be avoided and maintenance operations are performed only when they are required.
While there are various strategies to this subject in other industrial sectors, plastics manufacturing has only a few. This is surprising because injection molding machines are mostly engaged in mass production, where unplanned downtime can have a significant financial impact, specifically when substitute parts are not instantly accessible. In the manufacturing industry, injection molding is one of the most extensively utilized production processes for generating high-volume plastic parts. In injection molding, the heating barrel is one of the long parts where a reciprocating screw is placed. The reciprocating screw functions as a shaft and is vital in the processing of molten material. According to their depth, a reciprocating screw is commonly divided into three different zones: feed, compression, and metering. In industry, production is interrupted due to a screw breakdown, resulting in a loss of time and money. Several numbers of heaters surround in different positions of the heating barrel and melt the plastic resin. Failure of any heater will drop the molten material's temperature at the specific position, causing it to solidify. This raises the stresses on the reciprocating screw, causing the shaft to break and this screw damage problem due to the heater is occurring frequently in the plastic industry and needs 4 to 5 working days to repair or change (Kulkarni et al., 2017).

2. Literature Review

Advanced sensors and modules, such as PLC, are becoming increasingly important in contemporary factories, since they assist to the collection of complete data about machines, processes, and human-machine interaction which plays a vital role in enhancing manufacturing performance, in-factory logistics, predictive maintenance, supply chains, and overall digitalization. (Kanoun et al., 2021). The development of sensors and other ways of collecting information in a manufacturing environment heightened interest in Prognostic Health Management (PHM), a term that encompasses prognostic techniques for measuring and utilizing asset health statuses, such as Predictive Maintenance (PdM) system (Yan et al., 2017). At TATA Steel company used data-driven model for the bearing wear behavior to anticipate maintenance activity decisions (Chen et al., 2021). Machine Learning and multivariate data analysis are used to predict machine behavior in which data are stored and extracted by PLC (Alladio et al., 2021). Over the last several decades, the food sector has improved product quality while decreasing manufacturing time and cost by automating production with programmable logic controllers (Eppinger et al., 2021). For condition monitoring of electric motor-driven mechanisms PLC controllers are used to develop a prediction framework (Barbieri et al., 2020).

Plastic is the most commonly utilized industrial material in the world. As a result, there are numerous machines available that can execute a wide range of specialized. In an injection molding machine, failure is related to temperature, cooling, and high pressure in the hydraulic system. If this type of information is available, the abnormal produced noise may be used as an actual failure indicator in addition to the temperature (Rousopoulou et al., 2020). The screw is a vital part based on its major activities, it is split into three main functional/geometrical zones (i.e. solids conveying, melting, and measuring)(Mahto & Murmu, 2015). Injection molding screws are components of injection molding machines that, when worn, have a negative impact on not only financial profits but also on cycle durations. This is why condition monitoring and predictive maintenance have been developed to forecast the screw condition before it wears out (Fruth et al., 2020). To save unnecessary expenses, numerous sensors' data from an injection molding machine were retrieved, with the ultimate goal of constructing a Predictive Maintenance model adapted to the particular machine operation (Pierleoni et al., 2020). PLC-based vibration and temperature measuring system is intended to identify servo motor problems(Girit et al., 2020).In the injection molding unit, a triple-combined FOS-sensor is used to calculate mold cavity pressure, which aids in the prediction of product output for the serial production line (Mata et al., 2021).

From the aforementioned discussion, it is clear that predictive maintenance is now a vital system to enhance productivity which includes time, cost, and energy. Different sensors and modules are used to forecast the process based on real-time data. Different data analysis tools like ANN, Fuzzy, Taguchi, regression models are used to predict the condition. There are many works on injection molding machine’s fault diagnosis which enchanted the machine’s life span as well as productivity.

2.1 Objectives

In injection molding, thermo-couple is used to check and control the heater temperature. But with the thermo-couple system, it is however not possible to identify heaters are working or not and predict screw damage due to the heater. The objectives of this paper are to develop a PLC-based live data-driven approach to monitor heater's state, prediction of screw breakthrough moment, and permanent solution of screw breakage problem due to heater damage.

3. Methodology

The method is divided into two i.e. experimental setup and data collection process. In the experimental setup, all connection is given and how data is documented is given in the data collection process.

3.1 Experimental Setup

Measuring the consumed current of the heater zone is the most critical step. The whole process of this monitoring and prediction can be divided into three simple steps. Those simple three steps are:

1. Power source to heater zone
2. Measuring and monitoring the current
3. Signal to motor

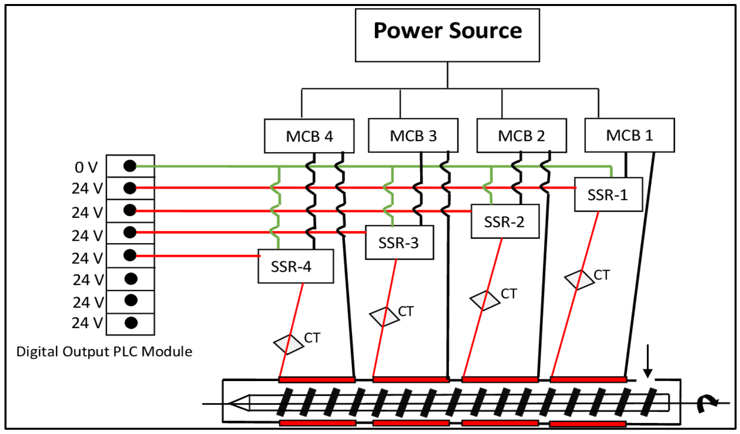

Figure 1: Step-1 Power to heater zone

At present injection molding machine, barrel heater zone gets current directly from an electric power source through Miniature Circuit Breaker (MCB). This MCB is so important because it protects the heater zone from over current. Here, in Figure 1, at step-1, Solid State Relay (SSR) has placed between the connection of MCB and the heater zone. SSR takes its running power (0-24V) from the Digital output (DO) PLC module. The number of MCB and SSR are the same as the heater zone because it provides advantages to control the machine more precisely.

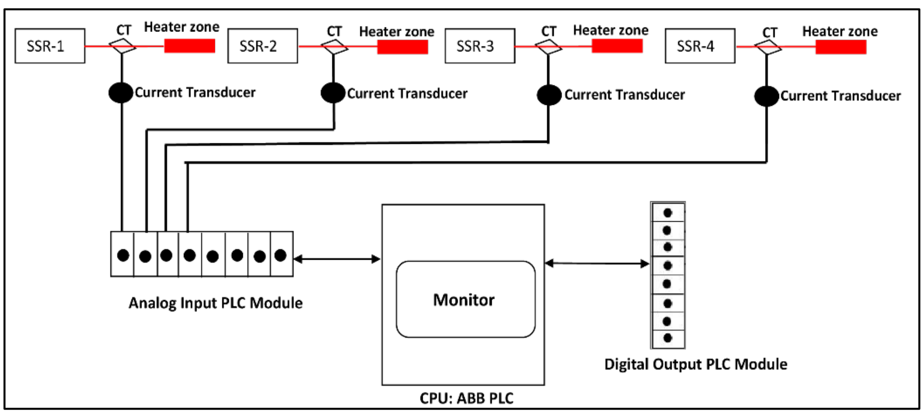

Figure 2: Step 2 Measure and monitor current

The second step in Figure 2 is the setup for measuring current. Step-down current transformer and current transducer have set in the connection line of Solid State Relay and Heater Zone which reduces the current many times than the actual and also converts in milliampere. This milliampere then has been passed into Analog Input PLC module which is connected with CPU (ABB PLC) where the input has been checked whether input current matches with set current or not.

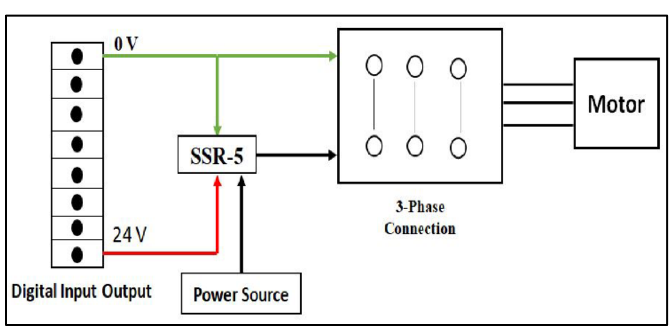

Figure 3: Signal to motor

The step-3 is illustrated in Figure 3, the connection is shown by which machine can be shut immediately. Generally, the motor gets power directly from a power source, but to control the motor and to rescue the screw before damage another Solid State Relay has been set. This Solid State Relay also gets power from the Digital Output PLC module. By installing these three connections, the heater's consumed current has been transformed to PLC-usable milliamperes, and thus the PLC stops its output signal to the motor by evaluating these currents to its logic, whether the consumed current shows abnormalities or not.

3.2. Data Collection Process

Data collection is one of the most important tasks performed by the cloud computing system. Ethernet ports on the HMI have been connected to an Ethernet switch via an Ethernet cable, which has then connected to a programmed MySQL database. MySQL is a database management system that uses a relational model. It may be used to store anything from a single piece of data to detailed information. The current value, temperature value, and machine running time have all been collected from a MySQL server that has been developed. The data collection process is illustrated in Figure 4 below.

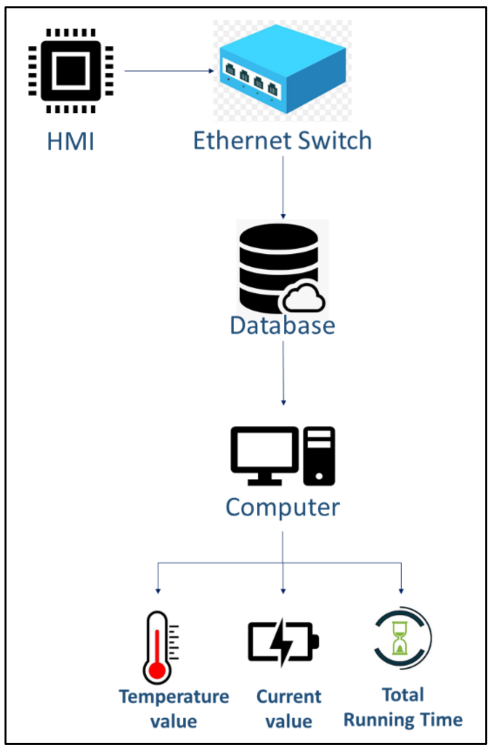

Figure 4: Data Collection via cloud computing

4. Results and Discussion

To ensure that the process is valid, the frequency of heater damage in each zone, as well as the current consumption for each minute, has been gathered. As screw breaks due to failure of heater and heaters are resistive load and consume fixed amount current, the breakthrough moment of a screw can be predicted by comparing current is taken to the current should have taken by the heater zone. From Collected data, the graph shows the heater zone consumed current with respect to time which provides the heaters functioning state properly or not by abnormalities of current consumption values. If consumed current value mismatch with set current means one or more heaters of the specific zone are not working properly.

4.1Graphical Results

After implementing the method into the injection molding machine, the frequency of heater damage, consumption current value to time has been documented for 30 days.

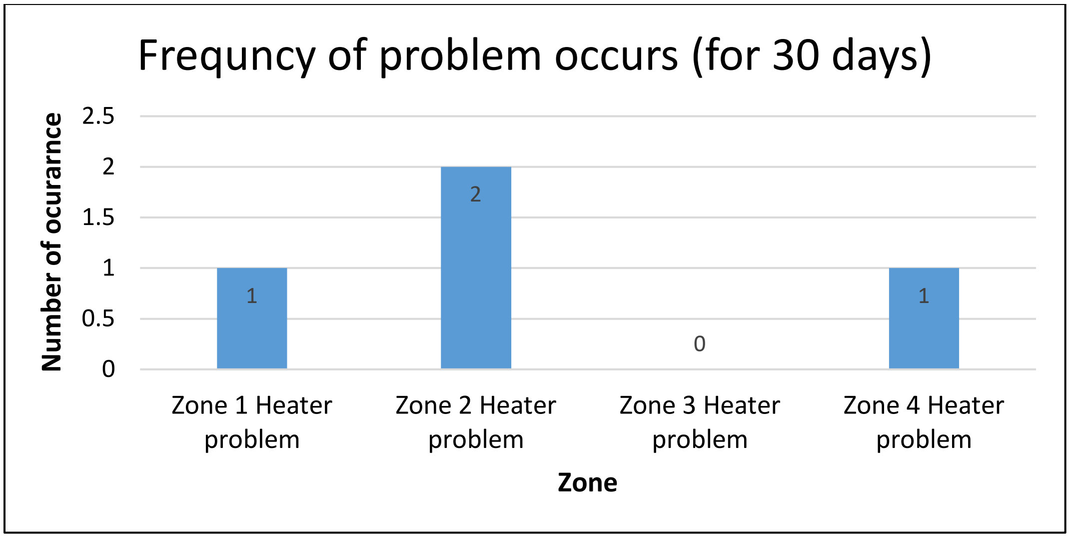

Figure 5: Heater damage problem frequency

Figure5 shows the frequency of heater damage with respect to the time where the heater of zone-2 failed 2 times as it is most failed. The heater zone-2 failed on the 11th day and 26th day respectively which makes us to analysis its current value and figure-2, 3, and 4 are the analysis of heater zone-2.

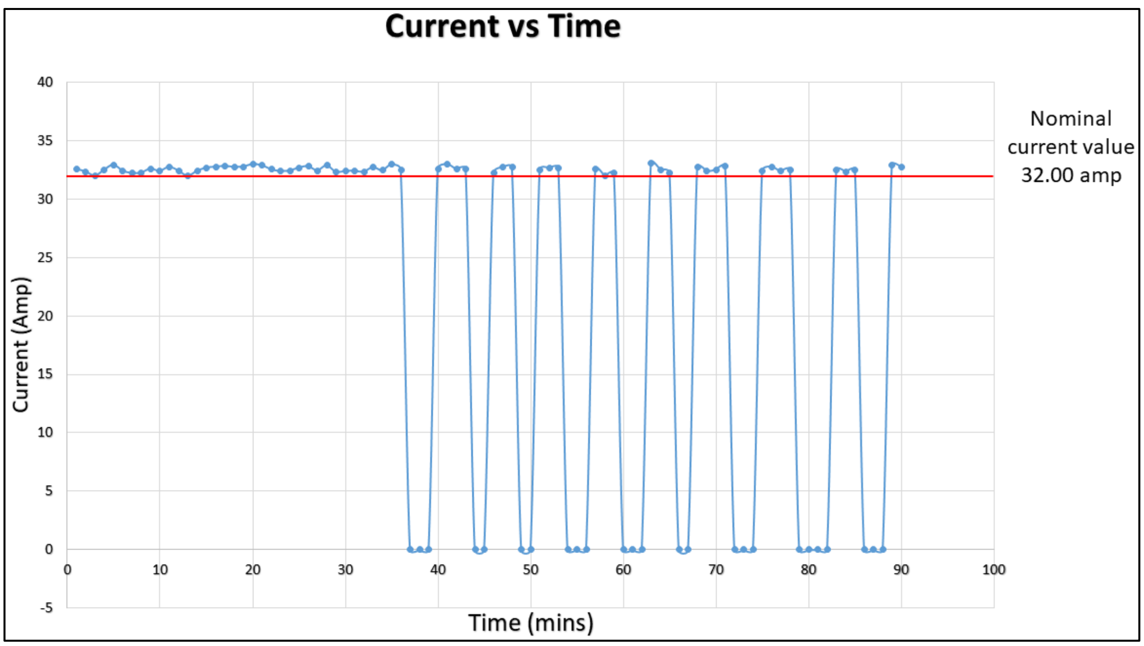

Figure 6: Current Consumption on Normal scenario

Figure-6 shows the first 90 minutes' current value respective to time as a normal scenario of consuming current, heater zone-2 is consuming 32 Amp current which matches with the set current. That provides heaters of heater zone-2 are functioning properly.

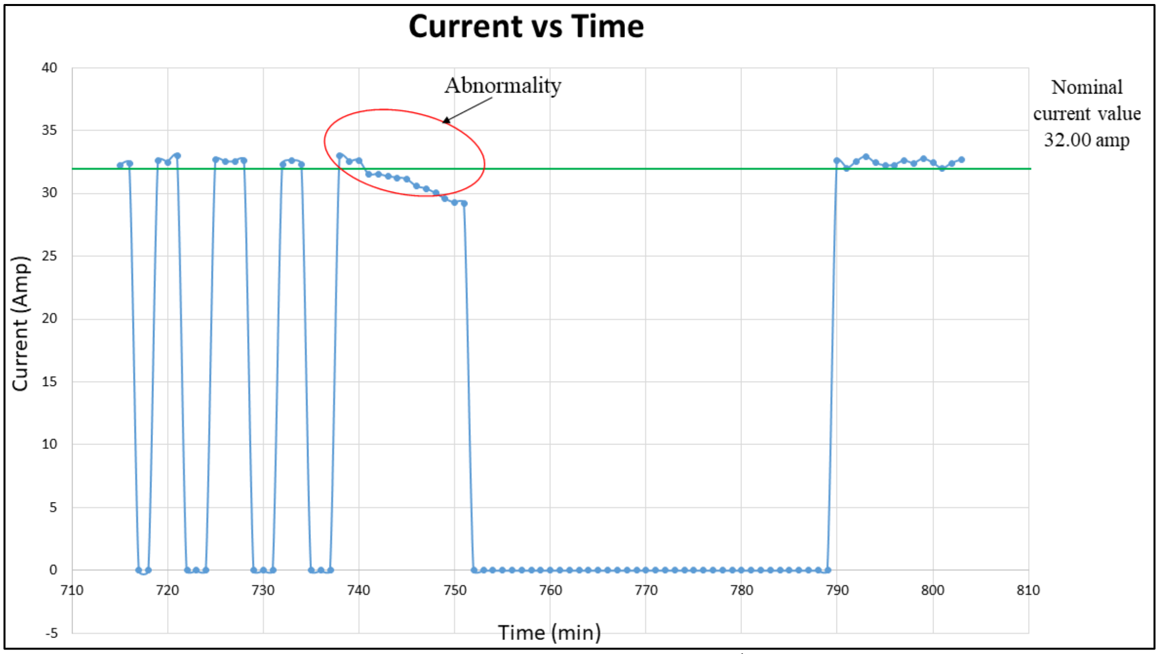

Figure 7: Abnormal scenario of 11th day

Figures 7 and 8 are from different times but their state is almost the same where the heater zone consumed current less than the set current. These abnormalities of current consumption and mismatch between consumed current and set current identify one or more heater of heater zone-2 are not in functioning state. After observing this mismatch for about 3 minutes, PLC digital output module has stopped its signal to shut the motor of the machine instantly. Then repair time had started and continued until the repair was finished, those time zone contains 0 amp.

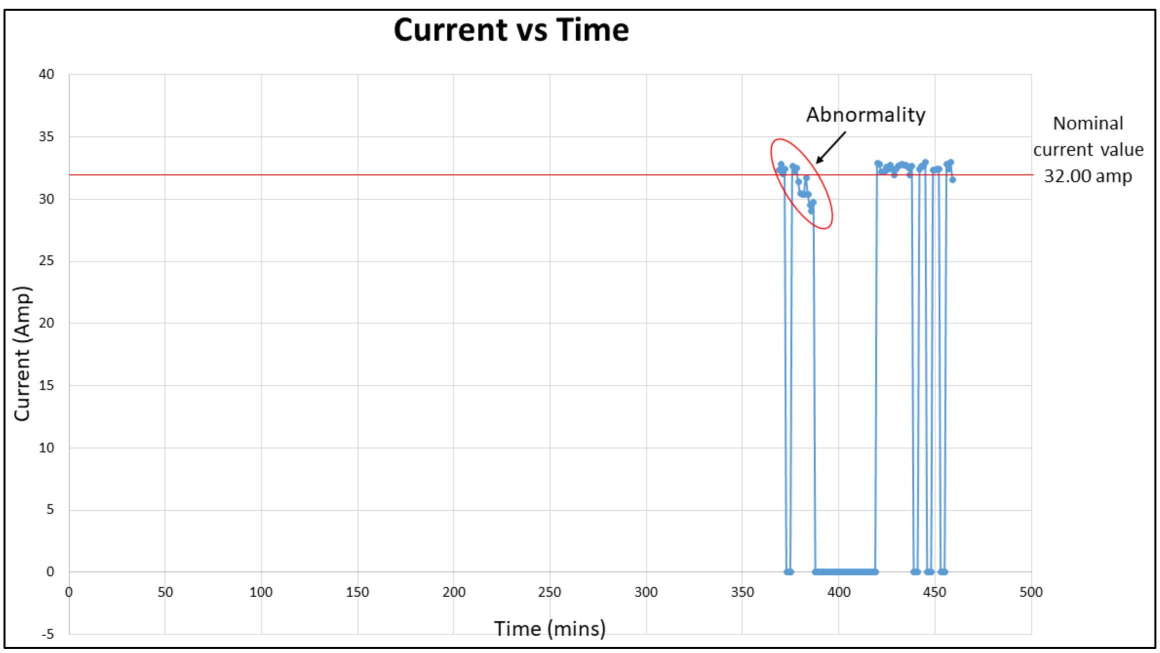

Figure 8: Abnormal scenario of 26th day

4.2Validation

For monitoring, the condition data are collected from one injection molding machine for 30 days data. From server machine breakdown time where include change time of reciprocating screw and its maintenance18.396 hours in 30 days is found which is before implementation of the proposed PLC-based maintenance system. But after implementation, heaters repair/change time is 1.537 hours in 30 days. In the factory, machine run time consider 22 hours per day. So, the percentage of productivity loss has been calculated to compare between before and after implementation, shown in Table 1.

Table 2. Time consumption for screw damage (30 days)

Failure components	Before implementation breakdown time (Hours)	After implementation heaters repair/change time (Hours)
Screw Barrel Damage	18.396	1.537

$$\text{Percentage of productivity loss} = 100 - \frac{\text{Machine operation Time} - \text{ breakdown time)}}{\text{Machine operation Time}} \times 100\%$$

$$\text{Percentage of productivity loss (before)} = 100 - \frac{660 - 18.396}{660} \times 100\% = 2.79\%$$

$$\text{Percentage of productivity loss(after)} = 100 - \frac{660 - 1.537}{660} \times 100\% = 0.2328\%$$

From the calculation, it is clear that there is much difference between before and after implementation. Before implementation data showed time consumption for screw damage due to heater problem is 18.396 hours which causes 2.79% productivity loss. After implementation, the productivity loss has come to down 0.2328%.

5. Conclusion

Condition monitoring and predictive maintenance have the potential to save a great deal of money. Rescuing the plastification screw-in injection molding machines, the most optimum use of the screw can be ensured, and financial losses can be avoided. The experiment has carried out on a single machine, and 30 days of data is analyzed. The graphs demonstrate that the 32 Amp consumption is normal, however, there are current abnormalities that could lead to screw breakage. This approach has reduced productivity loss from 2.79 percent to 0.2328 percent after it was implemented. This paper presents:

1. A PLC-based data-driven approach to monitoring the status of heaters of the injection molding machines by evaluating consumed and set currents
2. Prediction when the heaters need to be changed or repaired
3. Prediction of the screw breakthrough moment
4. Provides permanent solution of screw breakage due to heater damage

Though this method fulfilled its goal, it might be upgraded using various analytical tools, and the problem could potentially be solved through machine learning.

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