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The Study of Operational System in Tunnel Boring Machine (TBM) for Klang Valley Mass Rapid Transit (KVMRT)

Siti Nurnajihah Kori[1]**, Muhamad Faiz Abd Latif**[1]*, **Mok Wen Yao**[2]

[1]Department of Transportation Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

[2]Tunnel Department, Gamuda Berhad, Petaling Jaya, 47820, Selangor, MALAYSIA

*Corresponding Author Designation

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Abstract: Tunnel Boring Machine (TBM) operator is always burdened with his workload to monitor and control the parameters to ensure the condition and position of the TBM are faultless. This research aims to study the autonomous system in TBM that can reduce the burden on the operator significantly and at the same time ensure that TBM can operate efficiently with an autonomous system. The observation and comparison data has been done in both manual and autonomous system based on the data collected in the cloud data warehouse. The data shown the manual and autonomous system in steering and face pressure operation. Finally, it can be seen that the autonomous system able to steer and control the face pressure which the conventional TBM should apply this autonomous system.

Keywords: Autonomous System, TBM, A-TBM, PID Controller

1. Introduction

Tunnel Boring Machine (TBM) is a machine that used to excavate long tunnels through any ground condition and under widely different physical conditions [1]. Since it can excavate any sort of ground condition, the TBM has become one of the best tunnel excavation technologies. TBM is highly integrated and automated sets of tunnel excavation and lining system as the excavation speed of TBM is 4 to 10 times faster than the traditional drilling and blasting [2]. The Klang Valley Mass Rapid Transit (KVMRT) project is an example of project that has underground tunnel. This project consists of 13.5km of underground railway that crosses densely populated areas around Kuala Lumpur. Due to the construction area densely populated area, the detailed investigation of ground condition needs to be done to avoid any risk to the existing buildings and public.

*Corresponding author: mfaiz@uthm.edu.my

The TBM operators have crucial roles in order to ensure the safety of TBM and workers. The operators and their capabilities are important in to drive the TBM safely. The efficiency of TBM fully depends on the skills of operators which added burdens to the operators. Some of the operators would push the maximum force of TBM so that the excavation can be finished faster than scheduled which is a good thing. However, it is a bad for the health of TBM because the cutting tools may wear and broken fast. If the cutting tools wear fast, the operators need to stop the operation of TBM to do the maintenance at the cutterhead. Moreover, TBM operators faced fatigue or cognitive overload due to the large amount of data that need to be monitored and controlled.

1.2 Objectives

i. To identify the operation factor of TBM.
ii. To observe the data between manual and autonomous TBM.
iii. To compare between manual and autonomous TBM.

2. Methodology

This study provides the information on the benefit of autonomous system to the TBM significantly. Autonomous system in TBM execute important role in order to protect the TBM from being exploit. The data was obtained from the cloud data warehouse based on the KVMRT SSP Line. Other than that, the observation and comparison data also has been done based on the data gained. The flow chart has been created for better understanding in methodology and can be refer to the Appendix A.

2.1 Theoretical Studies

In order to gain a better comprehension into the operation factor of TBM, the analysis based on the journal that can be access through the library website has been done. The thematic analysis from the reading was performed to insert all data before identifying and assessing three operation factors that has significant autonomous operation which can clearly ease the burden on the operator of TBM. The conventional TBM relies heavily on the operator's skills and expertise to drive the TBM as it does not have any module to refer on. This method is the most suitable approach to answer the Objective 1 as it need to identify the operation factor of TBM.

2.2 Data Collection & Observation

Firstly, the data was observed to determine the correct axis for the graphs to be created. The data was collected from the cloud data warehouse which is a website that display all the relevant data that managed and hosted by the cloud service providers. PID Controller that known as proportional, integral and derivative is sort of automatic calculation to drive the plant to a specific set reference which in this case, controlling the steering of TBM to designed tunnel axis. The variables in PID were adjusted to achieve the desired stability and responsiveness.

There are a few factors that need to be taken into consideration such as;

- Ground condition;
- Ground penetration;
- Cutterhead torque;
- Contact force; and
- Others.

The PLC that capable to exchange data and process the information, will send the data to the local Inter-process communication (IPC). Local IPC is a program to communicate with data to synchronize the TBM activities with what has been set up at PID controller. The local IPC send the data to the cloud data warehouse to provide the graphical presentation or data to the tunnelling command and control center (TC⁴), thus the operator can know the current situation of TBM. The schematic diagram of the data collection from TBM as shown in Figure 1.

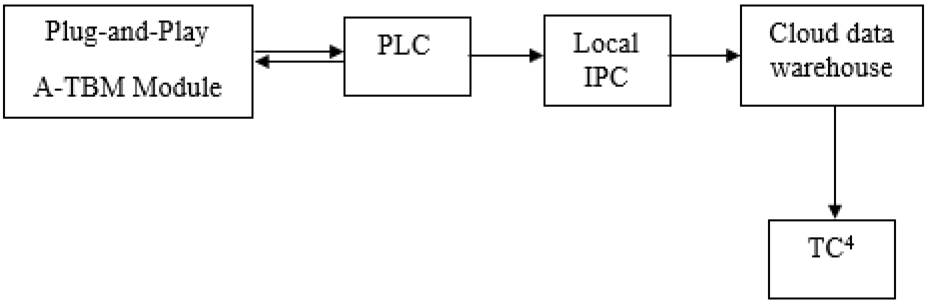

Figure 1: the data collection method from TBM

2.3 Data visualization and interpretation

In this section, the graphical representation was the suitable method to produce nice illustration for easier understanding and highlighting the useful information. Through bar charts, graphs, pie charts and other graphical representation, I can observe more information and make a comparison based on the data given especially when dealing with Big Data that contain various parameters on the operator's monitor in TBM. Thus, can gain the proof that autonomous system gives more benefit to TBM herself and safety to the operators. It is emphasized here that the data obtained from KVMRT SSP Line consist of manual and auto mode TBM operation.

2.4 Comparison and validation approach

After analyzing the data from TBM, the manual and autonomous operation will be compared and validate to gain the prove that autonomous system gives more benefit to TBM herself and safety to the operators. It is emphasized here that the data obtained from KVMRT SSP Line consist of manual and auto mode TBM operation. The comparison will be based on the control of TBM with AI algorithm, accuracy in steering and face pressure control.

3. Results and Discussion

In this chapter, the outcome of the autonomous system will be further explained. The results include the real-life monitor that produced by the cloud data warehousing. The data was collected as a result of the tunnel excavation in KVMRT SSP Line project.

3.1 The Operation Factor

Based on the studies that have been done in the several journals and articles the operation factor that may influence the TBM performance to operate efficiently, productively and accurately. Below is the list of the operation factors that have been identified during theoretical studies:

i. Face Pressure Control
ii. Tail skin clearance
iii. Delay in transportation of segment
iv. Accuracy in Steering
v. Reliance on the TBM operators
vi. Maintenance duration
vii. TBM Control System
viii. TBM Navigation with AI algorithm.

3.2 Descriptive Data

TBM navigation has been controlled by the TBM operators where their skills and expertise in handling TBM are important to ensure that the TBM can navigate through designed tunnel axis (DTA). The navigation of TBM heavily dependent on the operators' skills which give more burden on the operators. The findings shows that the TBM can be control using AI algorithm which has been proves when the deviations occur only ±5mm between the designed tunnel axis (DTA).

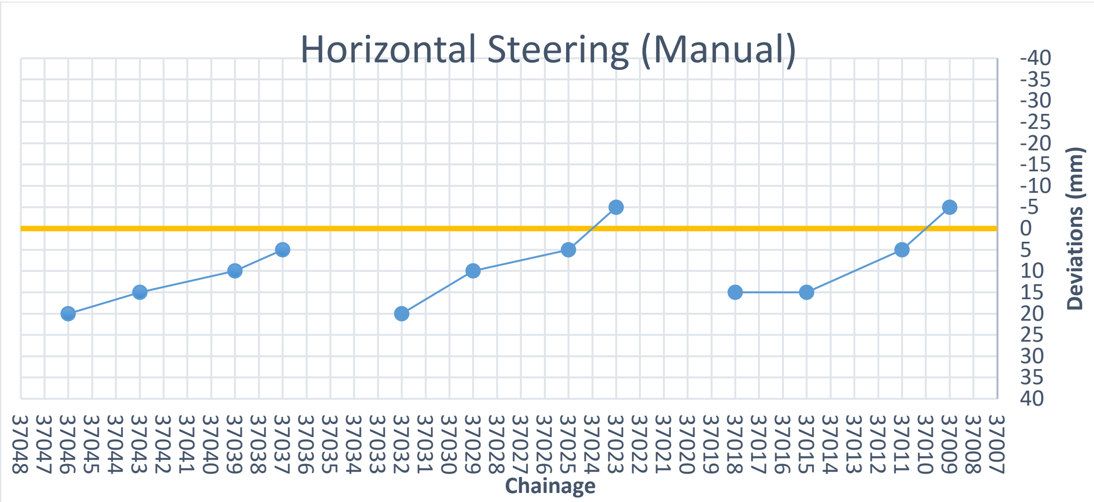

Figure 2: illustrated the horizontal steering in manual system

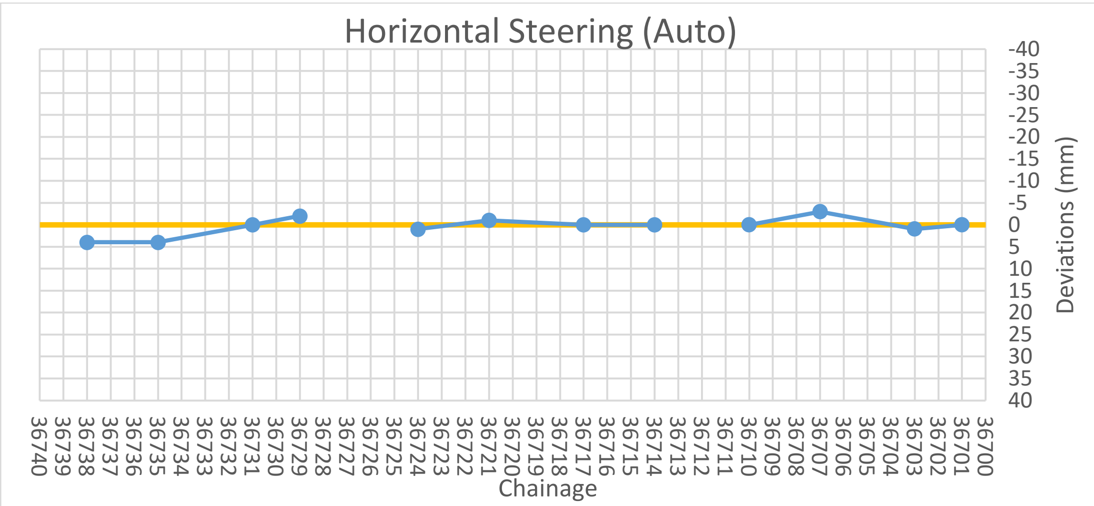

Figure 3: depicted the horizontal steering in autonomous system

Figure 2 and 3 shows the horizontal steering in manual and autonomous system respectively. The negative number is the TBM steer to the left while the positive number is the TBM steer to the right. Figure 2 present significant deviations from the DTA while Figure 3 shows the constant steering through the alignment with little deviation. The deviations do not follow the regulations that have been set up where the tolerance of deviations should be around ±10mm. In Figure 2, the operator trying to drive the TBM back to alignment. It is difficult to drive the full TBM with the shields along the DTA. However, the autonomous system shows contradictory results from the manual system. The speed of TBM always alternate autonomously as it has to meet the variety of ground conditions. Meanwhile in manual steering, the operators need to steer the TBM in the same time control the speed of the cutterhead. The manual system burdens the operators to constantly monitor the condition of TBM. This autonomous feature helps the engineers to reduce the time taken for changing the cutting tools. Thus, the operation of TBM can be done continuously as the cutterhead torque can be control to protect the cutting tools in autonomous system.

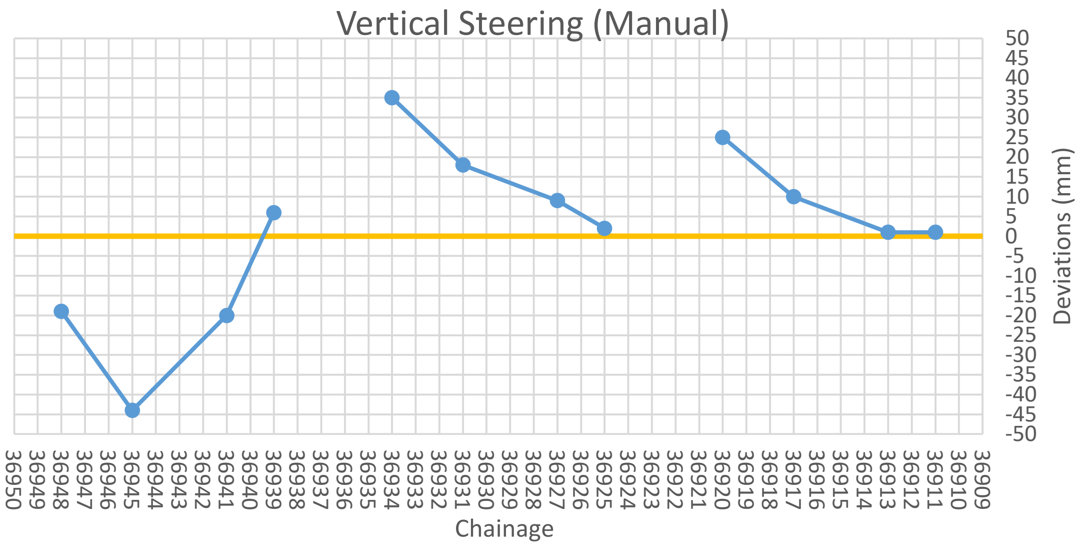

Figure 4: shows the vertical steering in manual system

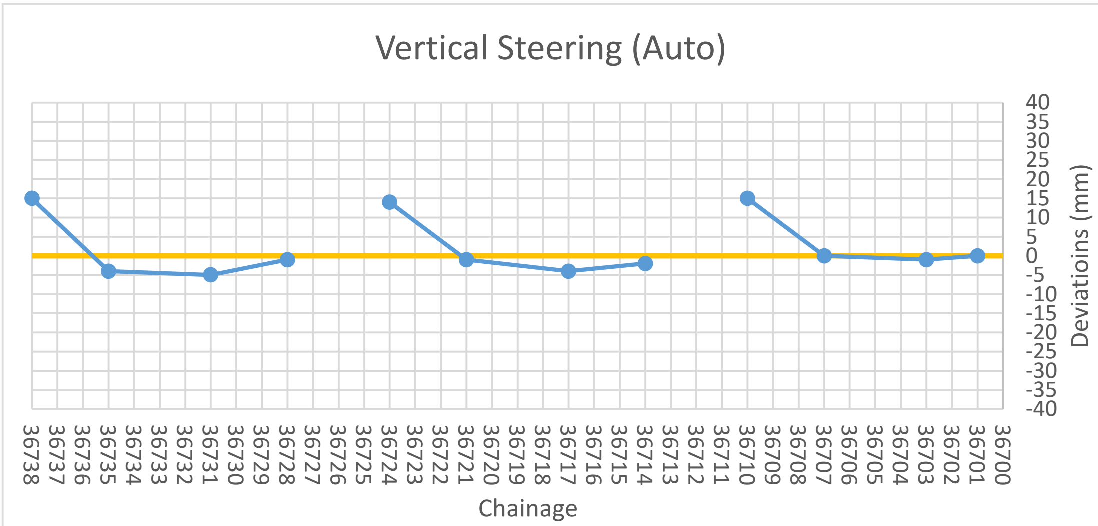

Figure 5: illustrated the vertical steering in autonomous system

In vertical steering as Figure 4 shows significant deviations whereas Figure 5 depicted the successful in autonomous system. The TBM can navigate through the alignment with less than ±5 mm which is a big achievement since the autonomous system has been introduce. There is obvious result between manual and auto steering in vertical steering. In Figure 3.3, you can see the operators trying to bring the TBM back to DTA. However, he tends to oversteer which results in massive deviations. The large deviation causes the misalignment and harms the TBM and the staff that work inside the TBM as TBM excavates through the ground condition that is not being studied yet. Excavating the area that does not bring explored yet by the surveyors potentially cause tunnelling problems such as ground settlement, risk of tunnel instability during excavation, sinkholes and others. Other than that, the segmental lining process also affected where at the end of excavation the concrete segment does not enough to finish a ring as misalignment occur which in plant, they do not expect the TBM to deviate away from the tolerance. Thus, it cost the contractor to order extra concrete segment to finish the ring.

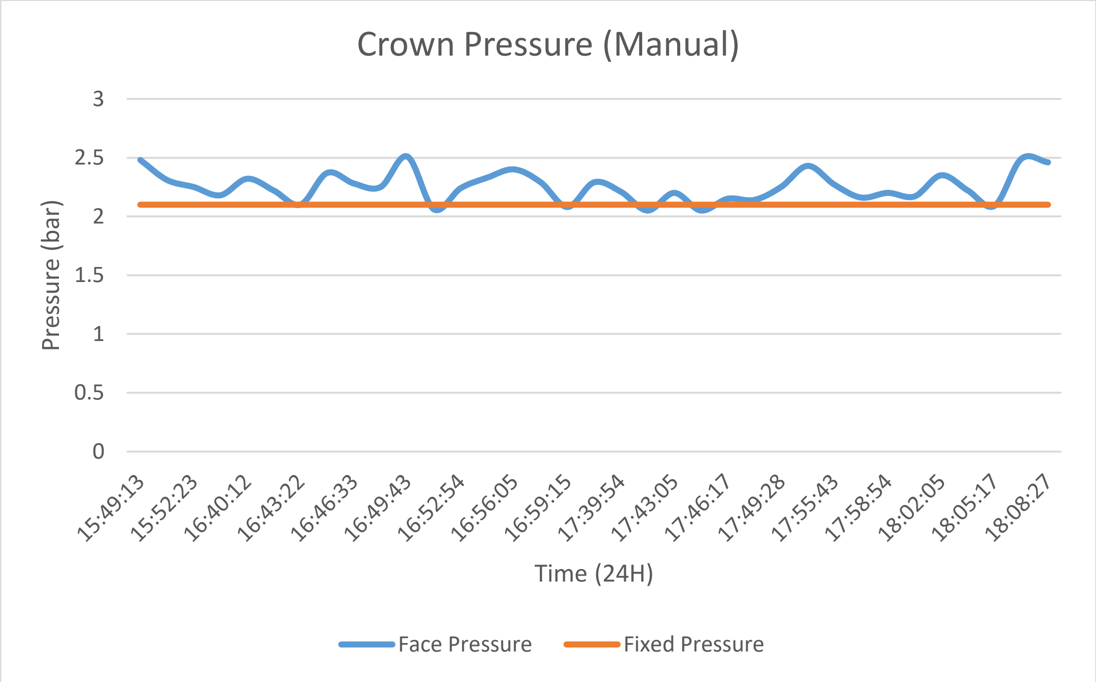

Figure 6: shows the face pressure control manually

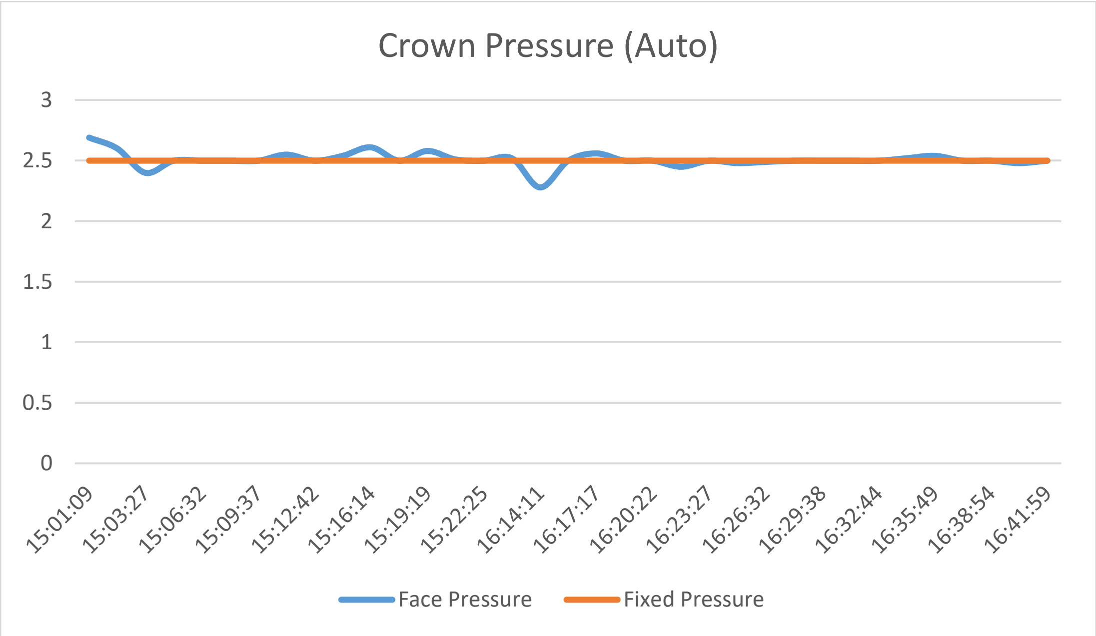

Figure 7: shows face pressure control autonomously

The autonomous system will keep changing the pressure onto thrust cylinder in order to protect the cutting tools. It is important to protect the cutting tools from damage due to the time taken for changing the cutting tools at the front of the TBM. The changing cutting tools process need a compression/decompression work which consider as idle time since the process of compression work requires a few hours due to the requirements given by the Department of Occupational Safety and Health (DOSH) to ensure the pressure both in excavation chamber and human body are the same. This idea has been supported by Camus and Moubarak [3] where they produce maintenance robot to eliminate the idle time related to the compression/decompression work.

In Figure 7, it is unexpected to see at 16:14:11H, where the face pressure cannot be tuned to meet the fixed pressure. This is might due to the present of cavity which cannot be detected during the soil investigation. Somehow, the autonomous system can fix back the cutterhead torque and the speed of conveyor belt to ensure the pressure on the right track. The system increases the speed of conveyor belt and in the same time, increases the cutterhead torque to produce more excavated material in the purpose to ensure the pressure in the excavation chamber same with the face pressure.

4. **Conclusion**

It is stressed here that the Figures 2, 3, 4 and 5 are the results from the courtesy of third parties' reports. The discussion here may not answer all the questionable graphs due to the lack information. This is the unavoidable limitations since those figures does not have any raw data and just depend on the graphical data obtained.

The main focus of the research is the operation factors of the TBM based on the auto mode operation. By theoretical studies of TBM operation factor in the past ten years, this thesis has shown three main operation factors which are TBM navigation with AI algorithm, accuracy in steering and face pressure control. This research also focused to observe and compare the data between manual and autonomous system. Based on the research design and data observation of the manual and autonomous system, it can be concluded that the autonomous system can drive the TBM without pilot and manage to control the situation efficiently. The results indicate that autonomous system able to drive the TBM according to the set-up alignment with minimal deviations and able to control the face pressure within the fixed pressure.

In order to increase the automation in TBM, further research on the segment erection process is needed to ease the workers burdens. Currently, the industry begins to create new autonomous system for erector in which the present function of erector such as reading the serial number of segment and measure the tail skin has been done manually by the workers.

Acknowledgement

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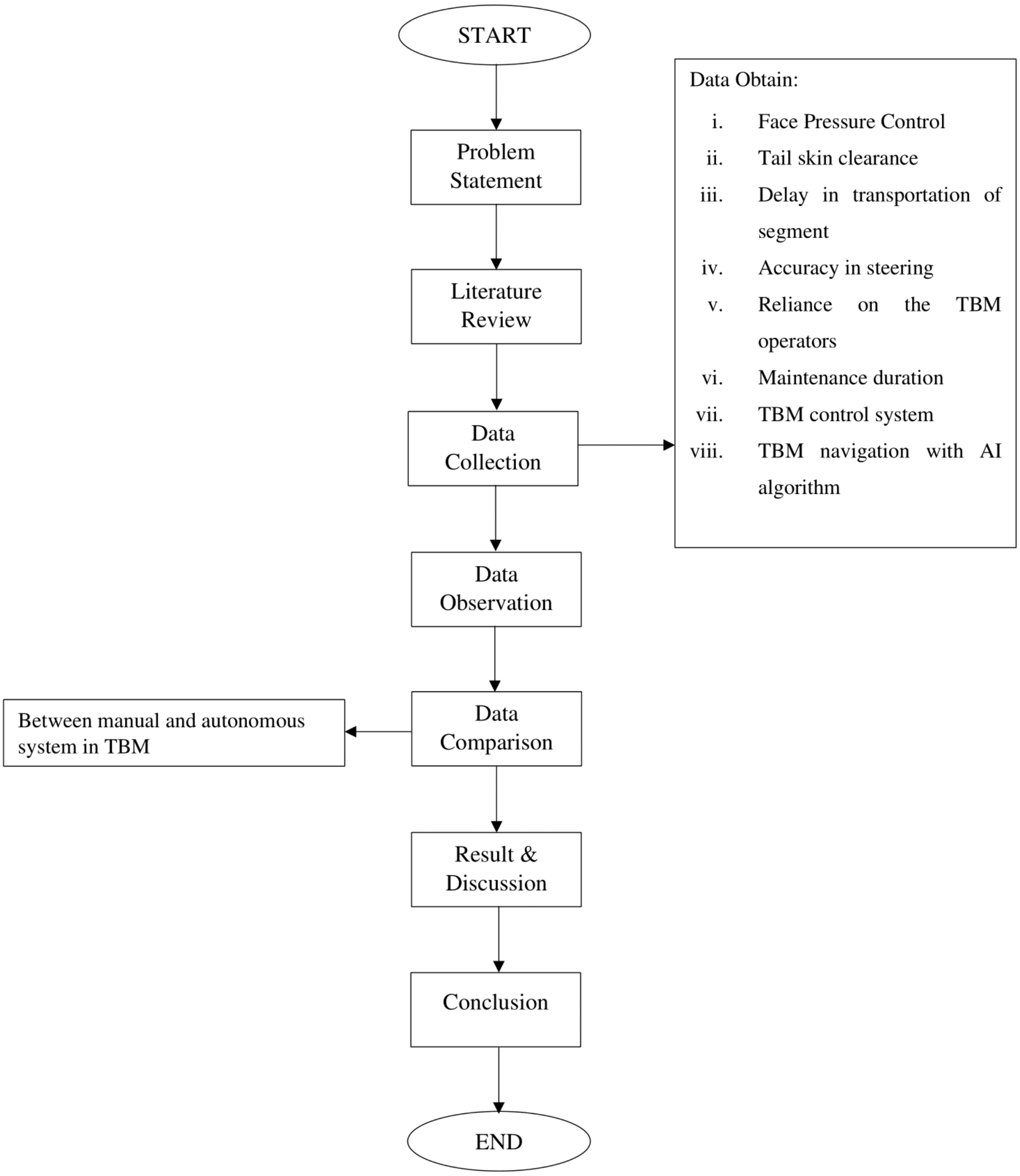
Appendix A



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