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APPIRO: IoT and GPS-Based Brake Failure Detection and Early Warning Device for Freight Vehicles

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ABSTRACT
Traffic accidents due to brake failures in freight vehicles in Indonesia account for around 90 percent of the total traffic accidents. This condition prompted researchers to create APPIRO (*Brake Blong* Detection and Early Warning Tool) based on IoT and GPS, which functions to provide early warning of potential braking system failures in real-time to reduce the number of accidents caused by freight transportation that experiences brake failure. This study aims to design, calibrate, and evaluate APPIRO tools in detecting over-temperature in brake systems and loads in freight transport vehicles. R&D (Research and Development) research methods include hardware design, application manufacturing, calibration of Thermocouple Type K, Loadcell Type S sensors, and limited scale trials. APPIRO's main components consist of thermocouple type K temperature sensor, S type loadcell, ESP32 microcontroller, GPS Tracker NEO6MV2 module, HX711 module, MAX6675 module, dual channel relay, 16x2 LCD, IoT-based Kodular application that displays real-time temperature, load, vehicle location data and early warning notifications. The calibration results at the Center for Standardization and Industrial Services showed a relative error of the thermocouple sensor of –1.11% and the loadcell of 1.48%, which is still within acceptable accuracy limits. Limited trials showed that in pick-up vehicles with a load of 2476.9 kgf, the brake oil temperature increased to 212.4°C so that the system gave a "Danger" warning, while in *engkel trucks* the maximum temperature was only 95.7°C with the status of "Safe".
Keywords: temperature; load; Thermocouple Type K sensor; Loadcell Type S; GPS IoT.

INTRODUCTION

In Indonesia, traffic accidents are one of the serious problems (Purnomo & Wicaksono, 2020; Nugraha, 2021). Based on data from the Indonesian National Police Traffic Corps (Korlantas Polri), the number of traffic accidents in Indonesia in 2024 will reach 118,452 cases, this number is higher than the 2021 data of 103,645 cases. One of the causes of accidents is based on the condition of the vehicle, the biggest cause is the failure of the brake system (Sutrisno, Widodo, & Hartono, 2022). The number of traffic accidents involving buses and trucks experiencing brake failure is very dominant, which is around 90 percent of the number of accidents (Korlantas Polri, 2024; Fitriani & Rahman, 2023; World Health Organization, 2023; Jusnita et al., 2022).

Based on data in Indonesia, vehicle accidents with excessive load (overloading) are cases that in recent years have become the main factor in vehicle accidents due to braking system failures, due to many violations of limits and loads known as *Over Dimension Over Load* (ODOL) (Wijayanta et al., 2019). This is reinforced by the results of the study that increasing the moisture content above a certain threshold can lower the boiling point of brake fluid, which in turn can lead to the phenomenon of '*vapour lock*', where the steam formed reduces the effectiveness of braking and has the potential to cause brake failure (Komang Yudhi, 2024).

The friction between the drum and the lining produces excessive heat in the vehicle's brake system (Ćatić & Ćatić, 2025; Khatir et al., 2022; Umaras et al., 2021). Therefore, to reduce excessive heat in the brake system of the vehicle to be stopped, the driver must pay attention to the amount of mass (amount of load) and the speed of the vehicle when descending must be reduced. This explains why vehicles that are ODOL and/or vehicles that use high transmission gears during descent often experience braking failures or brake failures (Sulardjaka et al., 2023). Brake failure cases cause accidents and cause fatalities, minor injuries and serious injuries, and considerable economic losses (Farista et al., 2025).

The urgency of this research is underscored by the human and economic toll of brake failure accidents in Indonesia. With approximately 90% of freight vehicle accidents attributed to brake failure, the potential for life-saving impact through early warning technology is substantial. The persistent problem of ODOL violations further compounds this urgency, as overloaded vehicles place extreme demands on braking systems that were not designed for such loads. Current regulatory approaches focusing on weight stations and periodic inspections have proven insufficient to prevent accidents, suggesting the need for technological solutions that provide continuous monitoring and real-time alerts. Additionally, the growth of e-commerce and logistics industries in Indonesia has increased the volume of freight vehicles on roads, amplifying the potential for accidents if the underlying safety issues remain unaddressed.

The researcher presented APPIRO (*Brake Blong* Early Detection and Early Warning Tool) which uses Thermocouple and Loadcell temperature sensors and utilizes IoT (Internet of Things) technology with Kodular and GPS (Global Positioning System) Module programs NEO6MV2 integrated online through the APPIRO application. This tool will emit an alarm sound and a hazard display if an increase in temperature is detected on the thermocouple sensor connected to the ESP32 microcontroller and the 16x2 LCD screen display placed on the vehicle dashboard. Meanwhile, other road users get early information in real-time about the coordinates of the location of vehicles that have damaged the braking system which can be monitored through the APPIRO Application.

METHOD

Research Time and Place

This research was conducted in March – September 2025 on several pools of freight transportation vehicles in the Jakarta area.

1. Tools and material
2. Tools
3. The tools used in this study are laptops, smartphones and solder.
4. Ingredients

The materials used are Thermocouple Type K which functions as a temperature sensor, MAX 6675 Module converts analog signals from Thermocouple Type K into digital that can be read by microcontrollers, Loadcell Type S functions to measure loads, HX 711 Module converts analog signals from Loadcell Type S into digital that can be read by microcontrollers, GPS Tracker Module NEO6MV2 functions to determine the location of vehicles along with coordinate points, The ESP32 microcontroller functions to collect and process the data that enters the system connected to wifi, jumper cable, USB micro data cable, Dual channel relay functions as a switch, lead wire, 16x2 LCD to monitor temperature and weight. The tools and materials used in the research can be seen in figure 1 below:

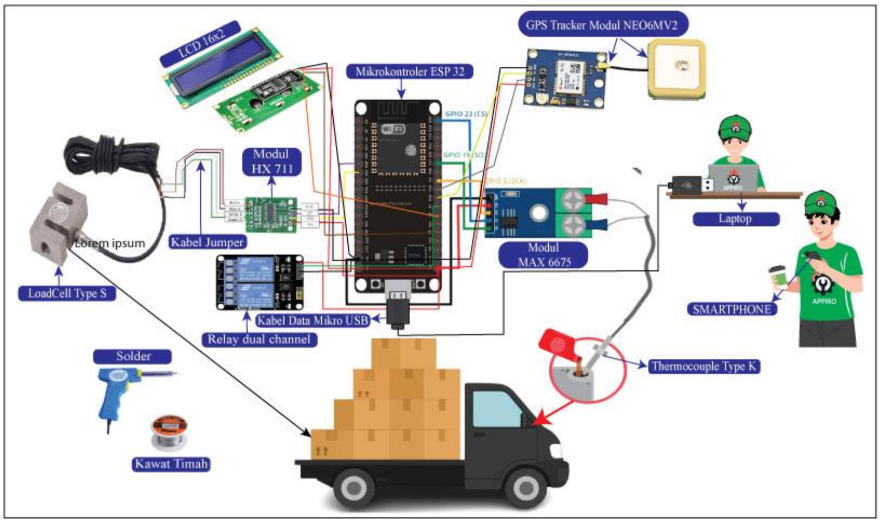


Figure 1. Research Tools and Materials

Research Design and Procedure

The design and procedure of the research aims to design a system that can be tested and adapted dynamically based on the results of each stage of product development (Fadilla et al., 2020). The research design carried out is Research and Development (R&D). R&D research is a research methodology through a series of steps or stages that have the goal of creating a new product or to improve a pre-existing product (R. Ekawati et al., 2021).

This research consists of several stages, namely: needs analysis, system design, tool calibration, and limited scale trials.

a) Preliminary analysis (analysis)

Needs analysis is the first stage in R&D to determine precisely the specifications of the system to be developed (Putri et al., 2019). Needs analysis is an important stage that determines how the specifications of user needs are outlined in the final product in the R&D method (Budiningsih, 2020). The analysis was carried out by determining the maximum temperature limit that caused brake failure, the influence of vehicle load on the braking system, the importance of an early warning system that is able to provide information in real-time, and determining the location of vehicles that experience disturbances in the braking system, so that other road users can avoid accidents.

b) System design

System design aims to design a system that can be tested and adapted dynamically based on the results of each stage of product development (Fadilla et al., 2020). The system design is divided into three parts, namely the diagram block, user interface design, and the APPIRO operation steps.

1. Block diagram

   The block of the diagram is seen in the following figure 2:

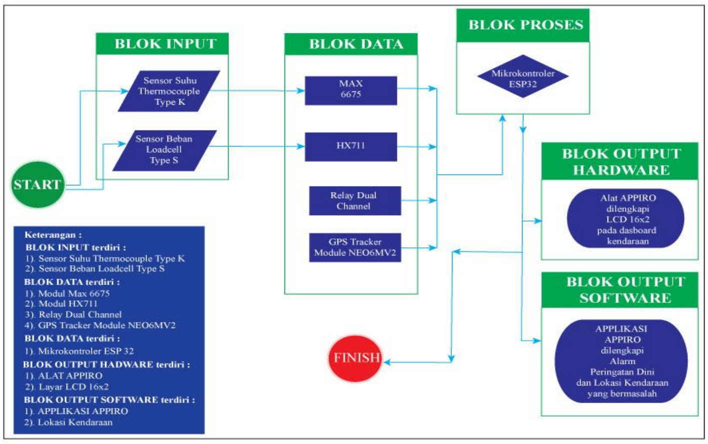


Figure 2. APPIRO Diagram Blocks

The block diagram above consists of input blocks, data blocks, process blocks, and output blocks.

1) Input Block

The Input Block consists of the Type K Thermocouple Temperature Sensor and the Type S Loadcell Load Sensor serve as the main device to capture the initial data from the system. The Thermocouple Type K sensor is used to detect brake oil temperature in real-time, to monitor temperature increases that can cause brake failure. Meanwhile, the Type S Loadcell Sensor functions to measure the load of the vehicle, because the amount of load has a direct effect on the performance and safety of the braking system. The data obtained from these two sensors is then sent to the data block for further processing before being analyzed by the main control system.

2) Data Block

The Data Block acts as a link between the sensor and the main control system. At this stage, data from the Thermocouple temperature sensor and the Loadcell load sensor are processed first through modules such as MAX6675, HX711, Dual Channel Relay, and GPS Tracker NEO6MV2. The main function of this block is to convert analog signals into digital data that can be read by a microcontroller, while providing accurate vehicle location information.

3) Process Block

The process block serves as the main control center of the system that uses the ESP32 microcontroller to process all the data received from the input block through the data module. The results of this processing are used to determine the condition of the braking system, activate the relay in case of hazardous conditions, and send data to the hardware output block and software output block in real-time to the application.

4) Block Data

The Output Block is divided into two parts, namely hardware output and software output. The hardware output is in the form of an APPIRO device equipped with a 16x2 LCD on the vehicle dashboard to display temperature and load data directly. Meanwhile, the software output is in the form of the APPIRO application which displays early warning information and vehicle location, so that users can monitor the condition of the braking system remotely quickly and accurately.

2. Application User Interface Design

The design of the application's user interface can be seen in Figure 3 below:

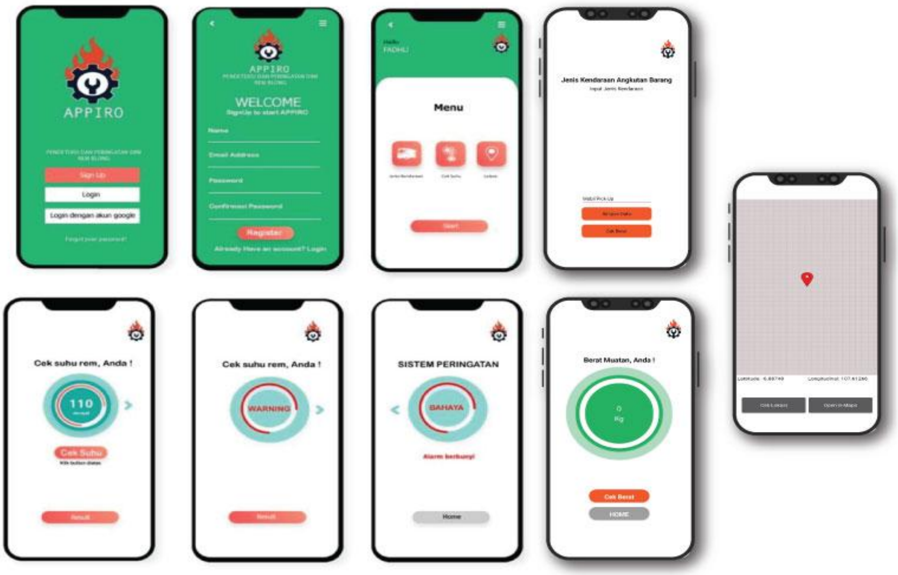


Figure 3. Application User Interface Design

From the image above, the application is used to display temperature, type of vehicle, location and notifications in the form of alarms that sound. The interface display is in the form of a login menu, sign up, vehicle type, temperature check, location and hazard warning.

3) Steps of APPIRO operation:

a) The user opens the APPIRO application on a smartphone.
b) Sign in or register using your email or Google account.
c) After successfully logging in, the user is redirected to the main menu of the application.
d) The user chooses the features according to their needs, such as checking brake temperature, checking the payload, or vehicle location.
e) The application displays the results of real-time vehicle temperature and load measurements.
f) If the temperature or load exceeds the safe limit, the app provides an early warning in the form of a "Danger" status.
g) When hazardous conditions occur, the application displays the location of the vehicle on the map so that immediate action can be taken.

c. Tool Calibration

The calibration phase is an important step in the application of R&D methods (Pratiwi et al., 2024). Meanwhile, according to Prasetyoaji, calibration is the process of comparing the tools produced with standardized tools to find faults (Prasetyoaji et al., 2021). The calibration of the equipment will be carried out at the Standardization and Service Center for the Industrial Materials and Technical Goods located in Bandung. The temperature sensors that will be calibrated are Thermocouple Type K and Loadcell Type S. Thermocouple temperature sensors use a temperature range of 0 – 250 °C, while Loadcell capacity ranges from 500 – 4500 kgf.

d. Trial of the tool on a limited scale

A limited-scale trial was carried out to test the ability of the APPIRO tool to detect brake temperature and vehicle load in two types of freight transport vehicles, namely pick-up cars and *engkel truck*s. The Thermocouple Type K sensor is installed on the brake oil tank to detect the increase in temperature due to the braking process, while the Type S Loadcell is installed on the tailgate to measure the load of the load carried. Meanwhile, the APPIRO Application test with a tool function test to ensure that the system is able to display vehicle temperature, load, and location data in real-time.

Data Processing and Analysis

Data processing is carried out and collected during testing to obtain structured information ready for analysis. Data obtained from Thermocouple temperature sensor testing, loadcell load testing data, main component function data, application function data, vehicle sample testing data. The data is then analyzed, the threshold of the Thermocouple temperature sensor is 250°C, the loadcell load is from 0-4500 kgf, the function of the main component provides sound warnings and the application function when the temperature is at the threshold provides notifications in the form of alarms to road users and vehicle positions.

RESULT AND DISCUSSION

Research Results

The results and discussion of the research consisted of 7 parts, namely: tool design, application design, Thermocouple sensor calibration, Loadcell calibration, Tool function test, Application function test, Temperature and load sample test.

Tool Design (Hardware)

APPIRO design consists of a connected circuit between Thermocouple Type K temperature sensors, Max 6675 Module, Loadcell Type S, HX711 Module, ESP32 Microcontroller, 16x2 LCD, Dual Channel Relay, Jumper Cable, GPS Tracker NEO6MV2 Module. Seen in picture 4 below:

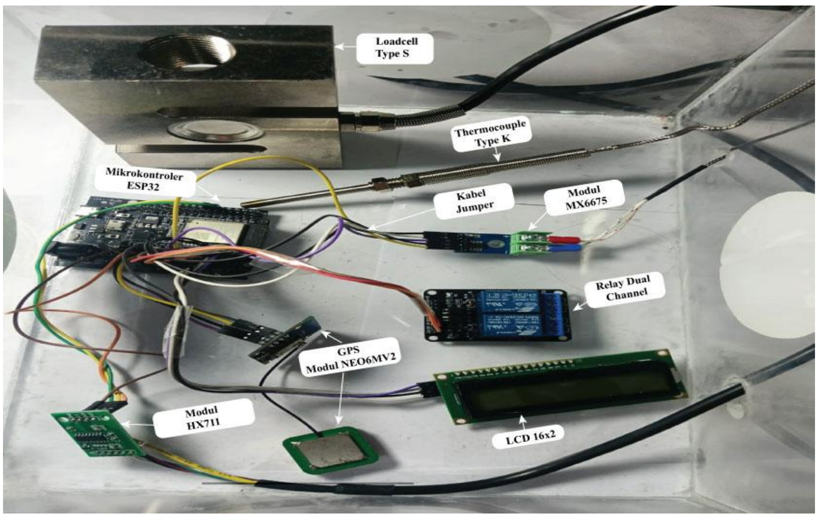
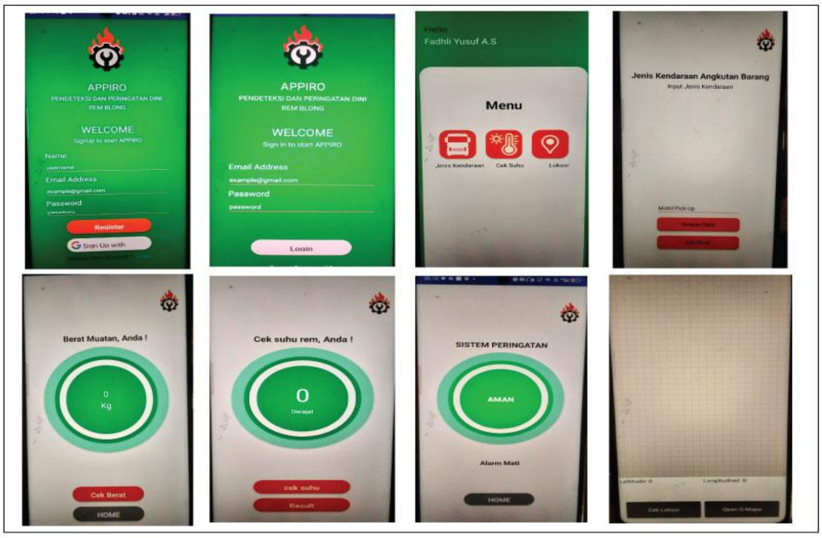


Figure 4. Design of the Brake Failure Detection Device

Application Display (Software)

The design starts with a Sign Up or Login view for user authentication. The Sign Up view allows new account registration, while Login allows access to the system. After successfully entering, users are greeted on the Main Menu, which displays features such as the type of vehicle temperature check, and the location and sub-menu of the weight check. The most important system is an early warning system in the form of notifications accompanied by an alarm sound. This display provides safe visuals when the brakes are working normally and alerts if the brakes are not working normally. The appearance of the application design can be seen in the following figure 5



APPIRO calibration results

The calibration of the tool includes the calibration of thermocouple and loadcell sensors.

a. Thermocouple temperature sensor calibration.

In the calibration of thermocouple temperature sensors, Type K thermocouples with a capacity of 0 - 400°C and a resolution of 0.25°C are used. This tool was calibrated on September 23, 2025 at the Center for Standardization and Service of the Industrial Materials and Engineering Goods located in Bandung. The calibration results of the Thermocouple temperature sensor can be seen in the following table 1:

Table 1. Calibration results of the Thermocouple Type K Temperature Sensor

Tool designation (°C)	Designation Standard (°C)	Error (°C)	Uncertainty (°C)
0	-3,66	3,66	**1,01**
20	16,13	3,87	
40	36,30	3,70	
60	56,17	3,83	
80	75,95	4,05	
100	95,97	4,03	

Tool designation (°C)	Designation Standard (°C)	Error (°C)	Uncertainty (°C)
160	158,79	1,21	**2,2**
180	179,09	0,91	
200	200,39	-0,39	
250	**251,11**	**-1,11**	

From the table above, at a critical temperature of 200°C, which is the threshold for brake failure, the APPIRO sensor shows 200.39°C, so there is a relative error of –0.39°C and with an uncertainty figure of 2.2°C. Meanwhile, at a higher temperature, namely 250°C, the APPIRO sensor shows a temperature of 251.11°C, so there is a relative error of –1.11°C with an uncertainty figure of 2.2°C.

Loadcell Calibration Results

Although the Type S loadcell with a maximum capacity of 5000 kgf is not explicitly mentioned in the components section of the proposal, the calibration certificate shows that this tool is owned by SMPN 1 Jakarta and has been calibrated. This tool is likely proposed as an addition to measure the potential for *Over Dimension Over Load* (ODOL) which is the main factor in braking failure in freight vehicles. The loadcell is calibrated at the compression position with a load between 500 and 4500 kgf. The calibration results can be seen in Table 2 below

Table 2. Loadcell Calibration Results

Relative Resolution 0.20 %					
Zero errors; Relative 0.00 %					
Measurement Range (kgf)	Machine Designation (kgf)	Average Standard Designation (kgf)	Relative Error		**Uncertainty of Measurement Machine Range *) (%)**
			Precision (%)	Resilient (%)	
	0,0	0,000	0,00	0,00	
	508,0	501,192	1,36	0,24	
	1013,0	998,244	1,48	0,24	
	1511,0	1494,825	1,08	0,24	
0-5000	2000,8	1992,537	0,82	0,21	**± 0.21**
	2590,0	2565,212	0,97	0,23	
	3077,0	3045,688	1,03	0,24	
	3500,5	3467,496	0,95	0,21	
	4013,0	3975,858	0,93	0,21	
	4508,2	**4463,834**	**0,99**	**0,20**	

From the calibration table of the Loadcell Type S, there is a difference between the Loadcell in APPIRO and the standardized tool, while the lowest relative error is 0.82% at a load of 1992,537 kgf. The highest relative error was 1.48% at a load of 998,244 kgf.

Tool and Application Function Test Results

Functional testing of the APPIRO tool is carried out to confirm that each hardware and software component is integrated into each other in the APPIRO (*Brake Blong* Early Detection and Early Warning Tool) application that has been functioning according to the system design. The test covers the main components of the tool and the key features of the APPIRO application.

a. Test the function of the main components of the tool

The results of the tool and application function test can be seen in Table 3 below:

Table 3. Functional Test of the Main Components of the Appliance

Components	Function of the plan
Thermocouple Sensor (Type K)	Detects and reads the temperature of the brake fluid
Loadcell Type S	Detecting hauled loads on pick-up cars and *engkel truck*s
ESP32 Microcontroller	Primary microcontroller for processing data sensors and send them to IoT servers
GPS Tracker (NEO6MV2	Getting the location coordinates (latitude and longitude) vehicle in *real-time*
16x2 LCD	Displays brake temperature and load information directly to the driver

From table 3 above, it can be said that if the thermocouple sensor components, Loadcell, ESP32 microcontroller, GPS NEO6MV2, and 16x2 LCD function as they should.

b. Test the functionality of the APPIRO mobile app

The APPIRO mobile application function test obtained the results as shown in table 4 below

Table 4. APPIRO Mobile Application Function Test

Application Menu Functions	Test Results
Login page	The user enters the username and *password Listed*
Choice of vehicle type	The user selects the type of vehicle that is currently tested
Real-time *data connection*	The app displays the temperature, weight and GPS location data of the device attached to the vehicle
Early Warning System	When the temperature reaches 200°C a notification is sent All nearby app users give a "danger" notification
Map Display (GPS)	The application shows the vehicle's position along with the coordinate point

Limited Trial Results

A limited-scale trial was conducted to determine the ability of the APPIRO tool to detect brake oil temperature and vehicle payload under heavy braking conditions that have the potential to cause brake failure. The test was carried out on two types of freight transport vehicles, namely pick-up cars and *engkel truck*s, with each vehicle tested three times. The Type

K Thermocouple sensor is used to measure the temperature of brake oil installed in the brake fluid tank, while the Type S Loadcell is installed in the tailgate of the vehicle to measure the payload. The results can be seen in tables 5 and 6 below.

Table 5. Brake Temperature and Load Tests on Pick Up Cars

1st Test Pick Up Car		**2nd Test Pick Up Car**		**3rd Test Pick Up Car**	
Brake Oil Temperature (°C)	**Payload (kgf)**	**Brake Oil Temperature (°C)**	**Payload (kgf)**	**Brake Oil Temperature (°C)**	**Payload (kgf)**
36,42	598,5	37,60	1980,2	36,91	2476,9
39,78	598,5	45,31	1980.2	56,76	2476,9
45,90	598,5	56,99	1980,2	78,33	2476,9
52,21	598,5	68,55	1980,2	96,66	2476,9
68,73	598,5	80,11	1980,2	110,82	2476,9
100,57	598,5	100,98	1980,2	130,76	2476,9
110,98	598,5	120,93	1980,2	160,92	2476,9
130,77	598,5	150,43	1980,2	180,09	2476,9
145,97	598,5	170,66	1980,2	199,91	2476,9
150,50	598,5	197,70	1980,2	212,40	2476,9

The results of the limited test for Pickup Cars with a maximum load capacity of 1.5 Tons, the increase in load from 598.5 kgf to 2476.9 kgf caused a significant increase in brake oil temperature to reach 212.4 °C

Table 6. Brake Temperature and Load Stress Tests on *Engkel Truck*s

1st Test *Engkel Truck*		**2nd Test *Engkel Truck***		**3rd Test *Engkel Truck***	
Brake Oil Temperature (°C)	**Payload (kgf)**	**Brake Oil Temperature (°C)**	**Payload (kgf)**	**Brake Oil Temperature (°C)**	**Payload (kgf)**
36,03	2379,7	36,12	2603,2	36,77	3278,4
38,11	2379,7	37,32	2603,2	38,16	3278,4
42,91	2379,7	48,90	2603,2	42,19	3278,4
44,00	2379,7	51,50	2603,2	47,99	3278,4
46,21	2379,7	54,25	2603,2	52,01	3278,4
48,17	2379,7	58,77	2603,2	65,88	3278,4
49,10	2379,7	61,17	2603,2	70,19	3278,4
56,89	2379,7	68,28	2603,2	82,40	3278,4
62,09	2379,7	73,74	2603,2	90,10	3278,4
67,10	2379,7	78,20	2603,2	95,70	3278,4

The results of the limited test for the *engkel truck* with a maximum load capacity of 5 Tons, the increase in load from 2379.7 kgf to 3278.4 kgf caused an insignificant increase in brake oil temperature of 95.70 °C.

Table 7. Application Test Results

Yes	Vehicle Type	Experiment to-	Brake Oil Temperature (°C)	Payload (kgf)	System Status
1	Car Pick Up	1	150,50	598,5	Secure
2	Car Pick Up	2	197,70	1980,2	Secure
3	Car Pick Up	3	212,40	2476,9	Danger
4	*Engkel Truck*	1	67,10	2379,7	Secure
5	*Engkel Truck*	2	78,20	2603,2	Secure
6	*Engkel Truck*	3	95,70	3278,4	Secure

In the Pick Up Car trial, an increase in payload from 1980.2 kgf to 2476.9 kgf caused the brake oil temperature to rise dramatically to reach 212.4 °C, triggering a "Hazard" warning on the application. In contrast, the *Engkel Truck* trials with a larger payload range (2379.7 kgf to 3278.4 kgf) managed to maintain the brake oil temperature at normal limits, with a maximum temperature of only 95.7 °C, so the warning system showed a "Safe" status in all tests.

APPIRO tool design (hardware) consists of a connected circuit between Thermocouple Type K sensors, Loadcell Type S, ESP32 Microcontroller, 16x2 LCD, Dual Channel Relay, Jumper Cable, GPS Tracker Module NEO6MV2, HX711 Module and MAX6675 Module. It can be connected between components so that it becomes a single tool that can be used to detect brake failure in real-time according to the opinion of Zaki Badri & Putra who said that the connection between the thermocouple and the loadcell can be connected via GPS so as to provide precise and accurate information about position and speed. (Zaki Badri, 2018)

The APPIRO application design uses the display of three key features, namely the type of vehicle, temperature check, and location as well as a warning system when the brakes are functioning abnormally and alert. The use of applications that utilize GPS-integrated IoT technology can be used for real-time brake failure detection in freight vehicles (Arief et al., 2022).

The calibration results of the thermocouple temperature sensor on APPIRO show that the temperature of 200°C is the threshold for brake failure. Temperature changes can be displayed on the LCD monitored by the app on the android device. This is in accordance with the results of Muttar et al's research, which detects temperature as one of the markers of brake failure (Muttar et al., 2024) Loadcell Type S with a capacity of 5000 kgf owned by SMPN 1 Jakarta has been calibrated by the Center for Standardization and Service of the Industrial Materials and Technical Goods as an additional tool to measure the potential for ODOL (Over Dimension Over Load) which is the main factor in braking failure in freight transport vehicles.

Testing the function of the tool in the form of software that has the main components of the thermocouple sensor, ESP32, GPS Tracker NEO6MV2, 16x2 LCD, functioning as designed, gives alarm notifications and the display on the APPIRO application shows "alert" when the threshold reaches 80°C. Meanwhile, the alarm notification sounds loud and the display on the APPIRO application shows "danger" at the threshold of 200°C (*brake blong*). This is adjusted to the results of the study by Setya et al. that the boiling point temperature in the brake fluid affects the braking function which results in brake failure.

The calibration of the Type K Thermocouple Sensor, which ensures accurate temperature readings with measured uncertainty at the 200°C critical point in the sample test shows a multilevel system response. In pick-up cars, the hazard warning the average temperature read on the 16x2 LCD of 105.4°C successfully triggers the Alert notification on the display of the APPIRO application. Critical detection of brake failure on *engkel truck*s shows a temperature of 202.5°C which exceeds the threshold of 200°C.

Temperature and weight data are the result of data processing that can be obtained from the IoT-based ESP32 microcontroller and location coordinates from the GPS Tracker in real-time connected to the APPIRO application. The success of the brake failure early warning detection system resulting from the APPIRO tool is able to reduce accidents due to brake system failures in freight transportation.

CONCLUSION

APPIRO design successfully integrates the main components, namely the Thermocouple Type K sensor, Loadcell, ESP32 microcontroller, GPS Tracker NEO6MV2, HX711, MAX6675 and 16x2 LCD, which functions to transmit temperature, weight, and location coordinate data in real-time to the APPIRO application. A limited-scale trial on a pick-up car confirmed the full functionality of this system by recording a maximum temperature of 212.40°C which immediately triggered the entire warning chain and provided a "Danger" notification. The results of this trial show that APPIRO is a tool that can be used as a tool for early detection of brake failure in freight transport vehicles in real-time.

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