

Analysis of defects in the braking systems of commercial vehicles

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Abstract. The field of commercial vehicles has consolidated an indispensable place in society through aspects such as: the continuous development of delivered performance, increased reliability, raising comfort standards and increasing traffic safety to unprecedented levels. However, increasing performance and improving the braking process are aspects that require increased attention and can be achieved by timely identification of system defects and analysis of determinants. The complexity of current systems, both the complexity of braking systems and the overall complexity of commercial vehicles, sometimes make it difficult to diagnose and repair, but they come with significant advantages. The current study analyses data on the wear of the elements of the braking system at several trucks and identifies the main trends. In addition to data on wear and maintenance, this study also examines errors in electronic control units, looking to identify dangerous situations that can lead to issues such as: reduced braking capacity; premature decommissioning of the elements in the braking system; increasing downtime in the workshop or increasing maintenance costs. The identified solutions are based on the analysis of the frequency of errors and their distribution.

1. Introduction

At present, motor vehicles have an important position in society and this position will not only be maintained but will be further strengthened as motor vehicles evolve. New technologies will significantly increase performance and further increase vehicle dependence. However, it seems that vehicles will also undergo radical changes in terms of mainly propulsion and driving systems. If the problems related to pollutant emissions, increasing energy efficiency, or eliminating dependence on fossil fuels need to be carefully considered; on the other hand, related to driving assistance (or even autonomous driving) things are much more complicated because the interaction between the electronic elements and the mechanical elements of vehicles is only at an early stage.

The development of current braking systems has gone from the simple analysis of the braking of a rotor in a friction torque, to complex mechanisms that combine mechanical braking and electronic control in a complex system, whose performance depends on the exact operation of each component. There is a high potential for the development of the elements in the braking system so as to eliminate almost all situations of premature brake failure and further to significantly reduce maintenance costs. These issues would also lead to a significant increase in traffic safety. Increasing braking performance by combining mechanics and electronics also increases the complexity of the systems. This aspect leads to the need to analyse defects on both the mechanical and electronic side.

2. Elements of analysis and methodology

The current paper analyzes the defects encountered in the operation of trucks, during certain periods of time. Mechanical defects (wear, cracks, blockages) and errors generated in the brake command and control units were analyzed. The data obtained were grouped and analyzed following aspects such as: identification and analysis of the main causes that lead to the failure of braking systems; identification and analysis of the main failure areas; analysis of the frequency of errors in the electronic command and control units (ECCUs) to determine the extent to which mechanical defects are detected by the ECCU and how new methods of fault monitoring can be identified.

Current braking systems deliver extremely high performance based on the interaction between mechanical and electronic systems. At present, the following can be involved in the braking process: wheel grip control systems, stability control systems, friction torque wear monitoring systems, actuation pressure control elements depending on various external factors. The sketch in figure 1 shows the complexity of the current braking systems and marks the main areas prone to failure that were analyzed in the paper (Z1-Z7 are zones of defects, a-air supply zone, b-wiring, c-unmonitored zone).

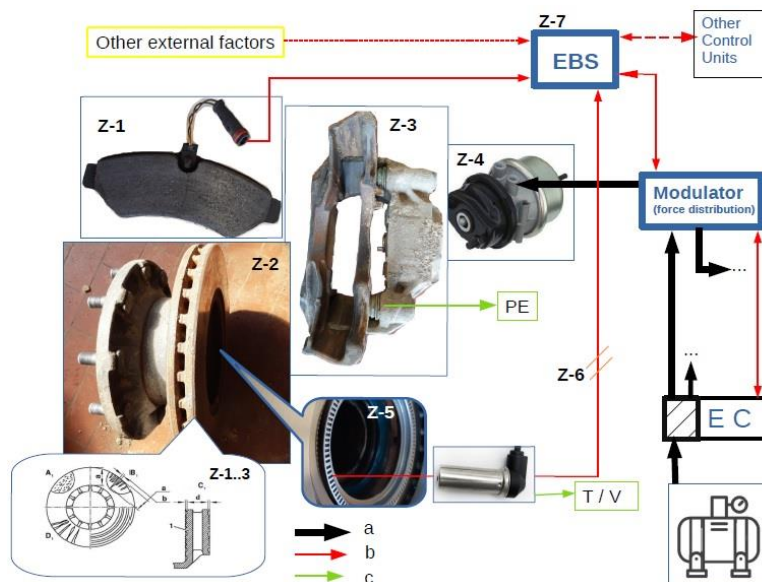


Figure 1. Schematic diagram and main fault areas of the braking systems: Z1, Z2—the area of the friction torque –characterized by different types and forms of wear. Z3—suppression of the brake caliper freedom –causes massive wear in areas Z1 and Z2, as there is no monitoring system for these defects. Z4—defects in this area lead to brake inefficiency. Z5—mechanical defects related to the wheel grip control system. The effects of these defects decrease performance and traffic safety. Z6—wiring defects. Z7—software errors.

Failure of parts of the braking system is a topic discussed in various articles [1-8]. Popa M, et all in [1], review the main defects in the braking system and in other articles [2,3] promptly analyze a series of wears in brake elements for heavy trucks and some performance of braking systems are evaluated. Defects in the brake disc area are also analyzed in other articles [4-7]. Reyes A M et all, in [4] identifies and analyzes the cracks that appeared on the surfaces of the brake discs of a bus running in areas with frequent ascents and descents. Da Silva S A M et all [5] identifies 4 types of brake discs used in vehicles and creates a mathematical model for their analysis, resulting from the simulation that the most prone to wear zone is in the area of attachment of the disc to the hub. Other studies [6,7] identify and analyze the self-loosening and breaking of the disc fixing screws on the hub on high-speed trains. However, similar situations were identified among the dump trucks used in heavy construction conditions between the trucks analyzed in the current study.

Figure 2 shows some critical situations encountered in the trucks analyzed. Starting from these situations, the main objective of the study is to analyze the defects and identify the main causes that trigger the defects and at the same time establish a link between mechanical defects and electrical defects. It is desired to identify new solutions for monitoring the operation in areas identified as high risk. For example, if Jegadeeshwaran R, in [8], identifies vibrations as the main cause of breaking the disc fastening screws, a sensor could be used to identify braking vibrations. In another study [6], for the same screws, a weakening of the screw structure due to local heating is identified as the main cause of breakage of bolts and damage of the brake disk.

Elimination of such defects could be possible if the ABS sensor in Figure 1 (Z5-T/V) would also provide the temperature in the reading area and if it could also identify some of the vibrations (by positioning the sensor relative to the polar wheel, which is attached to the brake disc). Also, in this order of ideas, monitoring the degrees of release from the brake caliper (figure 1, Z-3, PE) would help a more accurate identification of defects that lead to extreme wear situations such as those shown in figure 2.



Figure 2. The main defects identified in the braking systems: **A-** cracks in the brake disc in the area of the fixing screws; **B-** breaking the disc due to cracks; **C-** deposits that block the movement of caliper; **D, F-** thermal overload on disc surface; **E-** overloads effects on the brake pads.

In the current study, in order to prevent situations of advanced wear, the defects reported by the control units of the braking systems are analyzed. It was found that although both the diagnostic equipment and sensors present on the trucks provide accurate data, there are still unidentified defects which cause major damage in time. Based on the data obtained, the aim is to significantly reduce the incidence of serious defects while reducing maintenance costs and increasing traffic safety.

3. Results and discussions

The data analysis was performed on a number of 873 reports at the entrance to the workshop, for heavy trucks, during 14 months, starting with January 2020. During this interval, in a first stage were analysed at each entrance in workshop, the number of errors in the control units responsible for the operation and maintenance of the braking system. The data were divided into the following categories: errors related to the operation of the braking system; errors related to the maintenance part (wear); electrical errors (reports electrical faults such as: missing signal, signal interruption, erroneous signal, short circuit, etc.); mechanical errors (differences in wear, blockages, or defective parts).

Figure 3 shows the initial distribution of the defects encountered and the following main data can be outlined: the monthly distribution of the number of errors, the variation of the number of errors according to the date, the ratio between the number of errors in electronic units for operation and maintenance, the ratio between the errors that signal electrical defects and those that signal mechanical defects. It was found that both mechanical and electrical errors can be generated in both the maintenance unit and the EBS unit. Electrical errors in the maintenance unit refer to defects of the position sensors in the brake calipers or defects of the pad wear sensors (if applicable). The other errors relate to other defects in the operation of the braking systems.

Figure 4 allows the identification of periods when the frequency of defects is much higher and even the peaks are captured as the number of errors encountered in the winter months. The evolution of the number of tests performed may suggest to a certain extent the economic situation from that date, especially if we consider the fact that the study refers to commercial vehicles used for the transport of goods. Figure 5 shows the ratio between the errors reported by the central control unit of the braking system and the errors reported by the maintenance unit. There is a much higher share of errors in the central unit due to the complexity of the activities it manages. However, at a closer analysis of trends, it can be seen that, in the winter months, there are peaks in both the number of tests and the number of defects identified, which highlights the existence of influencing factors.

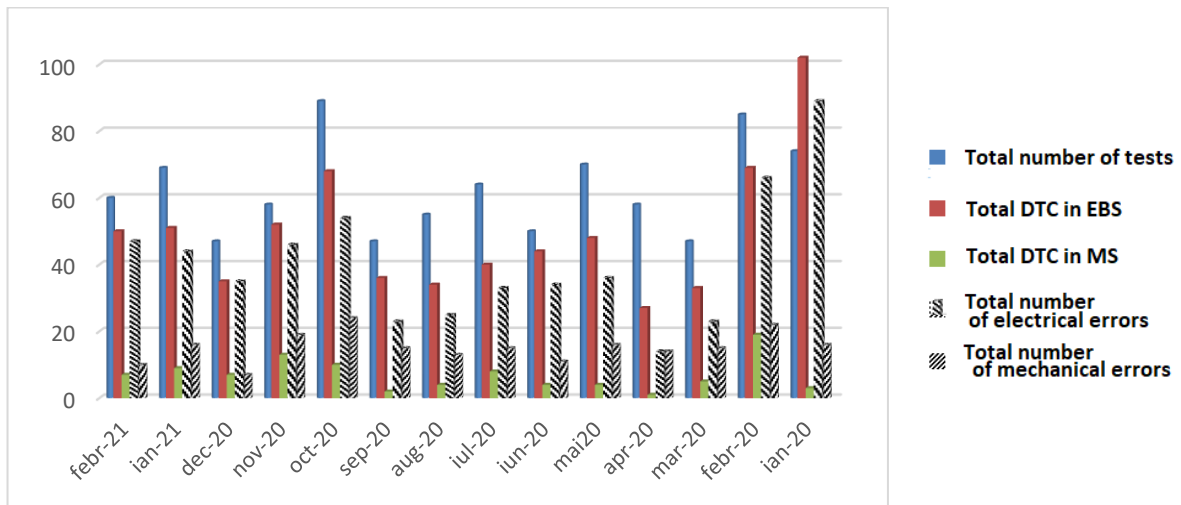


Figure 3. Distribution of defects in the first sorting (DTC- Diagnostic Trouble Codes; EBS-brake command and control unit; MS-control unit for monitoring wear on brake pads).

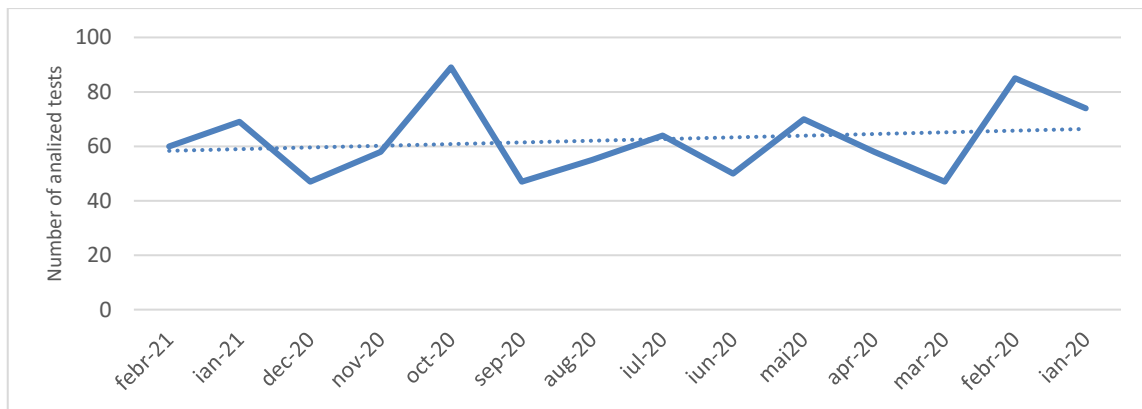


Figure 4. Number of tests analysed each month and linear trend.

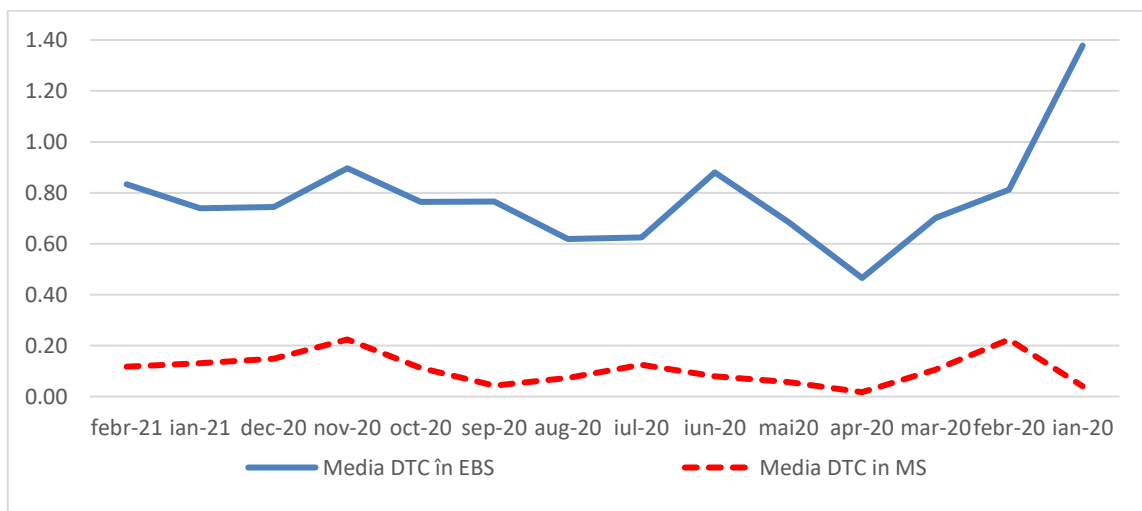


Figure 5. Average error distribution between the main brake control unit and the maintenance unit (DTC- Error Codes encountered; EBS- brake control unit; MS-control unit for wear monitoring).

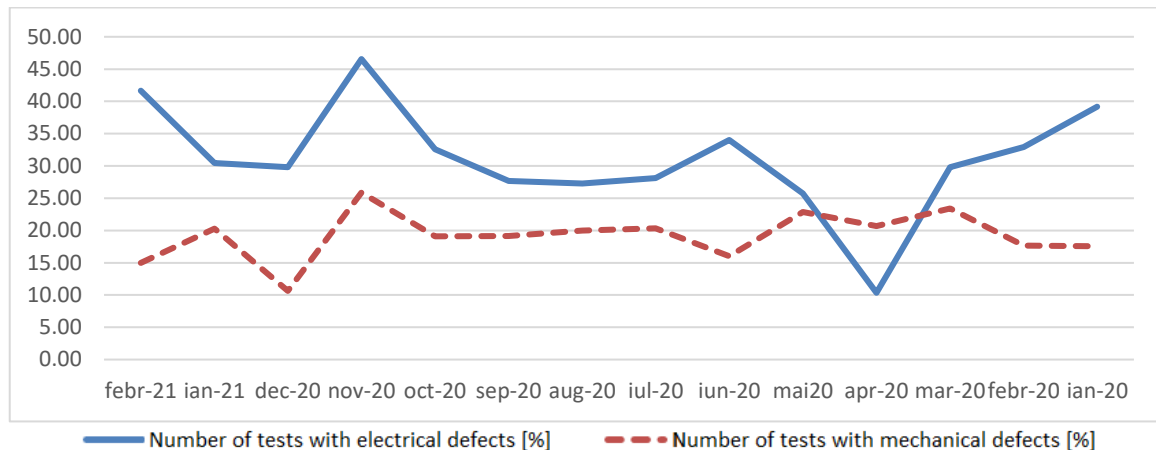


Figure 6. Defects distribution based on number of tests [%].

The analysis of the distribution of errors by type of error (mechanical or electrical) brings to the fore a significant increase in errors in the winter months. This can be explained based on the analysis of defects encountered in service and leads to the idea that humidity factors and low temperatures in the cold season favor the occurrence of electrical defects. The winter conditions on the road (humidity, mud, anti-skid materials) favor the increase of the failure rate on the exposed parts. Figure 6, in addition to the increasing trends of tests containing electrical and mechanical defects of the braking system in the winter months, also captures the effects of the corona-virus pandemic. In Romania, March and April represent the beginning of the pandemic and were characterized by a sharp decline in activity.

Another part of the study focused on the in-depth analysis of truck tests in four of the months analyzed (Figure 7). During these months, the tests were carefully analyzed following aspects such as: identification of all errors encountered and grouping by categories, identification of parts that have a high incidence of failure, identification of areas where errors occur (sensors, actuators, wheels, left / right, truck or trailer), identification of the type of error and the causes leading to the error, etc. The months of February (2020 and 2021), June (2020) and November (2020) were analyzed. A total of 240 tests were analyzed in which errors were identified in 46% of cases, which represents an average of 1.43 errors/test. From the analyzed tests, the errors encountered could be grouped into 15 categories according to the area of influence of the errors (figure 8).

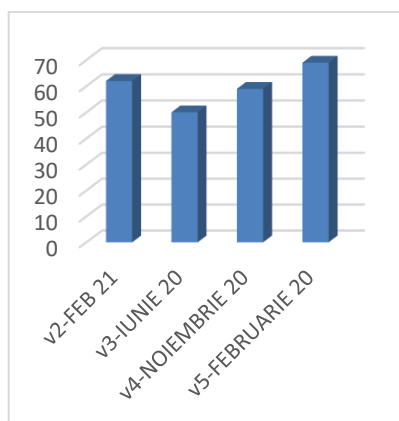


Figure 7. Total number of tests analyzed

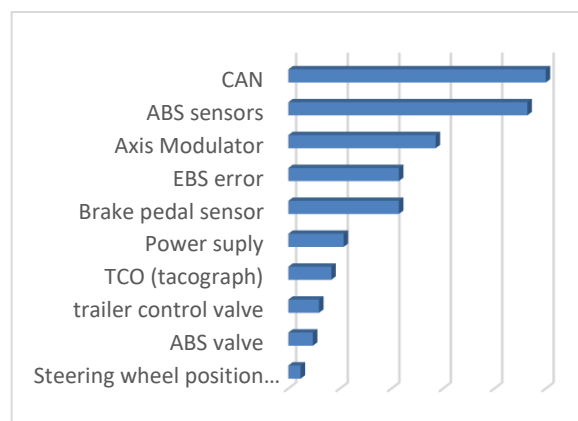


Figure 8. Distribution of defects in the 4 months analyzed [%]

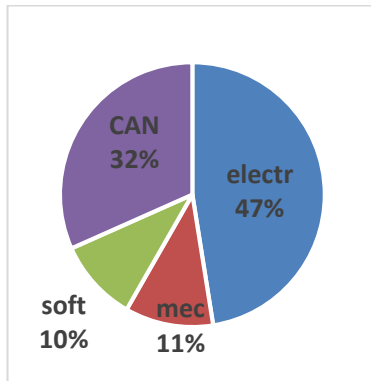


Figure 9. Error distribution

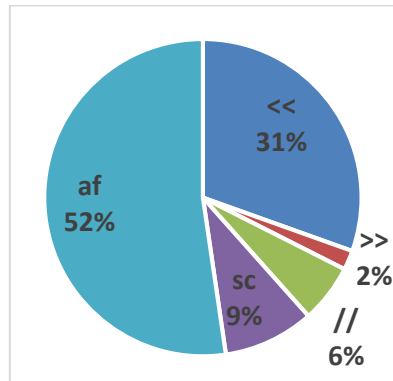


Figure 10. Causes of electrical errors

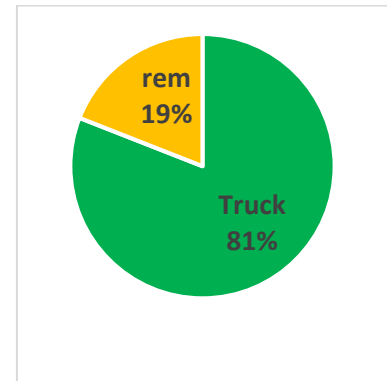


Figure 11. Frequency of errors

It was observed that the largest share is the communication errors between different command and control elements followed by defects in the ABS (anti-lock brake system) sensors. The study also divided the errors by type of error, cause of occurrence and area of occurrence. These aspects are illustrated in Figures 9-11. In figure 9 the distribution is the following: 47% -electrical errors; 32% - errors on the CAN communication bus; 11% - errors related to mechanical defects; 10% -software errors. In figure 10 the main identified causes that led to the errors were grouped as follows: 52% -external causes; 31% -insufficient voltage; 9% -short circuit; 6% -interrupted wiring; 2% -voltage too high. In figure 11 the errors were grouped by the area in which they appeared: 81% were identified on the towing vehicle and 19% on the trailer or semi-trailer.

In Figure 9, the defects are grouped according to the type of error in: electrical, mechanical, software or communication. A much higher share of electrical and communication errors was again identified to the detriment of mechanical errors. It should be noted that: electrical errors refer to faults of the electrical circuits of the type (short circuit, interrupted wire or voltage value); mechanical errors refer to mechanical defects of the parts (wear, blockages, ruptures), communication errors refer to the lack of information on a CAN bus; software errors can be fixed by updating the programming language. Analysing electrical defects, it was found that the largest share is external errors, which come from improper operation or use of non-compliant appliances. It has not yet been identified whether these errors affect the operation of the system in any way. Figure 10 shows the distribution of electrical faults caused by: external factors, too low voltage, short circuit, broken wiring, and too high voltage. In 81% of cases the defects were identified in the truck and only in 19% of the cases errors related to the operation of the trailer were reported.

The high weight of errors caused by too low a voltage once again underlines the sensitivity of current systems to voltage variations. The months analysed in the second part of the study include both winter periods and a summer month. However, a low voltage in the batteries does not necessarily have to be related to a fault. It was found that even in the hot season there can be frequent voltage drops in trucks. These issues were identified mainly against the background of declining transport demand during the covid-19 pandemic. This is explained by the fact that the driver stays in the cab and uses electricity from the batteries for a long time. The solution to eliminate such errors is to continuously monitor the truck's batteries and, in the event of a voltage drop, to display a message indicating the engine to start. This solution was found in the trucks analysed. However, during the winter, the voltage varies in much higher limits and in much shorter time intervals, an aspect that emphasizes once again the high number of errors during the winter and the sensitivity of electrical systems to certain external factors.

4. Conclusions

This study analyses the errors that occur in the electronic units of heavy trucks and identifies based on them the main trends of defecation. The reports from the entry into workshop of some trucks were analysed, regardless of the reason for entering, and in the case of intervention in the braking system, the

condition of the elements in the system was analysed. Otherwise the errors related to the braking system stored in the electronic units were analyzed. The high frequency of electrical errors emphasizes the sensitivity of electrical parts and highlights the need to develop new systems to monitor the braking process in the context of vehicles becoming increasingly dependent on electronics. Based on this analysis, risk factors can be identified that, once eliminated, would significantly contribute to increasing the performance of braking systems, increasing traffic safety and significantly reducing maintenance costs for commercial vehicles.

The main determining factors in increasing the number of errors in the braking system can be listed: high humidity, anti-skid materials used in winter, low ambient temperatures, how to use, mud and other impurities on the road. The sensitivity of electrical conductors and sensors to the identified factors, significantly favors the increase of the number of errors encountered in the braking system.

Reducing the number of errors caused by winter conditions and unforeseen wear and tear can be achieved by improving electrical wiring, by monitoring the circuit voltage more closely, or by introducing new sensors to monitor areas at high risk of failure (such as suppression of degrees of release to the caliper or pads, monitoring of temperatures or vibrations in the friction torque).

Although the share of electrical errors is much more significant compared to mechanical defects, the latter should not be neglected because they have much more serious effects and are most often detected too late, after having already caused significant wear to other parts. These issues lead to a significant increase in maintenance costs and a decrease in traffic safety and an improvement in the situation can be achieved by introducing additional monitoring systems for areas identified as high risk.

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