Experimental Study of Failures of Air Conditioners System Tram in Desert Areas by Applying Preventive Maintenance (Using Reliability Lows)

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Abstract

Preventive maintenance is considered the health record of industrial machines and transport vehicles in the world of industry because of its contribution to always protecting these machines and vehicles. Therefore, a tight preventive maintenance plan must always be developed to ensure reliability stability. This article aims to solve the problem of complete failure of the air conditioning (AC) system in trams in the desert region of Algeria, in the context of high temperatures, which resulted in the loss of many passengers and a significant drop in company income. Reliability laws will be applied to the way being obstructed as a result of an error applied in the welding process, which led to the ACHAPS shutdown of the air conditioning system, since the average reliability percentage was 59.01% before fixing the problem and became 81.73% after fixing the problem.

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Nomenclature	
GWP	global warming potential
HVAC	heating, ventilation and air conditioning
AC	air conditioning
PPM	periodic preventive maintenance
IOS 04	
MTBF	mean time between failure
TBF	time between failures
MTTR	mean time to repair
TTR	time to repaire
Letter	
R(t)	reliability function
F(t)	failure function
λ(t)	failure rate

1. Introduction

Transportation is considered one of the most important economic activities in the world, which effectively and directly affects the global economy. British economist Alfred Marshall explained this in his book Economic of Industry, who said that the dominant economic reality of our time is not industrial development, but rather the facilities provided by transport.[1] The development and improvement of transportation businesses directly leads to increasing and maximizing the national economy based on the facilities it offers. That is why preventive maintenance is considered the protective shield of these vehicles, especially modern and advanced trains that are used daily, because statistics have shown that wagons in general are the most used in transportation in recent years , and at the same time they are considered the most sensitive and vulnerable to failures in the industrial environment due to their structure which uses artificial intelligence technology and various electronic, electrical and mechanical systems, especially the air conditioning (AC) system, which is one of the most complex systems, including F. Jiang, Y. Wang and B. Yuetal stated that the majority of current air conditioning systems for transportation applications use high-GWP HFC refrigerants (Finckh et al., 2016). In Europe, currently available HVAC air conditioning systems use R134a (75%) or R407C (25%) as refrigerant (Trygstad, 2017) [2-4], making them vulnerable to breakdowns.

The air conditioning systems of these vehicles are considered an essential element, especially in southern regions where temperatures are high in summer. Trams are also often considered environmentally friendly compared to other forms of transportation because they generally run on electric power and produce fewer emissions. The reliability of these air conditioners must therefore always be maintained in order to guarantee a suitable atmosphere for passengers.

Preventative maintenance is a proactive approach to maintenance aimed at preventing equipment failure and ensuring the continued, efficient operation of machines, vehicles or other assets. The main objective is to ensure vehicle reliability, which is the indicator that combines vehicle quality and economic growth.

This research will present an applied study of the air conditioning system of trams in southern Algeria for the company CITAL in the Ouargla region, which is experiencing significant deterioration and a failure rate of 97%, causing the complete shutdown of these air conditioners and therefore a sharp reduction in the number of passengers. , especially in summer, because the tram operating company is in sharp decline. In revenue due to passenger interruption due to high temperature inside vehicles due to malfunction of air conditioning system.

Despite the implementation of the periodic preventive maintenance program (PPM), the problem was not resolved by the parent company FAIVELEY, despite the adoption of the maintenance manual attached to the tram, especially since the system air conditioning is still under the warranty period granted by the parent company FAIVELEY.

This research will focus on calculating the reliability rate based on the accumulation of breakdowns, then on creating a maintenance plan including all the components of the air conditioning system. After that, all breakdowns will be diagnosed and the problem will be resolved, which lasted for about years and cost the company significant losses. Finally, the reliability rate will be calculated after solving the problem and comparing it to the reliability percentage. Two years ago.

2. System Description:

Tram vehicles are considered one of many types of transportation, as their technical structure varies depending on the location and climate in which these vehicles are used. And are as follows: [5].

• Citadis™202 (Melbourne), length 20m

• Citadis™301 (Orléans, Dublin), length 27 m

• Citadis™ 302 (Adelaide, Lyon, Paris T2, Valenciennes, Rotterdam, Buenos Aires, Madrid, Melbourne, Murcia, Barcelona,), length 33 m

• Citadis™304, length 33 m

• Citadis™401 (Montpellier, Dublin), length 39 m

• Citadis™402 (Bordeaux, Grenoble, Paris T3, Tours), length 44m

• Citadis™404, length 43 m

2.1. Citadis™402 type wagon

The type of tramway found in the south of Algeria, in the Ouargla region, is the CITADIS 402, which is a vehicle manufactured according to the characteristics and climate of desert areas. These cars are of the two-way type, have 06 double entrance doors and 02 single doors on each side, are largely glazed, air-conditioned in the cockpit and air-conditioned and heated in the passenger cabin.[5

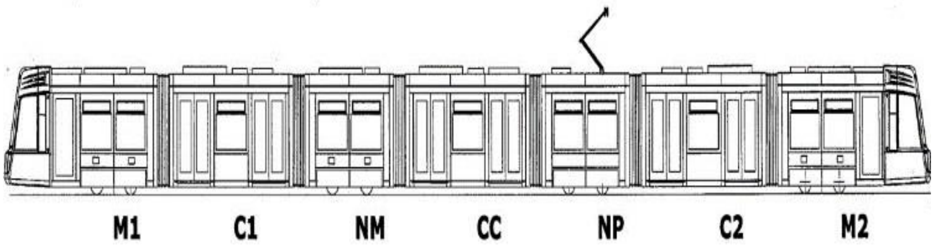

Fig.1.Schematic diagram of the Citadis™402 type tramway[5].

M1: motorized **C1:** suspended body **NM:** motorized platform **CC:** suspended

NP: carrying nacelle **C2:** suspended body **M2:** motor.

2.2. Characteristics of the Citadis™ 402 tramway[5].

Type	*CITADIS402*
Maximumspeed	80 km/h
Commercialspeed	50 km/h
Linelength	9.7 km
Length	44 m
Height	3.5 m
Numberofpassengers	302
Numberofair conditioners	03
NumberofCandles	04
Numberofmodels	07

3. Tram air conditioning system

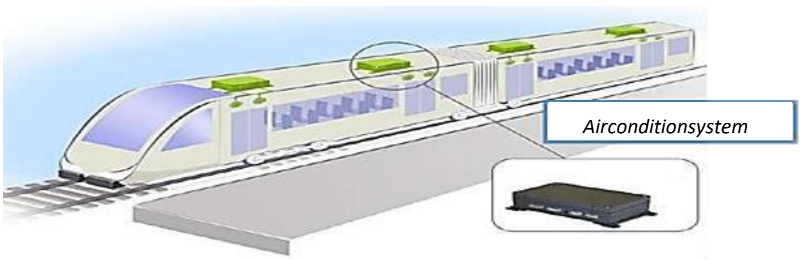

Fig.2.Location of the air conditioning system on the tram[6].

Air conditioning system Tram type CLU45The air conditioning system is located in the upper part (roof) of vehicles, as shown in (Fig.2). The CLU45 air conditioner is equipped with two independent cooling circuits, a heating system and an air handling unit. The HVAC system consists of a single box whose components are mainly made of aluminum sheets. The vehicle's air conditioning system is divided into 3 zones, electrical zone, air treatment zone and cooling circuit zone (Fig.3), and each car is equipped with 03 HVAC kits ensuring accessibility to all

components. This type of air conditioner ensures heating, cooling and ventilation of passenger spaces in order to guarantee good thermal quality and comfort throughout the flight.[6].

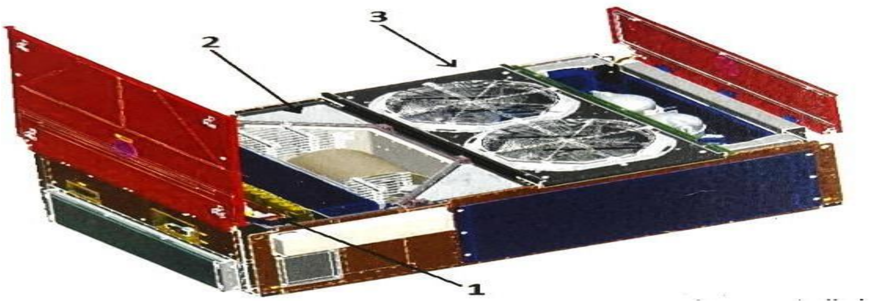

Fig.3.Imagezone of the air conditioning system[6].

1. Electrical panel 2.Air treatment zone 3.Cooling circuit zone

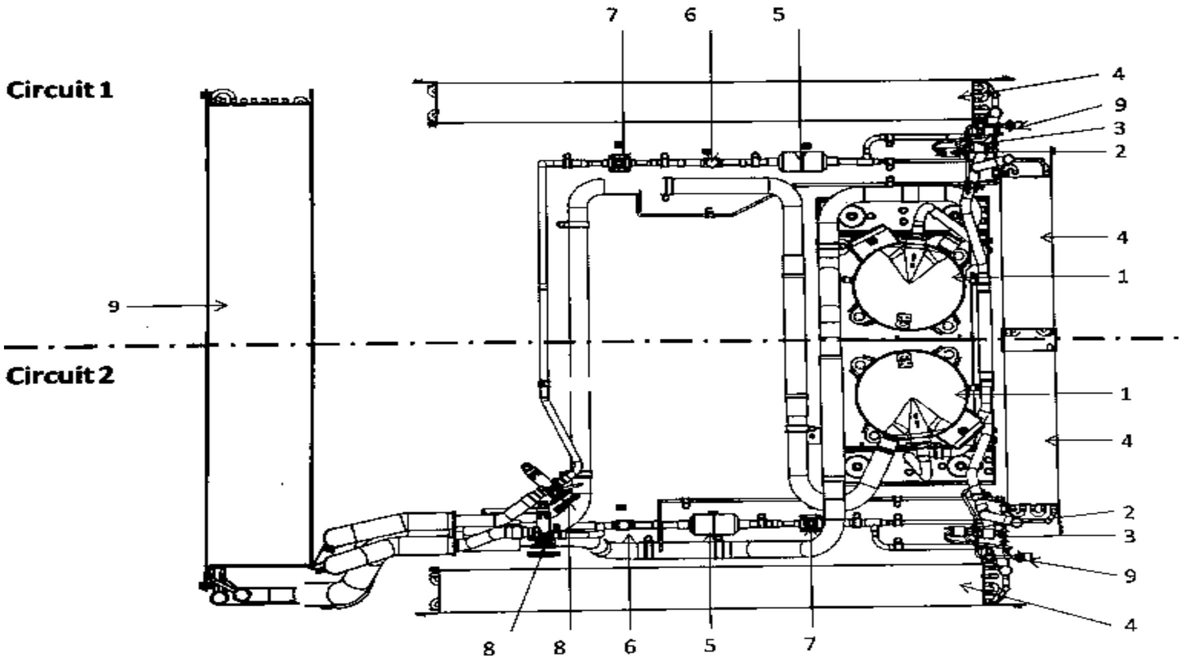

Fig.4. Schematic diagram of the tram air conditioning system [4].

1.Compressor 2.High pressure switch HP 3.Low pressure switch LP 4.Condenser 5.Drier filter

6.Sight glass 7.Solenoid valve **8.** Expansion valve **9.**Evaporator

3.1. Filterdrier

The filter drier is an essential element for the reliability of the system as well as its lifespan. The Danfoss filter drier range covers both hermetic and exchangeable core types. The core allows the filter drier to absorb water and acids more efficiently to prevent corrosion of the compressor's metal surfaces and ensure that oil and refrigerant do not decompose[7].

The filter drier must absorb any residual humidity from the refrigeration circuit. It has an extractable cartridge retaining all kinds of impurities such as particles, sludge and oil decomposition products coming from the refrigeration circuit. [6].

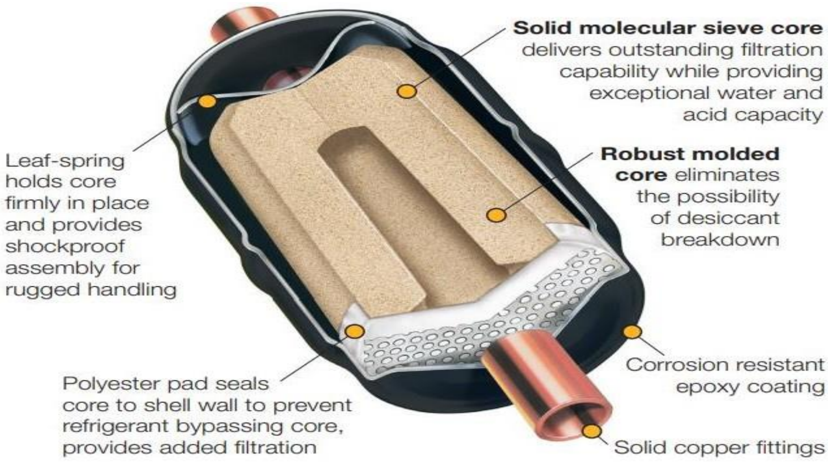

Fig.5.Image of the internal section of the filter drier [5].

4. Methodology

Theworkplanis asfollows:

1- Study and analyze the climate of the area where the tram is located

2- 2-Reliability, laws and indicators.

4.1. StudyandAnalysisoftheclimateofOuargla

The geographical distribution of the city of Ouargla is located in the north of the Algerian Sahara. It is located at a latitude of 31.56° and a longitude of 5.19°. This region is characterized by a hot desert climate and high temperatures most months of the year and low biological life in the ecosystem. [8].

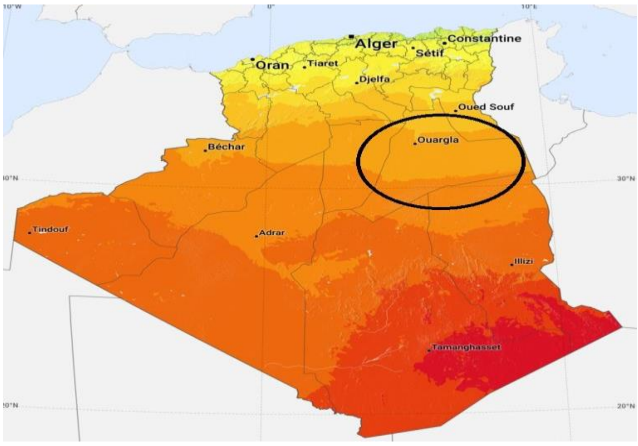

Fig.6.Photo of the location of the city of Ouargla on the map [9].

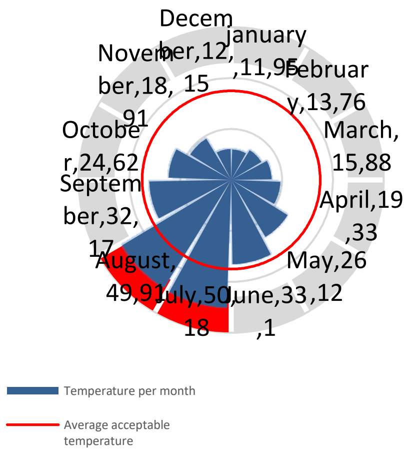

Fig. 7. Schematic diagram for temperatures in the region in 2021.

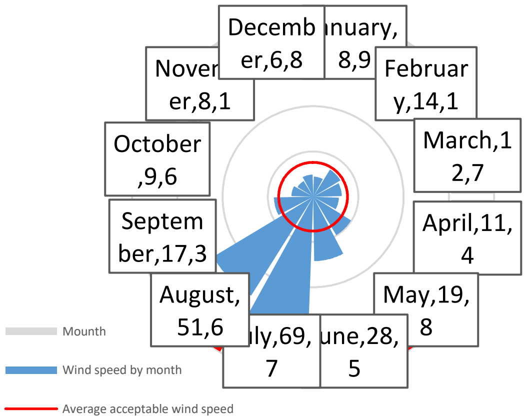

Fig. 8. Schematic diagram for wind speed in the region in 2021

Here are some weather-related numbers for 2021 [10].

-The hottest average temperature is in July with an average temperature of 49.94°C. And the coldest is in January with a temperature of 11.95°C.

-The air is very dry, the relative humidity level varies from one season to the next, it reaches its threshold

-Maximum annual winds are 69.7 m/s and peak in summer. As shown in the following curves.

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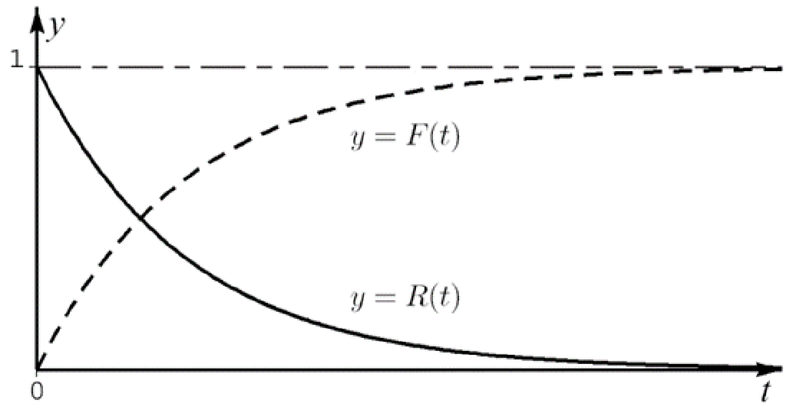
We see from the data that the climate of the region is hot and dry with strong monsoon winds, especially in summer, where the maximum temperature reaches 49.94°C and the wind speed is 69.7 m/s. This climate requires constant use of air conditioners throughout the year and with more effort in summer, which exposes the air conditioning structure to numerous breakdowns due to fatigue.

4.2. Reliability, laws and indicators

Reliability is the ability of an entity to perform a required function, under given conditions and during a given time interval, which is generally measured by the probability of failure-free operation during a specified time interval (0, t) [11-13].

Reliability is one of the components of operational security. This can be compared to the science of chess. It is the ability of an entity to perform a required function or satisfy the needs of a user, under given conditions, for a given period of time [14,16].

Reliability is a decreasing function of time (Fig. 1), reflecting the fact that the ability of a system to perform correctly decreases with time.



$(t_1) > R(t_2)\ if\ t_1 < t_2$

Fig.9.Diagram showing the inverse relationship between reliability function and failure [11].

4.2.1. Laws and Indicators

A reliability function, defined for all (t ≥ 0):

$R(t) = P(T > t)$

$= 1 - P(T \leq t)$

$= 1 - F(t)$ (1)

The failure function F (t) and the reliability function R(t) are expressed from the density function f(t) by the following relationships: [14-17].

$F(t) = \int_0^t f(u)du with f(u) = \int_0^t f(u)du$

$$F(t) = \int_0^t \lambda e^{-\lambda u}\, du$$

$$And R(t) = 1 - F(t)$$

$$= 1 - \int_0^t f(u)du = \int_t^\infty f(u)du$$

$$R(t) = 1 - \int_0^t \lambda e^{-\lambda u}\, du$$

$$= 1 - [1 - e^{-\lambda t}]$$

$R(t) = e^{-\lambda t}$ (2)

Failure rate λ(t)

The instantaneous failure rate λ(t), represents the conditional probability of having a failure in the time interval [t, t + dt], knowing that there was no failure in the interval of time [0, t]. Thus, by applying the conditional probability theorem, then the total probability theorem [17-19].

$$\lambda(t) = \lim_{dt\to 0 dt} \frac{1}{dt} P\left(t < T < t + \frac{dt}{T} > t\right)$$

$$= \lim_{dt\to 0 dt} \frac{1}{dt} \frac{P[(t < T < t + dt) \cap (T > t)]}{P(T > t)}$$

$$= \frac{1}{P(T > t)} \lim_{dt\to 0 dt} \frac{1}{dt} P(t < T < t + dt)$$

$$= \frac{f(t)}{R(t)} = -\frac{R'(t)}{R(t)}$$

$$= -\frac{d}{dt} ln R(t) \geq 0$$

Therefore, we have $R(t) = exp[-\int_0^t \lambda(u)du]$ (3)

Average operating time

MTBF (Mean Time Between Failures): is often translated as mean operating time but it represents the average time between two failures. In other words, average operating time of an entity before the first failure. [17-19].

$$MTBF = \int_0^\infty R(t)dt$$

Physically the MTBF can be expressed by the sum of the lengths of the operational periods divided by the number of observed failures:

$$MTBF = \frac{\sum(start of downtime - start of uptime)}{number of failures} (4)$$

Assuming a constant failure rate λ:

$$MTBF = \frac{1}{\lambda} (5)$$

MTTR (mean time to repair): is the average time it takes to repair a system (usually technical or mechanical). It includes both the repair time and any testing time. The clock doesn't stop on this metric until the system is fully functional again. [17-19]

$$MTTR = \frac{\sum time to repair}{number of repair} = \frac{\sum TTR}{n} (6)$$

. Results and discussion

As time passed and the trams continued to operate, the IOS 04 fault began to appear on the driving screen of most trams although it was only present in three vehicles. It therefore became necessary to develop a precise action plan to resolve the problem.

The first step is to use calculation and curve drawing programs to calculate the reliability and breakdown rate of the tram during the year 2021, because the breakdown rate is terribly high and the air conditioning system is broken by 97%. The results are presented in Table 1.

Table 1. Reliability and failure rate in 2021

Month	*Numberfailures*	*TBF(h)*	*TTR(h)*	*MTBF*	*λ(t)*	*R(t)%2021*	*F(t)% 2021*
January	11	5596,23	22	5594,23	0,00017	87,53	12,47
February	15	5483,75	30	5481,75	0,00018	88,48	11,52
March	12	5913,21	24	5911,21	0,00016	88,18	11,82
April	21	4063,59	52,5	4061,09	0,00024	83,76	16,24
May	33	1321,24	82,5	1318,74	0,00075	56,89	43,11
June	57	2080,83	199,5	2077,33	0,00048	70,72	29,28
July	80	532,21	280	528,71	0,00189	24,49	75,51

August	71	720,03	248,5	716,53	0,00139	36,6	63,4
September	69	597,521	310,5	593,02	0,00168	31,6	68,4
October	59	1013,324	206,5	1009,82	0,00099	49,02	50,98
November	29	1075,14	101,5	1071,64	0,00093	49,94	50,06
December	73	815,61	328,5	811,11	0,00123	40,95	59,05

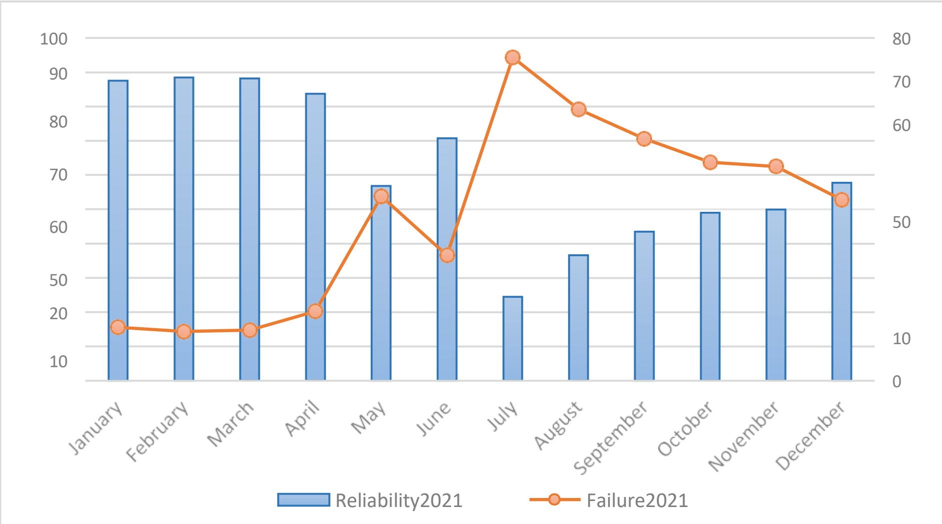


Fig.10. Schematic diagram of the evolution of the reliability rate depending on a breakdown in 2021

Through the reliability table, we notice that the vehicle reliability rate was good at the beginning of the year, more particularly during the winter season, compared to the summer season in June, when breakdowns began to increase significantly. significant and reached a maximum rate of 75.51%.

The second step is to choose tram 101 to work and operate the air conditioning system to the maximum until the IOS 04 error appears on the steering wheel.

According to the parent company's guide, the IOS04 error indicates hot and cold failure.

After that, we connect the train roofs own program (FAIVELEYLOG13NSF0015) equipped with artificial intelligence technology to accurately analyze defects.

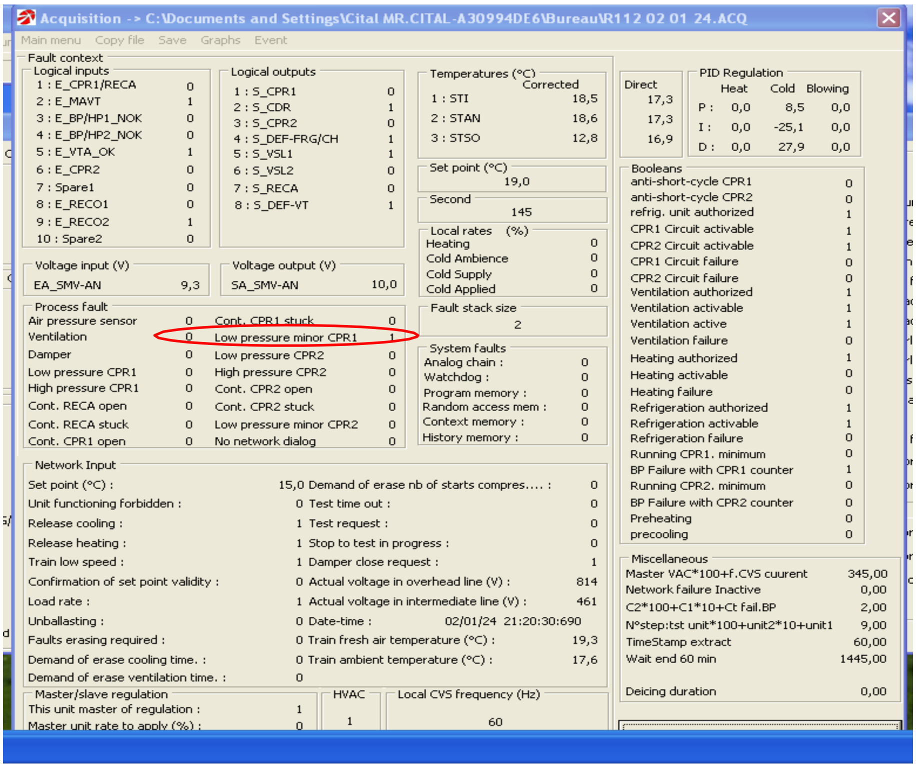


Fig.11. Image of a FAIVELEY program showing an LP failure on an air conditioning system [20].

The FAIVELEY LOG13NSF0015 program detects an LP failure (low pressure valve failure), according to the rams guide provided by the FAIVELEY company which presents a failure of the tram's air conditioning system. The LP failure indicates that:

- Evaporation pressure less than 0.5 bar.
- Lack of coolant in the circuit.
- Malfunction of the solenoid valve.
- Malfunction of the capacity regulator.

The third step Diagnose the faults and send a report to the parent company, as they are responsible for operation and maintenance decisions in accordance with the agreed tram warranty program. After examination of the results by the parent company, a group of Alstom technicians arrive in Algeria to carry out maintenance.

Decisions of parent company technicians:

- Change the version of the air conditioning system of tram 103 (version 1, version 2, version 3)

- Change the solenoid valve of tram 104.

- Change the capacity regulator of tram 105.

The failure of the low pressure LP valve is high in tram 108, train 108 will therefore be a battering ram to compare the results obtained in the rest of the tram. The results are represented in the following curves:

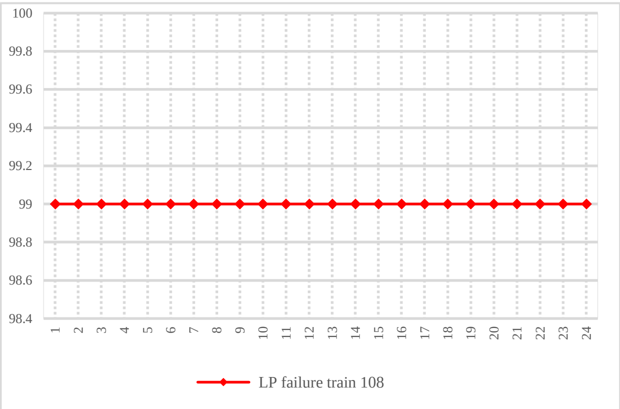


Fig. 12. Chart showing the percentage of LP failure in tram 108.

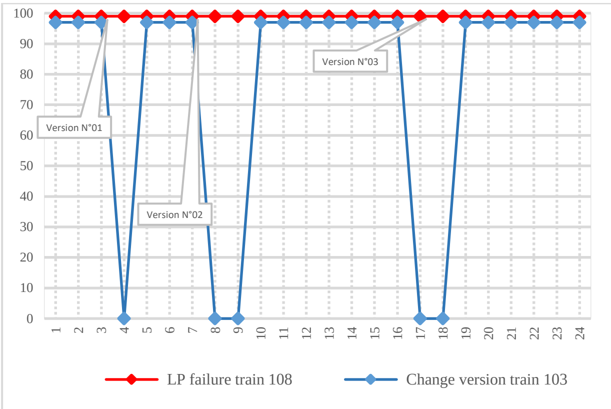


Fig. 13. Chart showing the failure rate of LP in tram 103 after changing the

Comparing the results of the three trains with train 108, we noticed that the LP failure disappears for only a few minutes when changing the three versions of car 103 and then reappears when the air conditioners are turned back on directly compared to cars 104 and 105 where we noticed that the fault disappears for a period of more than an hour when changing the

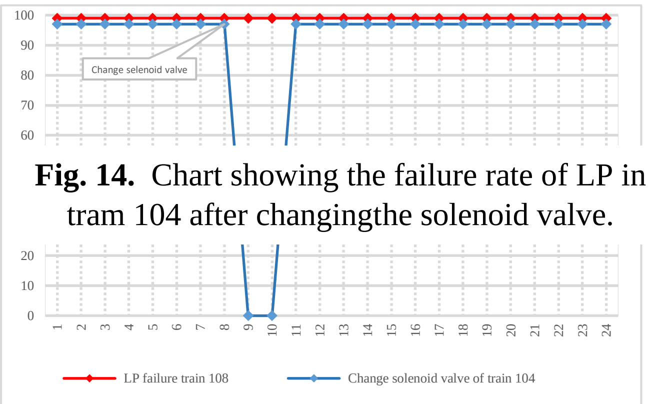


Fig. 14. Chart showing the failure rate of LP in tram 104 after changingthe solenoid valve.

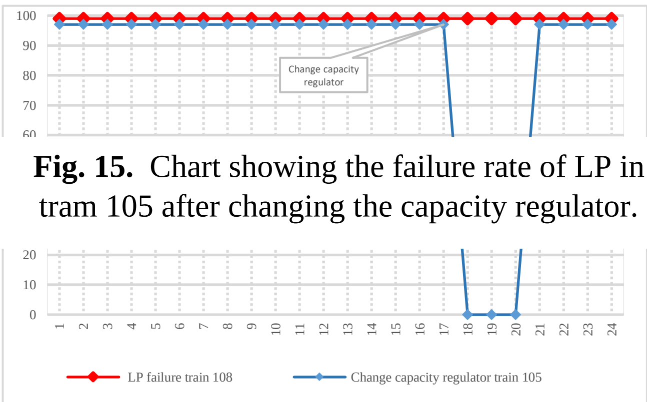


Fig. 15. Chart showing the failure rate of LP in tram 105 after changing the capacity regulator.

solenoid valve and the capacity regulator, but the fault appears again, and therefore all the

operations are considered negative because the LP failure has not disappeared.

Step Four A quarter of a step after the parent company's technicians failed to resolve the problem and the situation worsened, especially with increasing climate temperatures, we sent a detailed report on the high rate of malfunctions of vehicle air conditioners, which led to a sharp increase in temperatures. inside the trailer and a serious shortage of passengers, thus causing the company's transportation to waste a lot of money and time.

The request submitted to the parent company to approve our intervention to help resolve the issue. After approval from the parent company, a preventative maintenance plan was developed that included examining all components of the vehicle's cooling system 101, HVAC, and through initial diagnosis we achieved the following results:

The coolant is too high in circuit 2 between the compressor and filter drier and too low afterwards.

• The end result is a possible blockage in the filter drier (circuit 2).

Parent company decisions

The possibility of a complete filter blockage is unacceptable because the filter life is greater than 10 years and there is no reason for the blockage once both compressors appear to be healthy through diagnosis.

• The approaching possibility is to change a new version of air conditioners.

Decisionsofthe TechnicianCITAL

Perform two operations on two different vehicles to verify the results:

• Change the version of tram 104

• Replace the filter drier with the tram101

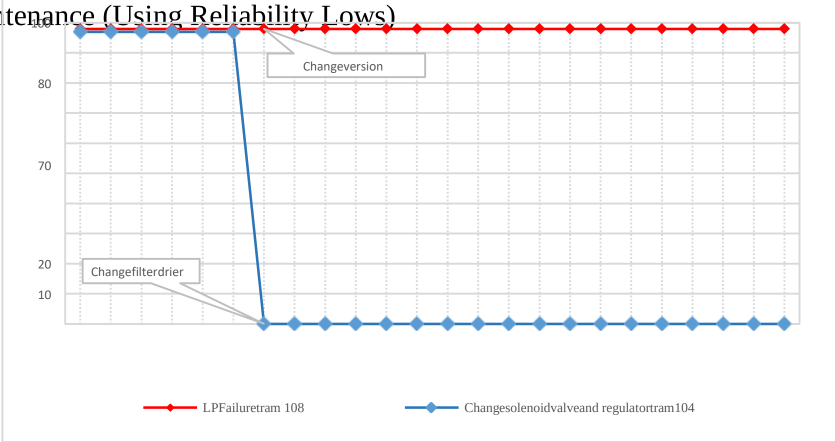


Fig.16. Graph showing the failure rate of LPintram104 after changing the filter drier.

Total disappearance of LP pressure failures on train 101 after changing the filter drier of circuit 2 and their persistence on train 104.

After our diagnosis and the impressive results obtained after the complete disappearance of LP failures on train 101 after changing the filter drier and switching on the air conditioners, the parent company decided to verify the validity of the results we obtained by conducting three experiments different on three vehicles as follows:

• Tram108 change solenoid valve with filter drier.

• Tram109 changing the tumble dryer filter with the capacity regulator.

• Tram110 changes the filter drier only.

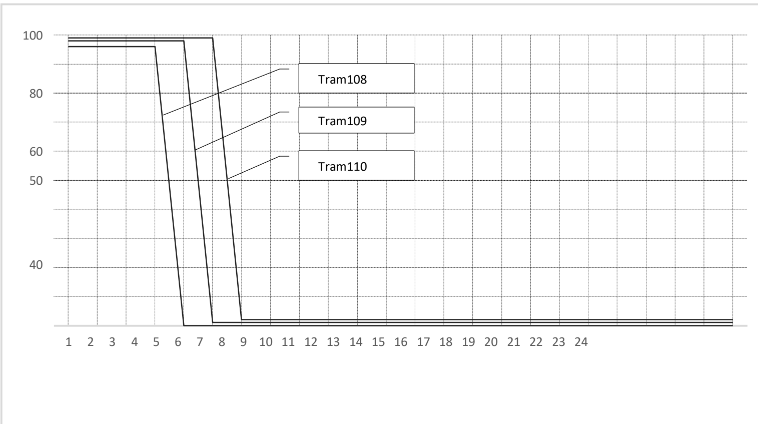


Fig.17.The diagram shows the breakdown of the LP after three different operations for three different trams.

The LP low pressure valve failure completely disappeared on all three vehicles, even after running the air conditioning on the bikes at maximum all day.

• The end result is that the filter drier is blocked in all vehicles.

Diagnosing Drier Filter Failure

Through this step we will look for the source of the failure in the drier filter, by opening one of the damaged filters that was replaced in circuit 2 of the air conditioning system and comparing it with an internal section of a new one filter (Fig.18 and Fig.19) shows the difference between a good filter and a damaged filter.

Fig.18.Picture for an internal section of the new filter drier

Fig.19.Photo of a damaged internal section of the filter drier

We notice in the photos that the inner cotton of the good filter is white in color and in good condition compared to the damaged filter, in which the inner cotton appears black and completely burned, forming a solid insulating layer for the liquid, and it is the reason for its blocking.

Having understood that the cause of the blockage is due to the melting of the cotton layer at the bottom of the dried filter, we can say that the cause of the melting is largely due to an error that occurred during the installation process of the filter. filter in circuit 2 of the air conditioning system, because the tram is still in its first two years of operation and there is no other reason for its blockage.

To confirm this, we welded two different filters, the first by welding respecting the recommendations attached to the filter drier (Fig. 20) and the second by welding without respecting the recommendations (Fig. 21). The results are shown in the photos.

Fig.20.Photo of filter drier, (A) the correct welding method, (B) the inner part of the filter drier after welding

Fig.21.Photo of filter drier, (A) the wrong welding method, (B) the inner part of the filter drier after welding

We can see from the photos that the Dreyer filter, which was soldered as recommended, remains healthy. As for the second filter, which was welded without respecting the recommendations, it was completely destroyed. The main reason for Drier filter clogging is the melting of the inner cotton layer due to incorrect welding method.

- After identifying the main problem and its cause, the filters of all vehicles were changed using the correct welding method. The results are presented by the reliability rate after changing the filters as follows:

Table 2. Reliability and failure rate in 2022

Month	*Numberfailures*	*TBF(h)*	*TTR(h)*	*MTBF*	*λ(t)*	*R(t)%2022*	*F(t)% 2022*
January	41	1196,23	82	1194,23	0,000837	53,73	46,27
February	29	1283,75	58	1281,75	0,000780	59,2	40,8
March	12	3913,21	24	3911,21	0,000255	82,65	17,35
April	16	4563,52	32	4561,52	0,000219	85,41	14,59
May	11	5921,24	22	5919,24	0,000168	88,18	11,82
June	10	4988,82	20	4986,82	0,000200	86,52	13,48
July	13	6232,01	11	6231,16	0,000160	88,38	11,62
August	17	5020,33	34	5018,33	0,000199	86,65	13,35
September	16	4997,51	20	4996,26	0,000200	86,17	13,83
October	14	5513,31	28	5511,31	0,000181	87,34	12,66
November	12	5927,45	24	5925,45	0,000168	88,18	11,82
December	13	5821,93	26	5819,93	0,000171	88,35	11,65

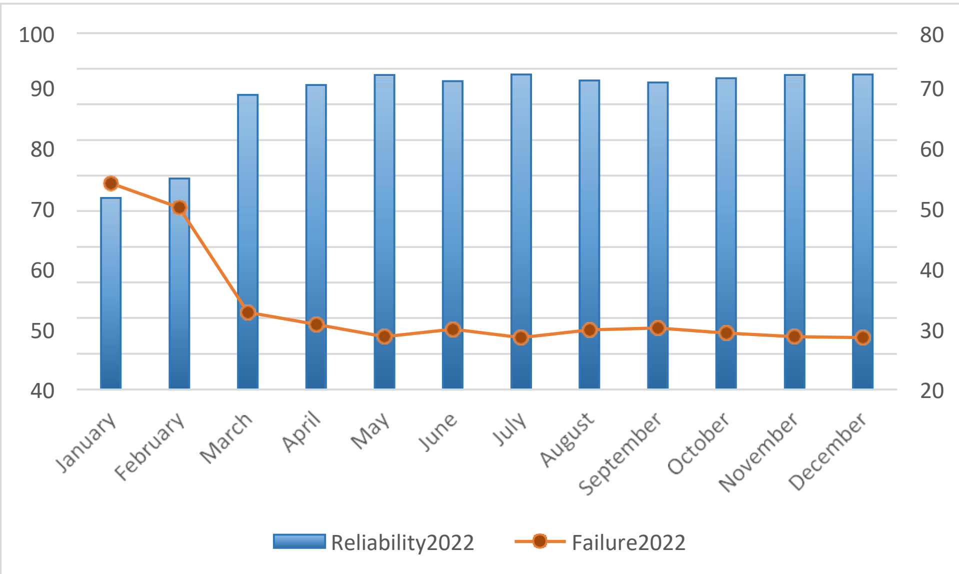


Fig.22. Schematic diagram of the evolution of the reliability rate depending on a failure in 2022

From the results we notice that the reliability increases up to 88.33% in summer, with a significant drop in the percentage of failures compared to the year 2021 in which the LP failure appeared, and thus the vehicles return to normal function with a notable increase in company revenue in 2022.

6. Conclusion

A breakdown in the air conditioning system of a tram has been diagnosed in desert areas. The findings are summarized as follows.

- The air conditioning system is an efficient and sensitive system at the same time

- Desert areas with a hot and dry climate among the areas where defects and malfunctions of industrial equipment appear, in particular air conditioning systems.

- Failure to follow recommendations when assembling industrial parts leads to the appearance of malfunctions of unknown origin, which leads to an increase in maintenance costs.

- Preventive industrial safety schemes constitute the protective wall of industrial equipment, which facilitates the process of identifying faults more quickly and at lower maintenance costs.

- Reliability is the effective element in the world of manufacturing. The higher the reliability of vehicles and machines, the higher the production and revenue percentage.

- Transport vehicles are among the most influential machines in the industrial environment due to their direct impact on the economic indicator, so they must always be protected.

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