Planning Guideline for Failure Handling in Onboard CBTC Device Using RCM (Reliability Center Maintenance) Analysis

Widhi Bayu Aji and Maya Arlini Puspasari
Industrial Engineering Department, Faculty of Engineering
University of Indonesia
Depok, West Java, Indonesia
Widhi.bayu@ui.ac.id, mayaarlini@ui.ac.id

Abstract

Nowadays, the need for public transportation keeps on growing rapidly. One of the globally rapidly growing transportation modes is the Train. Train operation has something to do with the signaling system. Communications-based train control (CBTC) is a modern type of signaling system based on two-way communication using radio waves between Wayside and Onboard devices. CBTC System is a fully automated system that requires robust maintenance of many components in order to prevent failure. Even after the maintenance, a CBTC failure may still occur. Focused on the Onboard CBTC device, a Reliability Centered Maintenance (RCM) method is adopted as an effort to discover the severity level of failure and what kind of maintenance should be given to the Onboard CBTC device. FMEA and FTA methods are also included in the RCM method to conduct the evaluation. The evaluation result indicates that Remote Input Output (RIO) is the most vulnerable equipment to experience failure, in severe conditions, it's resulting in an emergency brake and threatening the safety of passengers. It also indicates that the frequently unclear reports from Mainline officers and different directions from the control center significantly impact poor handling, resulting in delayed traveling. In addition to the need for maintenance, this research aims to produce guidelines in form of a Standard Operating Procedure (SOP) for dealing with Mainline failure during operating hours. It is expected that any different direction from the control center and engineer's action can be eliminated in dealing with the Mainline failure.

Keywords
OnBoard CBTC, Failure, RCM and SOP.

1. Introduction
In recent years, many countries started to develop mass transportation to reduce road congestion. One of the common mass transportation used in urban cities is Urban Rail transport. The massiveness of Developing Urban Rail Transport also needs advanced technology to make it always in good operating condition. Train operation has something to do with the signaling system. Communication-Based Train Control (CBTC) is a system that used radio Communication from onboard components to Wayside components. CBTC used radio communication to ensure train information in real-time (Dimitrova and Tomov 2020). The CBTC system aims to ensure a highly reliable seamless and Redundant connection between the Urban Rail Transit and the track (Dimitrova and Tomov 2020). CBTC system also made by an interlocking system so, if one of the CBTC Component doesn't run or gets failure it means the other component can't run perfectly. So, it is necessary to always ensure the CBTC equipment is in a ready-to-operate condition but in mainline operations, there are still failures in the CBTC component subsystem. To handle failures that occur in the mainline, guidelines are needed in handling failures. guidelines are needed so that there is no disagreement between the machinist and the operation control center when carrying out the handling. using one of the train operators in Indonesia which is currently the only one that operates the CBTC signaling system in Indonesia, this research is intended so that when a failure occurs, the handling carried out is standardized.

1.1. Objectives
This study's main objective is to know what kind of failure occurs on the CBTC On Board device. Then it can be given handling recommendations that can be obtained from specification documents or from expert opinions and experience in the Mainline.

a. Expected Output
As a guideline in dealing with operating disorders, it is hoped that this study will produce several outputs that are beneficial for the operation of facilities that run the CBTC system as the operating system. A

Standard Operating Procedure (SOP) with more complete and detailed handling of the equipment type, what damage occurred, its severity, and what should be done to re-normalize the failure of the system.

b. Research Benefits

There will be guidelines for handling failures on CBTC onboard devices that contain the type of failure on each device, what consequences can be caused, and good handling instructions. This is also expected to reduce handling time or make quick handling decisions so as to reduce or even eliminate train travel delays.

2. Literature Review

CBTC is a signaling system that allows a train to detect itself using two-way radio communication between the equipment that is on the train and in the Mainline. The CBTC system is a continuous system, that uses automatic train control systems, high-precision train location determination, independent circuit tracks, high cross capacity, two-way data communication between trains and equipment in the Mainline (Wayside), the capability of implementing the functions of Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) between facilities and Mainline combat (IEEE Std 1474.1,2004). Another author explained that CBTC is a train control system that is currently applicable to urban trains, in general, CBTC consists of a Zone Controller, Computer Interlock, Automatic Train Supervision on the rail side or in the Mainline, and Vehicle On Board Controller on the railway facilities (Mang Chang et al. 2022). for additional information, Jing Lie et al (2019) explains that The CBTC system is an automatic train control system that provides safe movement of railway facilities using two-way communication between railway facilities.

It can be concluded that the CBTC system is divided into two parts, namely on-board and wayside, here are the on-board and wayside CBTC components (IEEE Std 1474.1,2004) in the following Table 1.

Table 1. komponen CBTC

On Board Equipment	*Wayside Equipment*
1. *VOBC (Vehicle On Board Controller)*	1. *Station Computer*
2. *Balise Antena*	2. *Wayside Radio Set*
3. *VRS (Vehicle Radio Set)*	3. *Station Computer Interface*
4. *TG (Tacho Generator)*	4. *Balise*
5. *DMI (Driver Machine Interface)*	5. *GPS Antena*
6. *TIS (Train Information System)*	6. *Balise Encoder*

2.1. Signaling System

Rail control systems play an important role in ensuring the safety of train operations and improve transportation efficiency (Jiang Liu 2022). One of the control systems of the railway is the signal system, Signaling or Signal itself has the meaning a tool or device used to convey commands for train travel arrangements with color demonstrations and/or other forms of information (Ministerial Regulation 2018).

2.2. Interlocking System

An interlocking system in a railway is a train control system that gives rise to collaborative control to determine the direction or permit for a train to run, to prevent a train collision or crash (Takata et al, 2019). As explained at the beginning that the CBTC system is an Interlocking or interlocking system and broadly speaking this interlocking system serves to ensure that the route is Safe and Locked.

2.3. Component Function

based on the documents from the operator (*Technical Specification for SIG – On-board CBTC*), the functions of each CBTC Subsystem are as follows:

VRS (Vehicle Radio Set) Serves as a device that transmits and receives train condition data signals and receives signals from Wayside Devices. *Balise Antenna* Serves to receive signals from Balise who are on the cross as a tool to find out the position of the train, and as a train stop point right at the station. *VOBC (Vehicle On Board Controller)* Ensuring the safety of the train, controlling door opening and closing permits, and receiving information from TIS, is a major piece of equipment in the CBTC and is redundant. *TG (Tacho Generator)* There are two TG at each end of the train, where TG will function to calculate the number of wheel rotations based on the diameter of the wheels to be able to know the mileage and speed of the train. The working system is in the form of verification between TG 1 and TG 2. *DMI (Driver Machine Interface)* In the form of a screen that displays signaling information to the machinist (As a substitute for Mainline Signal). *TIS (Train Information System)* Performs data acquisition on Rolling Stock equipment and controls trains as well as train circuits, as well as communicating with CBTC On Board subsystems for example VOBC, SC, and other devices useful for CBTC-based train operations.

3. Methods

3.1. RCM (Reliability Centered Maintenance)

Reliability Centered Maintenance (RCM) is used to assess maintenance needs and issues regarding the sustainability of a component, RCM is a method that can be applied in investigations related to maintenance and sustainability issues of a component (Stig Eriksen, 2021). RCM itself can be combined with other methods such as FMEA with certain limitations. Mourbray (1997) explains that RCM is basically spelled out through seven basic questions that are used as a reference in the process of working on this method, the aim of which is

1) Function and Performance Standard – What is the standard function and performance of existing equipment in the context of the current operation?
2) Functional Failure – In what ways does the Component fail to perform its function properly?
3) Failure Modes – What is the cause of every failure that occurs?
4) Failure Effect – What will happen if a failure occurs?
5) Failure Consequences – Under what conditions does each failure matter?
6) Preventive Task – What can be done to prevent every failure from happening?
7) Default action – What to do when preventive activities cannot be found

3.2. Failure Mode

Using the FMEA (Failure Mode and Effect Analysis) method FMEA handbook, Fisrt Version, (2019) explains that FMEA is a team-oriented, systematic, qualitative method and analytical method that aims to: Determine the potential risk of failure of a product or process, Analyze the causes and consequences of the intended failure, Take precautions and detect potential risks, Make recommendations to overcome or reduce the risks that will arise. Each potential failure will later be assessed using three main keys, namely: Severity (S), Probability of Occurrence (O), and Detectability (D). The set of the three parameters above is called the Risk Priority Number (RPN) and mathematically the RPN value itself is obtained by: RPN = S x O x D ...(1). There are seven stages in conducting an FMEA analysis (Laura Halleck, 2019). Step 1 Preparing and Project Planning, Step 2 Structure Analysis, Step 3 Function Analysis, Step 4 Failure Analysis, Step 5 Risk Analysis, Step 6 Optimization, Step 7 Documentation of Result

3.3. Failure Effect (Visualisation)

Basically, humans are visual beings, data in visual form will be easier to process than other forms of data such as writing. The human brain will process images 60,000 faster than writing and 90% of the data processed by the brain is in the form of images or visualizations in the form of diagrams, and the visual display will be better than text (Wahyuni Eka, W. 2021). The FTA (Fault Tree Analysis) method was chosen to describe what could cause a failure of the CBTC On Board system. Fault Tree Analysis (FTA) is a tool or method used to analyze, visually present, and evaluate the failure of a part of a system, and then provide an effective mechanism for conducting risk evaluation (Clif Ericson, 1999). NASA (2006) also provides knowledge about the stages of conducting FTAs, namely: Identification of the Purpose of the FTA, Determining the Top Event of the FTA, Determining the scope of the FTA, Determining the FTA resolution, Define the Ground Rules for FTAs, Establishing FTAs, FTA Evaluation, Interpreting and Presenting the Results. FTA itself is derived from several symbols, each of which has its own meaning, examples of the use of these symbols are as follows in Figure 1 (NASA, 2016)

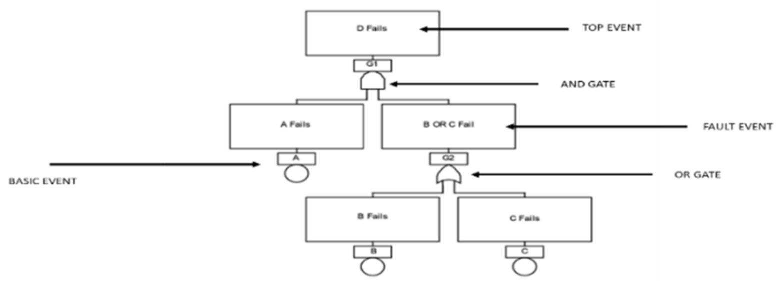

Figure 1. FTA example

Next is to calculate the probability, Probabiltas is required to assess each basic event that occurs so that the existing value can be entered into the formula that has been formed previously, Heldman (2005) there are five assessment ladders in the probability ranking where the value of 0 is the value of events that have no effect on the Main Event and the value of 1 is the failure that occurs. The probabilities value of each event itself can be known by the formula **P = 1 – R** ...(2) where P is Probablitas and R is Reliability. Xiaoyang Zhou (2019) wrote in his journal the equation for knowing the probability in FTA is **F = f1 x f2 x f3 x....x fn** ...(3) for AND Gate and **F = 1 – (1 – f1) (1 – f2) (1 – f3) .... (1 – fn)** ...(4) for OR Gate where f is probability and n is the number of event inputs.

3.4. Operations Readiness

To assess the readiness of train operations, there are several aspects that can be assessed including availability, Reliability, and maintainability. Ramesh Kumar. A and Krishnan. V (2017) the formulation for determining the value of Reliability is $\mathbf{R= e^{-\lambda t}}$ ...(5) where R is Reliability, λ is the failure rate, which can be searched by $\boldsymbol{\lambda = f/t}$ ...(6) where f is the number of failures and t is the time of default. It is also explained for **Availability = MTBF/(MTBF+MTTR)** ...(7) where MTBF is the Mean Time Between Failure obtained with the formulation **MTBF = 1/ λ** ...(8) and MTTR is the Mean Time To Repair. The next category is $\mathbf{Maintainibility = 1 - e^{\mu t}}$ ...(9) where μ is the Repair Rate obtained by the formulation **μ = 1/MTTR** ...(10).

4. Data Collection

The data itself is divided into two, namely primary data and secondary data (Sugiyono 2018)

4.1. Primary Data

Failure Type Data Collection, To obtain data on the types of failures that have occurred and may occur, direct interviews are conducted with Control Center officers and machinists whose daily lives are in direct contact with the operation. Furthermore, the failure type data will be developed with the cause of the failure which will later be used as data to complete the data needs in the FTA method. Furthermore, Probability data is obtained through FGD. The type of failure that occurred can be seen in the image below. **Data Collection of failure mode (FMEA),** Data collection for FMEA analysis was carried out with FGD (Forum Grub Discussion) which was carried out together with a team from the Operation Control Center who have expertise in their respective Mainlines consisting of the Chief Dispatcher, Power System Dispatcher, Train, and Traffic Control Dispatcher. The data obtained will later be used to be able to analyze the severity of each possible failure that will occur.

Data collection for the Number of Failures, and Handling time. The number of failures is obtained through annual Failure report data and data on handling time is obtained through interviews with the care team. The failure data can be seen in Table 2.

Table 2. Number of failures from 2019 to 2022

Component	Failure Name	Failure per years				Total
		2019	2020	2021	2022	
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure				11	11
	Lower And Upper VRS Failure		2		2	4
Balise Antena	Balise Antenna Fail		2	1		3
VOBC (Vehicle On Board Controller)	1 VOBC Fail	2	1	1	2	6
	2 VOBC Fail		2	3	3	8
TG (Tacho Generator)	1 TG Fail					0
	2 TG Fail					0
	Verification Error		2			2
DMI (Driver Machine Interface)	DMI Fail					
	DMI Frezee				2	2
TIS (Train Information System)	1 RIO fail	1	1		27	29
	2 RIO fail	1			2	3
	CCU abnormal transmission				7	7
	CCU/MON UNIT CPU abnormaly				8	8

Report execution flow when the failure occurs, when a failure occurs in the Mainline and is not detected or detected in the control center (OCC), the machinist as the crew in the Mainline must immediately report to the OCC so that further treatment or direction can be carried out immediately. Figure 2 shows the Communication flow in the event of a failure.

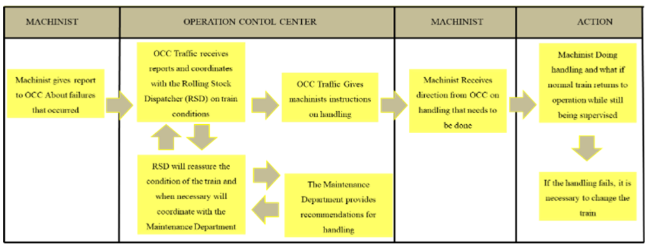

Figure 2. Communication flow in the event of a failure

4.2. Secondary data

Secondary data will be obtained through specification documents from the CBTC device currently owned by the operator as the object of study and also from journals and reverential books relevant to the study being carried out.

5. Results and Discussion

In accordance with what has been explained in point 3.1 that the RCM analysis has seven stages (Stig Erikson, 2021), then here are the seven stages that will be guidelines in the analysis.

a. Step 1 - Function and Performance Standard

CBTC system has many characteristics such as knowing the location of the train with high accuracy, an independent track circuit, CBTC system is an automatic train control system that uses several high technologies and components to operate the train (Wenhao Wu 2019).

So it can be concluded that the operating function of the CBTC is two-way radio communication between the equipment on the train and the equipment in the field. Then CBTC also has standards that can be in the form of a continuous system, a train control system through determining the location of trains with high resolution, a circuit track or virtual track that is independent, two-way communication capabilities to accommodate ATP, ATO, and ATS, (IEEE Std 1474.1,2004). The standard functions of the CBTC OnBoard subsystem that have been mentioned are further presented in Table 3:

Table 3. Function And Standard SubSystem CBTC OnBoard

Component	Function	Standard
VRS (Vehicle Radio Set) Antena	Transmitting Signals from trains to Wayside (SC) devices	Redundant, signal direction according to the direction of the train, connected by coaxial cable
Balise Antena	Captures signals from balise on the track to determine the position of the train and the stopping position	Max kec 160 km/h, Redundant, frequency 1708kHz, Distance with balise 175mm to 185mm, connected by cable to VOBC
VOBC (Vehicle On Board Controller)	Main devices for train control (Door operation, P/B, LOMA, Train location etc.)	Redundant, connected with a cable to each subsystem,
TG (Tacho Generator)	Calculating the rotation of the train wheels to get information on speed and mileage	Able to send messages to VOBC, the number of wheel revolutions calculation is the same
DMI (Driver Machine Interface)	Displays signaling information and other parameters of train travel (Information from VOBC)	Touch screen, On-screen information can be seen clearly, secure communication circuit
TIS (Train Information System)	untuk melakukan data akuisisi, dimana informasi dari sub sistem CBTC contohnya adalah VOBC akan digunakan untuk mengendalikan kereta	Information displayed on DDU, Resistant to certain humidity and temperature, resistant to vibration and bumps, hung with coaxial cable

b. Steps 2 and 3 – Functional Failures and Failures Modes

At this stage, the results of the FMEA analysis will be displayed, and the RPN value will be obtained which will be used as a basis for ranking.

For example, the failure mode above is VOBC Fail where there are two VOBCs that are redundant if one VOBC experiences an operation failure can still take place but the reliability of the system will decrease and when two VOBCs fail then the operation of the train concerned must be stopped if it cannot be handled directly.

Table 4. FMEA Assessment Results

Jenis Failure	Akibat	Severity	Occurrence	Detection	RPN
		Nilai	Nilai	Nilai	Nilai
Lower Or Upper VRS Failure	Auto Recovery with Supervision	8	7	5	280
Lower And Upper VRS Failure	Trains cannot transmit and receive radio signals to and from Wayside devices. Emergency brake will work	10	5	4	200
Balise Antenna Fail	1. Failing to stop exactly where it should be 2. systemically the train cannot run using Automatic mode because the position of the train is not detected	10	3	6	180
1 VOBC Fail	can still run normally with supervision, is redundant, can also be reset VOBC	6	8	4	192
2 VOBC Fail	The position of the train is not detected, it has an Emergncy Brake, if it cannot be handled, it is necessary to restart the train.	10	5	6	300
1 TG Fail	the train can still run, there is a possibility of improper stopping, it needs supervision	7	2	5	70
2 TG Fail	It is necessary to change trains, LOMA is unacceptable, Failing to detect the speed and mileage of the train.	10	3	5	150
Verification Error	No LOMA Receive	7	4	4	112
DMI Frezee	Touch screen does not work, does not support operations, needs supervision	5	7	5	175
DMI Mati	The machinist cannot see the indications (Signals and mottoes) so it can interfere with the operation, And if the DMI screen is off then the train cannot id operate	10	3	6	180
1 RIO fail	Auto Recovery with Surveillance, redundant	6	10	7	420
2 RIO fail	1. Train (TIS) cannot provide data to VOBC because the channel with Logic Block is Disconnected 2. Propulsion Fault, experiencing emergency brake, if it cannot be handled then it is necessary to restart the train	6	10	6	360
CCU abnormal transmission	Emergency Brake and Propultion Fault	4	8	7	224
CCU/MON UNIT CPU abnormaly	Unable to send the condition of the train to the TIS monitor screen so that the machinist cannot monitor the condition of the train while operating, Emergency Brake and propultion fault	5	8	7	280

From the assessment in Table 4 using a range with a value of <100 is very light, 101 - 200 is light, 201 - 300 is Medium and 3001 - 400 is high, and >400 is very high.

The focus of the assessment is not only on the risks caused but also on the number of failures that occur and in terms of checking, it is obtained that the subsystem on TIS namely 1 RIO fail is the part with the highest assessment while for one TG Fail is the device with the lowest assessment (Table 5).

Table 5. Failure Assessment Results

Failure	RPN	Level Failure
1 RIO fail	420	Very High
2 RIO fail	360	High
2 VOBC Fail	300	
CCU/MON UNIT CPU abnormaly	280	Medium
Lower Or Upper VRS Failure	280	
CCU abnormal transmission	224	
Lower And Upper VRS Failure	200	Low
1 VOBC Fail	192	
Balise Antenna Fail	180	
DMI Mati	180	
DMI Frezee	175	
2 TG Fail	150	
Verification Error	112	
1 TG Fail	70	Very Low

c. Step 4 – Failures Effects

The next analysis is the effect of each failure that occurs. This fourth stage will focus on the local effect or the effect that results in the train instead of the system. Through documents and through direct interviews with experts in their fields. To be clearer about how this failure occurred, using Fault Tree Analysis (FTA) here are the results:

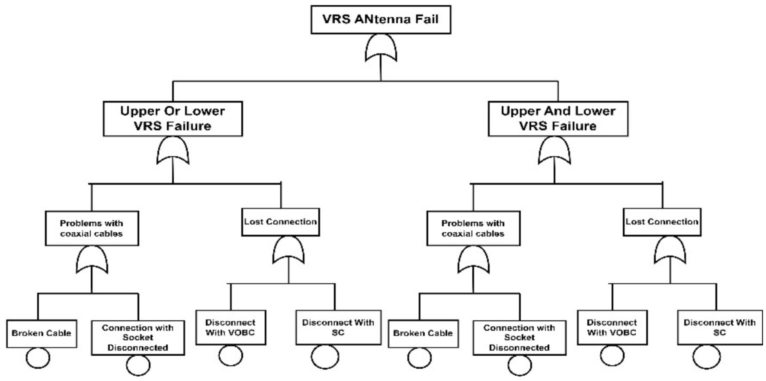

Figure 3. FTA of VRS Antenna

Through the FTA picture, the basic event that causes the VRS antenna to fail is very thick with connection problems, this is in line with the function of the VRS Antenna which connects information between the train and the wayside components in the train itself VRS antenna obtains information through coaxial cables from other subsystems for smooth operation (Figure 3).

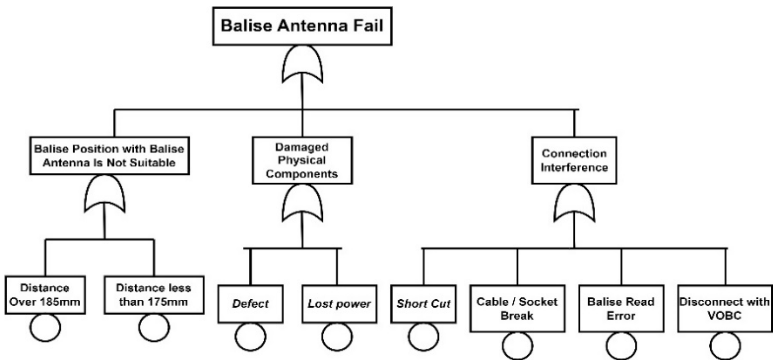

Figure 4. FTA of Balise Antenna

With the function to read the balise installed in the track so that the position of the train can be known, through the analysis of the error tree above, it is obtained that the basic events that cause the balise antenna to fail include distance, damage to the device, loss of power sourced from electric current and a disconnected connection. This balise is very useful for trains to stop right at a predetermined point. Damage to the balise antenna will reduce the accuracy of the train in determining its location (Figure 4).

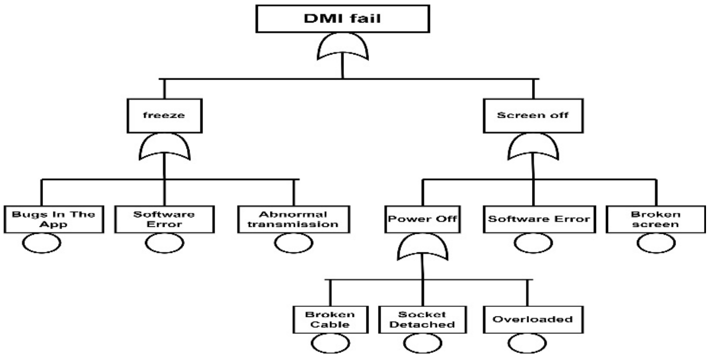

Figure 5. FTA of DMI

In the FTA analysis on the DMI component, basic events are obtained with the majority being about applications, this is because DMI works to receive transfer data with cable media and displayed on the screen using special applications. Bugs that occur in the application can result in DMI feeze and cannot operate but its function to display information is not affected (Figure 5).

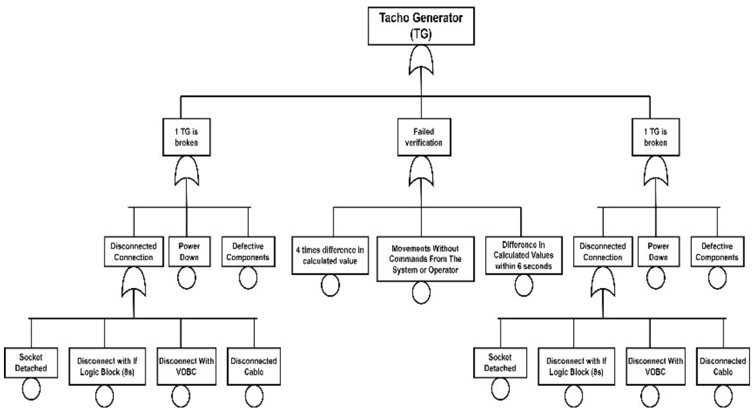

Figure 6. FTA of TG

From Figure 6 of the FTA's analysis of TG, information can be taken that the basic event of the analysis includes a disconnection with VOBC. This disconnection resulted in TG not being able to transmit information to VOBC so VOBC failed to calculate the number of wheel revolutions so that the speed, mileage, and location of the train could be less accurate or even unknown at all if the connection with the two TGs failed or broke.

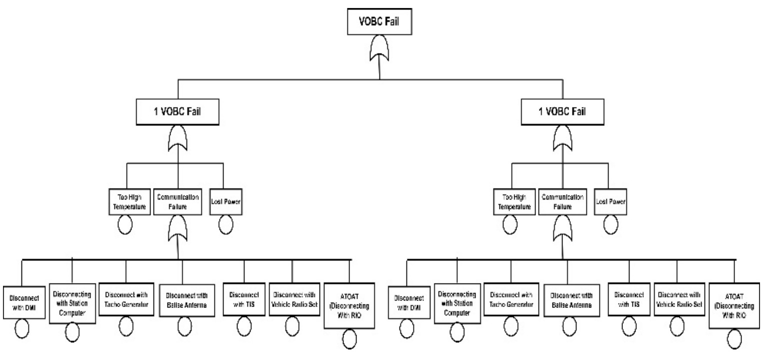

Figure 7. FTA of VOBC

VOBC is a vital component that receives and passes a lot of information from and to other CBTC OnBoard subsystems. It can be seen that disconnections become the most common type of failure. When one device fails to establish a connection or the connection is lost with VOBC, the existing information cannot be processed for the benefit of the operation and is prone to cause events with a risk that can reduce the safety of the operation.

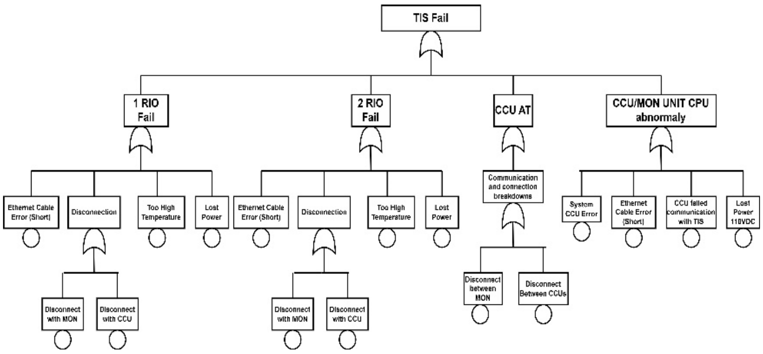

Figure 8. FTA of TIS

TIS works using an electric power supply so what if electrical power is lost, TIS also cannot work. This statement is in line with the basic event of Lost Power. Then this TIS also processes a lot of information by receiving and forwarding information, a broken connection can later cause TIS to fail to work (Figure 8).

d. Step 5 – Failures Consequence

Step 4 has explained the local effects that occur due to failures in the CBTC OnBoard subsystem, so it is also necessary to know how the consequences that occur in the system (System Effect) can interfere with train operation:

Table 6. System effect

Komponen	Failure	System Effect
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure	Redundant, autorecovery, has no effect on the operating system (needs supervision and checking)
	Lower And Upper VRS Failure	Disconnected Communication (Onboard - Wayside) Emergency Brake Switch to Manual Operation Train Stop Operation
Balise Antena	Balise Antenna Fail	Works Redundant 1 balise antenna error will be backed up, needs supervision 2 pieces balise antenna error, cannot read balise, Overshoot/undershoot, train stop operation
VOBC (Vehicle On Board Controller)	1 VOBC Fail	Redundant, Decreased reliability, needs to be reset
	2 VOBC Fail	Emergency Brake Data and information process failed Train stop operation Manual train operation
TG (Tacho Generator)	1 TG Fail	Operations can continue with surveillance
	2 TG Fail	Failed to Calculate wheel spin The system cannot detect the speed of the train
	Verification error	Autorecovery, needs supervision
DMI (Driver Machine Interface)	DMI Fail	Machinist Fails to See Signal LOMA display off The train cannot operate
	DMI Frezee	Normal Visual Function The touch screen cannot be pressed does not result in surgery
TIS (Train Information System)	1 RIO fail	Autorecovery, needs supervision
	2 RIO fail	Disruption of Communication Systems between subsystems Severe Failure Commands from the Master Controller are disconnected
	CCU abnormal transmission	Communication between CCU Units was disrupted. If both CCU units are disturbed the train should be replaced
	CCU/MON UNIT CPU abnormaly	CPU pada CCU terganggu Informasi Ke TIS terganggu

An example is an antenna balise which is redundant so that if one interference antenna balise can still be replaced by another balise. The system will not be too influential, but it needs to be monitored because it is feared that the train will stop incorrectly at the point it should be. Unlike if the two balises are impaired so that the ability of the train to read the balise on the truck disappears, this can result in the loss of the train's position and the train system will fail to stop exactly where it should. Furthermore, through the FTA analysis at stage three and through the known effect system juxtaposed with the number of failures of each component, the following indicators can be known as in Table 6.

Table 7. Probabilities

Component	Failure	Number Of Failure	Operation Time/Years	Probabilitas
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure	11	288,96	0,5668
	Lower And Upper VRS Failure	2	288,96	0,3141
Balise Antena	Balise Antenna Fail	0	288,96	0,3366
VOBC (Vehicle On Board Controller)	1 VOBC Fail	2	288,96	0,6236
	2 VOBC Fail	3	288,96	0,6831
TG (Tacho Generator)	1 TG Fail	0	288,96	0,2649
	2 TG Fail	0	288,96	0,2649
	Verification Error	0	288,96	0,1426
DMI (Driver Machine Interface)	DMI Off	0	288,96	0,2262
	DMI Frezee	2	288,96	0,5440
TIS (Train Information System)	1 RIO fail	27	288,96	0,6913
	2 RIO fail	2	288,96	0,3484
	CCU abnormal transmission	7	288,96	0,4300
	CCU/MON UNIT CPU abnormaly	8	288,96	0,4224

Using the standard value from Heldman (2005) as a reference in determining the probability of basic events and then using calculations using the formula previously described, the highest probability value is obtained at 1 RIO Failure (Table 7).

Table 8. Reliability

Component	Failure	Number Of Failure	Operation Time/Years	λ (t) = f/t	R = e ^-λ(t)
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure	11	288,96	0,0381	0,9626
	Lower And Upper VRS Failure	2	288,96	0,0069	0,9931
Balise Antena	Balise Antenna Fail	0	288,96	0,0000	1
VOBC (Vehicle On Board Controller)	1 VOBC Fail	2	288,96	0,0069	0,9931
	2 VOBC Fail	3	288,96	0,0104	0,9897
TG (Tacho Generator)	1 TG Fail	0	288,96	0,0000	1
	2 TG Fail	0	288,96	0,0000	1
	Verification Error	0	288,96	0,0000	1
DMI (Driver Machine Interface)	DMI Off	0	288,96	0,0000	1
	DMI Frezee	2	288,96	0,0069	0,9931
TIS (Train Information System)	1 RIO fail	27	288,96	0,0934	0,9108
	2 RIO fail	2	288,96	0,0069	0,9931
	CCU abnormal transmission	7	288,96	0,0242	0,9761
	CCU/MON UNIT CPU abnormaly	8	288,96	0,0277	0,9727

The amount of train operating time is obtained through information that the operating time starts at 05.00 and finishes at 24.00 so that the operating time is 19 hours that the operating time used is = 19/24 x 365 and the result is 288.96 days. The highest reliability is TG and DMI because in the observation period, there is no failure, and the greatest reliability is in RIO (TIS Component) (Table 8). When viewed through the CBTC SubSystem.

Table 9. Availability

Component	Failure	Number Of Failure	λ (t) = f/t	MTBF (Day)	MTTR (f*t/f)	Availibility (MTBF/(MTBF+MTTR))
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure	11	0,0381	26,269	0,917	0,966
	Lower And Upper VRS Failure	2	0,0069	144,479	0,917	0,994
Balise Antena	Balise Antenna	0	0,0000	0,000	0,000	1,000
VOBC (Vehicle On Board Controller)	1 VOBC Fail	2	0,0069	144,479	0,917	0,994
	2 VOBC Fail	3	0,0104	96,319	0,917	0,991
TG (Tacho Generator)	1 TG Fail	0	0,0000	0,000	0,000	1,000
	2 TG Fail	0	0,0000	0,000	0,000	1,000
	Verification Error	0	0,0000	0,000	0,000	1,000
DMI (Driver Machine Interface)	DMI Off	0	0,0000	0,000	0,000	1,000
	DMI Frezee	2	0,0069	144,479	0,917	0,994
TIS (Train Information System)	1 RIO fail	27	0,0934	10,702	0,917	0,921
	2 RIO fail	2	0,0069	144,479	0,917	0,994
	CCU abnormal transmission	7	0,0242	41,280	0,917	0,978
	CCU/MON UNIT CPU abnormaly	8	0,0277	36,120	0,917	0,975

It can be interpreted that availability is the availability of a series of trains or components to be used in operations (Table 9). The MTTR value obtained is the value of Daily Maintenance which takes 55 minutes. This value is taken because checking and correcting actions will be carried out during Daily Maintenance.

e. Step 6 – preventive Task

Divided into two main aspects, namely preventive action, are intended to deal with failures that may occur before the train is operated on the main line. The proposed action is Double Check Inspection. The creation of a Work Instruction (WI) to check train facilities before departure so as to reduce the possibility of undetected system failure. The second is First Time Action or the first action when a failure occurs, intended in the Standard

Operating Procedure (SOP) form of what action must be taken if there is a failure in accordance with the previous analysis. CBTC devices are not entirely capable of handling on the main line, sometimes under certain conditions, there is a possibility that replacing operating trains with spare trains will have to be carried out, which will affect the decreased availability of trains.

f. Step 7 Default Actions

The current communication line available to the Control Center Officer to determine the condition of the train and the type of failure that occurred is through information provided by the field officer (Machinist). This condition is prone to communication errors due to human factors and communication system factors. For this reason, if it turns out that the communication is still not good, and handling is also still not optimal, changes to the product design are needed both with upgrades and new procurement. The system required is TCMS (Train Control Management System) which allows central control officers to monitor train identity in real-time from the Control Center Room and can know what kind of failure is happening

g. Implementation

Preventive measures and handling measures will be implemented at this stage, following are the results of the research conducted.

1) Preventive Action

The recommended preventive measure is a double-check inspection where the results are expected to minimize the possibility of failure on the mainline. Carried out by conducting a two-stage inspection so that it becomes a barrier to the existence of failed components. The possibility of component failure is also expected to be smaller along with the frequency of checking. Starting from the planning team providing information about the Train ID that will be used, checking by the maintenance team, reporting to the OCC and machinist, then re-checking by the driver and the train is ready for operation. Figure 9 shows the preventive action.

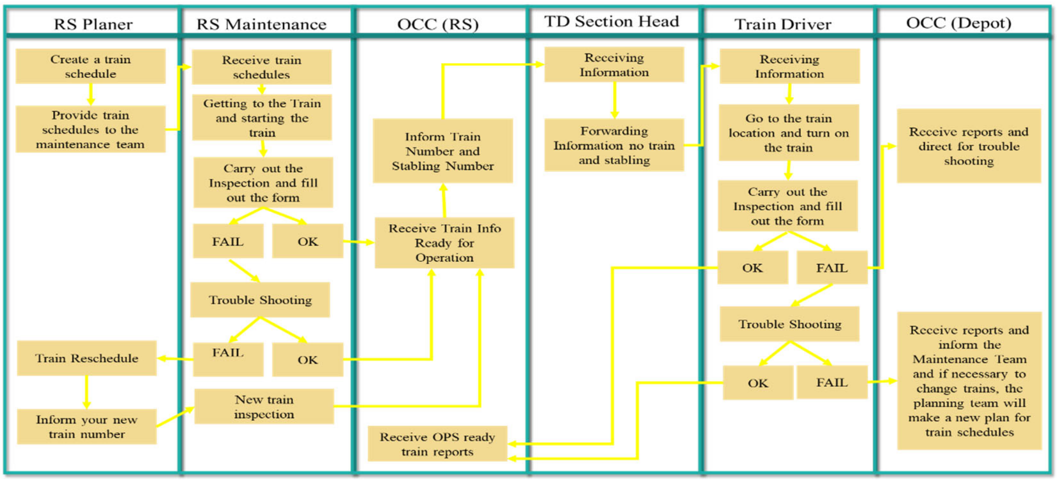

Figure 9. Preventive Action

2) First Time Action

Quick action is needed when there is a failure on the mainline. adjacent train headways, possible collisions, panicked passengers that can threaten safety, disrupted operations due to train delays, possible cancellations of train trips, and other possibilities that can occur as a result of failures that are not immediately addressed, therefore this study proposes handling failures in Onboard CBTC as follows in Table 10:

Table 10. Handling of OnBoard CBTC Failure

Component	Failure	Handling	Estimate Time
VRS (Vehicle Radio Set) Antena	Lower Or Upper VRS Failure	If one balise fail = continue the operation carefully, under supervision, there is a possibility of improper stopping (undershoot/overshoot). Train replacement in accordance with the manager's decision	----
	Lower And Upper VRS Failure	Drop off passengers at the nearest station. move the train to the nearest station pocket, or return it to the depot, change to a new train, adjust the train ID number	depending on distance and number of passengers
Balise Antena	Balise Antenna Fail	If one balise fail = continue the operation carefully, under supervision, there is a possibility of improper stopping (undershoot/overshoot). Train replacement in accordance with the manager's decision	----
		If two balise fail = Drop off passengers at the nearest station. move the train to the nearest station pocket, or return it to the depot, change to a new train, adjust the train ID number	depending on distance and number of passengers
VOBC (Vehicle On Board Controller)	1 VOBC Fail	If DMI is not Freeze = can be reset on the menu on DMI If DMI Freeze = Can directly restart VOBC through the CB panel	00:01:30
	2 VOBC Fail	Stop the train immediately. Restart the train. If it fails, change the manual mode, drop off the passenger at the nearest station, and save the train at the pocket station or depot to replace it with a new train	00.04.00 (For restart) depending on the distance and number of passengers for fail scenario
TG (Tacho Generator)	1 TG Fail	If one balise fail = continue the operation carefully, under supervision, there is a possibility of improper stopping (undershoot/overshoot). Train replacement in accordance with the manager's decision	----
	2 TG Fail	Drop off passengers at the nearest station. move the train to the nearest station pocket, or return it to the depot, change to a new train, adjust the train ID number	depending on distance and number of passengers
	Verification Error	Failure indications appear, need supervision, report to OCC, continue operations with caution	----
DMI (Driver Machine Interface)	DMI Off	Drop off passengers at the nearest station. move the train to the nearest station pocket, or return it to the depot, change to a new train, adjust the train ID number	depending on distance and number of passengers
	DMI Freeze	do not interfere with operations, conduct surveillance, and report to OCC	
TIS (Train Information System)	1 RIO fail	Auto recovery, normal operation with supervision, report to OCC for the follow-up to the maintenance team	----
	2 RIO fail	Restart the train, if it still fails change the manual mode, drop off the passenger at the nearest station, and save the train at the pocket station or depot to replace it with a new train	depending on distance and number of passengers
	CCU abnormal transmission	Auto recovery, normal operation with supervision, report to OCC for the follow-up to the maintenance team If a propulsion fault occurs, perform a VVVF reset	00:01:00
	CCU/MON UNIT CPU abnormally	Auto recovery, normal operation with supervision, report to OCC for the follow-up to the maintenance team If a propulsion fault occurs, perform a VVVF reset	00:01:00

h. ***Validation***

Validation is obtained through direct practice using train test equipment. Practice is also witnessed by the maintenance team and at the same time as material for training on handling failure. What is written in Table 5.6 has been tested so that it is expected to be a reference in the future for operators who are test materials, as well as other operators who operate systems like research materials.

6. Conclusion and Discussion

CBTC is a signaling device consisting of OnBoard and wayside equipment connected using two-way communication radio signals. CBTC devices are designed with high standards in order to have good durability and can work optimally in accordance with standards. The high standards provided include the CBTC Onboard device, but in practice, it does not rule out the possibility that there will still be failures in the device. Failure itself can be fatal to operations, tight headways, distances between trains that are not far apart, high speed, failure to detect locations can result in collisions, double track lanes with heavy traffic, making a failure in the field must be handled immediately so that operations can still run well and smoothly. This study provides recommendations to prevent and reduce the possibility of failure on the mainline and treatment if failure is forced to occur. The proficiency of the control center officer in providing direction and the field officer in carrying out the direction is critical to the successful implementation of the handling. All forms of CBTC OnBoard failures that occur in the field cannot be underestimated and must always receive more attention so as not to become a bigger problem in the future. The author also recommends more in-depth research and research updates considering that technology continues to develop and does not rule out the possibility that there will be faster, safer, effective,e and efficient ways to handle it so that wasted time can be reduced to the maximum level. And for further research, more in-depth research is needed for components with the largest number of failures, whether the fault is in the treatment, or the device is not in accordance with the standard function that should be.

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Biographies

Widhi Bayu Aji is a student of master's degree at the Department of Industrial Engineering of the University of Indonesia. He graduated with a bachelor's degree from Land Transport Academy (STTD), is passionate about everything related to Railways, and currently works as an Operation Control Center officer in one of the Indonesian Railway operators.

Maya Arlini Puspasari obtained her doctoral degree in Industrial Engineering and Management from Bandung Institute of Technology in 2020. She has been an academic staff of the University of Indonesia for 11 years. Her research interests include transportation safety and mental workload. She currently serves as head of the Ergonomics Centre Laboratory and assistant secretary of the academic section.