Modelling and Simulation of the Automatic Train Protection on LabVIEW

[1]Ram Kumar,[2]Poonam Kumari

[1, 2] University Centre of Instrumentation and Microelectronics,
[1,2] Panjab University, Chandigarh, India

Abstract: Ever since its inception, railways has become an integral part of in-land transportation of freight and passengers. Over the period Speeds, rail-road traffic and freight tonnage has increased rapidly, with this, the risk of accidents has multi-folded and monetary loss & causalities have increased proportionally. Manual control and inspection systems could be major cause of such accidents. Approximately, 47% of total accidents from 2009 to 2015 were due to derailment of trains. [1]

Through this work we aim to propose, model and simulate an automatic train protection (ATP) system on LabVIEW software that would assist the locopilot and will be applicable on one or all self-propelled rail road vehicle. For this purpose different parameters, such as Sanctioned speed, Caution Speed, Kilometerage, Safety & Warning limits are considered.

***IndexTerms*— Automatic Train Protection, Locomotive, Safety Limit, Warning Limit, Sanctioned Speed, Caution Speed, Kilometerage, Automatic Deceleration, LabVIEW**

I. INTRODUCTION

Modern rail transport commenced with the British development of the steam locomotive in England when Richard Trevithick ran a steam locomotive and loaded in 1802. Since then many business person and engineers continuously improved and advanced railway. [2]

With India's first passenger train in 1853 from Mumbai to Thane, India formally entered the rail-road era. Today, Indian Railway manages the fourth-largest railway network in the world by size, with a route length of 67,956 km (42,226 mi) as of 31 March 2020. 45,881 km (28,509 mi) or 71% of all the broad-gauge routes are electrified with 25kV 50Hz AC electric traction as of 1 April 2021. IR runs 13,169 passenger trains daily, on both long-distance and suburban routes, covering 7,325 stations across India. [3]

Definitions [4]

Sanctioned speed: Every train shall be run on each section of the railway, within the limits of speed sanctioned for that section by approved special instructions. This speed is called Sanctioned speed or Booked speed.

Caution Order: Whenever, in consequence of the line being under repair or for any other reason, special precautions are necessary, a Caution Order detailing the kilometres between which such precautions are necessary, the reasons for taking such precautions, and the speed at which a train shall travel, shall be handed to the Loco Pilot. And the speed restriction is called Caution Speed.

Accidents

The term 'accident' envelopes a wide spectrum of occurrences with or without significant impact on the system. Consequential train accidents may be due to collisions, derailments, fire in trains, road vehicles colliding with trains at level crossings, and certain specified types of 'miscellaneous' train mishaps.[5]

According to the NCRB Annual Report 2020, there were 27,987 train accidents in 2019. Out of the 13,018 train accidents in 2020, as many as 12,440 of them took place due to the fault of the loco pilot (LP), the person responsible for driving the train and ensuring its proper maintenance during transit. Other reasons include errors on part of the signalman, mechanical errors, poor track repair infrastructure, bridge/tunnel collapse, and the likes. [6]

Derailments

One may notice ratio of derailments in total number of accidents is quite high as indicated in Table 1. Apart from other uncontrollable reasons Train Derailment can be avoided with proper inspected tracks and following the prescribed Caution Speeds (caution orders). In other category of accidents, over speeding may not be the sole reason but it does plays a part. Yet the present method of Train protection does not tackle this issue and will be inadequate for the future of Indian Railways. Hence, an automatic train protection system is proposed.

Table 1: Year-wise comparison of Derailments with total number of accidents.[5]

Year	Total Accidents	Derailments	Percentage
2000-01	473	350	75
2001-02	414	280	68
2002-03	351	216	62
2003-04	325	202	62
2004-05	234	138	59
2005-06	234	131	56
2006-07	195	96	49
2007-08	194	100	51.55

2008-09	177	85	48.02
2009-10	165	80	48.48
2010-11	141	80	56.74
2011-12	131	55	41.98
2012-13	122	49	40.16
2013-14	118	53	44.92
2014-15	135	63	46.67
2015-16	107	65	60.74
2016-17	104	78	75.00
2017-18	73	54	74.00
2018- May	13	8	61.5

Present Train Protection

Present train protection methodology includes following steps:

1. Track is inspected by Permanent Way Dept, and Track health certificate is generated.
2. As per the direction from Permanent Way Incharge, Speed Restrictions are implemented on the section.
3. These Restrictions are conveyed to the LP and Guard of the Each Train entering the section through speed boards and caution order.
4. While running LP is responsible for maintaining train speed in the prescribed range, and the guard acts as supervisor. Guards too have control of breaks in case of emergency.
5. Datalogger can be checked for the speed of the train over the journey.
6. In case of negligence of speed restrictions, both loco pilot and guard are punished and penalised as found suited after proper investigation.

Hence, we can conclude that there is no specific method to foresee the accidental condition in anticipation and train protection is solely responsibility of LP & Guard.

Objectives

Objective of this work is to design and simulate an ATP system that will:

1. Receive Caution Speeds with respect to kilometerage for the train.
2. Calculate Warning Limit (WL) and Safety Limit (SL).
3. Measure or receive speed of the train and its position.
4. Compare speed with limits.
5. Warn the LP or if necessary, apply brake and/or disconnect acceleration to keep the speed of train below the specified limits.
6. Have a By-Pass system for manual overtake.

For implementation of this system we have used LabVIEW 2010.

II. LITERATURE SURVEY

Different papers were studied while working on this project. Following are the inferences made from this literature survey:

Table 2: Summary of the papers reviewed

Author	Title Of The Paper	Platform/Implementation	Methodology
Chen, Dong & Zhang, Run & Zhu, Xiao & Xiang, Xi. [7]	Modelling and simulation for automatic train protection systems using an integrated algorithm	Uses integrated algorithm to model and simulate the ATP system on the LabVIEW platform	1. Calculation of speed curve with the use of predictive control and fuzzy control. 2. Features include warning, removing traction, applying brake & emergency brake. 3. Focused on stopping the trail on or before prescribed location and avoid collision.
Compiled by: Kaushal Kumar (Dir./S&T, RDSO) [8]	TECHNOLOGY SURVEY REPORT: HS - Automatic Train Control: Concept of System	Studies and compares different ATP and ATO systems of different countries to device an appropriate ATP system for full range practical implementation over Railways.	1. Tracking trains, 2. Controlling the train intervals, 3. Setting routes in the railroad compound, 4.Controlling level railway crossings, 5. Setting provisional speed limits, 6. Controlling parallel operation on a single track, 7. Controlling system entry and departure, 8. Ensuring maintenance safety, 9. Controlling train protection control.
B. Y. Guo, W. Du & Y. J. Mao [9]	Research on the simulation of an Automatic Train over speed Protection driver-machine interface based on	Platform Independent Model of the ATP driver-machine interface using ICV (Core Interface-Frame Controller-View).	The View was used for the description of interface visualization. The Frame Controller accomplished the communication between the driver and the on-board vital computer (VC) by the display of different views. The Core

	Model Driven Architecture		Interface provided the information bridge among View, the driver and VC.
Flammini F [10]	Automatic Train Protection Systems	A computer-based railway interlocking system (IXL) is composed of CPU, MMI, TC and CC.	In case of an erroneous or late intervention by the train driver, which interacts with the system by a Man Machine Interface (MMI), the on-board control system automatically commands the braking procedure, directly acting on train-borne apparels via a specific interface, namely the Train Interface Unit (TIU).
K.C.Kumaresh, S.Janana Sandeep, R.Ramkumar, G.Vijayalakshmi [11]	Auto Pilot Security System for Railway Gates using LabVIEW	To replace manual railway level crossings with an automatic system by using myRIO with LabVIEW	The proposed system uses the IR sensors to detect the arrival and departure of trains and the gate is opened or closed accordingly. The gate is operated by Servo motors.

Inferences

Following inferences were drawn out of the literature survey in Table 2.

1. Prior ATP systems only control speed with respect to maximum permissible speed and doesn't account for temporary or engineering speed limits.
2. Prior ATP systems are found to be using expensive and delicate equipment and software. Practical implementation of such system would need extensive training and capital investment.
3. ATP systems have been focused on avoiding collisions by stopping the train before the signal or obstruction.
4. Prior ATP systems use application of brakes and/or emergency brakes to halt the train when required.
5. LabVIEW has been found to be effective software to simulate such ATP systems.

III. PROBLEM FORMULATION

We aim to design a system that would assist LP to control the speed of a locomotive and maintain it well within the Sanctioned speed and/or Caution Speeds. Such a system would ensure proper running of the trains as well as avoid accidents that are caused or assisted by over-speeding.

Following features will be provided in ATP system that is proposed here:

1. The system shall be able to measure the speed, acceleration and location in real time.
2. System shall allow and accept Caution Speeds inputs. Preferably, controller will be able to update Caution Speeds during running too.
3. The Input medium and output mediums shall be user-friendly and shall not require technical knowledge.
4. The system shall calculate SLs and WLs and from the given restrictions. And Audio-Visual Warnings should be provided to the LP when WLs are surpassed.
5. This shall be equipped with a tool which would apply breaks, or cause deceleration when SLs are surpassed. Break pressure or magnitude of deceleration can be prefixed or can be updated in the run-time.
6. To ensure that in no condition, the Locomotive shall pass the given Caution Speeds, a sub-system should be given where the acceleration would be disconnected or cut-off as soon as real time speed is matched with the Caution Speed in the given section. Acceleration control will be back to the LP as soon as the speeds are within SLs.
7. A By-Pass system control shall be provided which would help the LP to start from dead-stop, or allow the loco-pilot to use his/her discretion when there is overlap in Caution Speeds or for some unforeseen situations.
8. This system shall be easily applicable on different and all times of rail-road vehicles.
9. The system should be simple & cheap, and shall have minimum components, so that fault identification and remedy would be easy.
10. Such system shall be easily adaptable, and have least possible deviation from the presently employed system.
11. Data of speeds and acceleration can be collected by the system and presented in easy forms at the controller end for quality assurance and future references, if required.
12. System shall be customizable with respect to value of deceleration.

In the absence of a real locomotive, we shall design and simulate this system on LabVIEW. We are employing use of LabVIEW to design a system which will take real-time inputs from the sensors and will control the output to a comparable limit set by the programmer to avoid accidents. Following block diagram in Figure 1 depicts the similar methodology to be adopted to implement this LabVIEW based system.

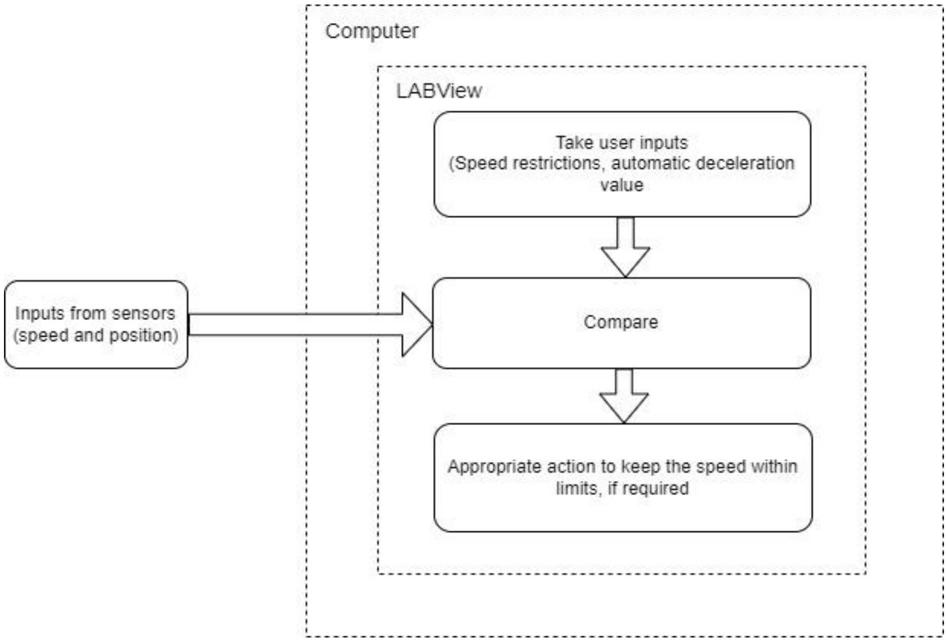

Figure 1: Block diagram of proposed methodology.

IV. IMPLEMENTATION AND RESULTS

A simplified flow-chart algorithm of proposed ATP system that would assist the LP in controlling over speeding in accordance with the permanent and/or temporary Caution Speeds, is shown in Figure 2. Inputs including speed, position, Booked or sanctioned speed, and Caution Speeds are taken from user and sensors/transducers. From those, appropriate Safety Limit (SL) and Warning Limit (WL) are calculated. The System then checks if the position of the Locomotive is in any Kilometer range of the entered caution. If yes, then system uses applicable Caution Speed and the corresponding SL and WLs. If no, then system uses Booked or Sanctioned speed and the corresponding SL and WLs. Thereafter, Comparator compares the speed with the Limits and decides the required output as per the program. Outputs are applied in the locomotive through actuators.

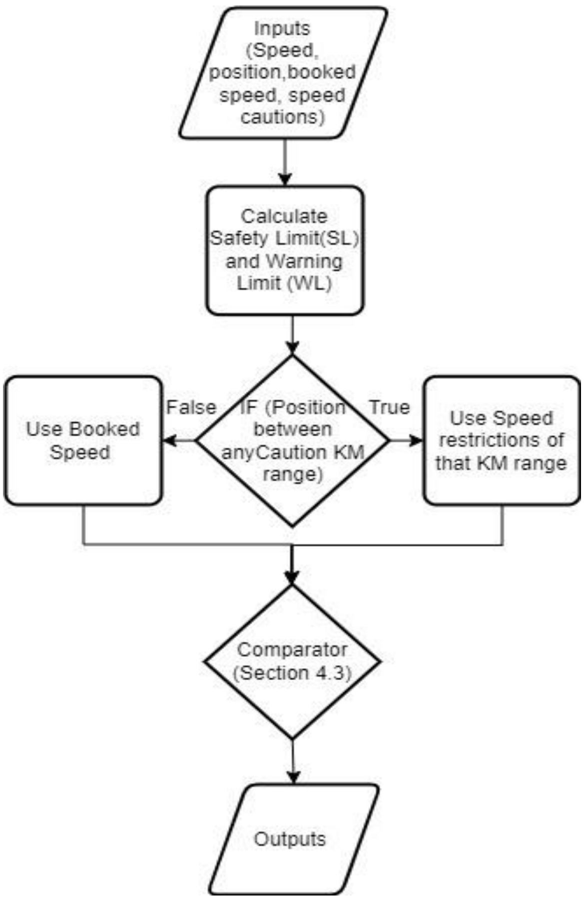

Figure 2: Simplified flow-chart algorithm of proposed ATP.

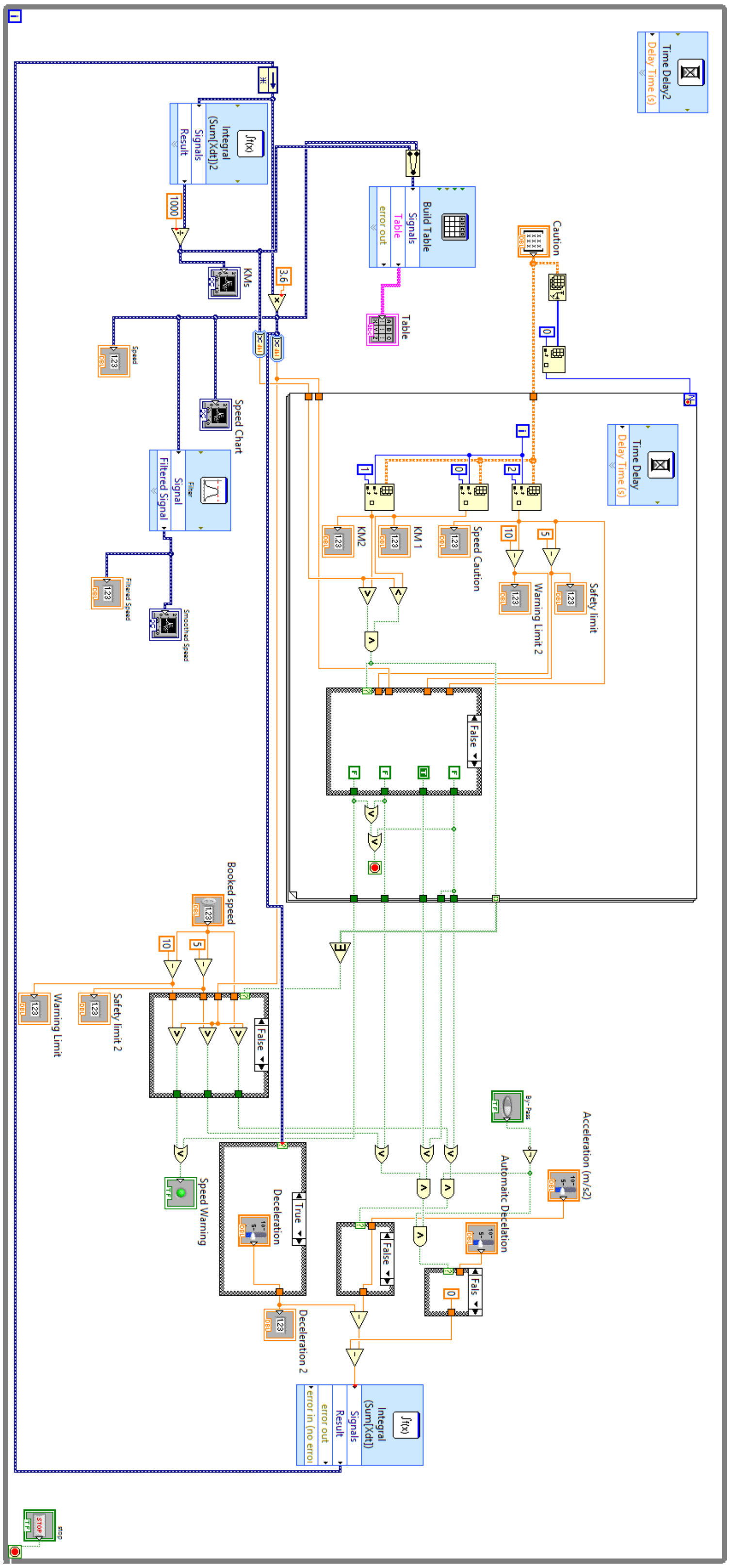

Figure 3: LabVIEW block diagram of proposed Automatic Train Protection system.

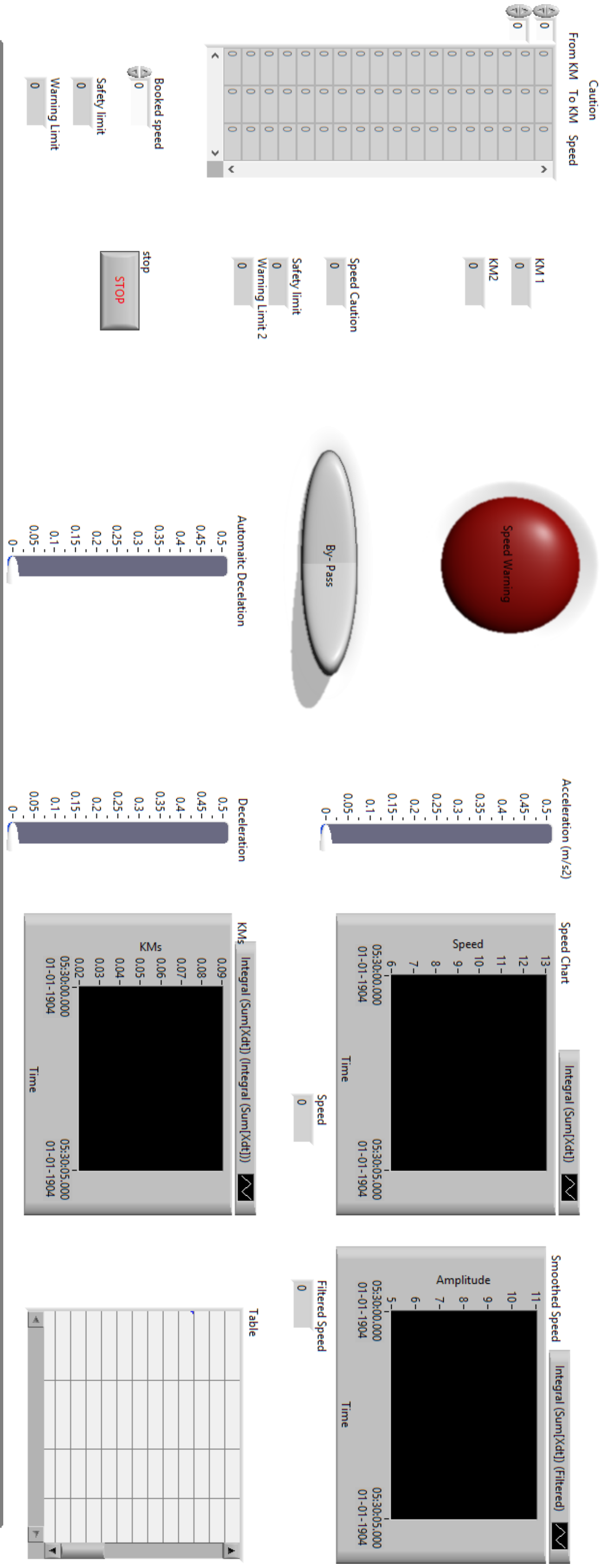

Figure 4: Front Panel of the proposed Automatic Train Protection System.

Test Run

The program was run many times, with different data sets, and has been working as expected. It was able to act according to the algorithm and control the speed.

Following is the details about one of such test run.

Initial Inputs are set as:

Booked Speed: 100 km/h (Figure 5)

Automatic deceleration: 0.05 m/s^2

And Caution (Figure 5)

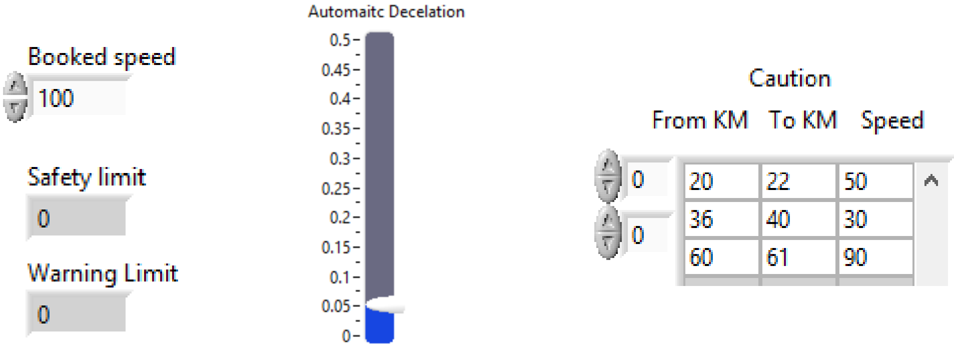

Figure 5: User inputs of Booked speed (Left) and Automatic Deceleration (Middle) and Caution (Right).

Run Time Inputs:

Acceleration is gradually increased from 0 to 0.1 and then not varied for simplicity.

To simulate/optimize a case where LP is inattentive, deceleration/brake has been set to 0 m/s^2.

Following are the snapshots of the front panel while running this program.

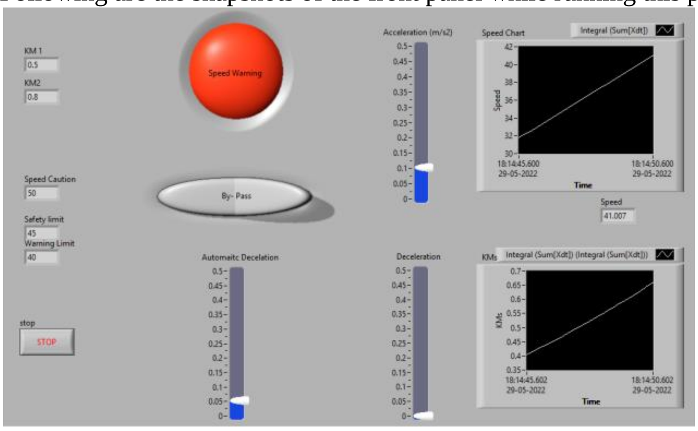

Figure 6: ATP running, Warning LED On.

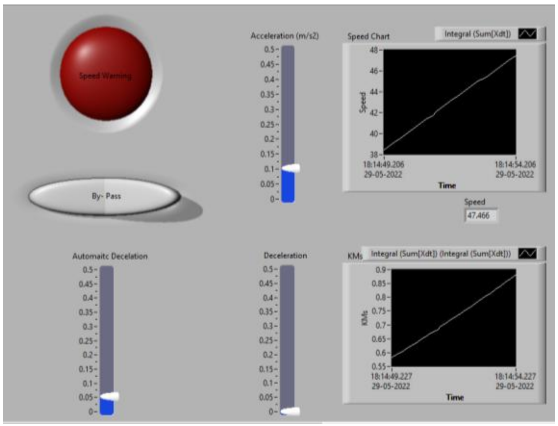

Figure 7: ATP running, Warning LED Off.

In Figure 6, on the left applicable KM range is shown (i.e. 05-08) and corresponding Caution Speed and limits are displayed. Since the speed is higher that WL (40 km/h), Warning LED is ON.

As soon as the train comes out of the caution KM range (Figure 7), system switches back to booked speed and its corresponding limits. Hence Warning LED goes back to OFF position.

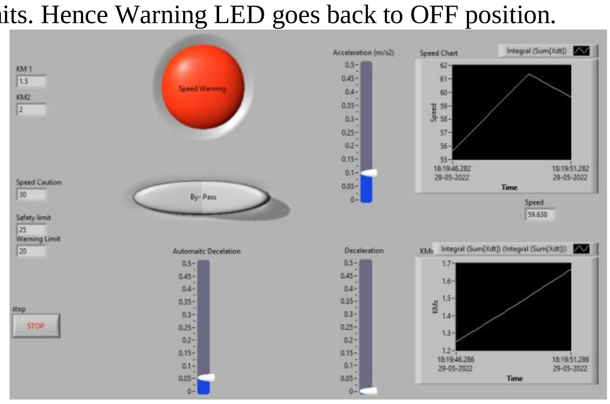

Figure 8: ATP running, when Caution Speed is surpassed

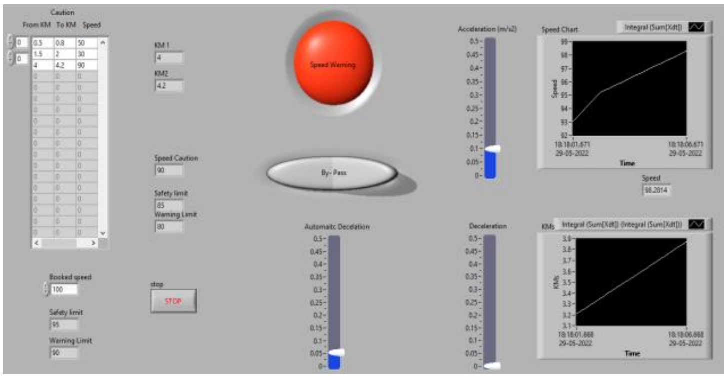

Figure 9: ATP Running, when SL is surpassed.

At left most in Figure 8, Since the speed is higher than Caution Speed itself, Acceleration is cut-off, and automatic deceleration is applied, hence the speed starts to decrease. This will be so, till speed come back to Caution Speed value (i.e. 30km/h).

Here (Figure 9), position of train does not lie in any Caution KM range, so applicable Speed restriction is Booked speed. As soon as the speed passes WL (i.e. 90km/h) LED turns on and further, when speed passes SL (i.e. 95 km/h) decrease in the rate of increase of speed is noted. It happens due to application of automatic deceleration (0.05 m/s^2). So the net Acceleration decreases to 0.1-0.05 = 0.05 m/s^2.

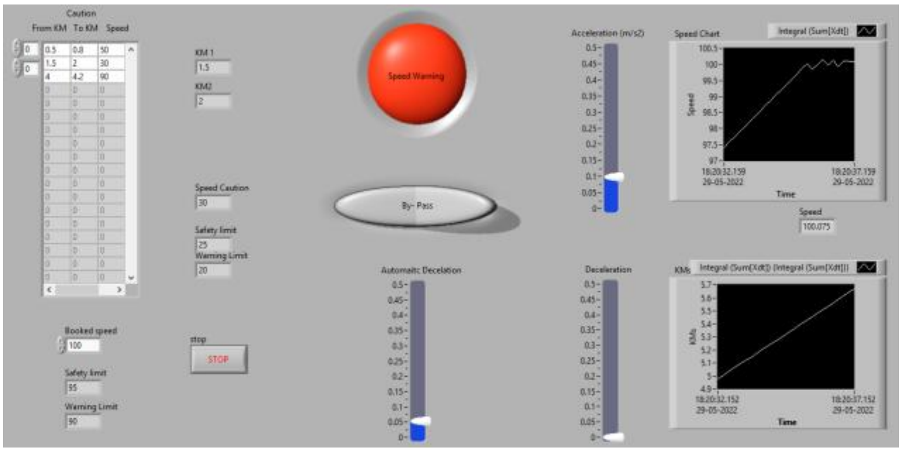

Figure 10: ATP running, speed not allowed to surpass Booked speed.

When there is further increase of speed (Figure 11), it would reach the booked speed (i.e. 100 km/h). Acceleration would be disconnected so that speed doesn't increase any further. From the graph we notice that speed is fluctuating at the mean of 100 km/h.

When the By-pass is On or True, complete safety system is by-passed except the warning system. The system would not intervene with the acceleration or deceleration of the locomotive.

V. Conclusions

Proposed ATP system was designed in LabVIEW 2010, and tested for different set of input values. System worked as per our expectations and kept the locomotive from surpassing the Caution Speed, even without any interference of LP.

Due to enormous cost and inaccessibility of life-size train, we had to simulate the situation on LabVIEW. Data inputs have been kept similar to those one may find in the real situation.

Such a system can be implemented in any and all types of self-propelled rail-road vehicles. This system can be easily used in combination with vast range of present and upcoming technologies.

This system is methodologically close to one used in the present time, hence it would be easy to implement this system with minimal training and capital cost. Owing to its simplicity, it requires minimal look-after or maintenance. Any malfunctioning can be identified and rectified easily.

Further Scope

Following are some of the many further developments that can be made in this system:

1. Panel in front of LP may display Digital Caution order or upcoming Caution Speed.
2. System can be developed so that it would identify Railway signals and modify the speed according to them.
3. This can be integrated with systems at other departments, so that any change in Caution Speeds would automatically be updated in the Train Protection system.
4. Position of the Locomotive can be inputted from the kilometerage marked on the OHE poles.

Such system can be used with a vast range of present or upcoming technologies.

References

1. Lecture Notes in Mechanical Engineering, 2020, 305- 313 Access at http://repository.iitr.ac.in/handle/123456789/19821
2. "Rail Transport", E-Article from https://en.wikipedia.org/wiki/Rail_transport
3. "INDIAN RAILWAYS YEARBOOK 2019-2020" access at https://indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/Annual-Reports-2019-2020/Year-Book-2019-20-English_Final_Web.pdf
4. "INDIAN RAILWAYS GENERAL & SUBSIDIARY RULES 2020" access at http://www.zrtich.in/Upload/G&SR_NR_184.pdf
5. INDIAN RAILWAYS – SAFETY PERFORMANCE -- LOK SABHA SECRETARIAT, NEW DELHI. Access at http://164.100.47.193/Refinput/New_Reference_Notes/English/Indian%20Railways-Safety%20Performance.pdf
6. Rail accident data by NCRB via https://www.hindustantimes.com/india-news/over-13-000-train-accidents-in-2020-32-lives-lost-daily-on-average-ncrb-report-101635646106710.html
7. Chen, Dong & Zhang, Run & Zhu, Xiao & Xiang, Xi. (2017). "Modelling and simulation for automatic train protection systems using an integrated algorithm". International Journal of Heavy Vehicle Systems. 24. 140. 10.1504/IJHVS.2017.10003613.
8. TECHNOLOGY SURVEY REPORT: HS - Automatic Train Control: Concept of System; Compiled & Prepared by: Kaushal Kumar Dir. / Signal & Telecommunication, Urban transport & High speed directorate, Research Designs & Standards Organisation. (Access at https://rdso.indianrailways.gov.in/works/uploads/File/High%20Speed%20%20Signalling%20Concept%20System.pdf)

9. B. Y. Guo, W. Du & Y. J. Mao. "Research on the simulation of an Automatic Train over speed Protection driver-machine interface based on Model Driven Architecture". https://www.witpress.com/Secure/elibrary/papers/CR10/CR10002FU1.pdf
10. Flammini F (2013) Automatic Train Protection Systems. Ind Eng Manage 2: 120. doi: 10.4172/2169-0316.1000120
11. K.C.Kumaresh, S.Janana Sandeep, R.Ramkumar, G.Vijayalakshmi. (2016) "Auto Pilot Security System for Railway Gates using LabVIEW" Access at https://www.ijareeie.com/upload/2016/february/55_%20Auto.pdf