ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 51, No. 3 July. 2022, pp.25- 40
Journal Homepage: erj.bu.edu.eg

Investigating Driver/ATC Performance Impacting Railway Train Operation Safety and Delays: A Field Study on Egyptian National Railways

Ahmed A. Khalil[a*], Moamen Mamdouh[b]

[a]Civil Engineering Department, Benha University, Faculty of Engineering at Shoubra, Egypt,
[b]Egyptian National Railways,
ORCID Ahmed A. Khalil: http://orcid.org/0000-0002-4211-6103
* Corresponding author

Abstract. Signalling passed at danger (SPAD) accidents are studied in this paper to find out the main causes as well as their negative impact. Although, ATC (Automatic Train Control) devices are installed to minimize the human factor in operation of the trains, they did not work properly due to cancelling their activity on some lines by the drivers or bad maintenance. The direct relation between SPADs and disordering of activeness of the devices are discussed; where the safety performance of two main lines on the network of Egyptian National Railways (ENR); during the period from year 2015 to year 2019 that have severe impacts have been collected, recorded, studied and analysed. The case of ENR has been taken as an application on the driver/ATC performance that impacting trains operation safety and train delays. It is found that signal passed at danger is a major cause of many severe and fatal accidents during that study period. Also, results of the analysis and lessons that have been learnt are concluded and recommended.

KEYWORDS: Automatic Train Control; Railway Signaling; Traffic Safety; SPAD; Train Delay and Cost**.**

1. INTRODUCTION

Signaling systems in many countries including Egypt have relied on the train drivers reacting to indications showed them by line-side semaphore or color light signals and controlling the train's speed in line with the instructions. During the 150 years of the utilization of railway signaling, drivers' failures to have response to commands transmitted by signal aspects of any type had led to a number of accidents, some of them caused very large numbers of fatalities [1]. Regarding the raising needs to reduce risks created by train drivers failing to reply to signal instructions, various types of driver warning devices and signal command enforcement systems have been developed. Those systems that continuously monitor actual train speed and enforce commitment to a commanded speed pattern are called Automatic Train Protection (ATP) systems [2, 3]. There are lots of variations of Automatic Train Control systems (ATC) around the world but all contain the basic principle that ATP provides safety and is the basis upon which the train is allowed to run. Other control systems such as Automatic Train Operation (ATO) provides controls that replacing the train driver, while Automatic Train Supervision (ATS) checks the running times and adjusts train running accordingly [3, 4]. ATC is a safety system ensuring the safe and smooth operation of trains on ATC enabled lines. Its main advantages include making possible the use of on-board (locomotive cab) signaling instead of track-side signals, and the use of smooth deceleration patterns in lieu of the rigid stops encountered with the older automatic-train-stop technology. On-board signaling refers to a railroad safety system that communicates track status information to the train cab (driving position), where the engineer or driver can see the information. The system can display allowable speed, location of nearby trains, and dynamic information about the track ahead. A track circuit in which the energy is interrupted periodically (coded track circuit) is used to transmit information from the track to the locomotive driver via on board equipment. Track Coupling Coils (TCC) may be installed on track for transmitting specific information [5, 6].

Four main variants of ATC system called ZUB, ZUB111 and ZUB111/RETB are proprietary ATC systems, presently installed on many locomotives. It is an obsolete solution, as the manufactures abandoned the production of ZUB111. However, ZUB212 was a newer generation of the manufacture proprietary ATC system, compatible with ZUB111, but it was declared on 2018 that ZUB212 was also abandoned. ZUB212 Plus is the last variant of ZUB and it is still supported by the manufacture [7]. Many train control systems were manufactured from fundamental components, including block systems for controlling train-to-train spacing for trains running between stations and traffic direction control in a single-track section, automatic train protection systems affiliated to the block systems, and interlocking devices for performing route control in station premises [7].

ATC systems vary depending on how they perform train detection and how they realize ATP. However, although these systems range from low-safety systems with only an automatic warning system (AWS) to the most advanced radio train control systems (European Train Control System (ETCS)), they are the same in interlocking devices that are responsible for route control and safety assurance for trains running in station premises [8]. As ZUB SIGNUM ATP equipment was obsolete, ZUB magnets were replaced by ETCS balises. However, they were programmed with ZUB and SIGNUM data as a migration step towards ETCS. Such installations are called: (Euro-ZUB) and (Euro – SIGNUM). The ZUB SIGNUM ATP-system was replaced by ETCS L1LS. This was the first step of the migration to ERTMS, providing a fast and cost-effective migration of legacy train control systems to ETCS [9]. While the safety level of rail transport is far higher than other transport modes, there exist possibilities to further enhance railway safety. According to the International Organization for Standardization (ISO), safety can be defined as the release from unacceptable risks. In the railway sector, the risk can be defined in relation to the events that damage safety (fatalities or injuries of passengers or employees) or transportation stability (delay) [10, 11]. ATC is the general designation for a variety of techniques by which machines regulate the movement of rail rapid transit vehicles for the purposes of safety and efficiency [12]. Yuxiang Yang et al. [13] demonstrated that there were more than 40 reasons for train delays such as dispatching and control system faults. Those faults included faults in (ATC) system, centralized traffic control (CTC) system, Chinese train control system (CTCS), monitoring system, risk prevention system, and so on. Many of those faults can lead to a very dangerous type of accidents which was called Signal Passed at Danger (SPAD).

Trains passed a signal displaying a stop aspect is a very dangerous occurrence with the risk of an immediate conflict with another train. (SPAD)'s occurrence has traditionally been relatively frequent incident. It can be caused by a single failure of a driver who approaches hundreds of signaling points every day. Fortunately, it is only a small fraction of all SPAD occurrences that leads to real accidents, but when they occur they are often of a catastrophic nature [14, 15]. A SPAD can occur due to several reasons [16, 17]:

1. Misjudging the effectiveness of the brakes under particular circumstances.

2. Over-speeding in relation to braking performance and warning signal distance.

3. Broken driving sequence (i.e. the train stops to exchange passengers between the warning signal and the main signal and the driver forgets the signaling aspect during the stop due to distraction).

4. Misjudging of which signal applies to the train in question (i.e. the train proceeds based

upon observation of a signal that was meant for another train).

5. Misunderstanding of signaling aspect.

6. Signal not seen due to bad visibility.

7. Complete oversight or disregard of a signal.

8. Driver is unconscious or falls asleep.

Regarding the classification of accidents, human factor that has led to signalling passed at danger (SPAD) played a major cause of many fatal accidents on different locations of railway networks [18, 19]. Therefore, this type of accidents was studied in detail in this paper to find out the main causes as well as the negative impact. Although, ATC devices have been installed on about 85 % of the Egyptian Railways to minimize the human factor in operation of the trains, they did not work properly due to cancelling their activity by the drivers or bad maintenance [20]. The direct relation between SPADs and disordering of activeness of the devices by the drivers are discussed in this paper; where the safety performance of two main lines on the network of ENR; during the period from year 2015 to year 2019 that have severe impacts have been collected, recorded, studied and analysed. The case of ENR has been taken as an application on the driver/ATC performance that impacting trains operation safety and cost of their delays. Also, results of the analysis and lessons that have been learnt from the human factor accidents are concluded and recommended.

2. Data Collection

ENR launches about 900 trips per day along its network; this study focuses on the two main lines Cairo-Alexandria and Cairo-Aswan. Maintenance loco's workshops are responsible of ATC recording disks and tapes change before they are full. The disks and tapes are delivered by maintenance departments to the ATC Data Analysis Centers, where the ATC Data Analysis Centers are responsible for:

1) Disk checks and data downloading

2) Trip's data analysis and reporting

3) Data filing and storage (4 years)

4) Return to maintenance of reusable disks

5) The ATC reports are weekly delivered to the ATC Central Data Analysis Safety Manager

6) The ATC Central Data Analysis Safety Manager prepares weekly reports of non-conformities to be submitted:

– To Safety Audit and Inspection (for the formal NC opening)

– To Regional Directors Infrastructure and Business Units (for Corrective action definition and implementation)

– The Director of Audit and Inspections prepares monthly ATC Data Summary for all ENR Vice Chairman and ENR Chairman

Only trips from Cairo to Alex and vice versa with travelling distance 210 Km, and trips from Cairo to Aswan and vice versa with travelling distance 900 Km are taken into consideration, this will give a clearer image about the problems and deficiencies of the current ATC technology and its effect on trip time and the quality of service [20, 21]. The total values of Train.Km for the network of ENR are given in Table 1.

Table 1: Values of Train.Km

Year	2015	2016	2017	2018	2019
Train.km	26,854,542	27,340,658	29,092,315	23,699,436	27,240,338

3.1 Total Trips that have ATC Switched-Off by the Driver during the Period (2015 - 2019)

Switching ATC off is a dangerous operating condition and risk of accidents occurring, that means there is no ATC protection available for the train's trip and the train is travelling under the full responsibility of the driver. Total trips

(ATC switched off by the driver) are given in Table 2.

Table 2: Total trips (ATC switched off by the driver)

Year	Line	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Cairo - Alex	735	550	540	519	471	446	728	647	459	453	604	501
	Cairo - Aswan	418	718	581	491	530	509	714	665	515	772	537	560
2016	Cairo - Alex	787	750	507	653	721	608	566	635	634	721	591	753
	Cairo - Aswan	700	615	546	519	541	444	472	479	438	541	521	735
2017	Cairo - Alex	754	444	548	584	455	640	705	625	567	560	780	737
	Cairo - Aswan	686	719	511	613	541	578	689	603	467	782	621	520
2018	Cairo - Alex	598	687	738	657	742	783	644	456	633	429	689	555
	Cairo - Aswan	660	419	584	525	452	736	527	674	523	441	693	765
2019	Cairo - Alex	630	760	562	582	651	671	768	743	765	537	749	757
	Cairo - Aswan	769	775	461	531	691	620	678	428	665	728	686	677

3.2 Total Number of Trips that have Breakdowns in the Onboard ZUB Systems (2015 - 2019)

ATC breakdowns can lead to a dangerous/downgraded operating condition and risk of accidents. Breakdowns varies between drop in air pressure in the main brake pipe, Failure of the interface between the onboard unit and the data unit of the active driver cab, and Failure of an odometer pulse generator or a channel of the position and speed and distance measurement sub-system. Total trips (defective onboard ATC devices) are given in Table 3.

Table 3: Total trips (defective onboard ATC devices)

Year	Line	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Cairo - Alex	221	211	202	221	218	217	220	208	204	220	213	212
	Cairo - Aswan	215	207	218	223	204	206	201	203	226	217	202	200
2016	Cairo - Alex	200	210	209	220	215	200	216	212	210	202	217	212
	Cairo - Aswan	208	217	214	199	208	212	219	205	198	198	201	220
2017	Cairo - Alex	188	196	188	191	197	181	179	196	195	197	181	192
	Cairo - Aswan	182	185	183	193	189	180	198	178	181	181	188	190
2018	Cairo - Alex	139	140	140	132	139	143	147	133	141	142	145	146
	Cairo - Aswan	149	137	143	142	133	137	131	141	143	157	150	147
2019	Cairo - Alex	138	145	147	151	160	159	132	132	150	133	145	144
	Cairo - Aswan	139	143	144	140	146	146	142	141	132	148	141	132

3.3 Total Number of Transmission Failure Events (888) from TCCs during the Period (2015 - 2019)

Transmission Failure can lead to a dangerous/downgraded operating condition and risk of accidents. For safety reasons, concealed speed supervision is carried out. Depending on the previous signal aspect, the next restricting signal aspect is assumed for the speed supervision. Total No. of faulty trackside coils transmission are given in Table 4.

Table 4: Total No. of faulty trackside coils transmission

Year	Line	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Cairo - Alex	2677	2694	2877	3154	1976	1932	1851	1627	2003	1764	2010	352
	Cairo - Aswan	2810	2864	2871	2701	1987	2017	1816	1746	1981	1956	1685	411
2016	Cairo - Alex	611	3071	3101	2689	1668	1885	1626	1713	1805	2005	2006	2915
	Cairo - Aswan	599	2938	2670	3105	1829	1760	1657	2037	1968	1828	2025	2614
2017	Cairo - Alex	2667	2777	2868	2813	2040	1930	1744	2031	1702	1735	2123	3127
	Cairo - Aswan	2702	2866	2579	2944	1746	1755	1975	1771	1805	2048	2201	3035
2018	Cairo - Alex	2891	3014	2899	2946	1844	1677	1789	1682	1813	1877	2331	2754
	Cairo - Aswan	3007	3046	3122	2800	1765	1902	1822	1597	1988	1762	1817	2630
2019	Cairo - Alex	2752	3047	3084	3057	2035	1891	1686	1617	1824	1572	1887	2631
	Cairo - Aswan	3031	3070	2923	2944	1892	2044	2033	1573	1758	2048	2015	2575

3.4 Signal Passing at Danger (SPAD) due to ATC/ZUB Breakdowns

SPAD is an event on the railway where a train passes a stop signal without authority. SPAD can lead to real accidents, such as Train collisions, or vehicle derailment. Two types of ATC/ZUB breakdowns were recorded on the two lines (Cairo – Alex and Cairo – Aswan), On-board breakdowns and trackside breakdowns. False positive SPAD occurs due to trackside equipment failures, such as damaged TCC, damaged cables, signaling failure. It results in immediate application of emergency brake (EB) which in turn, it might lead to injuries to passengers, flat wheel, excessive frictional heating, derailment, and rail damages. The obtained records are given in Table 5.

Table 5: No. of SPAD accidents due to ATC/ZUB breakdowns

Type of breakdowns	Line/Year	2015	2016	2017	2018	2019	Total
On-board breakdowns	Cairo - Alex	22	39	18	21	28	128
	Cairo - Aswan	31	27	26	27	35	146
Trackside breakdowns	Cairo - Alex	25	26	30	31	29	141
	Cairo - Aswan	120	103	143	147	146	659

3.5 Delays Induced by the Performance and Breakdowns of ATC/ZUB

The performance of the trains was affected by the ATC/ZUB condition so that it resulted in more train delays and additional operation costs. In Table 6, total ATC-related delayed trips during period (2015 – 2019) are recorded.

Table 6: Total ATC-related delayed trips during period (2015 – 2019)

Year	Line	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2015	Cairo – Alex	40	86	30	44	21	25	12	20	41	24	43	68	454
	Cairo – Aswan	48	63	76	87	25	30	19	37	66	28	28	44	551
2016	Cairo – Alex	38	65	46	59	20	24	13	20	44	25	35	65	454
	Cairo – Aswan	110	75	69	63	14	23	25	24	37	36	39	62	577
2017	Cairo – Alex	35	97	85	80	16	24	35	30	41	20	18	65	546
	Cairo – Aswan	59	95	47	36	41	34	27	33	17	35	26	35	485
2018	Cairo – Alex	111	60	63	61	29	27	14	30	36	43	12	114	600
	Cairo – Aswan	68	96	108	115	21	29	41	22	22	16	39	70	647
2019	Cairo – Alex	86	35	26	113	33	13	41	23	29	24	44	112	579

	Cairo – Aswan	115	90	32	63	22	41	23	23	33	28	13	81	564

3.6 ZUB/ENR: system outline

The ZUB system consists of on-board and trackside equipment. The train is controlled by means of a track-to-train spot (intermittent) transmission.

- The on-board equipment that is shown in Fig. 1 consists essentially of:
  1- The on-board unit, with processing logic and receiving/transmitting equipment, which operates the pneumatic or electric braking through a brake activation unit.
  2- The train coupling coil (ZUB on-board antenna), mounted on the bogie, that receives data from the line.
  3- The axle-mounted odometer pulse generator which supplies information for determining distance covered and the actual speed.
  4- The cab display and operating panel, with speedometer, lamps, buttons and hooter. The data recorder unit.

- The trackside equipment consists of:
  - A track coupling coil normally mounted outside the rails to transmit permanent or variable data to the on-board unit.
  - A signal interface board that scans the signal aspects and derives the information to be transmitted to the on-board sub-system through the controlled transponder (variable data).

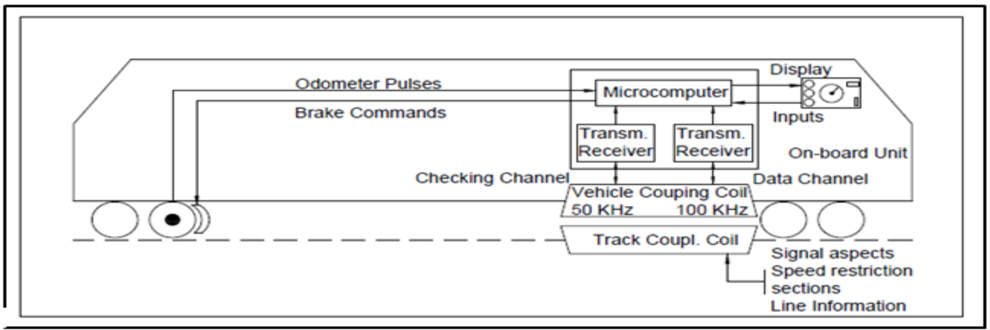

Fig 1: ZUB on board equipment

3.6.1 ZUB/ENR: data transmission

The operations of ZUB system are based on the inductive coupling principle. Data from line to vehicle are transmitted when the on-board antenna energizes the trackside passive transponder. The on-board unit provides two continuously operating transmitters, one for data with a working frequency of 100 kHz and the other one for monitoring purpose with a working frequency of 50 kHz. The 100 kHz frequency has a double function: it supplies the power for the track coupling coil by inductive coupling (tele-powering) and it is used for information transmission. In fact, the 100 kHz current is modulated in the track coupling coil in the accordance with the audio frequencies to be transmitted (2-out-of-7 code) as given in Table 7 and illustrated in Fig. 2.

Table 7: ZUB modulated audio frequencies

ID	**f1**	f2	f3	f4	f5	f6	f7
Frequency	280	360	440	520	600	680	760

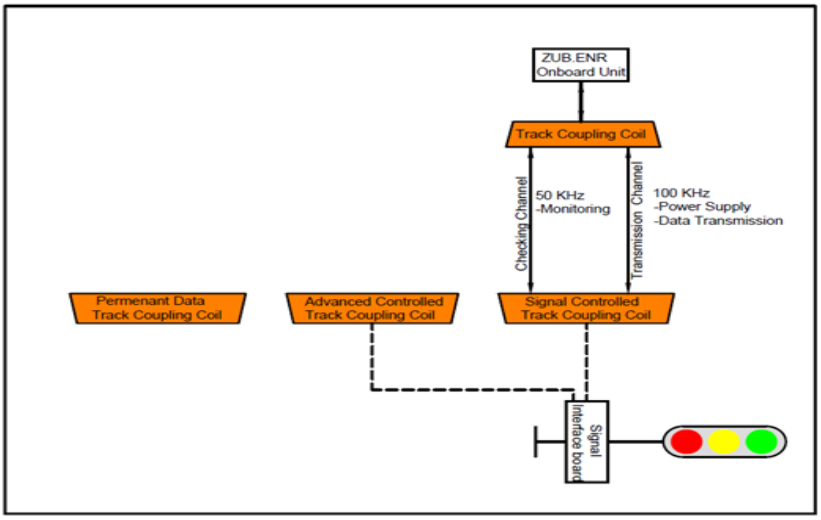

Fig 2: Trackside data transmission

3.6.2 Current ATC Technology in ENR

As regarded to the ATP/ATC systems, the core ENR network (about 2.282 km) is currently equipped with the ZUB 100 trackside, the current status of ATC/ZUB system in ENR is summarized in Table 8.

Table 8: The status of ATC/ZUB system in ENR

Name	On-board	Trackside	Notes
ZUB 111	Obsolete	Obsolete	trackside seems in good or at least in acceptable conditions
ZUB 111 / RETB	Obsolete	Obsolete	Not working since 2012
ZUB 212	Obsolete	Compatible with ZUB 111 Trackside / Obsolete	onboard seems in good conditions
ZUB 212 Plus	New	Compatible with ZUB 111 Trackside / Obsolete	Current

The current status of the ENR locomotive fleet that provided with ZUB Systems is summarized as follows:

- Locomotives fitted with ZUB on-board (ZUB 111 or ZUB 212): 596 locomotives, whose 329 regulated and 267 defected.
- Locomotives non-equipped with ZUB on-board: 89 locomotives.
- Fleet is employed in the Egyptian railway network for passenger (long and short distance) and freight operations.

4. Analysis and Discussion

The records of ATC/ZUB breakdowns, number of trips and delayed times that have been given in the tables at section 3 of this paper, will be processed, analyzed and compared at this section to obtain two different impacts. The first one is causes of ATC breakdowns and their impact on safety and operation performance of the two lines, whereas the second is impact of ATC breakdowns on train delays including delay cost calculation.

4.1 Major Causes and Impact of ATC Breakdowns on Train operation Safety

According to records in Table 7 for Cairo – Alex line, the total No. of SPAD accidents due to on-board breakdowns and the total No. of FP-SPAD accidents due to track-side breakdowns are 128 and 141respectevely. Also, total trips for (ATC switched off by the driver+ defective onboard ATC devices+ faulty trackside coils transmission) = 37764+10794+105086 = 153,644. Thus, ratio of total SPAD accidents to total trips = (128+141)/153644 = 0.175 %.

It is also obtained from the records of Cairo-Aswan line that total No. of SPAD accidents due to on-board breakdowns and total No. of FP-SPAD accidents due to track-side breakdowns are 146 and 659 respectively. However, the total trips for (ATC switched off by the driver+ defective onboard ATC devices+ faulty trackside coils transmission) = 35599+ 10653+ 104560 = 150,812. Thus, the ratio of total SPAD accidents to total trips = (146+ 659)/150,812 = 0.53%. Comparing the two lines, it is found that as shown in Fig 3 and Fig 4, max. No. of accidents on Cairo- Alex line was in year 2018, where the max. No. on Cairo-Aswan line was in year 2019. On the other hand the minimum occurrences were in year 2017 for the lines. Also, it was noticed that the rate of occurrences was in rising from year 2017 to year 2019. In order to compare the accidents with the traffic performance, the average (train.travelled distance) of the lines was recorded 26,845,458 train.km. So, it is noticed that ratio of total SPAD accidents to total train.km is 0.004%. It is also clear from the analysis that the ratio of total SPAD accidents to total trips for Cairo-Aswan line is about three times the value of Cairo-Alex line.

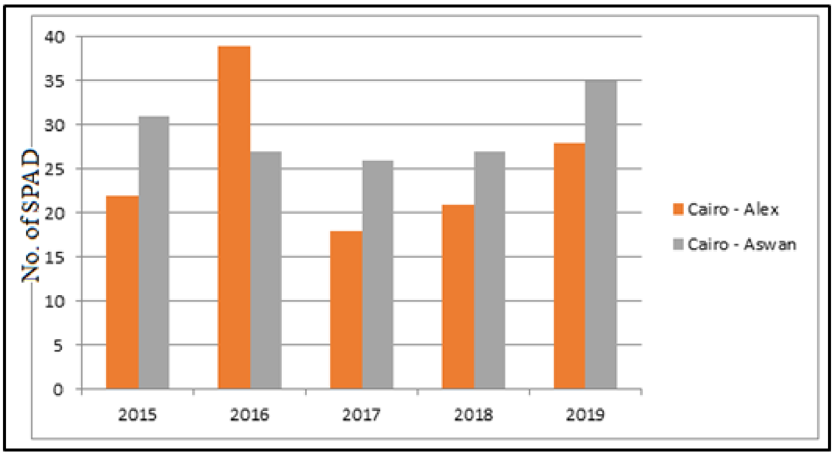

Fig 3: No. of SPAD Accidents due to ATC/ZUB on-board breakdowns

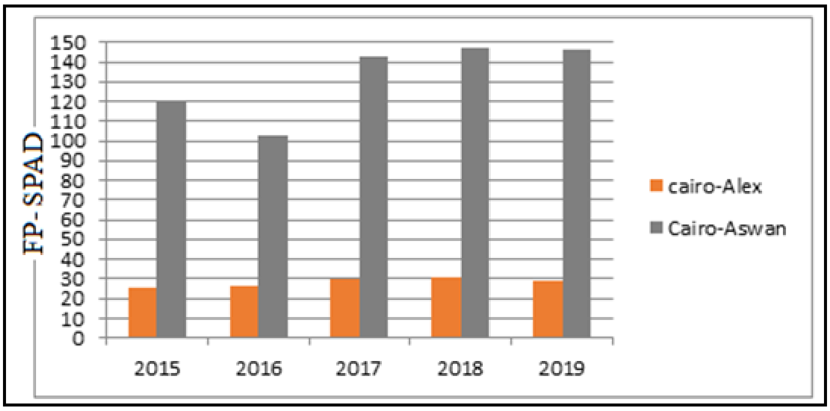

Fig 4: FP- SPAD due to ATC/ZUB trackside breakdowns

The reasons of this result are the bad behavior of the train drivers, less monitoring, less maintenance and the aging of the devices. It was noticed from Fig 5 and Fig 6, that drivers tend to shut down ATC/ZUB on-board devices due to unreliability and repeated breakdowns of the system, there is a peak of ATC/ZUB shut down action by drivers always occurs at the time of rains and bad weather conditions (i.e. winter season), so, it is obvious that ATC/ZUB system has no immunity to the bad weather conditions.

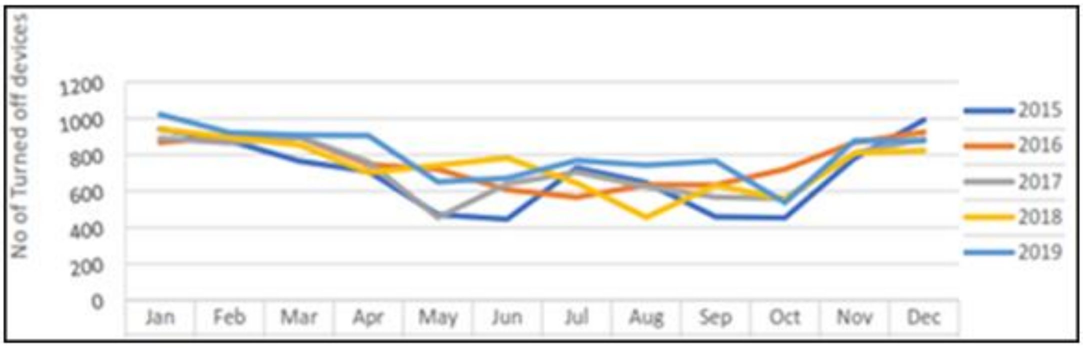

Fig 5: Total trips on Cairo-Alex (ATC switched off by the driver)

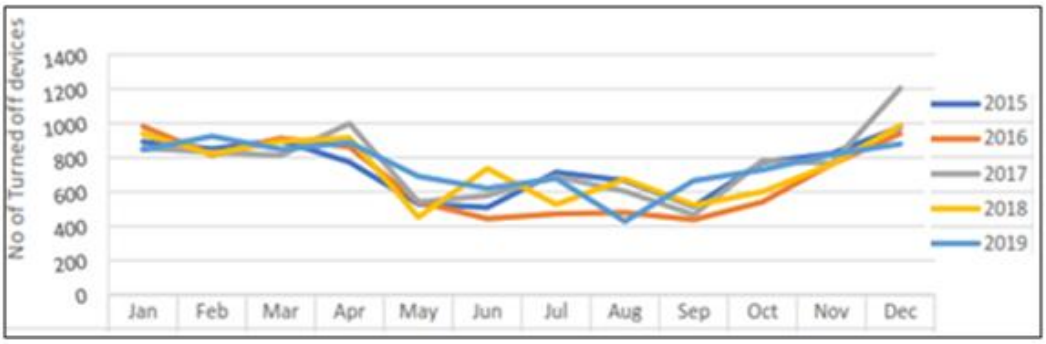

Fig 6: Total trips of Cairo- Aswan (ATC switched off by the driver)

A site survey was done to Damanhur/Sidi Gaber section on December 2020 to investigate the reasons behind the downgraded operation of ATC/ZUB systems in the rainy weather, and most of the reasons founded are related to trackside problems and they can be enumerated such as:

- Weak Seal

TCC has a casing consists of two parts separated by a rubber gasket seal, weak seal can lead to water and moisture leaks which in turn cause TCC oscillators to fail or to operate abnormally.

- Cable failures

Aged cables can cause transmission failure from TCC to the on-board unit; also aged cables have a weak or broken insulation that leads to moisture leak. In the same context, there is a peak of Transmission failure which known as (888) always occur at the winter season, as, noticed from Fig 7 and Fig 8 due to the same reasons mentioned before. It was also noticed from Fig 4 that FP-SPAD accidents tend to increase along the years from 2015 to 2019, the reasons for FP-SPAD are TCC failure, faulty TCC wiring, Cross-talking between adjacent TCCs, and Interference.

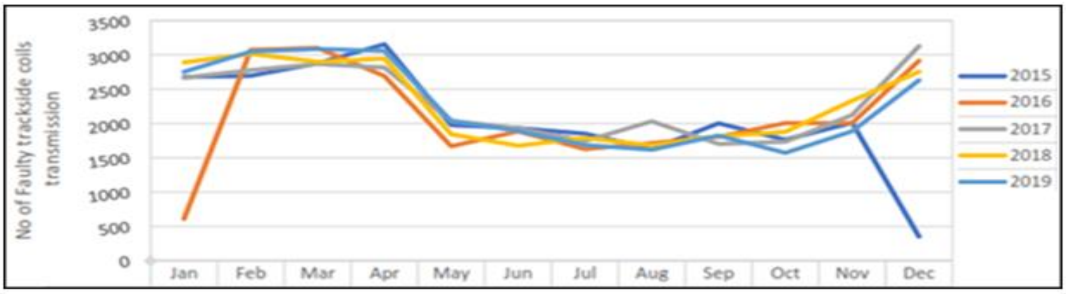

Fig 7: Total No. of faulty trackside coils transmission on Cairo- Alex line

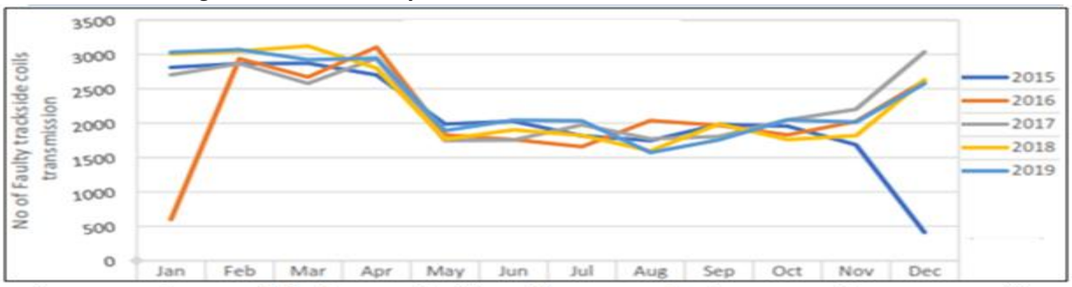

Fig 8: Total No. of faulty trackside coils transmission on Cairo- Aswan line

It is illustrated in Fig 9 and Fig 10 that the number of trips with defective ZUB on-board units in the years from 2015 to 2017 is higher than the years from 2018 to 2019 because a new recent ZUB on-board units (ZUB212Plus) with updated hardware are installed on about 50 Herschel locomotives and it is planned to be installed on 150 Locos by the end of 2021 , but, the upgrade to ZUB212Plus did not solve all the deficiencies of ATC/ZUB in ENR, as, it is still depending upon the same trackside equipment of ZUB111 for transmission of data to the driver cab. The transmitted signal from trackside is analog which tends to have a lower quality than digital, as, it is sensitive to external influences, cross talk of TCCs from the neighboring track, and data can become corrupted with no way to recover it.

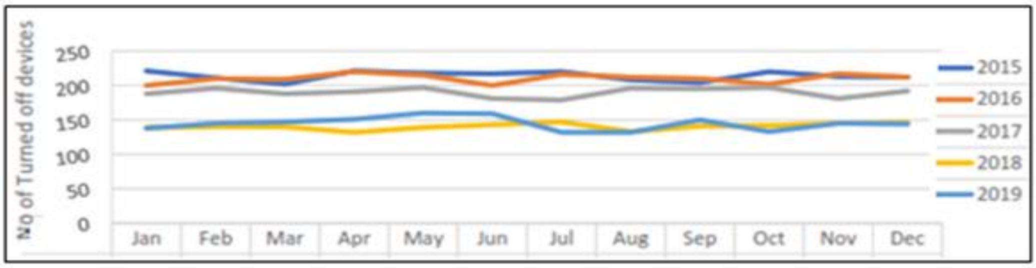

Fig 9: Total trips of Cairo- Alex (defective onboard ATC devices)

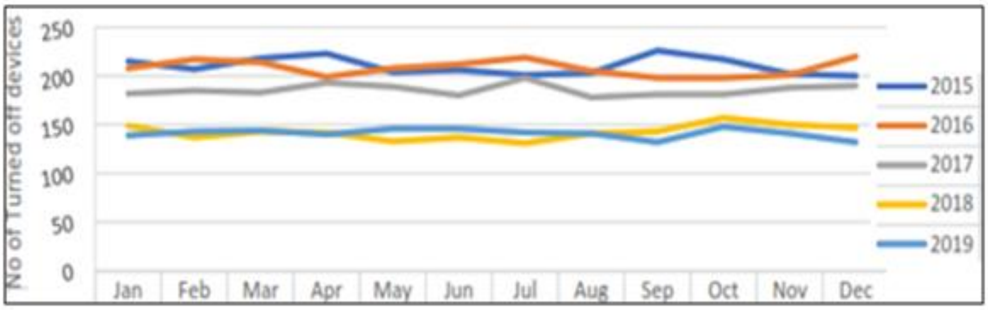

Fig 10: Total trips of Cairo- Aswan (defective onboard ATC devices)

Joining some trips through Cairo -Alex and Cairo – Aswan to identify the reasons for this safety deviation, the authors found many reasons why SPAD occurs from ATC/ZUB point of view:

- Wrong Configuration

  The maintenance technician entered wrong Brake Curve Number BRN into the diagnostic software. BRN ranges of [1-16] and it defines the braking capabilities of the train with respect to the maximum allowed speed of the train V_{targ} and the minimum distance between two consecutive signals according to the graph shown in Fig 11.

- Misjudging

  The driver misjudges the required speed to approach a stop signal. ATC/ZUB has stopping point monitoring function which ensures that a train does not run by the hazard point located behind the overlap. It allows the train to proceed to the signal and continue after the signal has cleared by limiting the speed of the train to the release speed V_{rel}. Driver should control the train's speed and keep it below V_{rel} in the way that driver manages to stop the train before the stopping signal according the procedure illustrated in Fig 12.

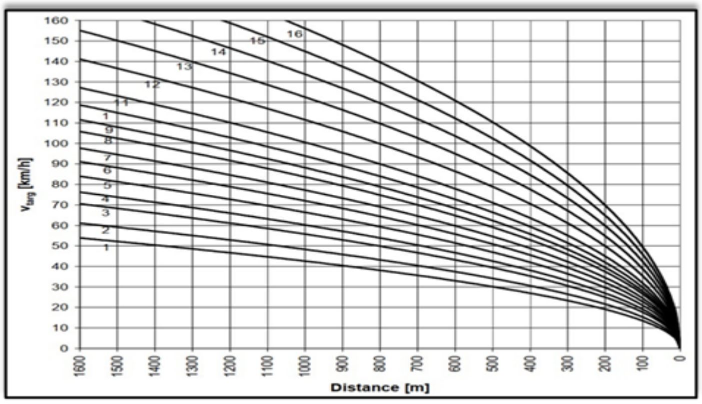

Fig 11: Chart of Distance/Speed Brake Curve Number

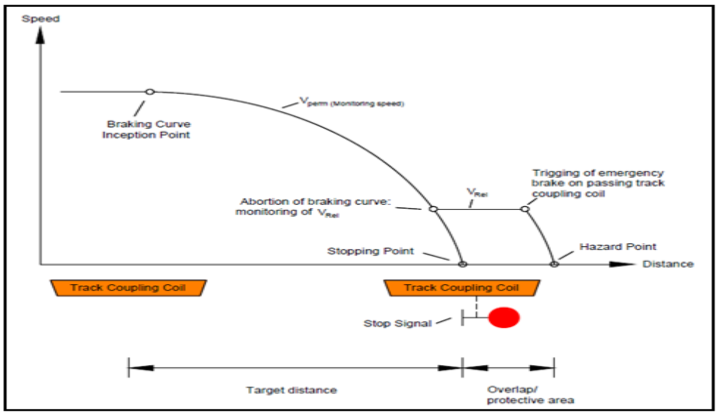

Fig 12: Distance/Speed braking curve showing the released speed (V_{rel})

As a clear example, on 11 August 2017 near Khurshid station as shown in Fig 13, two trains – one traveling from Port Said (Trip no. 571) and the other from Cairo (Trip no. 13)– crashed one into the rear of the other killing at least 41 people and injured 179 passengers. One of the key reasons of the accident was signal passing at danger, the driver of train no. 13 has passed two signals showing red light in a row, ATC/ZUB supervision was not active because the driver closed the stop cock to bypass EB, the driver attributed his misbehavior to his loss of confidence in ATC/ZUB system due to the many deficiencies he has experienced with the system before, such as breakdowns and FP-SPAD. So, one of the important learned lessons from that accident is that the current ATC/ZUB system is not only threatens the safety of the trains but it has a negative impact on the driver encouraging him to break the rules and procedures of the safe operation to avoid breakdowns and delays caused by ATC.

Fig 13: SPAD accident near Khurshid station

4.2 Impact of ATC Breakdowns on Train Delays

The second major consequence of the unreliability of the current ATC/ZUB systems in ENR and it is quite common is train delays; hence it was noticed from Fig 14 that delays on the lines tend to increase from the start of the study period to the end.

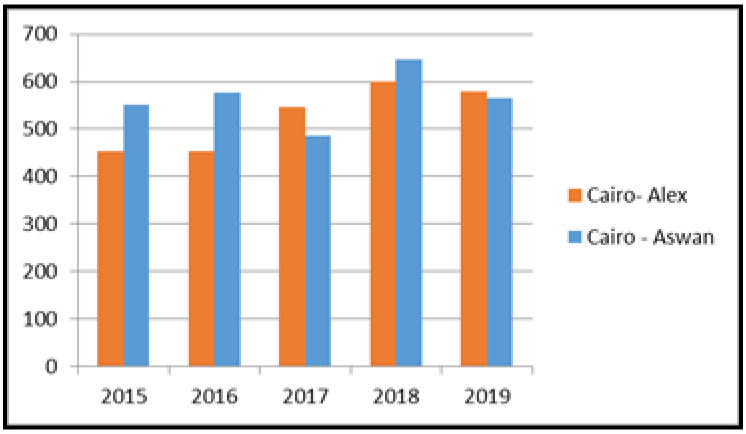

Fig 14: Comparison of total annual delayed trips

Also, as illustrated in Fig 15 and Fig 16, the delayed trips on the 2 lines increased excessively in the time of the bad weather (winter season). Also it is noticed from Fig 17 and Fig 18 that illustrate train delays categories for the lines in year 2019; however delays greater than one hour related to ATC/ZUB unreliability are the most recurring category.

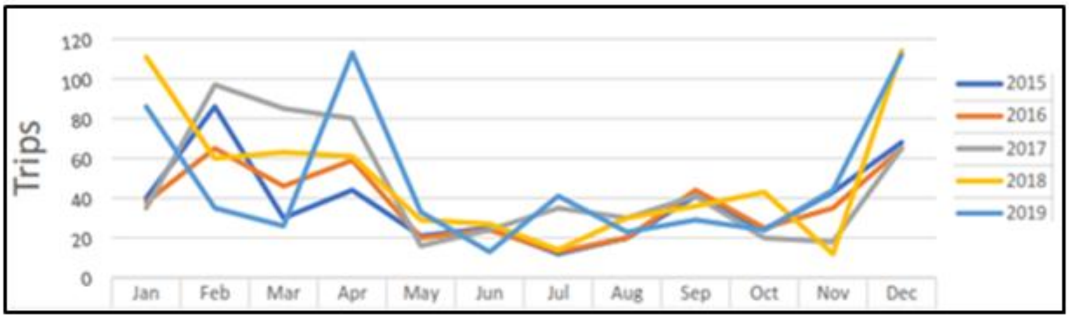

Fig 15: Monthly Delayed Trips on Cairo-Alex

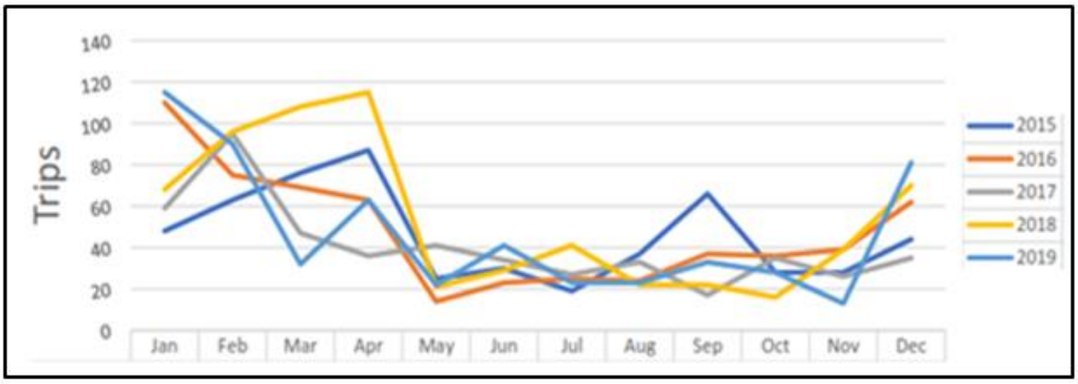

Fig 16: Monthly Delayed Trips on Cairo-Aswan

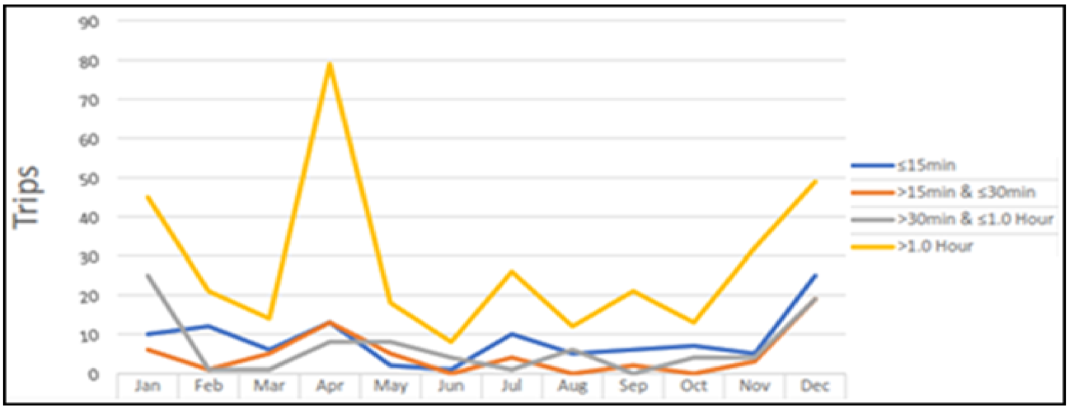

Fig 17: Train delays categories for Cairo-Alex line in 2019

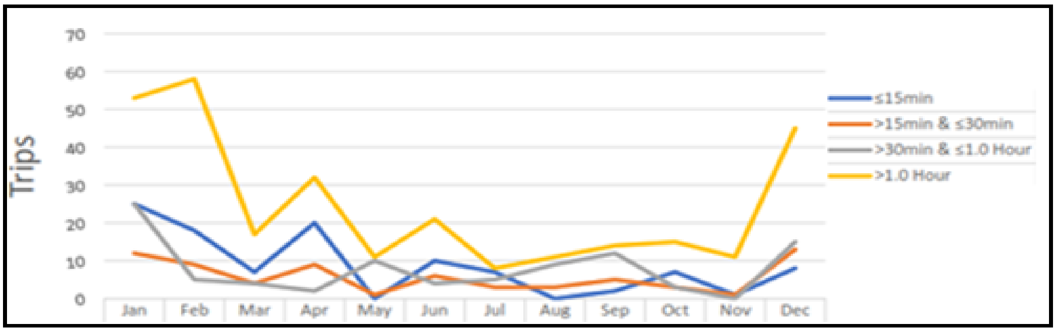

Fig 18: Train delay categories for Cairo-Aswan line in 2019

4.2.1 Train Delay Causes

As a result of inspection by the authors on the ATC/ZUB devices and the driving behavior, it was found that reasons causing train delays on the lines are summarized as follows:

1- ATC/ZUB low immunity for moisture and rainy conditions so the peak of delays occurs at winter time.
2- FP-SPADs will initiate emergency brake causing the train to stop, this situation consumes more time for deceleration, releasing of emergency brake procedures, and to accelerate to the required speed again. FS-SPADs affect the operation of the behind trains as well because it will operate at a lower speed or come to standstill by the signaling system to protect the trains from collision.
3- ATC/ZUB on-board equipment failures cause the train to move in downgraded operation conditions which increase the trip time. Current ATC/ZUB systems have a low risk reduction and performance level (SIL0).

4.2.2 Assessment of Train Delay Cost

ENR developed a formula for calculating cost of train delay taking into consideration the train speed, cost per minute and delay time. As previously estimated by ENR, the delay cost/minute is 2.105 L.E (2019 price), and the operational speeds for Cairo-Alex and Cairo-Aswan are 84 and 100 km/h respectively [21].

Delay Cost = Operational speed * Cost/minute * Delay time

Where,

Operational speed = Trip distance (km) * 60/ trip time (minute)

According to the delay records and categories that were given in Table 8, Fig 15, Fig 16 and records in Appendix A, the total delay time and cost for the study period 2015-2019 are given in Table 9. It is noticed that the total delay costs for Cairo-Alex and Cairo-Aswan are 29,212,078.56 and 36,192,738.5 L.E respectively. The increasing in the delay cost of Cairo-Aswan line than Cairo-Alex line is attributed to its higher delay time, higher operational speed and long trip distance (900 km).

Table 9: Total delay time and cost for the study period 2015-2019

Ave. Delay Category (min.)		10	22	45	90
Cairo- Alex	Time (min.)	4,350	4,708	22,410	133,740
	Cost (L.E)	769,167	832,468.56	3,962,536.2	23,647,906.8
Cairo- Aswan	Time (min.)	5,080	6,072	22,815	137,970
	Cost (L.E)	1,069,340	1,278,156	4,802,557.5	29,042,685

5. Conclusions & Recommendations

In this paper, the authors investigated the driver/ATC performance to find out the main causes of the fatal accidents on the railway lines as well as its negative impact on train delays. Thus, the safety performance of two main lines on the network of ENR; during the period from year 2015 to year 2019 that have severe impacts have been collected, recorded, studied and analysed. Summary of the main conclusions and recommendations have been found as follows:

1- Ratio of total SPAD accidents to total train.km on the main lines of ENR was 0.004%.

2- Ratio of total SPAD accidents to total trips for Cairo-Aswan line was about three times the value of Cairo-Alex line. The reasons of this result are the bad behavior of the train drivers, less monitoring, less maintenance and the aging of the ATC devices.

3- Delays greater than one hour related to ATC/ZUB unreliability are the most recurring category.

4- Drivers tended to shut down ATC/ZUB on-board devices due to unreliability and repeated breakdowns of the system.

5- The current ATC/ZUB system was not only threatens the safety of the trains but it had a negative impact on the driver encouraging him to break the rules and procedures of the safe operation to avoid breakdowns and delays caused by ATC.

6- The peak of ATC/ZUB shut down action by drivers always occurs at the time of rains and bad weather conditions (i.e. winter season), so it was obvious that ATC/ZUB system had no immunity to the bad weather conditions.

7- ATC/ZUB on-board equipment failures caused trains to move in downgraded operation conditions which increased trip times.

8- The upgrade to ZUB212Plus did not solve all the deficiencies of ATC/ZUB in ENR, as it is still depending upon the same trackside equipment of ZUB111 for transmission of data to the driver cab.

9- The analog transmitted signal from trackside tends to have a lower quality than digital, because it is sensitive to external influences, cross talk of TCCs from the neighboring track, and data can become corrupted with no way to recover it.

- Recommended pillars that should be included in a fast action plan to improve ATC system (on-board &Trackside) are as follows:

1- Speed up the steps of the migration to ETCS Level 1
2- Improve availability and reliability of the current ATC/ZUB system during the migration to ETCS Level 1 by the reuse of both old trackside and onboard equipment as spare parts to protect existing investments.
3- Introducing GSM-R to provide redundancy for trackside data transmission.
4- Optimize the human factor by improving training programs for skilled people in maintenance.
5- Enforce the use of ATC, and the penalties for violations

Acknowledgements
The authors thank the staff of the safety management department in ENR for providing them with the required presented data at this paper.
Disclosure statement
The authors declare no conflict of interest. The authors alone are responsible for the content and writing of this paper.
Funding
This research received no external funding

References

[1] Jochen Trenckauf et al., Railway Signalling & Interlocking, International Compendium, 2009, Eurail Press.
[2] Rob M.P. Goverde, Punctuality of Railway Operations and Timetable Stability Analysis, PhD thesis, Technische Universiteit Delft, 2005.
[3] Pyrgidis, Christos N, Railway transportation systems _ design, construction and operation-CRC Press, 2016.
[4] B. Ning et al, Advanced Train Control Systems, 2010, Wit Press, Southampton, Boston. Raj Kumar and Vijay Kumar, Automatic Train Protection (Cab Signalling) for Delhi Metro Railway, A Case Study, accessed on 23 May 2021.
https://www.techylib.com/en/view/licoricehealth/automatic_train_protection_cab_signalling_for_delhi_metro_railway
[5] Delhi Metro Rail Cooperation, Kerala High Speed Rail between Thiruvananthapuram and Ernakulam - Pre Feasibility Report – Sept 2011.
[6] Kaushal Kumar, HS - Automatic Train Control: Concept of System, UTHS / RDSO/KK, India, 2013.
[7] Hideo Nakamura, How to Deal with Revolutions in Train Control Systems, 2016.
[8] Arcadis Nederland B.V, Final Report - Digitalization of CCS (Control Command and Signalling) and Migration to ERTMS, 2018.
[9] Raja Gopal Kalvakunta, Reliability Modeling of ERTMS/ETCS, 2017.
[10] C. Pinedo, M. Aguado, Modeling and Simulation of ERTMS for Current and Future Mobile Technologies, 2015.
[11] Yuchen XIE, Formal Modeling and Verification of Train Control Systems, PhD Thesis, LILLE France, 2019.
[12] Jong- Gyu Hwang and Hyun- Jeong Jo, Hazard Identification of Railway Signaling System Using PHA and HAZOP Methods, 2013.
[13] Yuxiang Yang, Statistical delay distribution analysis on high-speed railway trains, J. Mod. Transport. (2019) 27(3):188–197, https://doi.org/10.1007/s40534-019-0188-z
[14] R.A.H. EL Rashidy et al, A Big Data modeling approach with graph databases for SPAD risk, Core.ac.uk, 2019.
[15] Ahmed A. Khalil, Analysis of Major Causes of Accidents in Egyptian National Railways and Cairo Metro Lines, Engineering Research Journal, number 17 July 2012.
https://www.google.com/url?sa=t&source=web&rct=j&url=https://www.bu.edu.eg/portal/uploads/openLearning/Analysis%2520of%2520Major%2520Causes%2520of%2520Accidents%2520in%2520Egyptian%2520National%2520Railways%2520and%2520Cairo%2520Metro%2520Linesabstract_en.pdf&ved=2ahUKEwif3Kz79sX0AhX_RPEDHTpVCx0QFnoECAgQAQ&usg=AOvVaw3X-p42y5YS1uXb-1LbaXoU

[16] Nora BALFE, Sean GEOGHEGAN and Brendan SMITH, SPAD Dashboard: A tool for tracking and analyzing factors influencing SPADs, Contemporary Ergonomics and Human Factors 2017.
[17] ITSR, Managing Signal Passed At Danger, 2011, Sydney NSW.
[18] Julia Burggraaf et al, What Employees Do Today Because of Their Experience Yesterday: How Incidental Learning Influences Train Driver Behavior and Safety Margins (A Big Data Analysis), (A Big Data Analysis). Safety 2021, 7, 2. https://doi.org/10.3390/safety7010002

[19] ENR, Technical inspection reports from 2015 to 2019.
[20] ENR, Database Department Reports from 2015 to 2019
[21] ENR, S.P.G, Important Cases Report from 2015 to 2019