REPORT

following the investigation of the incident happened on the 26th of January 2019 in the underground Depot BERCENI, belonging to SC TMB „METROREX" SA

TYPE OF EVENT	**Incident — (art. 8, point 2.2)**
DATE AND HOUR	**The 26th of January 2019, 09:54 o'clock**
LOCATION	**Underground Depot BERCENI**
TRANSPORT UNDERTAKING	**SC TMB "METROREX" SA**
INFRASTRUCTURE	**SC TMB "METROREX" SA**
RAILWAY MANUFACTURER	**CONSTRUCCIONES Y AUXILIAR DE FERROCARRILES S.A.**
ACTIVITY	**Shunting**
CONSEQUENCE FOR THE PERSONS	**1 injury**
TYPE OF REPORT	**FINAL**
PUBLICATION DATE	**The 23rd of January 2020**

WARNING

This INVESTIGATION REPORT presents data, analysis, conclusions and recommendations regarding the railway safety, resulted following the investigation performed by the commission appointed by the General Manager of Romanian Railway Investigation Agency – AGIFER, for the identification of the circumstances, establishment of the causes and setting of the factors that led to the occurrence of this incident.

The investigation was carried out in accordance with the provisions of the *Regulations for the investigation of the accidents and incidents, for the development and improvement of Romanian railway and metro safety*, approved through the Government Decision no.117/2010 and of the Law no.55/2006 *for the railway safety*.

In the organization and decision making, AGIFER is independent of any legal structure, regulation or railway safety authority, railway infrastructure administrator, as well as of any part whose interests could conflict with the tasks appointed

The investigation was performed independently of any legal inquiry and did not aim to establish the guilty or the civil, criminal or patrimonial liability, individual or collective responsibilities

The investigation has like objective the prevention of railway accidents and incidents, establishment of the causes and circumstances that led to the occurrence of this railway incident and, if case, issuing of safety recommendations necessary for the improvement of railway safety.

Consequently, the use of this INVESTIGATION REPORT in other purposes than those for the prevention of railway accidents and incidents and improvement of the railway safety, can lead to wrong interpretations that did not correspond to the scope of the present document.

CONTENT

LIST OF ACRONYMS

RI	*Regulations for the investigation of the accidents and incidents, for the development and improvement of Romanian railway and metro safety"*, approved by the Government Decision no.117/2010
OMT	Order of Minister of Transports
AGIFER	Romanian Railway Investigation Agency
ASFR	Romanian Railway Safety Authority
AFER	Romanian Railway Authority
CAF	CONSTRUCCIONES Y AUXILIAR DE FERROCARRILES S.A. Besain – Spain
METROREX	SC TMB „METROREX" SA
TEM	Electric metro train
BM3-CAF	București Model changed 3 CAF (type TEM)
S.TEM	Semi-train part of a TEM CAF-BM3 (two S.TEM compose a TEM BM3-CAF)
ATC	Automatic Train Control (automatic control of the train)
ATP	Automatic Train Protection (automatic protection of the train)
DsB	Underground Depot Berceni
DSB	Overground Depot Berceni
TCMS	Train Control Management System (system for the train control and monitoring)
CCU	Command Control Units
TCU	Traction Control Units (unit for the traction control)
BCU	Brake Control Units (unit for the brake control)
ICU	Invertor Control Units
HMI	Man - machine interface
DO	Door Open (unit for the control of the door opening)
MC	Master Control (joystick for the command of the traction-brake TEM from HMI)
M	Electric traction engine
TMB	Bucharest Metro Transport

A. SUMMARY OF THE INVESTIGATION REPORT

On the 26th January 2019, at 09:54 o'clock, during the shunting of the rake of vehicles, consisting in the electric train TEM no.1322-2322 (being in operation) and its hauling locomotive LDH no .92 53 0 86-0100-7, from the over ground depot DSB to the underground one DsB, during its movement by banking from the metro station Dimitrie Leonida to the underground depot DsB, the speed of the rake of vehicles raised un-controlled, it leading to hard hit of the buffer stop from the line no.8, by the unit of the electric metro train S.TEM no.1322, followed by its derailment and the injury of a REM driver.

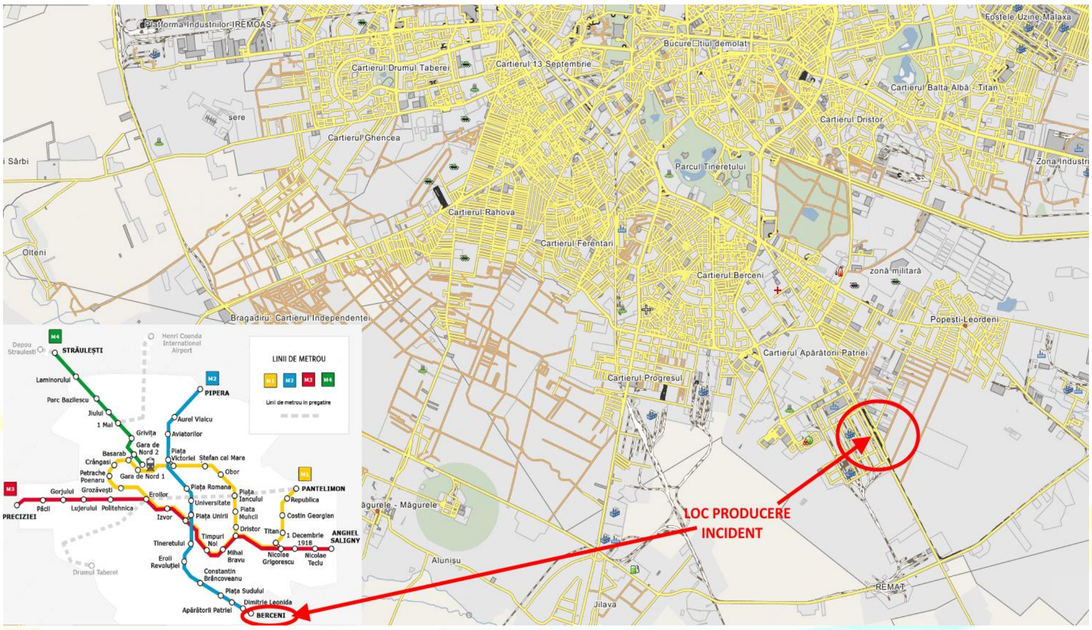

fig.1 -incident site (București map)

Following this incident, the driver, present in the unit of the electric metro train S.TEM no.1322, was injured, and the rolling stock was damaged, the estimated value of the damages could not be established by METROREX until the finishing out of this report.

Direct causes and contributing factors

The direct cause of the incident was the un-controlled increase of the speed of TEM no.1322-2322, generated by the application of an electric tractive effort on the train electromotors, it generating the impossibility to adapt the speed of the rake of vehicles at the distance line for shunting.

The contributing factors was the improper processing in the software logic of the next information:

- use like reference only of the sense imposed by the active driving cabin R2 of TEM. The software logic according which the reference of the active driving cab was priority for the reading sense from the bogie sensors led to the wrong interpretation of the real moving sense of TEM.
- wrong working of the device dead man in hauling condition, missing a sound warming before an emergency brake application, it being not in accordance with the logic working scheme presented in the Driver Manual at chapter 4.4.6 *Operation of the Driver Surveillance Device*;
- keeping in operation of the electric brake, when the service brake being off from the panel TCMS. With the isolation from TCMS of the service brake (consisting in the electric brake and the pneumatic one), made by the human operator, the electric brake was not isolated.

Underlying causes

None.

Root cause was the lack in the Driver Manual of some proper regulations regarding the working in hauling conditions of a rake of vehicles type BM3-CAF with a shunting locomotive.

Severity Degree

According to the accident and incident classification stipulated in the *Investigation Regulations*, considering the activity where it happened, the case is classified like incident in accordance with art.8, paragraph (2), group B, point 2.2 „passing the fixed or mobile signals on the position *„stop" or „shunting forbidden", passing the indicators that forbid the running or of the safety marks by the rake of wagons, light locomotive or other railway vehicles during the shunting, without meeting with the provisions of the specific regulations".*

If the technical needs had imposed the hauling of a TEM BM3-CAF, being in running and transporting passengers, and if the operation staff had done exactly as in case of the incident happened on the 26th January 2019 at the hauling by banking, the consequences in the operation activity could have been both for the passengers and for the tunnel infrastructure.

Safety recommendations

Considering the findings following the investigation, the commission recommends that for reducing the risk of occurrence and preventing some similar incidents, that in slightly different conditions can lead to serious accidents, Romanian Railway Safety Authority-ASFR ask:

- *METROREX take care that the manufacturer TEM BM3-CAF shall re-assess the vehicle software, so it ensures a proper safety level, including in case of its operation by hauling;*
- *METROREX takes care that the manufacturer TEM BM3-CAF shall added in the Driver Manual with the operations needed to be performed during the operation in hauling condition, if the rake of vehicles type BM3-CAF is coupled at a shunting locomotive.*

B. IMMEDIATE FACTS OF THE INCIDENT

B.1. Event

On the 25th of January 2019, at 22:22:06 o'clock TEM no.1322-2322 was stabled in the DSB on the line no.8, having S.TEM no.2322 to the direction of the metro station Dimitrie Leonida. The train ran during the day on the main metro line M2 Pipera – Berceni.

The stabling lines of DSB are constructed above ground and covered with a concrete build, called generic Hall DSB, and the connection lines between the stabling lines layout with the metro station Dimitrie Leonida is made through an over-ground line that enters into the tunnel. This line is not covered, being exposed to the external atmospheric environment.

Considering that TEM no.1322-2322 was scheduled on the 26th January 2019 for the periodical inspection and had to be put at the disposal of SC ALSTOM SA, operator responsible for the maintenance of TEM, and that has the repair workshop in DsB, the owner of TEM no.1322-2322 scheduled its routing and stabling in DsB for the morning of the 26th January 2019.

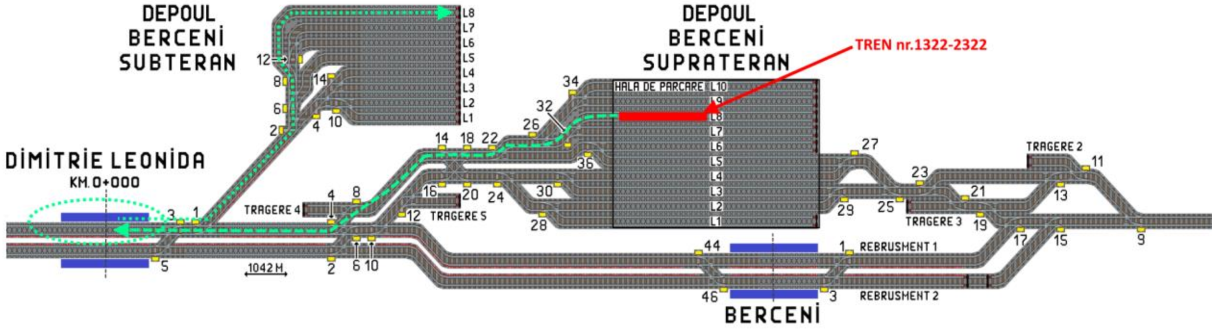

Figure 2 – incident site

Because on the 25th January 2019 and in the morning of 26th January 2019 the atmospheric conditions were particular, consisting in heavy hoar-frost, that deposited on the contact line between DSB and the entrance in the tunnel, it became unusable for the power supply of TEM no.1322-2322. In these particular conditions, one established that TEM no.1322-2322 be hauled from DSB to DsB, with the locomotive type LDH.

On the 26th January 2019, at 08:44:32 o'clock, TEM no.1322-2322 was activated from the driving cab S.TEM no.2322, then the train moved in" Shunting" way up to the front of the signal X8H, where it was sopped for its coupling to the locomotive LDH.

After coupling the locomotive LDH to the TEM no.1322-2322, at the end of S.TEM no.2322, the rake of vehicles consisting in those two vehicles ran to the metro station Dimitrie Leonida, where it was stopped at 09:48:17 o'clock.

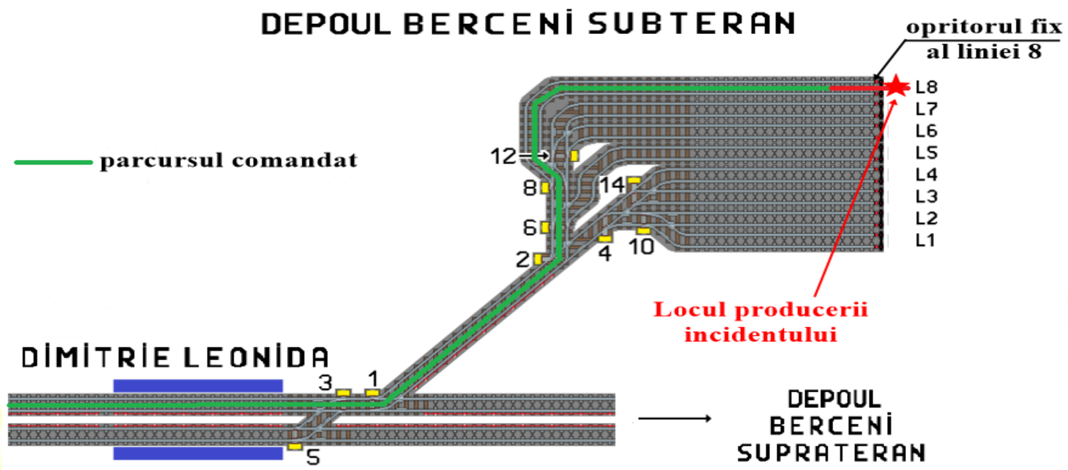

Figure 3 – route of the rack of vehicles before the incident

At 09:48:41 o'clock, the rack of vehicles changes the running direction, starting its running by banking in the sense of the command cab of S.TEM no.1322, to DsB. After running 95 meters, at 09:49:24 o'clock, the speed of the rack of vehicles starts to increase suddenly, following the application of a traction effort on the engines TEM, without being commanded by the driver of the locomotive LDH or MC of TEM no.1322-2322. The maximum speed of 63,129 km/h, was reached at 09:50:10 o'clock and rested constant until 09:50:16 o'clock, then it decreased on 152 m up to 44 km/h, at 09:50:26 o'clock. From this hour, during 2 seconds, the speed decreases suddenly from 44 km/h to 26,156 km/h, then there are no records. The sudden decrease of the speed was generated by the heavy hit of the buffer stop of the line no.8 by S.TEM no.1322, followed by its derailment and the injury of a locomotive driver-REM.

From 09:49:24 o'clock, when the speed increased suddenly and up to 09:50:28 o'clock when the records stopped, there were run a total of 864 m, during this period of time the emergency braking button being not record as switched.

Following the incident, the driver from the driving cabin S.TEM no.1322 was injured, the Emergency Unit 112 was notified.

Investigation process

Following the notification made by the central traffic department of SC TMB „METROREX" SA București, AGIFER acknowledged the incident happened on the 26th January 2019, at 09:54 o'clock, in DsB, during the shunting by banking of a rake of vehicles, consisting in TEM no.1322-2322 (in active condition) and its hauling locomotive LDH no.86-0100-7, by the hard hit of the of the buffer stop from the line no.8, by S.TEM no.1322, followed by its derailment and the injury of a locomotive driver-REM.

This event was preliminary classified by the central traffic control department of SC TMB „METROREX" SA, like incident happened in the shunting activity, according to the provisions of art.8, paragraph (2), group B, point 2.2 from the RI, respectively „*passing the fixed or mobile signals in stop position, ordering „stop" or „shunting prohibited", the indicators that prohibit the passing* *or of the safety marks by the rakes of vehicles, light engine or other railway vehicles at shunting, without meeting with the provisions of the regulations in force".*

Considering the fact that this incident, in slight different conditions, could lead to the occurrence of a serious accident, and taking into account its seriousness/relevance/impact for Romanian railway and metro network, upon the art.49 paragraphs (1) and (2) from the Investigation Regulations, AGIFER general manager decided to open an investigation in this case.

So, through the Decision no.294 from the 28th January 2019, AGIFER general manager appointed the investigation commission, consisting in an investigator in charge and 5 members, they being from AGIFER.

B.2.Incident circumstances

B.2.1. Involved organizations

SC TMB „METROREX" SA is the owner of the equipment, lines and tunnels on which the incident happened, getting licence for the metro transport.

The train TEM no.1322-2322 is owned by SC TMB „METROREX" SA, purchased from CONSTRUCCCIONES Y AUXILIAR DE FERROCARRILES, S.A., residing in Beasain, Spain. The vehicle is a railway critical product, homologated by AFER and it is part of a lot of 24 trains supplied by the railway manufacturer CAF. This vehicle is a construction conceived, designed and manufactured in the own workshops of the railway manufacturer, adapted to the requirements from the reference documents (technical specifications) of the buyer and supplied with the name BM3-CAF.

B.2.2. Staff involved

The whole crew of the locomotive LDH 86-0100-7 and of the train TEM no.1322-2322 is got by SC TMB „METROREX" SA.

The driver of the locomotive LDH 86-0100-7 was fulfilling from the function of driver of locomotive and REM II (LDH) being authorized:

- from the 14th April 2014, for the performance of the duty on his own, regarding the railway safety, the driving of the train and the operation of the braking equipment for LDH 450 HP and LDH 600 HP modernized with Caterpillar engine;
- from the15th June 2015, for the performance of the duty on his own, regarding the railway safety, operation of the braking device for the electric metro train type BM 3 – CAF at the coupling and hauling operations with LDH.

The crew of the locomotive LDH 86-0100-7 was fulfilling from 2012 the function of driver's assistant for the locomotive and REM, being authorized:

- from the 4th December 2012 for the performance of the duty on his own, with reference to the railway safety like driver's assistant of LDH (including Caterpillar), REM type IVA and type BM;
- to operate the equipment from REM type IVA (including the version Dimetronic) at the stabling in the depot and in running, in case the main driver is not able to work, with a speed of 30 km/h at most;
- to operate the equipment from TEM type BM at the reversal of the direction only monitored by the main driver and during the running in case the main driver is not able to work, with a speed on 30 km/h, at most.

The staff from the cabin S.TEM no.1322, was fulfilling from 2009 the function of driver of locomotive and of REM I, being authorized:

- from the 18th June 1991 for the reversal of the direction of TEM on his own;
- from the 12th February 2007 for the performance of the railway safety duty, the driving of the train for the direction reversal or in case the main driver is not able to work, with the speed 30 km/h at most;
- from the 31st May 1996, for the performance on his own like REM driver;
- from the 20th February 2008 for the performance of the duty on his own in the train running, operation of the braking systems for the trains BM;

- from the 7th July 2010 for the driving of the electric metro train type Bombardier, one driver system, on the main metro line I + III;
- from the 20th October 2014 for the performance of the duty on his own as driver, locomotive and REM locomotive examiner and shift leader;
- from the 26th September 2016 for driving, and operation of the railway safety equipment's of TEM type BM – CAF with passengers, one driver system, on the lines SC METROREX SA.

The crew from the driving cab S.TEM no.2322, has been fulfilling since 2009 the function of driver of locomotive and REM I being authorized:

- from the 23rd June 2009 for driving TEM type BOMBARDIER, one driver system, on 2nd main metro line, lines SC METROREX SA;
- from the 1st April 2014, for driving and operation of the railway safety equipment of TEM type BM – CAF with passengers, one driver system, on the lines SC METROREX SA.

B.2.3. Vehicle composition and equipment

The rake of vehicles involved in the incident happened on the 26th January 2019, consisted in the TEM no.1322-2322 (in working condition) and its hauling locomotive LDH no.92 53 0 86-0100-7.

B.2.3.1. Hauling locomotive

Locomotive LDH 450 HP

- type of diesel engine	MB-836Bb
- type of hydraulic transmission	TH1
- the driver's automatic brake valve	
- automatic brake	type KD2
- direct brake	type FD1
- gauge	1435 mm
- length over the buffer heads	11460 mm
- minimum radius within curve	
- running line speed 40 Km/h	100 m
- industrial branch speed 5 Km/h	50 m
-maximum speed with half-worn tyres:	
- light condition	60 Km/h
- heavy condition	30 Km/h
- maximum load in operation, with complete power supply	45 t ± 3 %
- maximum load on axle	11,25 t ± 5 %.

B.2.3.2. General presentation TEM

TEM no.1322-2322 consist in two identical vehicles (semi-trains) type BM3-CAF coupled back to back, each of them composed from three different units, designed to offer transports on the lines M1, M2 and M3 of Bucharest metro network. A TEM type BM3-CAF is a train electric power supplied, intended for the public transport and with the next composition (figure 4):

> R1 – MP1 – M1 – M2 – MP2 – R2 < , where:

- **R1 and R2** are carrying ones, with command cabin;
- **MP1** and **MP2** are motorised cars with pantograph;
- **M1 and M2** are motorised cars;
- – are couplers semi-permanent;
- < are couplers semi-automatic.

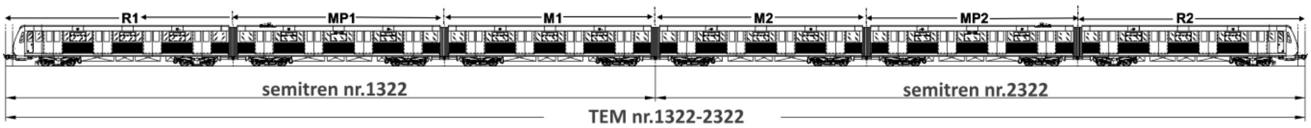

Figure 4 – general presentation of the vehicle CAF

Those two semi-trains, each of them has propulsion and braking system commanded and controlled by a system for control and monitoring of the vehicle (TCMS), that is based on logic software programable, and TEM type BM3-CAF is driven having like reference the cabin where the key is put into the contact by the human operator (considered to be ACTIVE).

So, for the train running forward (red arrow from the figure 5), reference of the semi-train with the cabin active supposes the software operation with the reference „FORWARD", and the reference of the semi-train with the cabin that is not active has the reference „BACKWARD" (arrows blue from the figure 5), so if the running forward of the train, the first semi-train the software commands the electric engines for the direction *forward*, and for the semi-train coupled at the first one the command for the electric engines is for the direction *backward*.

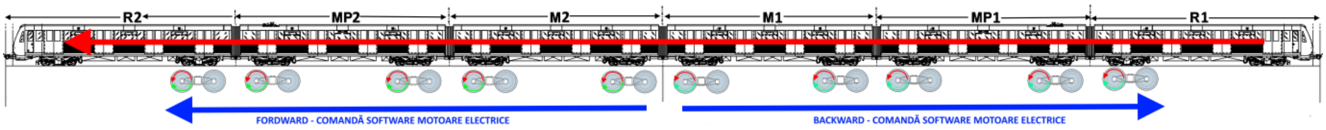

Figure 5 – direction of the commands and the stator field of the electric motors of the vehicle CAF

The sense of the stator field of the electric motors asynchronous is opposite to the wheel direction, that give the direction of vehicle running forward (to see figure 7).

B.2.3.3. Propulsion system of TEM

The propulsion system of the vehicle is based on the distribution of the high voltage power supply (HV) 750Vcc, that collects independently the high voltage current through the electric equipment fitted only in the units MP and M. In the vehicle logic the performances of power supply and braking are commanded independently by the load requirement between AW0 (tare weight) and AW3 (6 pasengers/m^2) for the traction and AW0 (tare weight) and AW4 (8 passengers/m^2) for braking.

Technical system of traction of the vehicle is provided with an electric engine for each axle of the motor bogie of TEM (two electric engines/bogie) of all wagons excepting the units R1 and R2 of TEM (16 electric engines of 145kW each one). For the power supply of the auxiliary services the electric energy is taken from the three different power supply sources: battery (110v and 115Ah) and the source from the third rail. The equipment and the battery are put on the units R1 and R2 and supply spare electric energy for the auxiliary and safety circuits, including the emergency lighting, signalling, communications, door control etc.

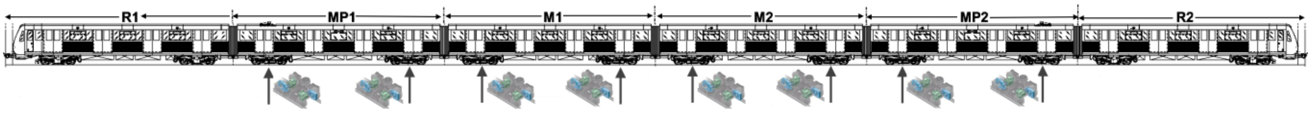

Figure 6 – bogies of the engines of TEM BM3-CAF

For the application of the traction effort there is a series of technical components that collect and supply traction power supply:

– *Third rail contact shoes* put each one on each side of the bogie, being designed for the vehicle maximum speed of 90km/h. This part has a locking device intended for the permanent and safety fastening of the oscillating lever of the sliding shoe on the position" without contact" to the third rail;
– *pantograph* put on the cover of each unit MP used when the vehicle is running on areas with power supply from the contact line;
– *selector HV* that is monitored and controlled from TCMS and it is used for the selection of the vehicle power supply: from the contact line or from the third rail;
– *box of the braking resistors*;
– *traction electric engine* (M) that is an asynchronous open unit with the short-circuit rotor that is with AC power supply (voltage 565Vca) and sends electric effort to the gear fitted on the axle through a mechanical couple. The engine M is power supplied with voltage and frequency variable in order to answer the couple requested by the traction control commanded

through ***on-board controller*** (master controller b from the figure 17) operated by the human operator or automatic from the equipment ATC on-board, using the driving way ATO.

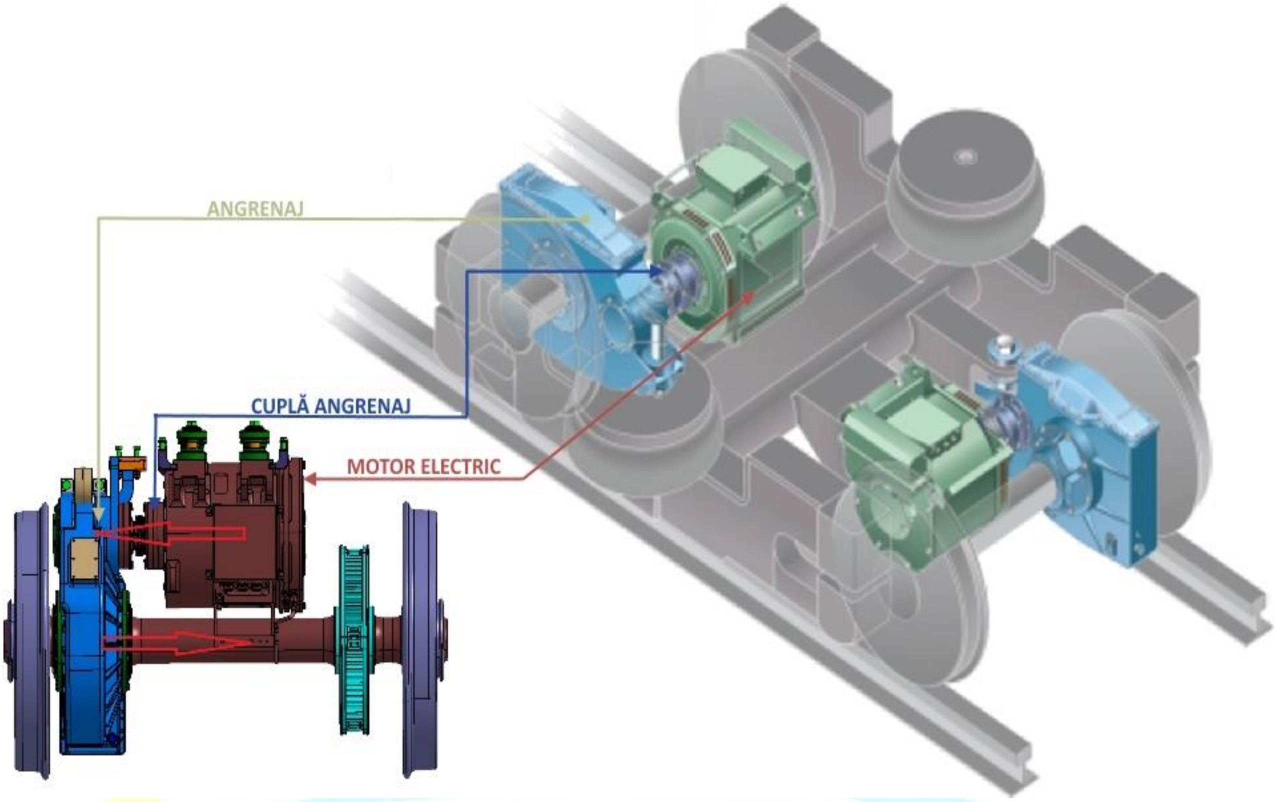

fig.7 – motor bogie and layout of the electric engines

From the construction of the ensemble motor bogie, one can observe that for the forward movement of the bogie, the turning direction of the electric engine is opposite to the sense of the axle engaged. The driving axle is mechanically joined to the rotor of the electric engine M through a kinematic coupling whose transmission from the engine rotor is made through the reducer and the coupling.

– *the box of the traction inverter* composed from two inverters independent, each of them ensuring the power supply for two electric engines on each bogie. This component has the next electronic parts constructed with static components: circuit contactor, filter, sensors for current and voltage, three-phase invertor, chopper for braking, cooling system and unit of control.
– internal protections of the vehicle for the overcharge and overvoltage;

Each electric engine **M** is commanded through an equipment that consists in an *inverter with interface* **ICU**, that transforms the direct current taken from the third rail in alternating current, and *a command block* **TCU**, constructed by the technology of transistors type IGBT. A TCU and an ICU offer to the traction engine M the voltage waveform and the frequency necessary to reach the performances imposed in any moment and they are constructed upon a technology based on microprocessors. The main function of **TCU** is to communicate with the cabin commands and the application for the high-level traction control. **TCU** sent to **ICU** the traction commands through the data bus CAN. ICU applies the strategies for the control of the low-level traction that generates the settings for the power semiconductors IGBT. The both modules interact with other components of the vehicle through serial communication lines and discrete inputs/outputs the communication logic is presented in the figure 8.

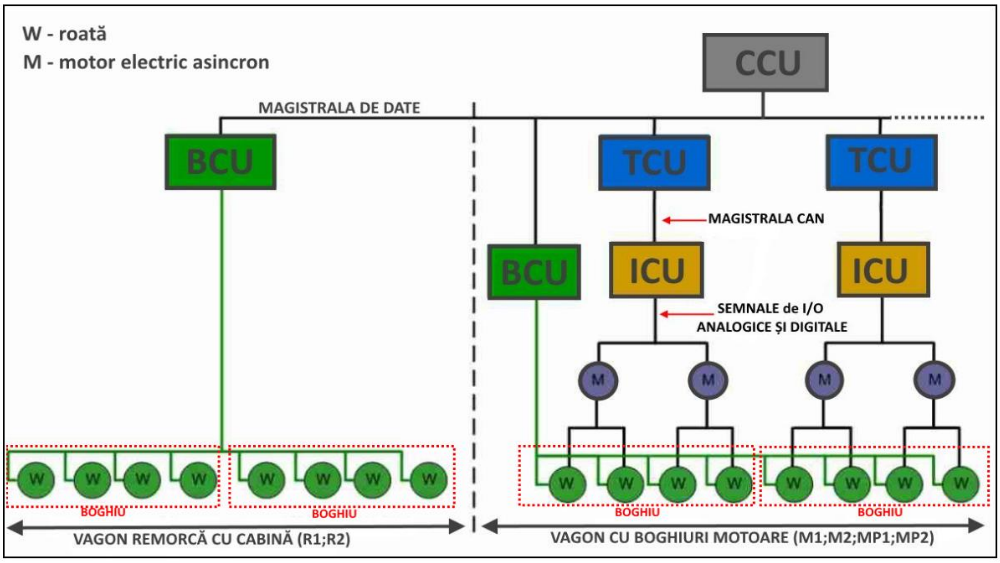

Figure 8 – hardware scheme of the braking and traction system

The control of the electric motor is made through a ***torque*** whose *sign* and *absolute value* are calculated by **TCU** according to the values of inputs, active cabin and direction, the electric engine control unit knowing permanently *the rotor magnetic vector*. In order to answer to the commands given by **CCU** the motor control unit calculates *the magnetic vector of the stator* necessary to follow the request of the couple transmission necessary to adjust the train speed (traction and braking). So, **ICU** reads the speed from its own speed sensors considering:

- the lowest value of the speed for traction, or
- the highest value of the speed for braking, or
- neutral.

This speed red is multiplicated with the wheel radius in order to get the *linear speed* (in m/sec) whose value **ICU** sends through the data bus to **TCU** that , than, calculates the *hysteresis of fading*, that results following the combination of the electric braking and the pneumatic one, through the release of the electric brake, or coupling the electric brake and release of the pneumatic brake. This function of the electric brake (ED) called, fading" has a hysteresis between 2,7788m/s (of **10km/h**) and 3,611m/s (of **13km/h**), that means that at a normal operation of TEM, when the linear speed of the vehicle:

- decreases under **10 km/h**, the electric brake is off after a second (considered a minimum necessary time for the pneumatic brake comes in service), and when
- exceeds the value of **13 km/h**, the electric brake becomes active firm (to see the figure 9).

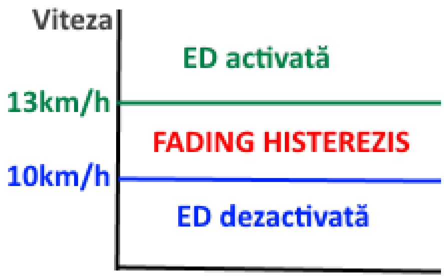

Figure 9 – fading process of the electric brake at the train CAF

In order to dispose the traction force of the vehicle in a normal operation, the human operator has to observe that the vehicle comply with five requirements, connected in a certain logic of the vehicle (traction loop, to see figure 10), and at the activation of any function the loop "*opens*" and cut the possibility of its normal operation, and for the running of the vehicle type TEM BM3-CAF is necessary the passing of its operation „*in emergency way*". So, for the normal operation of TEM it is necessary that the cabin be active, the safety and emergency braking systems be according the right working parameters, ATC system on board and the control and monitoring system TCMS with the controls and validities in accordance with the pre-established logic of the vehicle. For an operation, in *emergency way*", in case of activation of any function, the driver can isolate the functions from the switch ISOLATION OF TRACTION/BRAKING and can run operating MC with a restricted speed.

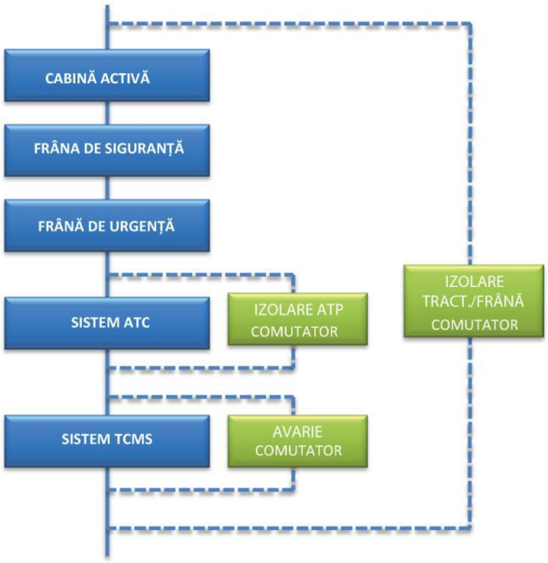

fig.10 –traction loop

B.2.3.4. Braking system of TEM

The vehicle BM3-CAF was designed to use the braking system based on standard EN 13452-1 (Railway applications. Braking systems in the urban and suburban public transports Part 1: Performance requirements), that establishes the next ***braking technics***:

- **a.** ***electric brake***, that uses the electric motors like generators to transform the kinetic energy in in electric current and it is effective only if the train runs with a speed over 13 km/h. The electric brake is applied and controlled only by the traction system;
- **b.** ***pneumatic brake***, that uses the effort of the air pressure applied on the braking pads, that according to the value of this, the pads rub the disc rigidly fixed on the axle (friction brake). The pneumatic brake ensures the vehicle braking when the capacity of the electric brake does not ensure any more the braking capacity sufficient for the safety braking distance and has to be completed in order to answer the requested performance;
- **c.** ***electromagnetic brake***, that is got by putting on the running rail a shoe especially constructed, operated through an electromagnetic device (friction brake). It is applied by the braking system of the bogies and controlled by the electric circuits of the train and it is used in combination with the pneumatic brake in order to guarantee the *safety braking distance,* even in case of poor adhesion;
- **d.** ***parking brake (hand)*** that is applied automatically by the braking system of the bogies due to the air losses, being practically a spring operation mechanism. It is designed to ensure that the train stay stopped by mechanical spring actuator.

In order to meet with the requirement regarding the electric brake technic, the manufacturer stipulated a technical equipment (chopper), consisting in two parts of diodes IGBT+, that, when the command of electric brake is applied, allows and controls the dissipation of the kinetic energy so it discharge into the power supply system (regenerative braking) or it discharge into a box of external resistors, that transform it in heat , that dissipates into the air.

All the processes above mentioned are controlled through an electronic structure dedicated to each process (controller), where there is no need of the intervention of the human operator. These controllers include a *central unit for processing* (microprocessor) and a *memory* for data storage, that together with the necessary resources interact each other under the coordination of CCU. In order to perform each specified function, each microprocessor was provided with an adequate software for the achievement of the objective of each controller.

For the safety operation of the vehicle, the need of brake request can be generated into the technical system for the brake command, as follows:

1. manually, by the human operator (driver) or passengers.
2. automatically, by the technical devices for automatic safety or control (ATC/ATP, dead man, etc.).

TEM has ***five braking ways,*** in accordance with the way to initiate the technical system for the vehicle braking:

A. ***service brakes*** that is operated manually by the driver and automatically by the safety and control system ATC/ATP. It is used for the control and adjustment of the vehicle speed, in normal operation, for its quick and effective stop and effective at any speed or load of TEM. The service brake is applied by acting with priority the *electric brake* as against the *pneumatic brake*, in order to return the recuperative energy and to reduce as much as possible the wear of the braking pads by friction (pneumatic). This braking way is working as follows:

1. the system TCMS, through CCS, **sent** information regarding *the braking request* on the data bus MVB, so TCU and BCU can read this request;
2. after reading the request value TCU **applies** *the maximum effort of electric brake* possible, calculated according to the vehicle load and the maximum adherence rate;
3. by the bus MVB, TCU **informs** BCU about the *size of the braking effort necessary* to be applied to adjust the commanded speed and the *value of the size of the electric braking effort commanded by* TCU;
4. BCU **calculates** *the value of the pneumatic effort necessary* to complete the braking effort necessary to get the performance of adjustment the required speed;
5. BCU applies the pneumatic braking effort calculated.

This braking way applies automatically the *function of gradual damping* through which, when the *unit from the vehicle* (R1, MP1, M1, M2, MP2, R2) applies the brake and reaches low speeds, the electric brake is replaced with the pneumatic one before the first braking be completely damped.

B. ***Safety brake*** is applied when, in a certain safety logic of the vehicle, (called safety loop, to see figure 11) when any of its functions is activated (a requirements) (from those three ones) through which the loop, opens" (the circuit is cut).

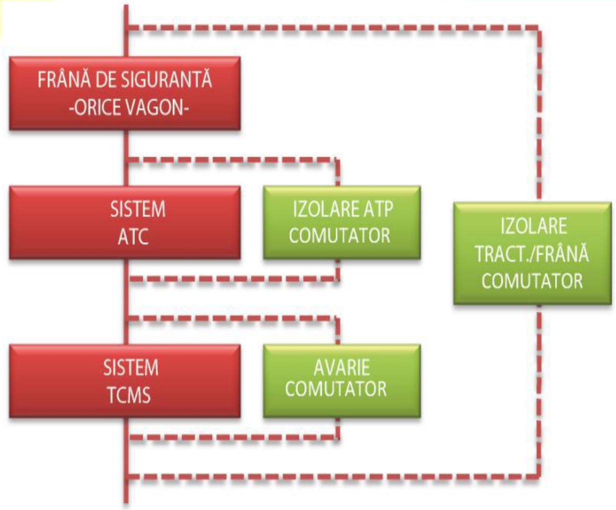

fig.11 – safety loop

In this braking way there is only the application of the pneumatic brake completed with the electromagnetic brakes (shoes), because the electric brake is inhibited from the vehicle software. In the operation logic of the vehicle this type of braking has the highest level of security, being involved only the software WSP. This braking way is an automatic one, and its application can be caused by:

- switch of the button of the safety braking from any cabin of the vehicle;
- the system ATC of the vehicle asks for the application of the safety braking (collision danger);
- TCMS sent the request for the application of the safety brake.

C. ***Emergency brake*** is an automatic one that protects the vehicle when a danger appears, acting when in a certain safety logic of the vehicle (called emergency loop, to see figure 12) when any of its functions is activated (a request) from its composition (being six ones) through the loop ,,*opens*" (the circuit is cut).

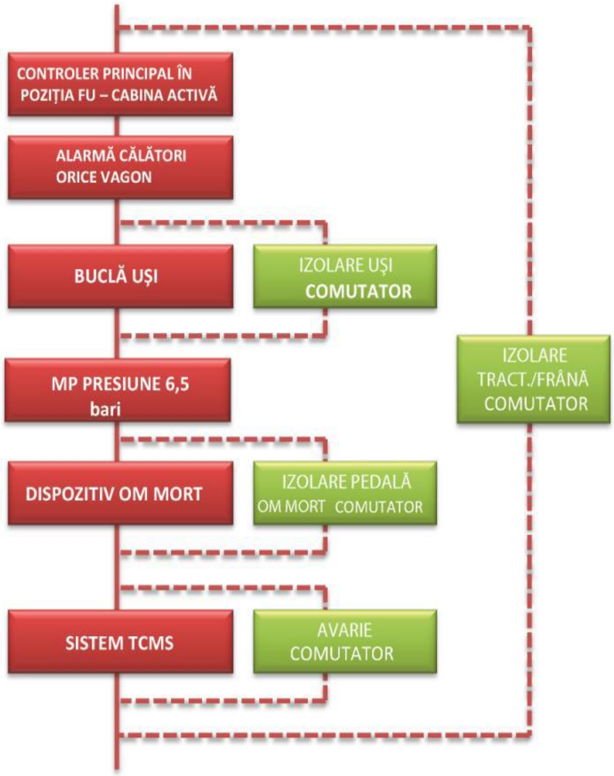

figure 12 – emergency loop

The emergency braking is the most effective and it is the shortest way for stopping the vehicle. This type of braking is done only by the technical systems for braking with friction (pneumatic and electromagnetic) but also with the electric brake calculated at a pressure with limited load. This braking way can be caused:

– manually operating the main controller by the human operator when a danger appears;
– manually, switching the alarm button by a passenger. This requirement is bypassed by TCMS when the train is moving and it is not in a station, in order to avoid the vehicle, stop in the tunnel;
– automatically, the loop of the doors is open, confirming that one door for the passenger, at least, is not closed and locked. This requirement can be bypassed when a failure in the loop of the doors appears;
– automatically, when the pressure MP is under the minimum level of 6,5 bar. After the application of the requirement, the vehicle is conditioned that the value of pressure MP be minimum 7,5 bar;
– automatically, when the device dead-man communicates to the device for the events recording, asking for the application of the emergency brake;
– automatically, when TCMS sent request for the application of the emergency brake.

D. ***Stop brake*** is an automatic braking way of the vehicle, predefined, that is applied when it stops and has to stay stopped on a gradient and a weight predefined, preventing the vehicle run away. This braking way is applied only by the pneumatic technical system (friction braking) and it is released automatically through the software command, when the traction coupler applied to the vehicle is enough to put the vehicle in movement on a gradient of maximum 4,5%, without running back;

E. ***Parking brake*** is an automatic braking way pre-established to prevent its movement when it is stopped and not in service (blocking brake). The parking brake is released when the springs of the accumulator are compressed by the pressurized air coming from MP and it is applied automatically when the air from the brake cylinders with spring decreases under the value 6,5 baryes. This braking way cannot be controlled by the human operator in the normal operation of the vehicle, but in emergency conditions the driver can command the release of the parking brake through the actuators, remote commanded from the interface man-machine, or manually using a special device dedicated to the positioning of each system from each unit.

B.2.3.5. System for the control and monitoring TEM (TCMS)

The system for the control and monitoring of TEM (called TCMS) is designed by the manufacturer upon a modular architecture, based on the standard for communication through network and has three basic functions:

1. **communication management** between all the electronic equipment based on discrete components and microprocessors, through a communication channel TCN, with the management of the information sent on the level of the data bus of the vehicle MVB;
2. **interface of the management/implementation of the vehicle logic** through the digital, analogical and communication modules, distributed in the train in order to collect information about the condition and to act according to the logic scheduled by software in the automatic systems and/or the control units;
3. **surveillance, monitoring and recording of the vehicle performance** through the interface man-machine (monitor HMI) that displays both the technical condition of the different technical systems and their recording, and for the installation of different settings necessary for the train operation.

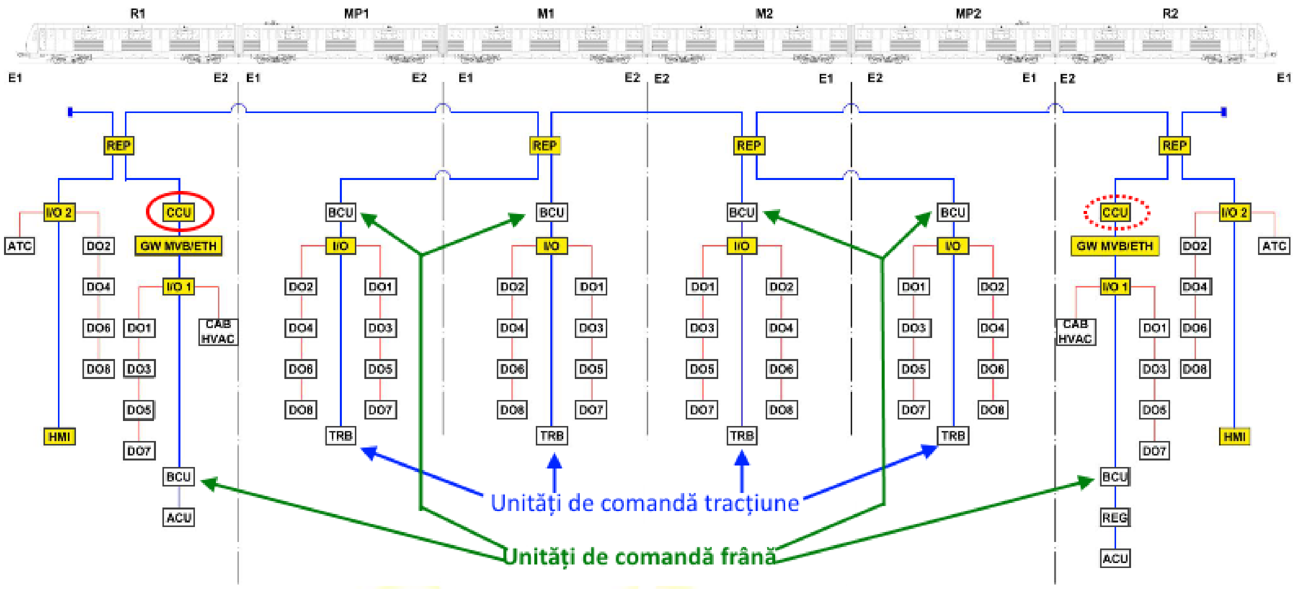

Figure 13 – the scheme of the system TCMS of TEM BM3-CAF

As one can see in the figure 13 the system TCMS consists in an interface man-machine (HMI) and different equipment with pre-established functions (CCU, TRB, BCU, DO, etc.) that communicate through the data bus MVB (in blue). The control unit CCU is responsible for the global logic of the vehicle and performs simultaneously with the function mentioned and the management of the redundancies and the selection of the signals that have to be used at a time in accordance with the commands given by the human operator (driver). In the logic of the system TCMS, the active unit CCU (from those two existing) where the key for putting in operation the vehicle was introduced, detects the driver position and filters the commands in order to send to the other equipment only commands generated from the active cabin and not those from the inactive cabin. Those two CCU works redundantly, that is when that one active detects a problem in its own functioning, the another passive one takes the function CCU active.

The interface HMI consists also in equipment for the recording of the events (called TELOC 1500) used to explore, surveillance and record the signals generated by the equipment of the vehicle and to calculate the distance covered and the real speed. The main functions of this equipment are for:

1. ***recording of the significant signals*** that can be digital or analogical, got through the bus MVB or directly through the sensors cabled in the vehicle;
2. ***checking of the driver surveillance*** by the equipment man-dead, ensuring the fact that the human operator is permanently alert, while driving the vehicle;
3. ***supply of the signal speed zero*** necessary in the logic for the vehicle operation, used for the control of other systems of the vehicle (doors, etc.);
4. ***calculation of the vehicle speed and km***, that is got from the speed sensors put on the axles of the free wheels from the unit R2, that is permanently monitored.

B.2.3.6. Safety systems in the operation of a TEM

For the safety and security operation for the passengers, TEM BM3-CAF is provided with the next technical systems for control:

1. ***systems for the automatic protection of the vehicle (ATP),*** that operates its braking systems when, after comparing the value of the real speed measured at the vehicle wheel, it is found that it is higher than the allowed speed value communicated by the system ATC of the track. It is a safety system that protects the vehicle when a driving error of the drivers appears (exceeding of the allowed speed);
2. ***the system for the control of the vehicle movement (ATC on board)*** that receives the messages sent from the track of the track system for the speed control (ATC in track). This system ATC is the architecture for the operation of the transport on the metro lines that regulates the metro train traffic and it is based and includes from construction the systems ATP and ATO;
3. ***automatic system for the vehicle operation (ATO)*** that overtakes all the operations that a driver was performing in the driving of a TEM, adjusting the vehicle speed up to its stop at a fixed point, upon the data previously input in the train system, communicated through the system ATC.

B.2.3.7. Vehicle operation

Upon the technical systems above mentioned, for a normal operation, the manufacturer imposed in the design logic of TEM BM3-CAF, like reference the cabin where the human operator introduces the key (considered to be ACTIVE). Introducing another key in another cabin did not make it active and eventual all the possible commands from this cain shall not be considered by the vehicle logic, only meeting with a specified procedure in [NI.5]. Once the human operator overtakes the control of the vehicle introducing the main key, the running direction is predefined implicitly like „FORWARD", being set up by the vehicle software, the vehicle initializing those three loops (safety, emergency and traction) through which there is checked the meeting with all the operation technical requirements in normal operation. The operation of the vehicle by the driver supposes its movement with all the safety and traction functional systems active and validated, it moving individually, the coupling of a TEM BM3-CAF to another vehicle (CAF, BOMBARDIER, IVA, locomotive) following to be an exception in operation, called in [NI.5] "*emergency condition*". In order to drive autonomously the vehicle TEM reversely the active cabin, it has to be set up by the human operator, switching the button for the selection of the operation way on the position MAN (shunting) and pushing the button „Backward".

For the vehicle movement, the management of the command for its traction and braking is done in accordance with the signals received either from the human operator (through the main controller or master controller), or from the system for the train automatic command (ATC). As it can be seen in the figure 12, through the digital signals (red arrows) and/or the analogical ones (pink arrows) there are sent the orders generating the commands necessary for the vehicle running (traction or braking) to CCU of the system TCMS. *The systems for the control and monitoring of the vehicle* (TCMS) commands through the data bus digital signals software (blue arrows) to the units of traction and/or braking to reduce the speed of the vehicle TEM in key with the information collected by its sensors for movement, speed, etc. (*Train lines – fig.14*)

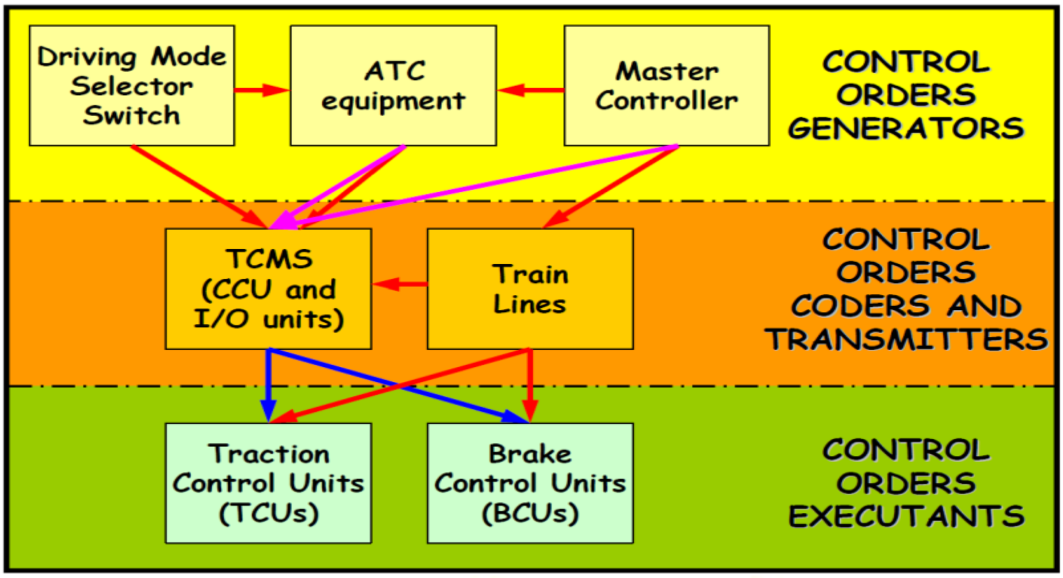

Figure 14 – logical scheme of the management of the commands for traction and braking of the vehicle CAF

The selection from the active cabin the vehicle operation by the driver is compulsory in accordance with [NI.5] for the operation activity and it is made through a switch handled in the next driving modes (*Driving Mode Selector Switch – figure 14*):

1. **mode ATO** where the system ATC controls TEM speed in accordance with the speed profile that was communicated from the track ATC system, its speed being controlled automatically by the system ATO, the driver role being to monitor;
2. **mode ATP** where the system ATC on-board controls the maximum speed of TEM in accordance with the speed profile communicated by the track ATC system, its speed being controlled manually by the driver, using the controller;
3. **mode depot** where TEM runs on areas without getting information about the speed profile from the system ATC, its speed being controlled manually by the driver, using the controller;
4. **mode shunting** (MAN) where the movement, both forward and reversely the active cabin, is allowed.

In table from the figure 15 there are the next working modes of the vehicle, given by the manufacturer:

Mod ATC	Poziție buton selecție	Mod de operare vehicul	Direcție vehicul	Poziție controller	Viteza maximă (km/h)
ON	ATO	ATO - Automatic Mode	Înainte	poziția neutră	în concordanță cu viteza comunicată din cale
ON	ATP	ATP - Semi automatic Mode	Înainte	independent	în concordanță cu viteza comunicată din cale
ON	ATP	YARD - Yard Mode	Înainte	independent	V_{rec} = 15 km/h V_{EB} = 21 km/h
ON	MAN	YARD - Yard Mode	Înainte	independent	V_{rec} = 15 km/h V_{EB} = 21 km/h
ON	MAN	Backwards	Înapoi	independent	5 km/h
OFF	-------------	BYP - ATC Bypass Mode	Înainte	independent	60 km/h

Figure 15 – table with the operation logic scheme for the vehicle CAF not-hauled

In the vehicle operation it is possible to appear failures on display TCMS that impose some constraints and according to the nature of the failure appeared, the driver has the possibility to isolated through a special switch, intended for the technical system affected by the failure, in order to continue the vehicle movement up to the first station where the passenger get off safely (figures 11 and 12 – green blocks). In both safety systems and in the traction one there is a function called” ISOLATION ***OF THE TRACTION/BRAKE***”, inactive on OFF and active on ON, that has like result the bypassing of the requirements of the traction, safety and emergency loops, necessary to operate TEM in normal conditions. The bypassing of the loops leads to the need of operation by the driver” in *emergency conditions*”.

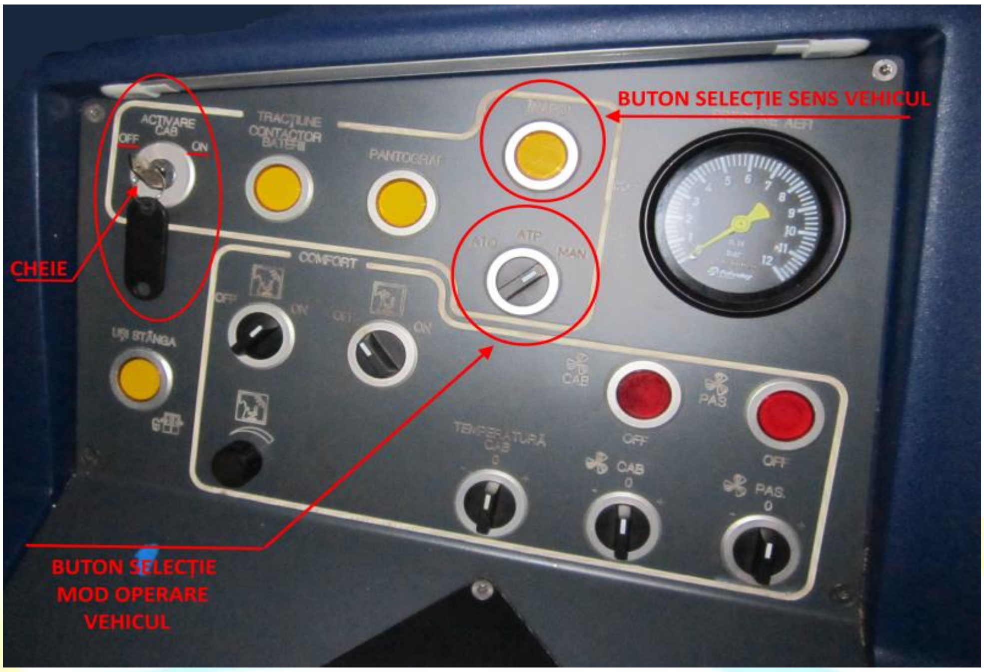

Figure 16 – left panel of the vehicle CAF

B.2.4. Presentation of the infrastructure and signalling system

Rail type 49;

Signalling system:

- in the station: Interlocking;
- in the depot: CED type CRM.

B.2.5. Means of communications

Means of radiocommunications are type Motorola maintained by the staff of Metrorex SA, Section ATC.

B.2.6. Start of the emergency plan

Soon after the incident, the intervention plan was released through the information flow stipulated in RI, following which at the incident site came staff of Romanian Railway Investigation Agency – AGIFER, of the metro undertaking SC TMB „METROREX” SA and CAF.

B.2.7. Release of the emergency plan of the public services

Following the incident, the driver from the cabin S.TEM no.1322 was injured, the Emergency Department 112 was notified.

B.3. Incident consequences

Following the incident, TEM no.1322-2322 destroyed the buffer stop from the line no.8 from DsB, left the running line, moving on a rectilinear trajectory and entering into the wall of the room for damper test CAF, of the water purification station and into the wall of the ventilation station, followed by the hanging of S.TEM no.1322 on the building resistance structure.

At the locomotive LDH, on the running surface of its wheels flats appeared, following the effect of the action of the locomotive braking system, commanded by the locomotive driver in his attempt to stop the non-controlled increase of the speed of the rake of vehicles, generated by the traction effort developed by TEM BM3 no.1322-2322. At the same time, following the compression forces appeared during the impact, also the automatic coupling between the locomotive LDH and TEM BM3 no.1322-2322 was distorted.

B.3.1. Deaths and injuries

The driver from the cabin S.TEM no.1322 was injured and needed 26 days hospitalization and 21 days of sick leave.

B.3.2. Material damages

Up to the investigation report completion SC TMB ”METROREX” SA could not establish the value of the damages generated by the incident.

B.3.3. Incident consequences for the traffic

The incident happened in DsB had no consequences for the traffic with TEM BM3 on the main line 2, but the line no.8 of DsB stayed closed until the working out of this report.

B.3.4. Consequences of the incident for the environment

None.

B.4. External circumstances

On the 25 January 2019 and in the morning of the 26th January 2019 the weather conditions were special, that is serious hoar frost falls, that deposited on the contact line between DSB and tunnel entrance, it leading to the impossibility of it use for the power supply of TEM no.1322-2322.

C. INVESTIGATION RECORD

C.1. Summary of the testimonies

Movement activity

At 09.13 o’clock, the foreman from Berceni asks the movements inspector – IDM from the technical station the exit of the light locomotive LDH from DsB and its entrance into the Hall for its coupling at the TEM 1322-2322. At 09.16 o’clock, the foreman notifies the movements inspector IDM from the parking Hall about the shunting that has to be made, respectively the coupling of LDH at TEM 1322-2322 and then its shunting to the line of the underground depot. At 09.27 o’clock, IDM from the parking hall asks the movement operator the exit for shunting of LDH coupled at TEM 1322-2322. At 09.28 o’clock, the movement operator asks and gets the approval of the Central Traffic Controller Department for exit for shunting of LDH coupled with TEM 1322-2322. At 09.32 o’clock the movement operator sent the approval for shunting to the IDM of the technical station and the parking hall. After stabling the rake of vehicles on the line 1 in the metro station Dimitrie Leonida, the IDM of the Berceni technical station sent the arrival re-notification to the IDM – Parking hall at 09.44, o’clock, and at 09.45 o’clock the rolling stock foreman was asked for free route for dispatching the rake of vehicles on the line connecting with DsB. After the rake of vehicles ran the dispatching route, the train left upon the permissive position of the signal Y1 and upon the running order sent by radio equipment.

LDH crew

Upon the disposal of the foreman, the locomotive LDH ran and was coupled at TEM 1322-2322 on the line 8 in the parking hall. After coupling and checking of coupling, they notified the IDM from the Parking hall that they are ready for its shunting in DsB. Upon the exit signal from the parking hall, from the line 8 and upon the running order given by the IDM through the radio station, the rake of vehicles started to run up to the front of the exit signal X5.After the reception of the running order, for the passing of this signal, as well as of the entry signal, the rake of vehicles ran to the metro station Dimitrie Leonida.

After the reception of the running order from IDM Berceni, the rake of vehicles started to run from the station Dimitrie Leonida to DsB, with a speed of 13 km/h at most, and after running about 50 m, one found an increase of speed at about 30 km/h. The rake of vehicles was braked with the direct brake (Fd1) and the automatic brake (KD2), notifying, in the same time, through the radio equipment, TEM drivers that the braking of the rake of vehicles is not possible. The train speed increased progressively up to about 60 km/h in the conditions where LDH braked to maximum, applying the direct brake (Fd1), the automatic brake (KD2) and the hand brake.

After the impact, they contacted the movement operator for the notification of the firemen and the medical services.

Staff of TEM no.1322-2322

On the 26th January 2019, at about 09.00 o'clock, the driver of the locomotive R1was sent by the foreman to activate the train no.1322-2322, to start the power and prepare for shunting. The driver of the locomotive R1 activated TEM no.1322-2322 from the cabin R2. Meanwhile, the driver of the locomotive R2 arrived at the driving cab. After acquainting the shunting plan, TEM 1322-2322 began to run, upon the signals sent by the locomotive examiner, from the line 8 to Dimitrie Leonida, being stopped in front of the signal X8H for its coupling with the locomotive LDH. The shunting had to be performed by hauling with the locomotive LDH, TEM having the batteries activated. After the driver of the locomotive R2 took over the duty, the examiner communicated that for efficiency the train shall stay configurated from the cabin R2. After coupling the locomotive LDH at the train, one performs the coupling test by hauling with the locomotive LDH and it was confirmed by the examiner. The service and parking brake were isolated, from the menu of the display TCMS of the active cabin R2, the pantographs were moved down and operated the switch ATP on isolation. The driver R2 took over the active driving cabin (cabin R2), and the driver R1 took over the opposite driving cabin (cabin R1), the communication between them being done by a radio equipment. During the movement from the signal X8H to the station Dimitie Leonida, the rake of vehicles was stopped many times, the drivers realizing that the stop is generated by the electric braking, so the switch ISOLATION TRACTION-BRAKE was operated on isolated position (ON). After the arrival of the rake of vehicles in the station Dimitrie Leonida and changing of the running direction, the driver R1 stood up behind the driver seat in order to see better the route.

After passing by the switches area, one felt a serious increase of the speed of the rake of vehicles, so the drivers asked the locomotive crew to apply the locomotive brake, considering that this increase of the speed is due to the locomotive LDH. Then LDH driver asked then the staff of TEM the train braking. When the train got tangled, the driver R2 unbalanced and was thrown into the left door, then into the saloon door, and driver R1 fell behind the seat and hit his head against the right panel of the cabin. Seeing that there is no solution to stop the train, the driver R1 ran in the direction of the opposite cabin, and when he was in the area of the open gangway connection, following the pitch, fell and he catch with the hands and legs a vertical support bar in the middle of the vehicle, when the incident happened.

During the acceleration of TEM 1322-2322, none of the drivers switch the button of safety brake.

After the stop of the rake of vehicles, the drivers left TEM 1322-2322 and the driver R1felt inguinal aches and difficulty to stand up, they being taken to the hospital.

Staff in charge with training

Considering the information provided by [NI.5], for the emergency operation of the trains type BM3-CAF, it does not include all the stages regarding the intervention in case of some failures, and for the decrease of the immobilization time of the trains resting out of service, Metrorex management disposed the working out of the Guide for the operative intervention at the trains type BM 3 – CAF.

So, upon the connection of the provisions from [NI.5] (document worked out by the train manufacturer) with the findings from operation, regarding the train operation, in 2016 the „Guide for the operative intervention at the trains type BM 3 – CAF, Revision 0, September 2016" was worked out. In case of hauling a train type BM3-CAF with the batteries connected, with a locomotive LDH, in order to cover all the failures that can appear at the train, it was established like being necessary switching of the buttons Isolation ATP, Isolation Traction/Brake, Isolation of the pedal Dead Man on "ON", as well as the isolation of the service brake at all the train vehicles through the virtual commands from the display TCMS.

Isolation ATP is necessary because, following the train hauling with a locomotive LDH, on an area controlled by the system ATC, the train braking occurs.

Isolation Traction/Braking is necessary because when the train has a failure, the loop opens and the train is braked. This isolation requirement is also written down in [NI.5], when there are air losses at a vehicle R.

Isolation of the service brake, in case of train hauling with a locomotive LDH, is an operation stipulated by the manufacturer [NI.5].

The guide for operative intervention at the trains type BM 3 – CAF, Revision 0, September 2016 -[NI.7]- was presented and discussed with all staff authorized to drive the trains type BM3-CAF.

C.2. Safety management system

The metro transport is not covered by the Law no.55 din 2006 for the railway safety, because it is applied only to Romanian railway system, that can by divided in structural and functional subsystems. However, the state authority from the metro field considered that the management of the traffic safety is a priority for the metro transports and disposed through [NR2] that SC TMB ”METROREX” SA organizes and implements its own traffic safety system, that assure the compliance with the requirements for the safety operation of its activities.

C.3. Norms and regulations

C.3.1. National relevant norms and regulations

[NR1] Government Decision no.117/2010 for the approval of the Regulations for the investigation of accidents and incidents, for the development and improvement of Romanian railway and metro safety;

[NR2] Minister of Transports' Order no.1572/2018 regarding the Procedure for granting the safety authorization for the operation of the lines intended for the passenger transport;

[NR3] Minister of Transports and Infrastructure's Order no.1620/2012 for the approval of the Instructions for the metro movements, no.005M;

[NR3] Minister of Transports and Infrastructure's Order no. 794/2010 for the approval of the Instructions for metro signalling, no.004M;

[NR4] Minister of Transports and Infrastructure's Order no.395/2011 for the approval of the Instructions for the metro traction staff – no.201M

[NR5] Minister of Transports' Order no. 290/2000 regarding the technical acceptance of the products and/or of the services intended for the construction, modernization, maintenance and repair of the railway infrastructure and rolling stock, for the railway and metro transport.

C.3.2. Other informative norms

[NI.1] Technical specification Part 0 – General technical specification, March 2011;

[NI.2] Technical Specification Part 1 – Project general context and objectives, March 2011;

[NI.3] Technical specification Part 2 – Operational specifications, March 2011;

[NI.4] Technical specification Part 3 – Maintainability, packing, storing, transport, specification of the materials;

[NI.5] Diver handbook CAF, rev.7 – October 2016;

[NI.6] Technical specification electric metro train set type BM3, reference C.G5.96.400, edition B from the 24th July 2013;

[NI.7] Guide for the operative intervention at the trains type BM3-CAF, revision 0, September 2016

C.4. Working of the rolling stock and technical equipment.

C.4.1. Data about the working of the interlocking system

Following the examination of the technical condition and working of the interlocking system, one can point out that its condition did not influence the incident occurrence.

C.4.2. Data about the tracks

Following the examination of the technical condition and working of the track infrastructure, one can point out that the its condition did not influence the incident occurrence.

C.4.3. Data about the communications working

Following the examination of the technical condition and working of the communication installations, one can point out that its condition did not influence the incident occurrence.

C.4.4. Technical findings at the railway vehicles

C.4.4.1. Findings at the locomotive type LDH

Following the checking performed soon after the incident, at LDH no.92 53 0 86-0100-7, there were found out:

- the driving cab II was active;
- the speed recorder was on zero;
- controller on zero;
- driver brake valve KD2 on quick braking position;
- the direct brake valve Fd1 on complete braking;
- hand brake applied;
- flat spots on whole running surface of the wheels;
- the automatic coupling distorted.

C.4.4.2. Technical findings at TEM no.1322-2322

C.4.4.2.1. Findings at the interface man-machine (HMI)

Following the checking made after the incident, at TEM no.1322-2322, there were found:

A. at S.TEM no.2322:

a. key for putting in operation was into the contact in position **OFF** (inactive cabin);

b. on board controller was on, neutral” (the train has not commanded either traction force or braking);

c. the switcher of the selection of the vehicle operation way on, SHUNTING”;

d. indication of 28km/h speed at which the records stopped;

Figure 17 – left on-board display from S.TEM no.2322

e. switcher for, ISOLATION **ATP**” with the seal broken and put on, ON” (ATC system is made disable, to see figure 18);

f. the switcher, ISOLATION **TRACTION/BRAKE**” with the seal broken and on, ON” (to see the figures no.18 and 19);

g. the button of the emergency brake not pressed.

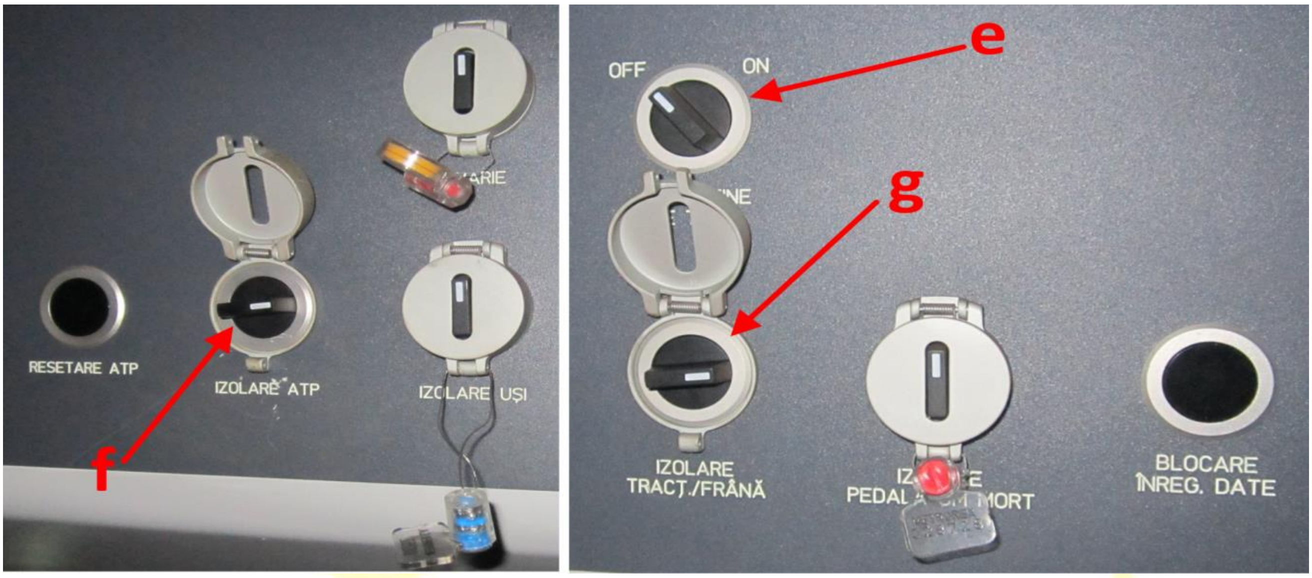

Figure 18 – the on-board panel above the driver seat in S.TEM no.2322

B. at S.TEM no.1322:

a. inactive cabin;

b. the button of the emergency brake not pressed.

C.4.4.2.2. Findings resulted from the reading of the records from TEM no.1322-2322

Following the downloading of the records from TCMS of TEM no.1322-2322 resulted a sequence of the signals stipulated in the figure 18:

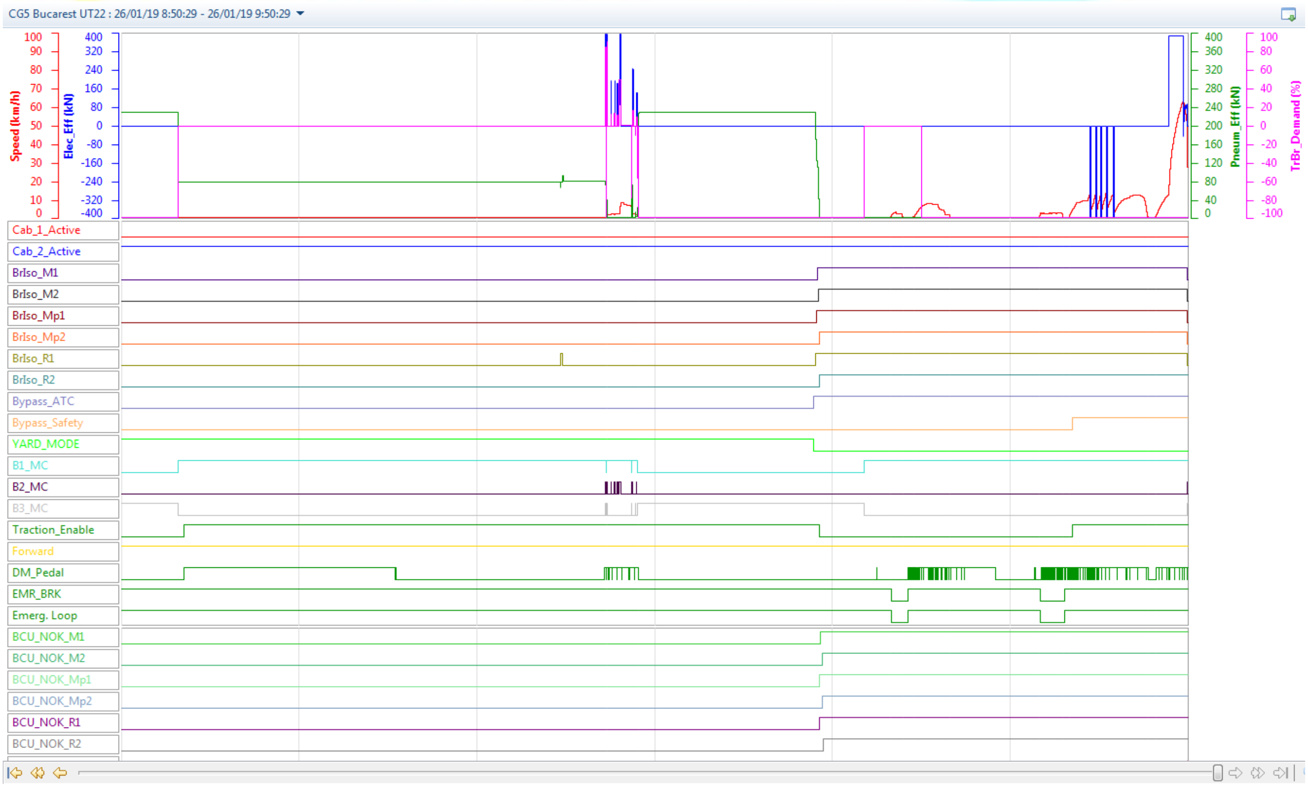

Figure 19 – records diagram TEM no.1322-2322

For the reading and interpretation of the records from the diagram stored in TCMS one used the next abbreviations:

Cab_1_Active	cabin S.TEM no.1 active if it has logic state ”1”; inactive if state logic ”0”
Cab_2_Active	cabin S.TEM no.2 active if it has the logic state ”1”; inactive if state logic ”0”
Bypass_Safety	The safety loop of TEM active if it has the logic state ”1”; inactive if state logic ”0”
Baypass_ATC	Technical system ATC of TEM active if it has the logic state ”1”; the equipment ATC is inactive if it has the logic state ”0”
EMR_BRK	technical system for emergency braking of TEM active if it has the logic state ”1”;
DM_Pedal	The logic signal for the confirmation of operation by the driver of the pedal ,dead - man”, active if it has the logic state”1”;
Traction_Enable	Logic signal that indicates the state of the traction request, inactive if it has the state ”0”;
SafetyBr_But_R1	State of the safety button from the cabin of the semi-train no.1322: pressed – logic state ”0”, not-pressed – logic state ”1”;
SafetyBr_But_R2	State of the safety button from the cabin of the semi-train no.2322: pressed – logic state ”0”, not-pressed – logic states ”1”
Forward	Sense” Forward*”* against the active cabin R2
Backward	Sense” Backward*”* against the active cabin R2
Elec_Eff	Electric effort on the electromotors (maximum +/- 400kN)
TR_Demand	Traction command

Following the analysis and interpretation both of the signal states recorded by the train equipment TEM no.1322-2322, and of the driver testimonies mentioned in the chapter **C.1. Summary of the testimonies**, one found:

a. starting with **8:44:32 o'clock** (the vehicle was put in operation) and up to **09:50:26 o'clock** (the data recording stopped), the next recorded signals did not suffer transitions:

cab_1:	*inactive* (the activation key was not put in)
cab_2:	*active* (the activation key of the cabin S.TEMui no.2322 was operated)
Forward	*active* (signal that defines the movement direction, against the active cabin R2)
Backward	*Inactive (*signal that defines the change of the movement direction TEM against the cabin R2 active)
SafetyBr_But_R1	*Logic state 1* corresponding to the not-pressing of the button of the hand brake from the cabin 1
SafetyBr_But_R2	*Logic state 1* corresponding to the not-pressing of the button of safety brake from the cabin 2

CONCLUSION: *the driver put in operation TEM (stabled on the line 8H in the parking hall) from the cabin S.TEM no.2322, that was used like reference in the logic for the command performance along the vehicle movement until the incident occurrence. The running direction was looking from the cabin S.TEM no.2322 to forward (FORWARD), to the exit from the parking hall.*

b. During the interval of time **09:17:44 —09:19:35** the vehicle *had been set in motion through its own force* (with power supply from the contact line) from the stabling position in front of the signal X8H, (change of the signals **MC**, **TrBr_Demand**, **Elec_Eff** and of the train speed);

CONCLUSION: *the vehicle has been set in motion FORWARD through a shunting movement performed by the driver, from the stop point of TEM to the exit signal X8H, being prepared for its passing by when it is on permissive position. The train had power supply from the contact line;*

c. at **09:29:14** o'clock the pantograph TEM is moved down from the contact line;

CONCLUSION: *the driver prepared TEM for its hauling with LDH, its services working only using the batteries, cabin S.TEM no.2322 rests active;*

d. at **09:29:18** o'clock it is observed the change of the signal **Bypass ATC** from,**0**" to,**1**";

CONCLUSION: *the system ATC of the vehicle is bypassed by the driver through the switch of the button, ISOLATION ATP" isolation necessary because it entered the section controlled by ATC and in front it had LDH that was occupying the section;*

e. from 09:29:33 o'clock to 09:29:47 o'clock the service brakes are isolated, the signal Briso corresponding to each vehicle changes from,**0**" to,**1**";

CONCLUSION: *the driver commands the isolation of the **service brakes** from the command panel TCMS, this imposing as reference the speed limit of 0km/h;*

f. at 09:30:32 o'clock the parking brake is isolated;

CONCLUSION: *The driver commands the isolation of the **parking brake** from the panel TCMS;*

g. at **09:32:15** o'clock the controller is put on neutral position (interpreted through the change of the signal **TrBr Demand** from **-100%** *-braking-* in **0%)**.

CONCLUSION: *the driver operated all the systems for the train braking release, for its hauling with the locomotive LDH;*

h. at **09:33:45** o'clock the rake of vehicles consisting in TEM and LDH started to run by hauling, the recording direction being „FORWARD";

CONCLUSION: *the rake of vehicles moves in the direction of the active cabin R2;*

i. at **09:33:49** o'clock the signals **Emerg_Loop** and **EMR_BRK** change from the logic state "**1**" to "**0**", and the signal **DM_Pedal** rested in the logic state "**0**".

CONCLUSION: *the driver did not push the surveillance pedal of the Dead Man equipment, the emergency loop opened, followed by the command of the emergency brake and the getting in operation of the electromagnetic brake;*

j. at **09:34:26** o'clock the train stops.

k. at **09:34:44** o'clock the pedal dead man is pressed (signal **DM_Pedal** in logic state "1"), and the signals **Emerg_Loop** and **EMR_BRK** change from" **0**" to" **1**".

CONCLUSION: *the DEAD MAN device has reset; the emergency loop closes and the electromagnetic brake has been disabled;*

l. from **09:35:04** o'clock to **09:37:06** o'clock, the train runs 173 m on the direction R2, when the signal **DM_Pedal** changes periodically from the logic state "0" to "1", it reaches the maximum speed 7 km/h, and at the speed of 6,009 km/h signal **TrBr_Demand** changes from the state "**0**" to **"-100**".

CONCLUSION: the driver pressed the pedal of the equipment dead -man, the emergency loop rested closed and at the speed of 6,009 km/h it was recorded the request of maximum braking ("-100%");

m. from **09:42:07** o'clock up to **09:43:32** o'clock, the rake of vehicles is running and at 09:42:10 o'clock, the signals **Emerg_Loop** and **EMR_BRK** changes from the logic state "**1**" to "**0**",then the signal man-dead **DM_Pedal** changes periodically from the logic state "**0**" in "**1**".

CONCLUSION: *the driver did not press the surveillance pedal of the equipment dead man, the emergency loop opened, followed by the command of the emergency brake and coming into operation of the electric brake;*

n. at **09:43:32** o'clock the speed of the rake of vehicles decreases at 0,495 km/h, the signal **DM_Pedal** changes the logic state "0" in "1" and the signals **Emerg_Loop** and **EMR_BRK** changes from" **0**" in" **1"**;

CONCLUSION: *when the speed decreased under 0,5 km/h and the pedal for the surveillance the equipment DEAD MAN has reset, the emergency loop closes and the electromagnetic brake was disabled;*

o. from **09:43:48** o'clock **the** speed of the rake of vehicles raises and at **09:43:58** o'clock the signals **Bypass Safety** and **Traction Enable** change from "**0**" n "**1**";

CONCLUSION: *the button for Isolation Traction/Brake was switched from" OFF" to" ON" (the traction, safety and emergency loops were bypassed) and the traction conditions were activated;*

p. at **09:44:56** o'clock the rake of vehicles reaches the speed of 12,483 km/h and at **09:44:59** o'clock it is recorded a change of the value of the signal **Elec_Eff (KN) from "0" to "-400"**, followed by the speed decrease up to 4,569 km/h, reached at **09:45:03** o'clock;

CONCLUSION: *when the speed of 12,483 km/h is reached, on the train engines is applied an electric effort for braking, following the application of the electric brake;*

q. at **09:45:03** o'clock, at the speed of 4,569 km/h, the value of the signal **Elec_Eff (KN)** changes from **"-400"** in **"0",** then the speed raises to 13,335 km/h and the phenomenon repeated;

CONCLUSION: *when the speed of 4,569 km/h is reached, there is no electric braking effort on the train motors, the electric brake is no more active;*

r. from **09:44:56** o'clock to **09:46:17** o'clock when the rake of vehicles was stopped in the station Dimitrie Leonida, the electric brake entered into action 5 times when the speed of about 13 km/h was reached;

CONCLUSION: *reaching the speed of about 13 km/h, an electric braking effort is applied on the train motors, following the activating of the electric brake, and after the speed decrease at about 4 km/h, the electric braking effort disappears and the electric brake is no more active;*

s. at **09:48:41** o'clock, the rake of vehicles started to move by banking to DsB (with the cabin R1 in front), the direction **"Forward"** and the traction system registered a warning code **"Warning_Rollback_detected"**;

CONCLUSION: *the train movement reversely the active cabin R2, the direction recorded was "Forward" (similar to the train movement to the direction of the active cabin R2), and the traction system noticed the wheel turning reversely the sense given by the active cabin R2 and recorded a warming code "Attention detection of wheels turning reversely";*

t. after running 95 m, at **09:49:24** o'clock, at a speed of 13,433 km/h, it is recorded the change of the value of the signal **Elec_Eff (KN) from "0"** to **"+395"**, followed by the sudden increase of the speed;

CONCLUSION: *reaching speed 13,433 km/h, an electric braking effort is applied on the train motors, it leading to the sudden increase of the speed of the rake vehicles;*

u. from **09:49:24** o'clock to **09:50:10** o'clock, on 575 m, the train reached the speed of 63,129 km/h, the speed maintained up to **09:50:16** o'clock, during this time it running 118 m;

CONCLUSION: *the electric traction effort applied on the train motors led to the increase of the speed of the rake of vehicles;*

v. from **09:50:16** o'clock to **09:50:26** o'clock, the speed decreases to 44 km/h, during this time it ran 152 m;

CONCLUSION: *the speed of the rake of vehicles decreased following the cut of the power supply from the third rail;*

w. from **09:50:26** o'clock to **09:50:28** o'clock the speed decreases suddenly from 44 km/h to 26,156 km/h on 19 m, it being the last recording of the train equipment;

CONCLUSION: *the speed of the rake of vehicles decreased suddenly following the hit of the buffer stop of the line no.8.*

C.4.4.3. Findings at TEM no.1323-2323

On the 21st February 2019, the investigation commission made checking for restoring the operational environment of the shunting activity from the incident occurrence (a LDH locomotive coupled with a TEM BM3-CAF no.1323-2323, with the cabin active, on an area with power supply from the third rail). On that occasion, one found that during the shunting by hauling, over an area with power supply from the third rail, with the locomotive LDH coupled with S.TEM no.2323, whose cabin R2 was active, at a speed of about 13 km/h the electric brake has activated, the speed decreasing at about 5 km/h. After the stop of the rake of vehicles and changing of the running direction (shunting by banking), at a speed of about 13 km/h the speed of the rake of vehicles increased non-commanded, following the application of a traction effort on TEM electric motors.

CONCLUSION: *the software logic of TEM no.1323-2323 behaved identically like TEM no.1322-2322 involved in the incident.*

C.4.4.3. Findings at TEM no.1303-2303

On the7th November 2019, the investigation commission performed tests and checking with the locomotive LDH coupled at the active cabin of S.TEM no.1303, the shunting being carried out on an area with power supply from the third rail, with the operation of the equipment from the active cabin on the same positions to those of the incident occurred on the 26th January 2019. One found that during the shunting by hauling with the locomotive LDH coupled with S.TEM no.1303, whose cabin was active, at a speed of about 13 km/ h, the electric brake has activated and the speed decreased at about 5 km/h. During that movement the running direction recorded by TEM was "Backward", although the train was moving in the direction of the active cabin R1.After the stop of the rake of vehicles, the disactivating of the cabin R1 and activation of the cabin R2, during the shunting by banking performed with the locomotive LDH, to the direction of the cabin R2, reaching the speed of about 9 km/h, the pneumatic brake came into service, followed by the rake of vehicles stop. The coming into service of the pneumatic brake happened in the conditions where the service brake (consisting in the pneumatic brake and the electric one) was isolated. During this movement the running direction recorded by TEM was "Forward".

CONCLUSION: *the software logic uses like reference for the running direction only the cabin R2;*

CONCLUSION: *the software logic of TEM no.1303-2303, in hauling condition, has a behaviour different in accordance with the active cabin. When the cabin R1 is activated at a* *speed of about 13 km/h, an electric braking is applied and when the cabin R2 is activated at a speed of about 9 km/h, the pneumatic braking is applied.*

C.5. Interface man - machine-organization

Interface man – machine

The incident happened on the 26th January 2019 in DsB following an improper working of the software logic, being influenced by the poor definition of the work load.

On the 26th January 2019, the activity was carried out in special weather conditions, consisting in serious falls of hoarfrost, deposited on the contact line, that changed the current organization of the shunting.

The way of shunting organization, that was supposing the hauling of TEM with a locomotive LDH, corroborated with the provisions of [NI.5], section 5 *Operation in emergency condition chapters* 5.10.3 *Coupling with the shunting locomotive* and 5.10.4 *Operation with a coupled rake of vehicles*, that allows the hauling of a train BM3 active, as well as that, in this case, the hauled rake of vehicles does not apply no traction or braking effort, induced to the two drivers from the driving cabs of TEM the conviction that their duty should be limited to the activity surveillance, without any intervention in its performance. The operators were surprised by the vehicle reaction and were convinced that the speed of the shunting rake of vehicles is impressed by the action of LDH. The uncontrolled increase of the speed of the shunting rake of vehicles was an unpredictable situation, being outside their understanding capacity, they not having already a mental model about this working way of the vehicle.

Unpredictability of the situation, the conviction that the movement of the shunting rake of vehicles is generated by LDH, and the short time of noncontrolled working of TEM, did not allow to the human operators to take measures for braking the vehicle TEM, that should lead to the reduction of the incident consequences.

Interface man – organization

The shunting was performed in compliance with the provisions of the Operative guide for intervention at train type BM3-CAF, guide worked out by Metrorex SA upon the information from the Driver Manual worked out by CAF and upon the experience in the operation of these types of vehicles. Existence of some areas insufficiently covered and lack of clarity in the Driver Manual regarding the way the hauling of TEM has to be organized, within their shunting activity with the locomotives LDH, influenced the incident occurrence.

C.6. Similar events

Before this incident there was no similar event.

D. ANALYSIS AND CONCLUSIONS

D.1. Final presentation of the chain of events

Following the analysis of data, information, testimonies of the parts involved in the railway incident, presented in detail in chapter ***C. REGISTRATION OF THE INVESTIGATION***, the investigation commission found that the incident occurrence was generated by the events previously happened and presented chronologically:

A. *putting in operation of the vehicle TEM no.1322-2322 with the safety services initiated and validated from the active cabin no.2322.*

As it is mentioned in the chapter „*C.4.4.2. Technical findings at TEM no.1322-2322”*, the driver put in operation TEM, introducing the key and switching it on the position for the activation of the cabin S.TEM no.2322. The driver action was necessary in order to move the vehicle from the stabling place in front of the signal X8H from the line 8H of DSB. After ending the TEM movement and after its disconnecting from the contact line, the vehicle rested active through the power supply source of the batteries necessary for the coupling with LDH.

B. *Shunting of the vehicle TEM no.1322-2322 with the locomotive LDH*

After coupling the locomotive LDH to TEM no.1322-2322 at the end of S.TEM no.2322 and moving down of the pantographs, the button „Isolation ATP” was switched ON and the service and parking brakes were isolated from the panel TCMS. At 09:33:45 o'clock, the rake of vehicles, consisting in two vehicles, started to run to the station Dimitrie Leonida.

C. *Activation by TCMS of the train braking requirement*

After exceeding the speed of 6 km/h, the signal **TrBr_Demand** changes from ”0” to ”-100”, the requirement resting active until the incident.

D. *Switching of button ”Isolation Traction/Brake” from OFF to ON*

After the rake of vehicles started to run, two emergency brakings were applied (electromagnetic brake), following the coming into operation, without any previous sound warning, of the equipment dead man. In order to avoid other emergency brakes, at 09:43:58 o'clock, the driver switched the button „Isolation Traction/Brake” from OFF to ON, being activated also the traction conditions.

E. *Running on an area with the third rail with power supply a TEM nr.1322-2322 put in operation*

Starting with the entrance into the tunnel, the hauling of TEM was made on an area with third rail with power supply of 750V. This movement of the rake of vehicles was made by hauling TEM no.1233-2322 from DSB to the station Dimitrie Leonida, the active cabin being in the running directon. The fact that the vehicle, put in operation, entered an area with power supply from the third rail, led to the train power supply and to the possibility of the TEM software logic to use also the electric brake.

F. *TEM movement reversely the active cabin*

For introducing the vehicle TEM in DsB, in the station Dimitrie Leonida there was necessary to reverse the movement direction of the rake of vehicles. So, after changing the driving cabin of the locomotive LDH, one started TEM banking reversely the cabin R2, that rested active. The compulsoriness to change the active cabin when the shunting direction is changed is not stipulated in [NI.5].

G. *Improper process into the software logic of the information collected from the sensors and actuators TEM*

After changing the running direction in the station Dimitrie Leonida, at the movement of the train reversely the active cabin R2, the registered sense was *”Forward”* (like the train moved to the direction of the active cabin R2). Although the traction system TCU realized the turning of the wheels reversely the direction given by the active cabin R2 and registered warning code *”Attention detection of turning of the wheels reversely”*, this warning was ignored by the software logic, considering priority the direction registered by the active cabin R2, direction that did not correspond to the real movement of the train.

So, when the speed of about 13 km/h was reached, the software logic used like reference the direction imposed by the active cabin, with priority against the direction red by the sensors of the bogies (real running direction), it leading to the application of the stator field in the traction direction of the vehicle and implicitly to acceleration TEM BM3-CAF.

D.2. Interpretation ad analysis

On the 26th January 2019, TEM no.1322-2322, had to run from DSB to DsB. From its leaving DSB and up to its entrance into the tunnel the trains power supply is made by the contact line that is in the open air. Considering that on the 26th January 2019 there were special weather conditions, that led to serious falls of, hoarfrost, that deposited on the contact line, it could not be used for the train power supply. In these conditions it was necessary to haul TEM nr.1322-2322 with the locomotive type LDH.

This activity supposed the coupling of the vehicle TEM no.1322-2322, in active condition, to a locomotive LDH, that was made by the employees from operation activity, in accordance with the provisions from [NI.5], section 5 *”Operation in emergency conditions”* chapter 5.10.3 *Coupling with shunting locomotive.* According to the provisions of chapter 5.10.4 *Operation with a coupled rake of vehicles from* [NI.5] it was established that the maximum hauling speed is 40 km/h a well as the hauled rake of vehicles does not apply any traction or braking effort.

Figure 20 – recordings of the human operator actions

At 08:44:32 o’clock, with the introducing of the key and activation of the cabin S.TEM no.2322, the software logic of the vehicle established like reference the cabin R2, respectively the direction ”FORWARD” to the direction of the cabin R2. With the setting of the operation direction of TEM BM3-CAF, after putting the switcher for operation way and moving up of the pantograph on „MAN”, in accordance with the table of operation ways stipulated at points 4 and 5 from the chapter ***B.2.3.7. Vehicle operation***, TEM could run upon the commands received from MC up to the front of the signal X8H, where it was stopped for its coupling with the locomotive LDH.

After coupling the locomotive LDH with TEM no.1322-2322 at the end of S.TEM no.2322, that was active and moving down of the pantographs, the button „Isolation ATP” was switched ON and the service and parking brakes were isolated from the panel TCMS.

The switching of the button „Isolation ATP” on ON was necessary because the shunting was going to be performed with the train active on a section controlled by ATC, and the locomotive LDH, being in front of TEM, could cause the command of the braking by train ATP system. The isolation of the service and parking brakes (stipulated also in [NI.5], chapter 5.10.3.1) was necessary for the train braking release.

This action was also in accordance with the provisions from [NI.7] worked out by METROREX, that recommends, that in case of hauling a train type BM3-CAF, having the packs of batteries connected, with a locomotive LDH, in order to cover all the failures that can appear at the train, the switching of the buttons ”Isolation ATP”, ”Isolation Traction/Brake”, ”Isolation pedal Dead Man” on ”ON”, as well as the isolation of the service brake in all the train vehicles through the virtual commands from the display TCMS.

After switching the button „Isolation ATP” on ON, the logic scheme for the management of the commands of traction and braking, valid for the normal vehicle running, is changing in that one detailed in the figure 21. So, through the inhibition of the on-board system ATC and putting of MC on neutral position, the vehicle shall not receive generator orders that the units TCU and BCU be able to execute through the software logic, instead the sensors TEM are communicated to CCU, that can dispose software commands to actuators BCU and TCU. The isolation from the panel TCMS of the service brakes of each vehicle led only to the cut of the pneumatic brake of TEM, without cutting off the electric brake, that is part of the service brake.

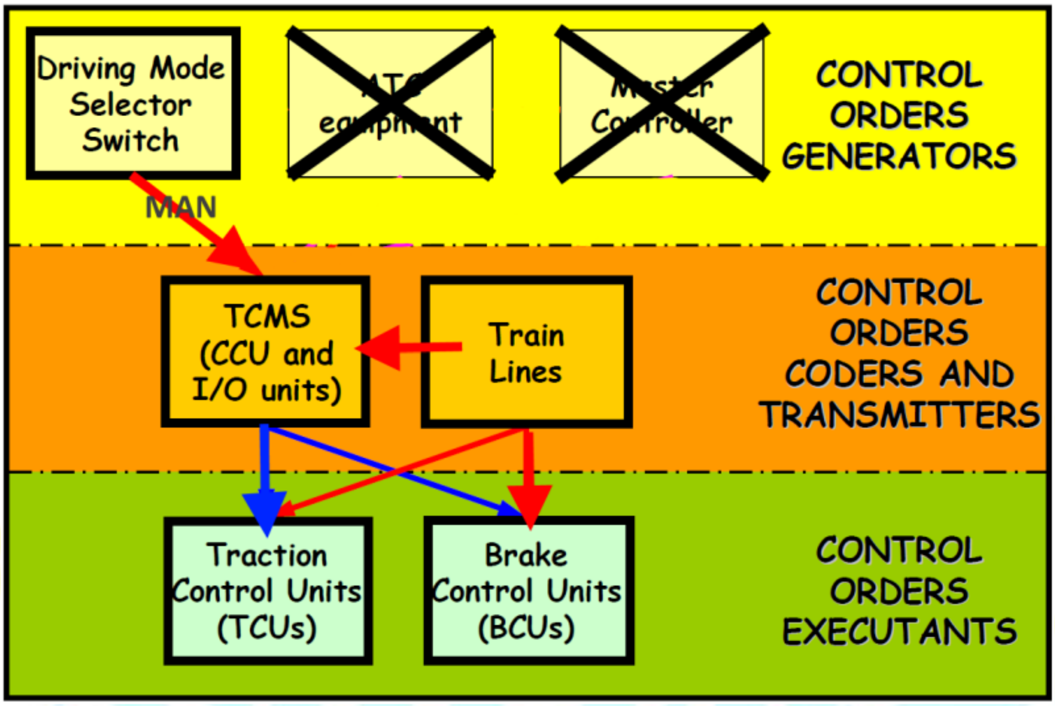

Figure 21 – logic scheme of the management of the commands for traction and braking of the vehicle CAF no.1322-2322 after the operation intended for shunting

After the rake of vehicles started to run, two emergency brakings were applied, generated by the coming into operation of the device dead man, without a sound warning previously, and following the lack of connection between the pressing of the pedal dead man and starting to move of the rake of vehicles. According to the scheme presented in the *Figure 4-1 Sequence of the device dead man* of [NI.5], if the train speed is over 0 km/h and the pedal was not pressed, after 3 seconds the BUZER had to ring, and only after another 3 seconds, the emergency brake be applied. During the tests performed after the incident, with other trains BM3-CAF, one found that, after the train started to run, the emergency brake is applied following the coming into service of the device dead man without a sound warning notification, that is not in accordance with the logic scheme of operation presented in [NI.5], chapter 4.4.6 *Operation of the device for the driver surveillance*.

This improper operation way of the device dead man generated an doubt for the driver, regarding the cause of the emergency brakes, and for avoiding other brakings at 09:43:58 o’clock, the driver switched the button „Isolation traction/brake” from OFF to ON, leading to the bypassing of the safety loop and of the emergency loop. The justification of this action is stipulated in [NI.5], chapter 5.3.2 *Emergency loop*, that stipulates:

”In case of a failure at any part, the driver can cancel the emergency loop, switching the button ISOLATION TRACTION./BRAKE (33S02) from the active cabin on ON.”

Switching the button *ISOLATION TRACTION/BRAKE* has like result *”bypassing of the traction, safety and emergency loops”* and change of the digital signal ”Traction Enable” from ”0” (existing at the isolation from TCMS of the service and parking brakes) to ”1”.

CONCLUSION: semantically, switching of the button *ISOLATION TRACTION/BRAKE* should lead also to the isolation of traction. In fact, the digital signal ”Traction Enable” was changed from ”0” to

”1”, leading to the activation of the traction, although the service brakes rested isolated.

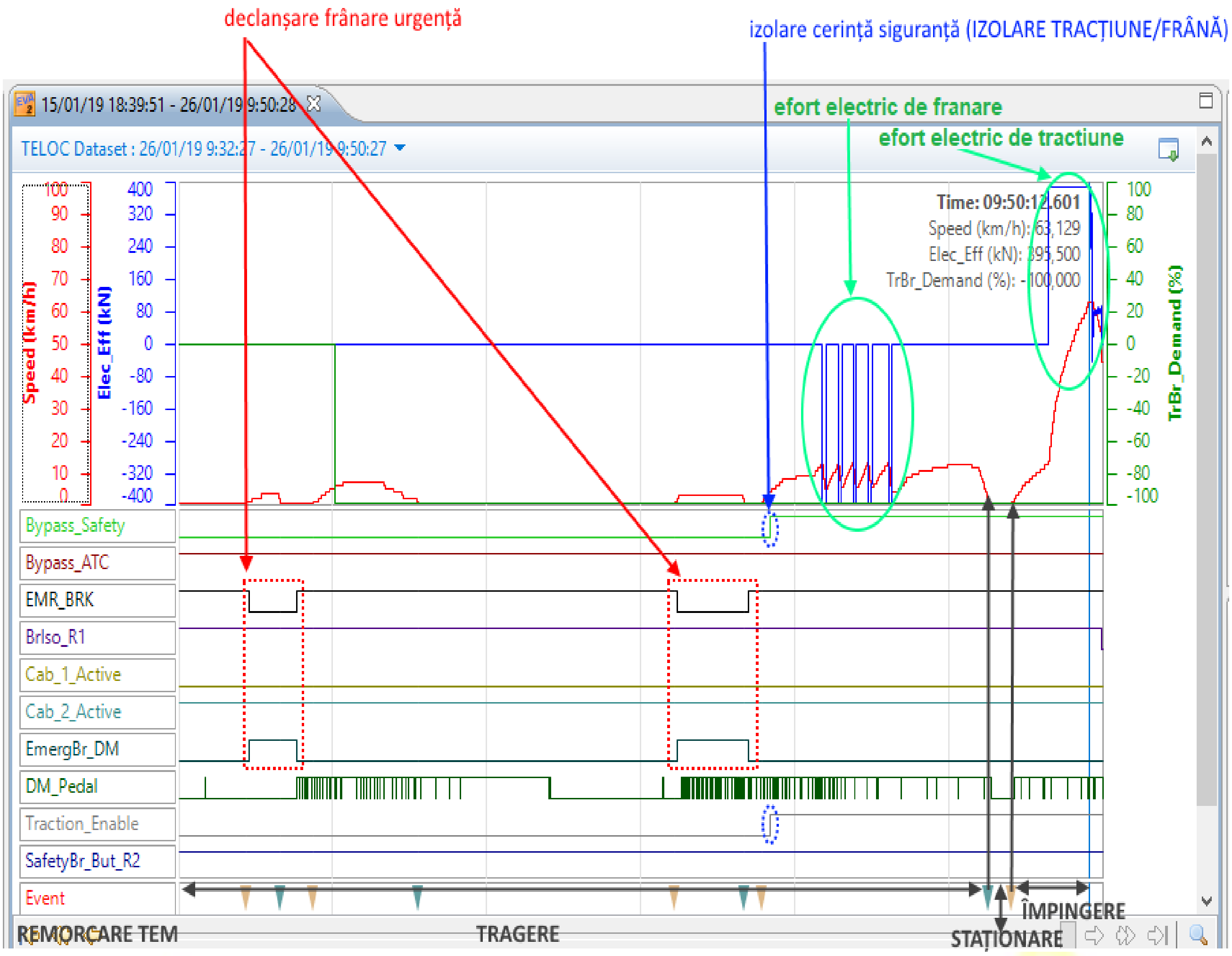

Figure 22 – detail from the recordings in TCMS with the actions of the human operator

Before switching the button „ISOLATION TRACTION/BRAKE” from OFF to ON, when the speed 6,009 km/h was reached, the vehicle records the changing of the signal **TrBr_Demand** from ”0” to ”-100%”, that is a request for maximum braking.

Bypassing the request ATP of TEM BM3-CAF, the system COSMOS from TCMS became the only one responsible to control the train speed and with the isolation of minimum four service brakes, the system COSMOS established that the limit speed **PLC_Speed_Limit at** 0 km/h (FT_MODO_DEGRADED4). When the TEM was hauled to the direction of the active cabin R2, the speed PLC (train speed) became PLC_Speed_Limit + 6Km/h, and when it was exceeded, COSMOS commanded a braking request of 100%, (TrBr_Demand = -100%). This braking request was maintained until the incident occurrence.

As the request of electric braking is applicable only for speed over 13km/h (to see function fading) the turning of the axles of the vehicle motor bogies was allowed by the logic TEM, because it had an speed more under the limit and was not on the area with power supply in order to command and control the stator couple of the electric engines.

When the rake of vehicles entered the tunnel and met the conditions of speed over 13km/h, respectively the power supply of TEM from the third rail, the electric brake of TEM came into action, the electric braking effort registered being -400 KN, then the speed decreased quickly under 5 km/h, when the braking effort became zero. In this situation the stator field was oriented reversely the vehicle traction and had like effect the train braking.

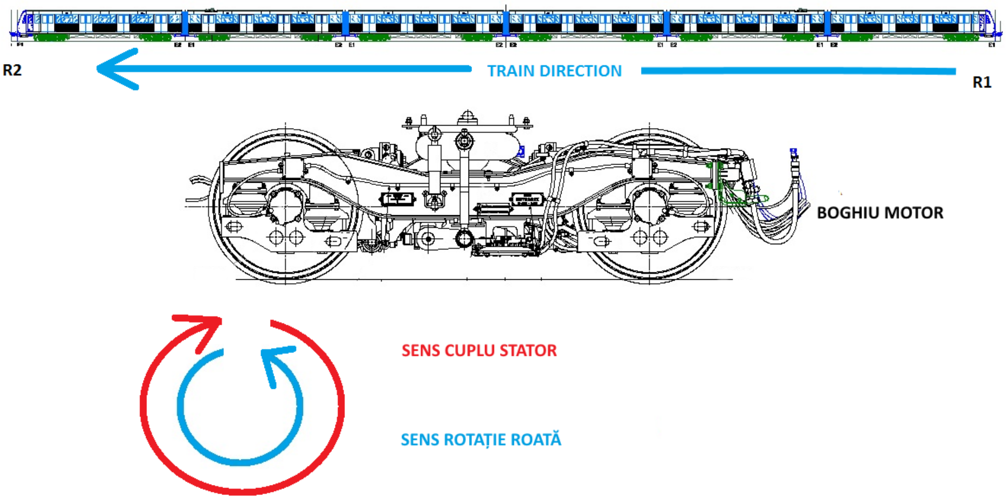

Figure 23 – turning of wheels, respectively of the stator field of TEM type BM3-CAF put in service, at the movement by hauling

Then, the speed of the rake of vehicles began to increase, following the traction effort of the locomotive LDH, up to about 13 km/h, the phenomenon repeated four more times until the rake of vehicles arrive in the station Dimitrie Leonida, the circuit being that stipulated in the figure 24.

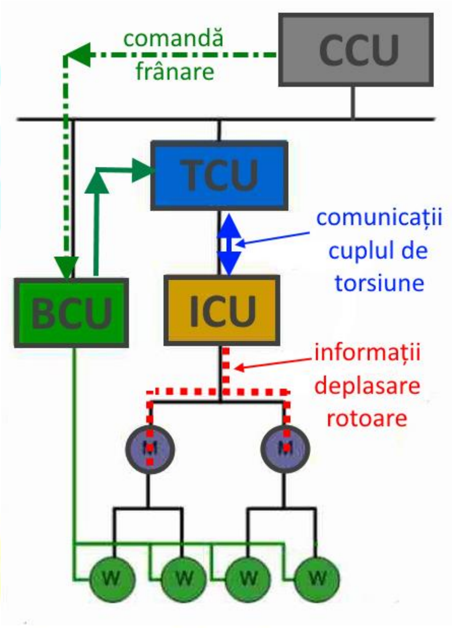

Figure 24 – communications between the equipment of TEM no.1322-2322

For efficiency, after the arrival of the rake of vehicles in the station Dimitrie Leonida, the cabin of the semi-train no. 2322 was kept active, and the shunting was done by banking upon, the communications given by the driver from the cabin S.TEM no.1322.

The only braking system rested operational at TEM BM3-CAF was the electric one through the electric engine. As it is stipulated at the chapter ***B.2.3.2. Propulsion system of TEM***, ***control of the electric engine*** is made through the generation of a ***torques*** whose *sign and absolute value* are calculated by **TCU** in accordance with the values of entries, active cabin and direction, the unit control of the electric engine knowing permanently the *magnetic vector of the rotor*. In order to answer to the commands given by the **CCU,** the unit for the engine control calculated the *magnetic vector of the stator* necessary for the compliance with the request of the couple necessary for the adjustment of the train speed for braking.

So, **ICU** red the speed value (that one the locomotive LDH was banking the train) from its speed sensors, considering the highest value of the speed for braking, that multiplicated with the wheel radius to get the *linear speed* (in m/sec) whose value **ICU** sends through the data bus to **TCU,** that, its turn, calculated the *hysteresis of fading*. As the pneumatic braking system was inhibited from TCMS of HMI, it could not operate on TEM up to the speed of about 13km/h, when the software was commanding the electric braking system.

After running 95 m, at 09:49:24 o'clock , when the speed of 13,433 km/h was reached, the TEM software calculated the *absolute value* of the couple according to the braking requirement commanded by CCU, but for the couple *sign*, TCU calculated a **false answer**[1] considering the values of the inputs, the active cabin (that was opposite the hauling movement) and the direction (real red), where the magnetic vector of the initial rotor was null (MC on neutral position), the sign being that stipulated in the figure 25. This logic of software through which the reference of the active cabin was priority to the direction red from the sensors of the bogies led to the orientation of the stator field to the direction of the vehicle traction, resulting in the recording of a traction electric effort +395 KN and the acceleration TEM BM3-CAF.

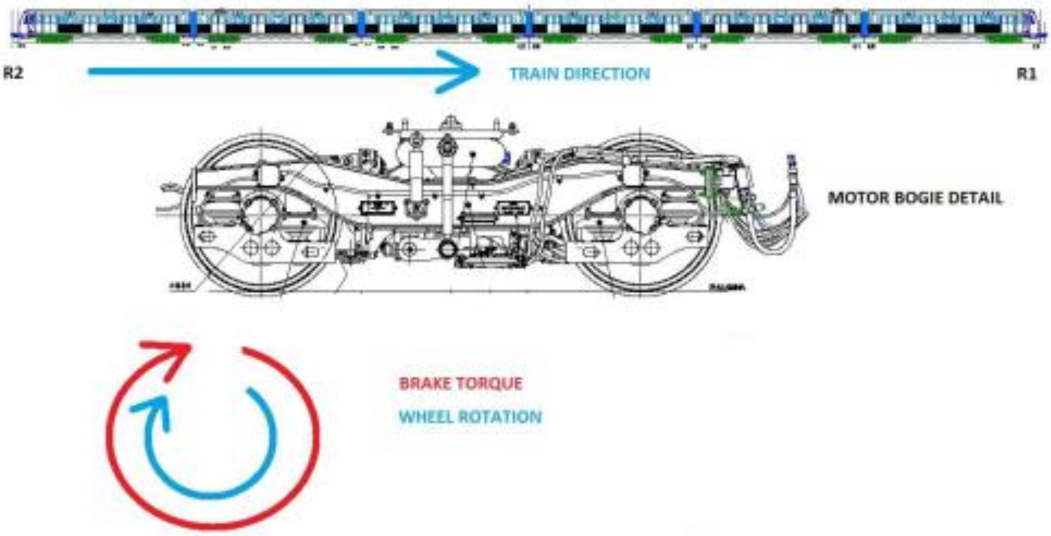

Figure 25 – turning of the wheels, respectively of the stator field of TEM type BM3-CAF put in operation, at the banking movement

The crew of the locomotive LDH took measures for braking the rake of vehicles, applying the brakes of the locomotive LDH, but the speed continued to increase, reaching the maximum value of 63,129 km/h.

The crew of TEM no.1322-2322 considered that this increase of the speed is due to the locomotive LDH and asked its driver to take braking measures. The driver of LDH asked, in his turn, the train braking by the crew of TEM. The conviction of the drivers that this increase of the speed is generated by the locomotive LDH and not by the train TEM was based on:

- MC was on neutral position (it was not commanding either traction or braking);
- all the train brakes were isolated from TCMS;
- all the safety systems of the train (ATP, Traction/Braking) were isolated;
- the provisions of [NI.5], section 5 *Emergency operation* points 5.10.3 *Coupling with the shunting locomotive*, 5.10.4 *Operation with coupled rake of vehicles*, allow the hauling of a train BM3 active, as well as that in this case, the hauled rake of vehicles does to apply any traction or braking effort.

The crew of TEM no.1322-2322, during the short time elapsed from the train acceleration to the impact occurrence, did not switch the safety button.

Starting with the value of 63,129 km/h, the speed began to decrease and the rake of vehicles ran on the line no.8 from DsB, hard hit the buffer stop of the line, then S.TEM no.1322 derailed.

[1] False answer – answer of the equipment that leads to an accident/incident (wrong answer leads only to a restriction of the operation activity)

Starting with 09:50:28 o'clock, speed 26,156 km/h, following the impact, there is no record.

CONCLUSION: ***impossibility to adapt the speed of the rake of vehicles to the shunting area was generated by the non-commanded increase of the speed of the vehicle TEM no.1322-2322, happened by the application of an electric effort of traction on the engines of the train, following the inadequate logic of the software, that used like reference the direction imposed by the active cabin of TEM and ignored the real direction of the vehicle movement.***

D.3. Conclusions

D.3.1. Direct cause and contributing factors

The direct cause of the incident was the un-controlled increase of the speed of TEM no.1322-2322, generated by the application of an electric tractive effort on the train electromotors, it generating the impossibility to adapt the speed of the rake of vehicles at the distance line for shunting.

The contributing factors was the improper processing in the software logic of the next information:

- use like reference only of the sense imposed by the active driving cabin R2 of TEM. The software logic according which the reference of the active driving cab was priority for the reading sense from the bogie sensors led to the wrong interpretation of the real moving sense of TEM.
- wrong working of the device dead man in hauling condition, missing a sound warming before an emergency brake application, it being not in accordance with the logic working scheme presented in the Driver Manual at chapter 4.4.6 *Operation of the Driver Surveillance Device*;
- keeping in operation of the electric brake, when the service brake being off from the panel TCMS. With the isolation from TCMS of the service brake (consisting in the electric brake and the pneumatic one), made by the human operator, the electric brake was not isolated.

D.3.2. **Underlying causes**

None.

D.3.3. **Root cause** was the lack in the Driver Manual of some proper regulations regarding the working in hauling conditions of a rake of vehicles type BM3-CAF with a shunting locomotive.

D.4. Additional remarks

D.4.1. Remark no.1: The investigation commission found out that although the metro transport is a railway activity, there is no national reference document that stipulates the design, construction and performance requirements, as well as the standards for testing the equipment from the composition of the metro infrastructure and vehicles running on it, of railway type (Regulations for the Technical Operation). For new projects or for their maintenance, the authority responsible should have a list of the national applicable instruments, that regulate the basic issues of safety and security for vehicles, infrastructure and passenger travelling, like *safety management*, *means of intervention and saving passengers*, *traffic safety*, *radiocommunications*, *fires fights*, *electromagnetic compatibility*, etc., that should be updated with regularity and that be reference for all local administrations that wish to promote investments in the underground passenger transport. The main objective of this document has to be that of specifying the conformity standards for the construction, endowment and operation of the metro transport in a compatible way with their safety, where the passenger security prevail.

D.4.2. Remark no.2: For automatic safety critical systems that run complex tasks in the operation activity and are based on processes controlled by the software (vehicles, installations of command and control, etc), they have to meet the safety and security requirements for the dissemination of the confidence within the passengers and users of the metro and railway transport. The command and control both of some technical systems and of the railway product made upon the microprocessor technology are programmable systems through a software, that imposes the need to meet with the safety field standards, in order to ensure that the system or the product is safe and viable. In practice, all the equipment, of different sizes, that comply with certain specific task are associated, consisting so called machine. The program for the command and control of the machine (software) connects a set distributed by technical systems (controllers) and sensors in order to run repeatedly a certain task, according to requirement of human operator intervention. This software is used like an engine for decision making in the automatic complete processes and consists in a series of algorithms that have effect on a certain type of control on the machine, being a specific condition. In most part of the applications of command and control of the machine, the data are sent to it by sensors system, and the machine uses these data, combines them with the operator action, determines a certain condition and runs an algorithm predefined for condition.

In the railway and metro transport the single requirement of conformity for the use of the software at the railway critical products is [NR.5], that stipulates that the railway product is any „*software for the rolling stock, running track, railway signalling, power supply, control and command of the railway traffic (...)*” (according art.8 from the annex no.2), and has to be homologated. No matter how elaborated a software for command and control of a railway vehicle can be, in order to increase the confidence in this, the manufacturer has to meet with all the safety field standards, so ensuring that it is safe and reliable, and in order to introduce it on the market, the field authority has to use the practice from the quality management system: certification in accordance with the standards.

<u>D.4.3. Remark no.3</u>: The requirement to use the automatic safety critical systems for running tasks more and more complex increased continuously in the railway field, but, at the same time, the manufacturers have to be concerned also about the technical limits and constraints in the independence these systems can or have to run their tasks. In the current railway industry, the products and processes based on software are designed routinely, based on the technical acknowledge got in other fields. To work with elements known is a simple activity where the behaviour of the technical system can be anticipated, but it is fully justified to state that the software became a constituent of the critical safety systems, the human factors being, it itself, like an important component in their creation and use (functioning). The possibilities to integrate the human factor in a certain critical safety system based on software, these depend on its capacity to decide on the share for the processing of the information resulted from the respective system.

The human factor complies with the functions from the technical context in real time, the quality and the speed of answer in time (that is its performances), depending on the precision of estimation the time available for the running of the respective operations, especially in the situations with high risks. In these cases, the term „*operation*” includes: processing of the information received from stimulus, finding/awareness of the risk situation, making the decision and carrying out of the necessary actions on the critical safety system in order to eliminate the risk situation. For the human being to make a mistake is something natural, being one of the important components of the learning process based on the experience getting from mistakes, the human factor learning more from errors and less from successes. Generally, after a vehicle answer, non-anticipated by the driver, this has anxiety feelings, like a negative attitude against the critical safety system, this attitude inhibiting the learning process and the performance, increasing in a such way the error rate and cascade intensification of the anxiety, reaching the stress condition. In this situation, the stress factors become decisive in the allocation of the resources and driver attention payment, and it is important that he be prepared for the critical situations anticipated on a simulator, in order to decrease the stress. Upon it, the idea is that, it is very important to use the training of the human operator, in order to integrate into the technical context, the simulation through the involvement in the virtual realities, being appropriate the training using a simulator. The investigation commission found that the drivers of the metro trains are not trained for the critical situations, that the engineers simulate on equipment similar to the vehicle interface on which they work, in order to see their response and maybe to rectify the inconsistent actions. This type of training for the user of a modern vehicle becomes very necessary as a critical safety system has an elaborated software and as the uncertainty degree of its answer is not properly controlled by the manufacturer.

D.5. Measures taken

After the incident, on the 16th April 2019, in order to avoid some similar events, the management of the TEM Operation Depot issued an Order no.M.06.605.02/3866/16.04.2019 disposing that the hauling of the trains type BM3-CAF with shunting locomotive type LDH be made only with the train accumulators disconnected.

E. SAFETY RECOMMENDATIONS

Considering the findings following the investigation, the commission recommends that for reducing the risk of occurrence and preventing some similar incidents, that in slightly different conditions can lead to serious accidents, Romanian Railway Safety Authority-ASFR ask:

- *METROREX take care that the manufacturer TEM BM3-CAF shall re-assess the vehicle software, so it ensures a proper safety level, including in case of its operation by hauling;*
- *METROREX takes care that the manufacturer TEM BM3-CAF shall added in the Driver Manual with the operations needed to be performed during the operation in hauling condition, if the rake of vehicles type BM3-CAF is coupled at a shunting locomotive.*

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This Investigation Report shall be sent to Romanian Railway Safety Authority-ASFR, like public authority in the metro transport field, to SC TMB METROREX SA – metro undertaking and owner of TEM BM3-CAF, to CONSTRUCCCIONES Y AUXILIAR DE FERROCARRILES SA Beasain, Spain – railway supplier of TEM-BM3, to ALSTOM TRANSPORT SA Romania – maintenance operator of TEM-CAF BM3 and to the victim of the incident.