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# North American Joint Positive Train Control System Four-Quadrant Gate Reliability Assessment

## SUMMARY

The implementation of high-speed rail (HSR) technology, at speeds of 80 to 110 miles per hour (mph) on corridors with pre-existing conventional rail service (up to 80 mph), requires upgrading the crossing activation technology with additional emphasis on safety by adding four-quadrant gates. Frequently, these crossings cannot be closed or grade-separated, and they are equipped with insufficient warning devices to support HSR operations. One solution, four-quadrant gates with inductive loop vehicle detection, was installed at 69 grade crossings on a 120.7-mile segment of the future 280-mile HSR corridor between Chicago and St. Louis. This segment, as shown between Mazonia and Springfield, Illinois in Figure 1, will carry passenger trains at speeds up to 110 mph, including at many of the highway-rail grade crossings. These and other infrastructure improvements were completed to reduce the Chicago to St. Louis travel time from 5.5 hours to 3.5 hours and increase the number of daily roundtrips in each direction from three to five.


**Figure 1. Chicago-St. Louis HSR route, with PTC section highlighted in yellow**

The project conducted a reliability analysis of the four-quadrant gate/vehicle detection equipment based on maintenance records obtained from the Union Pacific Railroad (UP), the owner and operator of the grade crossings. The results of this analysis were used to assess the impact of the equipment reliability on the proposed HSR timetable.

The study showed that the total average delay to the five scheduled daily high-speed passenger roundtrips was an estimated 10.5 minutes, or approximately 1 minute per train. Overall, extensive analysis of the trouble ticket data showed that the four-quadrant gate and vehicle detection equipment are as reliable as the conventional crossing gate while providing additional protection.

## BACKGROUND

The North American Joint Positive Train Control (NAJPTC) system, a demonstration of PTC technology on the future HSR corridor between Chicago and St. Louis, received $50 million in funding from FRA. This route, along with Chicago-Detroit and Chicago-Milwaukee, constitute the three Midwest HSR corridors designated by the Intermodal Surface Transportation Efficiency Act of 1992.

This effort is part of the broader Midwest Regional Rail Initiative (MRRI) that would eventually link nine states over a 3000-mile system encompassing nearly 80 percent of the population in the Midwest. The overall goal of this program is to achieve reliable and frequent HSR service with trains operating at speeds between 90 and 110 mph. The features of this service include new train sets, track infrastructure improvements, four-quadrant gate warning device technology at high-speed highway-rail grade crossings, and railroad signals accommodating the increased speed regimens.

***Four-Quadrant Gate Technology***

A typical four-quadrant gate crossing/vehicle detection warning system on the HSR corridor is shown in Figure 2. The core of this system is a microprocessor-based exit gate controller (EGC). The EGC works in tandem with the inductive loop detection subsystem to identify motor vehicle presence within the grade crossing and supply the appropriate input to the exit gates. During a train event at the crossing, the EGC prevents the exit gates from lowering until the vehicle detection system no longer detects motor vehicle traffic in the crossing. If the health of the vehicle detection equipment is compromised, the EGC re-directs the crossing to a safe operational state by raising the exit gates.

**Figure 2. Four-quadrant gate grade crossing in Gardner, Illinois.**

Each crossing has a subsystem that monitors the health of the gate and vehicle detection equipment. In a process known as Advance Activation, grade crossing health status is transmitted to an approaching train over a data radio transmission link. If the grade crossing health is normal, then high-speed operation will be permitted. Any compromise in the grade crossing equipment health will preclude the operation of high-speed passenger service and will result in the issuance of restricted train speeds of either 79 mph or 15 mph (depending on the health of the grade crossing).

## RESEARCH OBJECTIVES

- Determine the frequency and mean time to repair (MTTR) of grade crossing/vehicle detection equipment malfunctions.
- Model the impact of equipment malfunctions on the future HSR timetable.
- Identify reliability trends that may have a negative impact on the HSR service.

## RESEARCH METHODS

The evaluation methodology consisted of identifying and characterizing the malfunction types, calculating the probability of occurrence and MTTR for each malfunction type, and estimating the resulting cumulative delay on the proposed HSR schedule.

When a crossing alarm event is triggered, a “trouble ticket” is automatically issued and a maintainer is dispatched to the crossing. Accordingly, the functionality of the crossing equipment may be impeded, resulting in the temporary speed restrictions. Once the issue is resolved, the maintainer updates and closes out the trouble ticket. These records are stored electronically by the UP at its central office in Omaha, NE.

In April 2005, the Volpe Center, through FRA, submitted a request to the UP for trouble ticket reports associated with the four-quadrant gate vehicle detection technology installed on the Illinois HSR corridor. In May 2005, the UP forwarded trouble tickets pertaining to the exit gates, EGC, and the vehicle traffic detection loops for the period from May 2003 through May 2005 (Data Set I). In November 2005, the Volpe Center made a second request to UP for trouble ticket reports relevant to both entrance and exit gate maintenance calls. UP fulfilled this request in February 2006 by providing trouble ticket reports from February 2004 through December 2005 (Data Set II).

These two data sets were evaluated by the Volpe Center for trends in malfunction occurrences and maintenance downtimes that may impact the future HSR timetable. The second set was employed as part of a comparative analysis of the four-quadrant gate/vehicle detection system and the pre-existing dual-gate grade crossing equipment.

## FINDINGS AND CONCLUSIONS

Data Set I consisted of 93 trouble tickets collected over 726 days. Three malfunction types totaling 27 percent of the trouble tickets – EGC, loop processor, and loop detector failure – were identified as specific to exit gate malfunction. As shown in the Figure 3 pie chart, loop detector equipment accounted for 23 percent, mostly arising from oversensitive detectors. This condition was typically resolved by decreasing detector sensitivity, but maintaining it above the motor vehicle detection threshold.

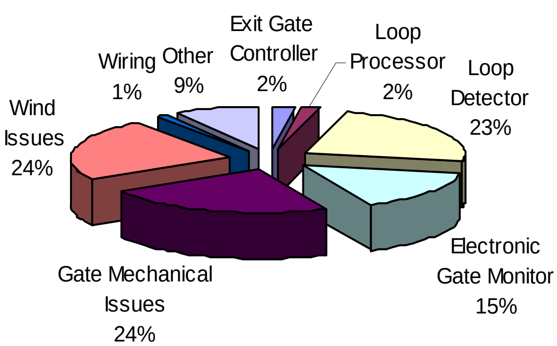


**Figure 3. Exit gate issues from Data**

Data Set II entrance and exit gate malfunction data were used to analyze the impact of the four-quadrant gate/vehicle detection system on the high-speed timetable. The data collection period spanned 677 days between February 2004 and December 2005. In total, 889 unique trouble tickets were tabulated, equating to an average of 1.31 malfunctions per day. Altogether, 37 different malfunction types were identified. Analysis of the data showed that 8

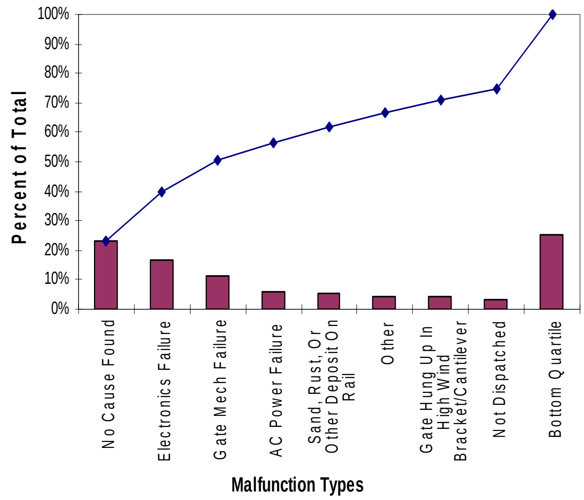


**Figure 4. Pareto distribution of malfunctions from Data Set II by reported cause.**

malfunction types, as depicted by the Pareto distribution in Figure 4, contributed to 75 percent of the total number of trouble tickets. Likewise, the other 29 types were associated with the remaining 25 percent.

The weighted probabilities of occurrence and MTTR for each malfunction type were used to calculate the impact of the four-quadrant gate/vehicle detection system on the proposed high-speed timetable. Further analysis of the MTTR data revealed a significant time-based component with several orders of magnitude between the highest and lowest values. This is more typical of a log-normal distribution rather than a normally distributed, symmetric distribution. For this type of application, the geometric mean, which is related to the log-normal distribution, provides a more realistic depiction for averaging data.

The geometric averaged weighted daily delay for each malfunction type is shown in the third column of Table 2. These values were calculated from the product of the event probability, number of trains affected per day, and the worst-case delay experienced by a single train from a malfunction (110 seconds).[1] This calculation yielded a probabilistic estimate of the contribution from each malfunction to the average of 1.31 malfunctions per day. These

[1] This is the difference between the times to traverse an operational crossing at 110 mph and a malfunctioning crossing at a restricted speed of 15 mph.

values, found in the third column of Table 2, also showed that the top eight malfunction types contributed approximately 8 minutes to the total 10.5 minutes of average weighted daily delay. Assuming a 10 train daily schedule, this equates roughly to an average of 1 minute per train.

The last column in Table 2, Delay Index (DI), is a measure of the delay incurred on the HSR timetable resulting from a particular malfunction type and is analogous to the expression for risk in safety-related research. DI is expressed as the product of the event probability and the average weighted daily delay (AWDD) resulting from each malfunction type where, AWDD is the severity term.

**Table 2. Expected delay on HSR timetable.**

| **Top 20% of Malfunction Events** | **Event Probability** (%) | **Average Weighted Daily Delay** (mm:ss) | **Delay Index** |
|---|---|---|---|
| No Cause Found | 23.17 | 1:40 | 38.37 |
| Electronics Failure | 16.54 | 2:22 | 39.08 |
| Gate Mechanical Failure | 11.02 | 0:47 | 8.38 |
| AC Power Failure | 5.96 | 0:42 | 4.10 |
| Sand, Rust, Or Other Deposit On Rail | 5.40 | 1:18 | 7.00 |
| Gate Hung Up In High Wind Bracket/Cantilever | 4.50 | 0:32 | 2.24 |
| Other | 4.50 | 0:19 | 1.25 |
| Not Dispatched | 3.49 | 0:19 | 0.35 |
| | | | |
| **Totals** | | | |
| **Highest 20%** | **75** | **07:50** | |
| **Remaining 80%** | **25** | **02:48** | |
| **For All Types** | **100.00** | **10:38** | |

Of importance is the marked difference from the AWDD values. More significantly, these results show that the AWDD may not necessarily be the best measure of the impact from a malfunction. For example, *Sand*, *Rust*, or *Other Deposit on Rail*, a rather low probability event, may occur concurrently at multiple grade crossings, potentially resulting in a significant impact on the HSR timetable.

The malfunction or improper operation of a small subset of components was predicted to result in potentially prolonged disruptions to passenger rail operations. The majority of trouble tickets were related to the maintenance of railroad signaling system components that are interconnected with the grade crossing electronics and not an indication of the four-quadrant gate/vehicle detection system reliability. One of these, *Sand*, *Rust*, *or Other Deposit on Rail*, could potentially result in loss of shunt and, under worst-case conditions, yield a delay of up to 1 hour per train. Multiple factors, including the number of impacted crossings and the repair time, are highly variable and could cause the effect to vary significantly. As a result, railroad inspection and maintenance procedures have been modified to minimize the frequency and impact of these events. Fortunately, longitudinal analysis of maintenance data will facilitate identification of such long-term trends.

Additionally, the majority of malfunction types did not originate from failure in any of the four-quadrant gate subsystems, but from external equipment such as the railroad signaling system. Moreover, an overwhelming majority of crossing malfunctions equally affected operations of both the entrance and exit gate equipment. Based on this research, railroad and state engineers will be able to review and, if necessary, modify maintenance procedures to optimize operation of the four-quadrant gate technology.

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