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Safety Analysis of Communication Timeout and Latency in a Positive Train Control System

SUMMARY

The goal of this Federal Railroad Administration (FRA)-sponsored study was to provide an independent safety analysis of a Positive Train Control (PTC) system as proposed by North American Joint Positive Train Control (NAJPTC) with regard to the effect of PTC's communication timeout threshold and latency on safety and performance at high speeds, as compared to ATS known levels of safety at speeds of up to 110 miles per hour (mph).

In January 1998, FRA, in conjunction with the Association of American Railroads (AAR) and IDOT, began to develop a high-speed PTC project for the Union Pacific Railroad (UP) between St. Louis, MO, and Chicago, IL, which is referred to as the IDOT Corridor (Figure 1). Development of this PTC system was terminated then revived at the Transportation Test Center, Inc. (TTC) in Pueblo, CO. However, analysis in this project using IDOT corridor traffic continues to provide valuable insight into the question of timeout and latency on the safety performance of PTC and other train control systems using wireless communication.

The analysis considered the effects of timeout and latency on a traffic mix of 6 passenger trains per day and one freight train almost everyday, unequipped freight trains that varied in frequency from one train every three days to more than 2 trains per day depending on the season, and an IDOT sub-corridor under consideration. Train speeds varied between 35 and 110 mph depending on the train type. PTC latency values were allowed to vary from 5 and 20 seconds and communications timeout values extended from 120 and 360 seconds. Initial conclusions from this risk assessment are that for this particular corridor, traffic volume, traffic mix, and PTC latency and timeout values, there was no material effect on safety. Contrary to pre-analysis expectations that safety considerations would be the primary factor in specifying maximum acceptable timeout and latency for a PTC system, non-safety considerations such as route capacity, delay reduction and cost may actually be the governing factors in specifying timeout and latency. The final analysis showed that the PTC system as tested, was as safe as, or safer than the UP cab signal/ATS system.

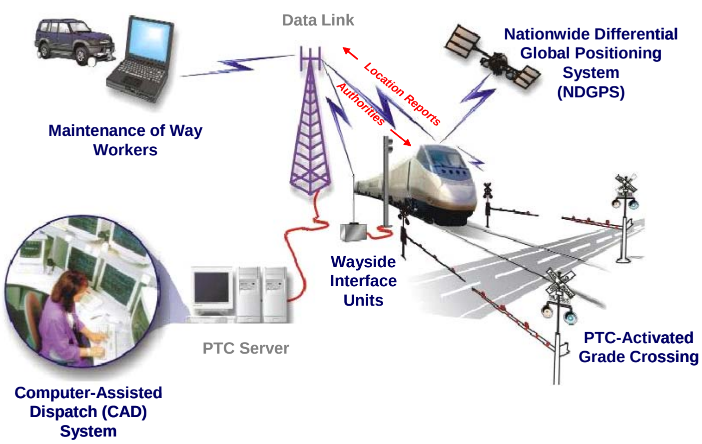

Figure 1. A Typical Positive Train Control System Configuration as Established by the North American Joint Positive Train Control Program

BACKGROUND

Positive train control (PTC) is a system for the safe control of railroad operations using wireless communications, position tracking using GPS combined with inertial navigation systems, and central processors to prevent conflicting train movements leading to collisions, overspeed events and failure to comply with work zone limits.

In general, two types of messages are communicated through the PTC system — those carrying functional data (e.g., location and speed of equipped trains, authorities for action, track circuit status, switch status) and safety heartbeats. The heartbeat messages from each system element inform other elements, including the central office system that it is healthy and the communication is intact, thereby achieving a closed loop. Two fundamental aspects of the communication system are defined as follows:

- Timeout - the length of time that the PTC system detects no communication or heartbeat message from a device within the system, before it declares a “fault condition” and imposes appropriate actions for fail-safe protection.
- Latency - the length of time passing between when a communications message is initiated at the point of origin and when appropriate actions corresponding to that message are initiated at the destination system. This time includes the response time of any PTC sub-systems involved in the message path and communications queuing delays.

This phase of the study evaluates the influence of the communications timeout threshold of the proposed NAJPTC system on the overall safety performance of the system, as compared with a base case train control system. The base case considered in this study is a cab signal system with continuous train stop system, or an ATS system. An ATS system will allow trains to operate above 79 mph in accordance to FRA regulations. The analysis provides insight into the general question of the influence of timeout and latency on the safety performance of PTC and other train control systems using wireless communication, compared to the originally intended system as the base case for the NAJPTC project.

APPROACH

A series of risk models is used to compare the safety performance of the PTC system on the IDOT Corridor employing various timeout and latency values with the same corridor equipped with the UP cab signal and ATS system. Passenger trains are assumed to operate at speeds up to 110 mph in all cases.

Quantifying risk is essentially an accounting exercise, and this study adheres to the traditional definition of risk as modeled below:

[RISK] = [ACCIDENT FREQUENCY] x [ACCIDENT CONSEQUENCE]

where:

- [RISK] is the total financial harm caused by accidents, measured as estimated fatalities, injuries, and property damage as reported to FRA multiplied by the dollar values assigned to these accident types [casualties (fatalities plus injuries) and property damage] using standard DOT figures.
- [ACCIDENT FREQUENCY] is an accident rate expressed as the number of accidents per unit of exposure. This study uses the most common measure, accidents per million train miles, for passenger train accidents. A combination of train and car miles was used for freight train accidents depending on accident cause; accidents due to mechanical failures of car or track components are a function of car miles rather than train miles. For grade crossing collisions, the exposure measure is the number of times a train passes over a crossing.
- [ACCIDENT CONSEQUENCE] is the harm caused a single accident (injuries, fatalities and property damage), and varies by train type, train size, speed, accident scenario, and similar factors.

To estimate total risk on a specific railroad corridor with a specific train control system, risk is calculated for:

- Each relevant accident scenario and sub-scenario;
- Train control system operating state (i.e., normal, timeout and downtime);

- Operating conditions by route segment and time period (i.e., train speed, traffic density and mix).

The calculations estimate individual accident frequencies and consequences for each combination of scenarios, operating states and sets of operating conditions; these values are then used to calculate the corresponding individual risks. Finally, the individual risks are totaled to give overall risk and breakdowns of risk by any selected parameter (e.g., location, train type, accident scenario).

Because risks are quantified numerically and the conclusions of the study are drawn from comparisons between the analysis cases, this approach is called a comparative quantitative risk analysis. This analysis focuses on estimating the number of accidents and per-accident consequences (e.g., fatalities, injuries, and property damage costs). All risk analysis results are considered to be estimates and results are highly dependent on the availability of good accident frequency and consequence estimates. Risk comparisons are more reliable than absolute risk estimates because many inputs do not vary between analysis cases. For the purpose of this study, a risk comparison is very appropriate.

The risk calculation is based on a spreadsheet model comprised of several elements. A primary calculation worksheet performs risk calculations for each accident scenario, operating state and frequency/consequence combination. Other worksheets calculate collision probabilities between different train types and collision frequency estimates. Lookup tables provide inputs needed to perform the following calculations:

- Per-accident consequences by speed, collision scenario and train type;
- Route segment lengths, speeds and traffic;
- Collision frequency for each traffic density and mix;
- Grade crossing details and risk categories.

The model results provide a measure of total risk for each analysis case that combines property damage with injuries and fatalities due to those train accident scenarios in which risk could be reduced or affected by the PTC variants or the cab signal/ATS systems. These scenarios include collisions of all types including collisions at grade crossings, overspeed, broken rail derailments, and work zone intrusions.

The relevant train accident risks associated with the PTC system operating with different timeout and latency values are compared with the same set of risks associated with the ATS base case operating on the same IDOT Corridor with the same traffic levels. This approach identifies the maximum timeout period for the PTC system as that which would result in the same level of risk associated with the ATS base case.

Accident frequency estimates for the base case were derived from historical experience. However, because there is very limited operating experience with the IDOT corridor, accident frequency estimates for PTC cases were estimated from system capabilities and expected failure modes, reliability and availability of individual system components and sub-systems. Because many of these values are not known with accuracy, confidence in the end result could be much lower than for the base case. This in turn means there is a potential for lower confidence in the comparison between the cab signal/ATS base case and PTC case. This comparability problem was minimized by using a methodology that started from a common reference point or reference case from which reductions in accident frequencies were estimated for the base case and PTC case risk analyses. In the risk models used for this analysis, the accident frequencies for conventional passenger and freight operations with Centralized Traffic Control (CTC) and conventional wayside signals, block and interlocking systems are estimated from historical data. Then, the fraction of accidents of each type with CTC that would be prevented by the particular train control system being analyzed, either PTC or cab signal/ATS, is estimated, leading to an estimate of actual accident frequencies with the particular control system of interest.

CONCLUSIONS

The primary conclusions from this analysis are that *for this particular corridor, traffic volume, traffic mix*, *and PTC latency and timeout values*, PTC latency and timeout do not have a material effect on safety. The analysis also showed that the PTC system as analyzed passed the test of being as safe as, or safer than the UP cab signal/ATS system.

The principal reservations concerning these results and conclusions are that the results apply to a single-track corridor with a low overall traffic level, predominantly comprised of passenger trains. Analyses of corridors with dissimilar operating and infrastructure conditions could yield different conclusions, particularly where there are higher traffic levels, a higher fraction of unequipped trains within those traffic levels, differences in reliability and availability between control systems, and two or more main tracks.

Further details on this analysis are provided in [1].

FOR FURTHER RESEARCH

Phase Two of this study is currently underway to provide a comparison of the NAJPTC system to a second base case - a cab signal system with speed control, or an Automatic Train Control system.

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REFERENCES

[1] A. Bing, E. Sherrock, "Risk Analysis for the IDOT Positive Train Control System to Determine Optimum Communications Timeout: Comparison to a Cab Signal System with Continuous Train Stop," ENSCO Report No. DOT-FR-07-04, October 2007.

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KEYWORDS

Positive train control (PTC), IDOT Corridor, timeout, latency, risk assessment