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REVIEW PAPER ON POSITIVE TRAIN CONTROL TECHNOLOGY

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ABSTRACT
This review paper focuses on the positive train technology also referred to as PTC (a technology which serves to ensure efficiency, safety and reliability during the train operations in the track) by automatically stopping the train when the train operator seems not to take the required appropriate action when need be, it serves mainly to get rid of accidents caused due to negligence of the train operator or inability to control the freedom of mobility of the train. It looks into the technologies such as Chinese train control systems, Communication based control systems, European train control system all of which can be considered to be part of the Positive train control, other than that, this paper tries to look into what led to creation of this system, the building units and operational layers of a complete PTC system, analyses each unit and its operations and looks further into the challenges affecting the operations of a PTC system try to explore the future trends in this field.

KEYWORDS: Train, system, control, track, signal, PTC, communication.

INTRODUCTION
Positive Train Control (PTC) is a cutting edge technology with an ability to automatically control train velocity/speed and movements, in an event that a train operator fails to take appropriate action in the prevailing conditions like slowing or stopping the train when required. This technique integrates GPS, wayside sensors and communications units with centralized office also known as centralized train control (CTC) dispatching system. This system track trains, communicate operating commands and remotely observe the crew's compliance to the signals and speed restrictions. PTC will automatically bring the train to a stop if the system detects that a violation or equipment failure is about to occur to prevent specific human-error accidents.

MILESTONES IN TRAIN CONTROL
[1] Highlights some major generational evolutions in the development of the modern train control system, the milestones can be groups as generations as described below basing on the unique strides as grouped into first generation, second generation, third and fourth generation.

First Generation Train Control Philosophy
This generation of train control detects the train by use of track circuits and wayside signal guides the train operators on movements along the track, if the wayside signal displays an eminent danger, the trip stops. With this train control concept, virtually all of the train control logic and equipment is located on the wayside, with train borne equipment limited to trip stops. Train operating modes are restricted to manual driving modes only and the achievable train throughput and operational flexibility is limited by the fixed-block, track circuit configuration and associated wayside signal aspects. This train control philosophy has served the industry well and continues in revenue service operation at many major transit properties around the world, such as London Underground and New York City Transit for example. In New York, the original signal system designs in the early 1900's were based on a fixed block overlap system, requiring at least two clear blocks for a caution signal and three clear blocks for a proceed signal. Track circuits were used for train detection, as they have been for all systems that followed up to the present day. Interlocking machines used both electric and mechanical locking to prevent conflicting moves. Local tracks were initially only signaled at interlocking and at locations where the train operator's visibility was restricted by sharp curves. To maximize throughput on the local tracks,

less signal protection was provided and greater reliance was placed on the train operator's ability to run on sight. However, as a result of accidents and incidents, in 1927 the New York State Transit Commission ordered the installation of block signals with trip stops (i.e. automatic train protection) on all local tracks throughout the subway and elevated system.

Second Generation Train Control Philosophy

This generation of train control philosophy just like the first generation relies on track circuit. However, Cab signal replaces the wayside signals therefore providing continuous ATP through the use of speed codes transmitted from the wayside through the running rails to the train, such coded track circuits were developed by signaling suppliers in the USA around the middle of the last century and although they were not immediately applied to mass transit railways, they ultimately were to make a significant contribution to this next generation of mass transit train control systems. [2] With this train control philosophy, a portion of the train control logic and equipment is now transferred to the train, with equipment capable of detecting and taking action based on the speed codes, and shows the signal aspects and allowable speed limits as Cab signal for the train crew. This phase of train control technology allows automatic driving modes, but train operational flexibility and efficiency are still bound by the track circuit layout and the number of speed codes available. This generation of signaling technology was applied to most new mass transit systems that entered service in the latter half of the 20th century including the Washington (WMATA), Atlanta (MARTA) and San Francisco (BART) systems in the USA, and the initial rail lines in Singapore and Hong Kong. Many mass transit agencies also adopted this technology in order to transition to automatic train operations (ATO) with continuous ATP, such as London Underground's Central Line re-signaling.

Third Generation Train Control Philosophy

The next significant evolution in train control philosophy continued the trend to provide more precise control of train movements by increasing the amount of data transmitted to the train this made it possible to supervise and control the train to operate basing on a specific speed/distance profile, as opposed to just responding to a confined number of individual speed codes. This generation of train control technology, also referred to as "distance-to-go" technology, can support automatic driving modes, and provide for increased train throughput. Under this train control philosophy, the limits of a train's movement authority are still determined by track circuit occupancies.

Fourth Generation Train Control Philosophy

This generation of train control concept is can also be referred to as transmission-based train control (TBTC) or a communications-based train control (CBTC). Previous generations discussed earlier supports automatic driving modes and supervises/controls train movements in accordance with a defined speed/distance profile which tend to be limited. However, as with CBTC technique the physical track circuit boundaries also referred to as sections does not confine the degree of movement but are determined by the exact train position reports described by "moving block" also known as "virtual block" control concept. Transfer of significantly more control and status information than it was not possible with the earlier generation train control systems is made possible through elaborate communication system which uses GPS has continuous train-towayside and wayside-to-train data communications network. In that regard, CBTC systems offer the greatest operational flexibility and can support the maximum train latency and optimum track capacity, limited only by the limitations of the physical track alignment and the performance of the rolling stock.

IMPLEMENTING NEW TECHNOLOGY TRAIN CONTROL SYSTEMS

The newer generation of train control systems discussed above represent a cost-effective means of improving the level of service offered to mass transit passengers in terms of safety, comfort, reliability and dependability while ensuring that optimum usage of track capacity is achieved and the travel distance is reduced on the available transport network and infrastructure. Such systems allow trains to operate safely at shorter headways and permit system operations to recover more rapidly in the event of a disturbance; all of which provides more regular and improved passenger service and translates directly to increased line capacity and measurable increases in ridership. Through this New technology train control systems, lower maintenance costs will be achieved (as a result of improved diagnostics and fewer trackside equipment), enhanced safety (due to continuous automatic train protection), greater operational flexibility, improved reliability, smoother and more predictable operation, and availability (through redundant/fault tolerant designs). They can also provide a foundation for further integration of transit system control functions. This extra role provided for by the wayside to train communication platform could be passenger related information, programmed and automated announcements and even relay information about the train general health and required maintenance schedule to the control and maintenance centre. The increased dependency on communications-based, computer-based, and software-based technologies associated with these systems introduces new project risks, however, and it is clear that realizing the benefits of new technology does not come without significant challenges. Experience from around the world has shown that a top-down systems engineering and systems integration approach to design, procurement and construction management are essential ingredients to project success. [1]

Chinese Train Control System (CTCS)

As described in [3]the concept of CTCS was put forward in 2002 for the Chinese railways by the Ministry of Railway. The working program for CTCS came into operation a few years ago. This system aims at ensure maximum efficiency, safety and reliability and guides the Chinese railway construction. Many signaling systems used in Chinese railways are not interoperable due to the reasons of historical and technical development. CTCS will solve the problem of lack of standard signaling system in Chinese railways. The existing signaling systems cannot be interoperable, and the direction of the new signaling systems is not clear. Due to the challenge of interoperability, the CTCS provides signaling standards for the Chinese railways so that the current and future signaling system can be interoperable. The problem of incompatibility was common in Europe some years back before the European Train Control System (ETCS) project started in 1992.

European Train Control System (ETCS)

This system began in 1992 as a requirement of the European railway network development, this was mainly to ensure interoperability between tracks and existing systems as there was at least 15 different Automatic Train Protection (ATP) systems in operation(these ATP systems were incompatible as they were made and supplied by different companies with their own unique operation standards) and also as a result of development of high speed train, train cross border became unavoidable and therefore to enable for smooth operations, a standard system was coined. ETCS is a subsystem of ERTMS (the European Rail Traffic Management System) and can also a time be referred to as ERTMS/ETCS. ERTMS includes Euro-interlocking, ETCS (Euro-cab), GSM-R (Euro-radio), Euro-balise. European railway signaling suppliers called as UNISIG with the support from European researchers and European Union, commenced working for ETCS ten years ago. The goals of ETCS can be described further in [3]

ERTMS (European Rail Train Management System)

[2] defines as the system that meets the ETCS standard and provides for everything from simple ATP functions to full moving block signaling. The equipment is supplied by a number of companies and has to be functionally compatible. Across Europe many ERTMS based signaling schemes have been introduced most of them at level 1 (which retains the basic signaling but adds automatic train protection by a spot transmission system), or level 2 (also fixed block but which introduces radio based signaling). The introduction of level 3 (full moving block signaling with no track circuits) has not, so far, been implemented on a commercial scale. For trans-border trains, a common radio communication system is required. This system (termed GSM-R) is based on the standard GSM mobile radios, but has additional functionality and a dedicated frequency allocation.

CBTC (Communication Based Train Control)

CBTC systems also known as Transmission based Train Control (TBTC) are known as comprehensive, integrated and intelligent control systems for rail systems including mainline railways, light rails and underground lines in cities. As the technology continue to evolve and development of more autonomous computers, communication system and data control and analytic system, CBTC is foreseen to be a very reliable tool for controlling most of the railway operations including speed controls etc in the near future. As described in [3]at present, CBTC has been used in light rail and underground lines in cities, at the moment not many mainline railways have been synchronized with CBTC as there are some hindrances i.e cost, technical complexities etc which shall be discussed later on this paper. This system has proved to be a very handy tool to ensure railway safety, efficiency and reliability as it also can optimize the capacity of the available track network; application of CBTC makes the dispatching system more flexible and efficient. It can be said that CBTC is the nerve brain of the railway system.

CBTC system comprises of the following four major subsystems as explained in [1]:

1. CBTC-ATS equipment
2. CBTC Wayside Equipment
3. CBTC Train-borne Equipment
4. CBTC Data Communications Equipment.

The CBTC-A TS equipment includes equipment installed at central and or wayside locations responsible for Automatic Train Supervision functions such as identifying, maintaining operating schedules, tracking and displaying trains and generally regulating train movements. The CBTC wayside equipment consists of a network of processor -based wayside controllers installed at central/wayside locations. The CBTC wayside system may interface with an external separate interlocking subsystem, or alternatively the interlocking functions may be incorporated within the CBTC wayside equipment. Each wayside controller interfaces to the CBTC train-borne equipment via the CBTC data communication equipment and may also interface to external interlocking and CBTC-ATS equipment. The CBTC train-borne equipment consists of a processor-based controller and associated speed measurement and location determination sensors. The CBTC train-borne equipment interfaces to the train subsystems and also interfaces to the CBTC wayside equipments and the CBTC-ATS equipment via the CBTC data communication equipment.

The basic principles of operation of a CBTC system include:

a) High resolution train location determination, by CBT train-borne equipment, independent of track circuits.
b) Communication between the interlocking about the status and the wayside equipments and from the wayside equipments to the interlocking equipment to support CBTC operations.
c) Communication of this train location information, and other train status data, to CBTC wayside equipment over the CBTC train-to-wayside data communications link.
d) Communication of movement authority information and other train control data to the appropriate train over the CBTC wayside-to-train data communications link.
e) Determination and enforcement of the ATP profile by the CBTC train-borne equipment.
f) Conveyance of information between wayside controllers which are neighboring each other to facilitate the hand-off of train control.
g) Sharing of vital information amongst a number of the CBTC train borne equipments so as to enhance the CBTC operations.
h) Determination of movement authority information for each CBTC-equipped train, by the CBTC wayside equipment, based on train location information and inputs from interlocking.

Other than the existing communication modes and CBTC technologies through GSM and GSMR [3]also proposes a new ground-to-train communication system using free-space optics between a train and the ground. In the proposed system, a cylindrical concave lens spreads the incoming beam from transmitter (Laser Diode, LD) horizontally to form a wide fan-shaped beam. The fan shaped beam is projected to a train and the width of the projected beam is equal to the length of a typical bullet-train car. In this concept, horizontally spread beams are received continuously from the transmitter with cylindrical concave lens by a corresponding receiver (Avalanche Photo Diode, APD) which are installed on a train and the ground. The train can keep a communication link continuously to the ground thanks to this spread beam.

MOVING BLOCK CONTROL SYSTEM

[3] gives a description of how a Moving Block (MB) concept works; The traditional Mass Transit systems using track circuits or axle counters as a method for detecting the presence of the train are ‘fixed block’; the block being defined as the fixed length of the track circuits and axle counters. With the advancement of the CBTC systems: it is now possible to know the real time position of the train as the train communicates its

exact position by GPS satellite to the Central Train Control or by use of radio as the communication medium thus making it possible to have a
'moving block' also known as (variable Block) operation, for this particular operation mode it is not necessary to have fixed signals installed along the track as the train can know information like the speed and the position of the train ahead and the train behind through active communication system between the trains which can also be displayed as Cab signal. A moving block system allows the trains to run closer to each other compared to a conventional fixed block system, thus reducing the possible headway and therefore increasing the line capacity. However, CBTC systems may also operate within a 'fixed block' mode, if required to, thus permitting increased compatibility with traditional systems, while compromising on the headway. [4]explains further how each train determines its own location and reports it to the Radio Block Center. The Radio Block Center calculates the safe movement limit of each train in real time, basing on the known position of all other trains in the area and track conditions.

What gave rise to PTC?

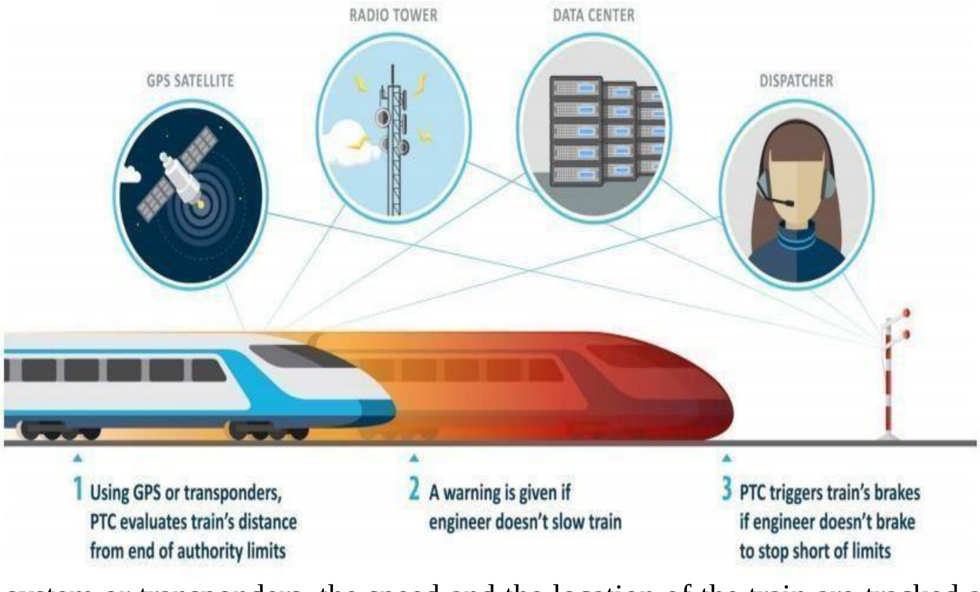
A vital accident which killed 25 people and injured 135 others occurred in California on Sept. 12, 2008. [5] The collision occurred as a result of human error as the accident report from the National Transportation Safety Board (NTSB, 2010) indicates that the driver was texting and failed to observe the red warning signal, On analyzing the context of the accident, reports states that it was avoidable. To avert such future occurrences, Congress passed the Rail Safety Improvement Act (RSIA) of 2008. The RSIA mandated PTC for the majority of locomotives and track in the United States although the use of the PTC is widely spread all over the world at the moment. This accident was PTC-preventable.

OBJECTIVES OF PTC

PTC is expected to prevent train accidents attributable to human error, by slowing or stopping trains automatically. [5] The main objectives of PTC are:

- To avoid/prevent collisions between trains i.e head on collision or head-tail collisions.
- To ensure that no derailments occurs due to excessive speeds.
- To prevent occurrence of accidents if trains are routed down the incorrect track.
- To prohibit unauthorized train movements on tracks undergoing maintenance.
- To ensure that there is no movements of trains through misaligned railroad switches.

HOW DOES PTC WORK



Using the GPS system or transponders, the speed and the location of the train are tracked and a relay of this information occurs between the wayside signals installed along the track and the central train control (CTC) and this information can as well be relayed to the train and displayed as Cab Signals. This integrated system ensures that the train movements along the track can easily be monitored and controlled. Positive Train control technique uses both the hardware i.e the wayside signals and the software to offer instructions and commands on what the train should do. A good example of how it works is that if a train is running at a prohibited speed or trespassing through an area which it should not be, then a warning signal is sent to the crew, and if the crew doesn't respond then the train applies brakes automatically stopping further movements.

There are two main PTC implementation methods currently being developed. The first makes use of fixed signaling infrastructure such as coded track circuits and wireless transponders to communicate with the onboard speed control unit. Whereas the other utilizes wireless data radios spread out along the line to transmit the dynamic information. This approach of wireless information makes it possible to implement the use of variable or moving blocks as the train continuously communicates its position thus creating a virtual block. The wireless implementation seems complex and needs sophisticated communication network however looking at the cost analysis it makes perfect sense as it achieves increased track capacity usage.

UNITS OF PTC CONTROL

PTC system can be described in basis of three common units considered to be its building blocks, [6], it **comprises** of train onboard systems, and equipment's installed along the track and a central control unit also known as a 'back office server'.

i. **Onboard or locomotive system**: They are located inside the train and it monitors the train speed and position and can control the train operations i.e braking the train hence stopping further movements.
ii. **Trackside/Wayside system**: They are located along the track line and are responsible for monitoring of switches, track signals and general track status and it relays data or information needed to permit the onboard system to allow or stop the train movement. iii. **Centralized control unit/ back-office server**: This is the unit that receives and stores all the data and information about a rail network and the information about the trains in that network i.e information about the speed restrictions, position of the trains with respect to each other, train compositions, train movement authorization etc, and relays this information to individual locomotive onboard enforcement systems.

PTC integrated system has to identify the precise location, the speed and the direction of the train and warn the train crew accordingly by comparing that information with the same data from the other trains using the same track and other track restrictions from the wayside equipments. Should the operator fail to take action as may be required, the PTC system must be able to stop the train

The fundamental operations of a PTC system should meet the operational requirements set in place by the Rail Safety Improvement Act (RSIA) of 2008 in terms of its ability to prevent accidents or collisions incase the train operator fails to take the required action.PTC is a group of a number of technologies serving to ensure safety of the train. [5].Rail tracks are allowed to use various PTC technologies once approved by the federal Railroad authority, a body which is in charge of performance standards. Various units namely the locomotive computer, wayside device, communication network, and back office the locomotive computer is an onboard piece of equipment that accepts speed restriction information and movement authority and integrated into the PTC system, so that these data can be compared against the train's location to ensure compliance. The wayside equipments are located along the track and they are responsible for communicating the status of the switches and signal status. Back-office if for communication and coordination of trains relative status i.e speed and its position. The back office can be categorized into three main parts: (the control/back office server (BOS), the geographical information system (GIS), and the dispatch office) interface with other components of the PTC systems. The BOS stores the information such as the composition of the track, speed limits, and the general track status to aid in operations of the trains, in a nut shell the Back office provides information regarding the movement authority and speed restrictions to the loco computers. There are however a number of communication technologies being researched on presently to make the PTC system more efficient

LEVELS OF OPERATIONS

The primary operations of a PTC system can be categorized into levels as shown below depending on the control action it offers: Each level has a distinct role it does to ensure proper efficiency of the PTC system as described by [6].

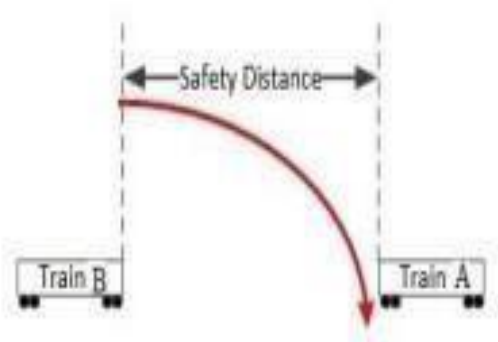
- **PTC Level 1**: Responsible for prevention of train collisions,protecting track workers and enforcing speed limits.

- **PTC Level 2**: Does the roles of level 1 and in addition responsible relay of train information I.e the position and speed and also responsible for digital transmission of authorities.
- **PTC Level 3**: Does the roles of level 2 and in addition to that it also monitors the wayside equipments i.e signals, protective devices in traffic control territory and the status of all switches.
- **PTC Level 4**: Does the roles of level 3 and also wayside monitoring for all mainline switches, signals and protective devices.

The basic characteristics of a PTC system are:
- Determine the exact position of the train precisely with no necessary reference to track circuits.
- Provide continuous communication between the train and the wayside and the wayside to the train to permit the transfer of status and control information.
- Wayside and train borne processors to process received train status and control data and provide continuous train control as required.

PTC offers significant operational advantages, such as improved safety, increased track infrastructure utilization, reduced maintenance costs through a significant reduction in the amount of wayside equipment, and the extension of signal operations in non-signalized territory.
Key considerations in PTC:

Safe Braking Distance
[3] defines a traffic management system generally based on a set of supervision curves relating the permitted velocity of the train to the running distance, the main objective a braking curve is to be able to ensure that the train can brake safely (decelerate from maximum velocity to stopping mode) without collision with other trains and the time of braking can easily be determined. The braking curve is important as it is used to determine the braking distance and compare it with the available distance: This can be clearly and accurately determined using safety defined coefficients.
For a PTC system this particular curve is very important because safety is the primary goal of such a system and this therefore ensures that the stopping of the train is made possible in a safely manner, the operation of traffic on a railway network necessitates a good control of the stopping behavior of the trains using a signaling system. For the majority of train operations currently in place, the train operator gets main information via signals placed at regular intervals along the track ordering the train to stop or decelerate before the danger point, for example: another train or switch or even station. The necessity of optimizing the traffic density and the new possibilities of technology have led to the design of on-board automatic train control systems that calculate, with data transmitted from the ground, the exact distance to prevent passing the danger point, this system automatically computes a "safe" distance, represented by a "safe" curve function of the train speed, beyond which the train is not allowed to run. A sample safe braking curve is shown below:



Key train parameters such as: the weight of the train, the speed, the rail friction coefficient, the distance available etc. is useful in determining braking curves. Safety is the priority in making such considerations and therefore the braking curves has to be 'safe', and have assurance that the actual braking performance of the train will be sufficient to guarantee the respect of the objective speed.
(The basic formula for calculating the braking distance from one speed v1 i.e maximum speed to a lower speed v2 i.e 0 velocity can be given as [3]:

$$\text{Braking distance (dbr)} = \frac{v_1^2}{2.\text{dec}} - \frac{v_2^2}{2.\text{dec}} \qquad (1)$$

Where braking distance can be represented as (dbr) and (dec) is the trains' deceleration ability, in m/s^2 . When dbr, dec and v2 are available, then v1 is given by:

$$v_1 = \sqrt{2.\,dbr.\,dec + v_2^2} \qquad (2)$$

Therefore, if the allowed speed at position p is known, then the allowed speed at position p-1 can be obtained as:

$$v_{p-1} = \sqrt{2.\left(pos_p - pos_{p-1}\right).\,dec + v_p^2} \qquad (3)$$

The trains' deceleration is dependent of the gradient and of the train speed. However, we know that the gradient over the distance is fixed and available as the next gradient change in the table (in tablerow (p) or later). Gradient and deceleration relationship is defined by the following formula:

$$dec = dec_0 + g.\frac{grad}{100} \qquad (4)$$

Where dec0 is the zero gradient deceleration, g≈9.82 m/s2 (gravitational acceleration) and gradient (grad) is expressed in percentage. To clearly understand the concept, we can consider a scenario where the slope is 100% and the dec0 is zero. The deceleration would then become approximately 9.82 m/s^2, which represents free fall acceleration.

As mentioned earlier, dec0 is dependent on the trains' speed, in accordance with the deceleration ability table. If we assume that there is a function fvtodec available which looks up the table and returns the dec0 deceleration as function of train speed, then we know that the dec0 is equal to fvtodec(vp) at position p. dec0 at position p-1 is however unknown at the moment, but we assume tentatively that it is the same as at position p, and can then calculate dec as:

$$dec = f_{vtodec}(v_2) + g.\frac{grad_p}{100} \qquad (5)$$

Using dec above, v1 is now tentatively calculated. If v1 has the same deceleration dec0 as v2, then v1 is correct. To check this, we assume there is a function frangehigh which again looks up the deceleration ability table and returns the highest speed which has the same deceleration as its argument. The condition for v1 to be valid is:

$$f_{range\,ig}(v_2) \geq v_1 \qquad (6)$$

If this is not the case, then a stepwise process is used to calculate the valid v1. First we calculate the position where the allowed speed = v2' = frangehigh (v2) using the basic brake distance formula (2) above:

$$pos_{v2} = pos_p - \left[\frac{v_2'^2}{2.\,dec} - \frac{v_2^2}{2.\,dec}\right] \qquad (7)$$

Where dec is calculated according to formula (5) above. Once we know the permissible speed at position posv2'. We can then perform tentative calculation of v1, again using equation (3) but now substituting v2 by v2' and posp by posv2'. The new tentative v1 is then compared with the new (higher) frangehigh (v2'). The process is continued until we reach a value v1 which is <= frangehigh (v2'). The value of v1 obtained shall be compared to the target speed at the new posp1, if there is one. The lowest value shall be regarded as the allowed speed at posp-1. The process continues towards the train, and is interrupted when the end of the brake delay distance is reached.

Reliable Communication System

Continuous, reliable and efficient communication between the PTC operational blocks i.e the locomotive on board devices, the wayside equipments and the back office is very important in making operations of PTC successful, there are many possible communication technologies being used and which are currently being researched for future use in the PTC system. [3]describes that one of the suitable communication system in modern CBTC systems is based on radio transmissions, common in the 2.4 GHz ISM band which has an ability to reduce chances of interferences from other systems by use of a spread spectrum technique. The communication medium chosen can be based on 'line of sight, or leaky coax using a RADIAX cable, or both depending on the application .However, [7] proposes a dynamic headway system for PTC which improves safety and increases track capacity. It employs an active communication system and is designed without compromising on reliability, safety and performance. The distinct features of the proposed system are: 1) Dynamic headway policy based on active communication between the control center and trains that lead to much smaller headways than existing ones that are based on brick wall scenarios and fixed-block policies. 2) A backup headway switching policy in case of loss of communications that gracefully increases headway to the new situation without sacrificing on safety. 3) A train dispatching system that utilizes the dynamic headway as well as the backup headway in case of communication failure in order to improve track capacity.

Interoperability

[5] Defines Interoperability as a state of compatibility in which PTC must be able to communicate with one another so trains can seamlessly move across track owned by different railroads with potentially varying PTC technologies. [8]Interoperability is achieved when the locomotives of any host railroad and tenant railroad operating over the same track segment can successfully communicate with and respond to the other railroad's PTC system, allowing uninterrupted movements over property boundaries. A good example is when a train crosses into another territory as a "tenant", that train needs information about that track such as interim speed restrictions due to works along the track or any other relevant information. This aspect of a "tenant" train can be best described as interoperability.

To achieve interoperability, railroads have to complete a series of steps including:

1) Additional installation work (such as installing equipment on a tenant railroad's locomotives) and scheduling.
2) Laboratory testing.
3) Field testing.
4) RSD or revenue service operations. Many railroads will complete much of the implementation for their own PTC systems, such as starting RSD on some or most of their track, before they begin to take steps to achieve interoperability with other railroads.

However, a railroad can take steps to achieve interoperability with other railroads while simultaneously completing field testing or other stages of testing on its own PTC system. [5]Interoperability among railroads is a significant challenge in the development and deployment of PTC systems, requiring both hardware and software upgrades.

HINDARANCES TO SMOOTH IMPLEMENTATION and Future challenges OF PTC SYSTEM

i. Resource constraints/Cost/Expense: PTC initial implementation cost is very expensive as it uses sophisticated technology.
ii. Interoperability: PTC systems adopted by various railroads must have inter-train communication so that trains can move seamlessly between tracks controlled by different systems. Achieving PTC interoperability in some rail lines might be complicated due to the nature of network available and system being used.
iii. Technology availability: [6]PTC technology is sophisticated and several providers have different standards i.e Chinese and Europe have different technologies, for an existing rail line that technological modifications needs to be incorporated . iv. Bandwidth availability: To support PTC-related transmissions, railroads must secure sufficient radio spectrum bandwidth from existing license holders.
v. PTC CYBER SECURITY: PTC cyber security Cybercrime is a growing threat to infrastructure. Any successful unauthorized intrusion to the system can pose serious safety threats, this can mainly be used by terrorist who have intent to cause havoc and safety threats, affecting the economy or other areas of national security. In the past, train to train intercommunication was not, so direct connections were used (such as one wire connecting to a device without shared communications). Modern railroad communications are digitally connected via Ethernet, Transmission Control Protocol/Internet Protocol (TCP/IP), or a similar networking standard this communication channels has its own risks like cyber attacks. A cyber attack on a PTC system can be catastrophic. [9]To solve this problem, detection-based approaches [e.g., intrusion detection systems (IDSs)], serving as the second wall of protection, can effectively help identify malicious activities.

vi. Communication failures: In an event that there is a disruption in the radio communications link between the trains, the whole system might have to enter a fail-safe state until the problem is sorted out. Equipment malfunction, weak signal strength, frequent handoff, electromagnetic interference, or saturation of the communications medium may result into communication breakdown [9]. Building a train control system over wireless networks is a challenging task. Due to unreliable wireless communications and train mobility and the threat of cyber attack as discussed above, the train control performance can be significantly affected by wireless networks. This is the reason why, historically, CBTC systems first implemented radio communication systems in 2003, when the required technology was mature enough for critical applications.

POSSIBLE FUTURE ADVANCEMENTS and EMERGING TRENDS IN PTC

Innovative cutting-edge technologies in train transport industry such as PTC s are focusing to achieve a zero accident rail operations. In the foreseeable future, it will be possible to incorporate artificial intelligence (AI) and Internet of Things (IoT) into the PTC system so that it can autonomously make its own decision even without necessity of wayside signals and instruction from central train control unit.

Furthermore, with more advancement in geo-mapping, advanced communications systems and upgraded locomotive hardware, railroads have new tools in their ongoing efforts to increase capacity, optimize customer service and reduce fuel use and emissions.

In addition, incorporating faulty or broken track detection system to PTC is very important as it will play a critical role in prevention of accidents due to track related failures.

Driverless trains which are automatically controlled by PTC systems are the trains of the future, more research need to be done in that area to make it possible.

Finally, there is ongoing worldwide interest in developing standards for these new technology train control systems to support interoperability across the globe and reduce costs.

This PTC technology can also be used in ensuring accident free operation in other modes of transport other than railway i.e in cable cars.

CONCLUSION

PTC is very instrumental not only in ensuring safety in the rail line but also improving the level of service offered to mass transit passengers in terms of dependability and comfort while providing increased capacity and reduced travel times on an existing transportation infrastructure, with the advancement in high speed rail system and more advanced technology developed every day in the transport industry, PTC will also experience more modifications and improvements to ensure more reliability in its operation, there exists some limitations to implementation of this system like the cost involved in the initial installation, however looking into the long term cost benefit analysis, it makes a lot of sense to adopt this technology. With this technology in place, most of the accidents which could have occurred as a result of human error will be greatly minimized.

This system will also optimize capacity of track infrastructure as it enables trains to operate safely at shorter headways and permit system operations to recover more rapidly in the event of a disturbance; all of which provides more regular and improved passenger service and translates directly to increased line capacity and measurable increases in ridership.

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