Impact of Communication/Detection Degradation on Advanced Traffic Management Systems Operations

Executive Summary

Prepared for

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Project Overview

Substantial capital investments have been made by the Florida Department of Transportation and many local transportation agencies throughout the state in Advanced Traffic Management Systems (ATMS). The benefits achieved by these investments often are affected by the failure of the various components of the system, especially the communication and detection components. The objective of this project is to understand and simulate the impact of communication and detection failure propagation through a typical control section of a traffic signal system. This can lead to the development of more effective management plans targeting cost-effective measures to critical portions of the ATMS communication and detection infrastructures.

The research team performed a thorough literature review of major traffic signal system architectures and conducted a comprehensive traffic agency survey throughout Florida to understand signal operations and maintenance practices. A practical traffic signal system performance concept and its corresponding performance measures were developed to evaluate the effects of detection and communication degradations. The traffic signal system degradation index developed in this study was used as the main quantitative measure of the system degradations. A series of sensitivity analyses was performed through traffic simulations to assess the impact of communication, detection, and traffic signal timing degradations on a typical control section.

Based on analyses of massive simulation data obtained from the sensitivity analysis, traffic signal degradation and performance models were developed to assist traffic agencies to effectively assess the performance of their traffic signal systems. Furthermore, the research team and its subcontractors developed short-term, mid-term and long-term improvement strategies that can be combined to provide transportation agencies with more cost-effective allocations of their maintenance resources for traffic signal systems.

Traffic Agency Survey

A comprehensive survey was conducted in January 2008 among 57 traffic/transportation agencies in Florida, with responses from 34 agencies that maintain approximately 12,000 signals. The survey results showed that the majority of detection equipment of surveyed agencies was inductive loop (92%). Video detection was the second most-used detection technology. Most agencies in the survey indicated that it took more than 15 days to repair broken loop detectors

and that 50 percent or more of the detection maintenance work was contracted out. For communication infrastructure (based on the number of signals), the survey found that the dominant traffic signal system architecture is centralized, followed by distributed without local masters (52% and 20%, respectively). Fiber optic and twisted pairs are the preferred technologies for communication between signals (39% and 37%, respectively), followed by leased lines (18%). For communication between signals and the central computer, fiber, twisted pair, and leased lines are fairly equally likely (31%, 35%, and 32%, respectively). The major causes of communication failures are device failure, cable cut, and lightning. Also, it was found that 52 percent of the agencies contract out 76 percent of communication repair work.

Effect of Detection and Communication on Traffic Signal Systems

To quantify the impact of detection and communication degradations in traffic signal system operation, a degradation index was defined as the main performance measure. The Degradation Index (DI) of a traffic signal system measures the increase in travel time with respect to the ideal travel time of the system. The ideal travel time for a given prevailing traffic condition is measured under fully-functional communication and detection components with an optimal timing plan. The DI is calculated as the percent of increased travel time due to system degradation relative to its observed travel time under degraded conditions (see Figure 1).

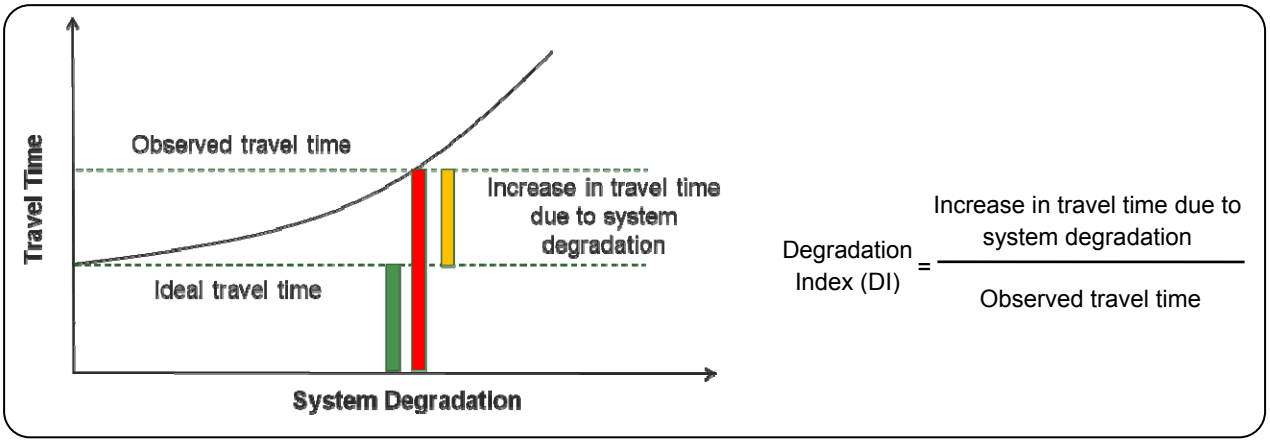

Figure 1 Degradation Index with Respect to Travel Time

A massive number of traffic microsimulation models were run to recreate the different scenarios for detection and communication failures. The simulation results showed that left-turn detection on the main direction was found to significantly affect the overall effectiveness of a control section. On the other hand, when detection was fully functional, it was found that communication failures significantly affected the system during high-volume scenarios. Communication failures were simulated by recreating the timeclock drifting behavior that typically occurs during these failures. Clock drifting was expressed as a percent of cycle length

as a measure of the severity of the communication failure. A series of charts was developed from this study to estimate the DI based on the combined effect of detection and communication failures under a specific traffic condition. For example, Figure 2 shows the combined effect of detection failures from a side street and left turns on a major street and communication failure due to 10 percent clock drifting on the DI for different traffic conditions, expressed as vehicles per hour per lane (VPHPL). Each section in the figure represents a set of detection failure scenarios. Each series of dots of the same color forms a trend line of DI under a particular traffic condition. It can be observed that combined detection failure and 10 percent clock drifting can account for 14 percent of signal system degradation. The degradation due to clock drifting is increased with longer communication repair times. Also, it can be observed that detection adversely affects system performance when traffic is moderate to low because most of the unused green time for a side street and left turns on a major street is lost due to detection failures. During high traffic volumes, only a little or no unused green time can be used for the major street; therefore, the system may become less sensitive to detection failures.

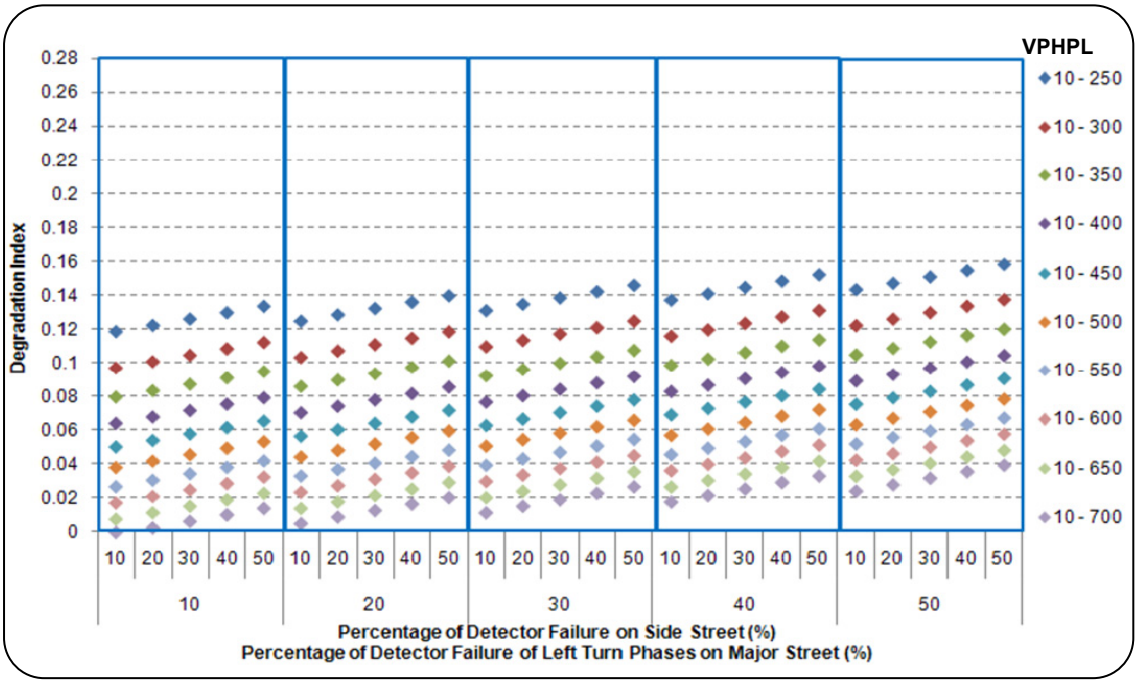

Figure 2 Degradation Index vs. Detection Failure by Different Volumes for 10% Clock Drifting

Resource Allocation Strategies

There are different sources of downtime in traffic signal systems, depending on the detection technology used, the present communication infrastructures, and the repair policies of the agency. In general, a resource allocation strategy should be targeted to reduce the impact of

communication and detection failures in the system, or equivalently, to increase the system operational status over time. The specific goals of the different resource allocation scenarios can be either to reduce the time it takes to get the system back to its ideal conditions (reduce downtime), or to increase the time the system is under its ideal conditions (increase uptime).

Based on this premise, the downtime of a component in a traffic signal system can be decomposed into passive downtime, discretional downtime, waiting downtime, and repair downtime, as presented in Figure 3. Passive downtime is the time interval between occurrence and detection of the failure. This component of downtime can be reduced by an effective communication infrastructure to identify problems early and/or through increased preventive maintenance. Discretional downtime is applicable only to outsourced maintenance jobs and comprises the time lapse between reporting of the failure and the instant when the work order for an external contractor is issued. Discretional downtime is the result of a service agreement between the external contractor and the transportation agency and may vary from one county to the other (e.g., issue a work order for six or more loops). The discretional downtime can be reduced through imposing high responsiveness restrictions on the contractors to promptly fix communication or detection problems at critical locations. Once the failure has been identified and scheduled for repair, the waiting downtime is directly related to the availability of maintenance technicians or contractors. The storage of proper inventories can also reduce waiting downtime. Ideally, with an infinite amount of resources, all downtimes can be reduced to the repair downtime.

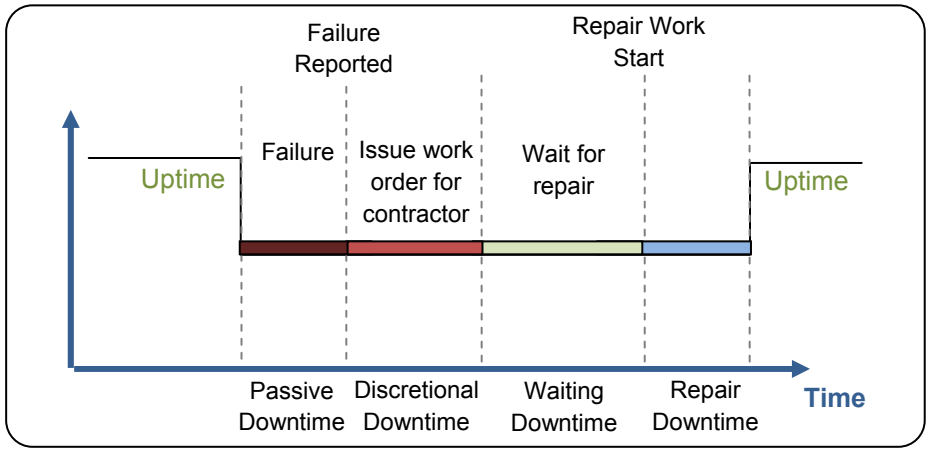

Figure 3 Decomposition of Downtime of a Traffic Signal Component

Based on the literature review, agency survey, detailed interviews, and input from subcontractors, a list of recommended possible resource allocation strategies is presented in Table 1. These short-term, mid-term and long-term resource allocation strategies are oriented to reduce the impact of the degradation of detection and communication systems and degradation of traffic signal timing and to improve system monitoring capabilities.

Table 1 Resource Allocation Strategies

Type	Improvement	Actions	Reduce Passive Downtime	Reduce Discretional Downtime	Reduce Waiting Downtime	Reduce Repair Downtime	Increase Uptime	Reduce Timing Degradation	Increase Monitoring Capabilities
Long-Term	Detection	Upgrade to video detection				x	x		x
		Upgrade to microwave detection				x	x		
		Upgrade pedestrian detection buttons							
	Communication	Upgrade communication to wireless	x				x		
		Upgrade communication technology to fiber optic	x				x		x
Mid-Term	Detection	Keep a safety stock of spare cameras and video processors				x			
		Impose high-responsiveness restrictions on contractors to promptly fix detection problems at critical locations		x					
		Increase available hours for in-house detection maintenance			x				
		Increase hours of preventive maintenance for detection equipment	x				x		
		Use of readily-deployable alternate detection technologies in cases of detector failures				x			
	Communication	Impose high-responsiveness restrictions on contractors to promptly fix communication problems at critical locations		x					
		Increase available hours for in-house communication maintenance			x				
		Increase hours of preventive maintenance for communication equipment	x						
		Use of readily-deployable wireless technologies in cases of communication failures				x			
		Install time-of-day receivers (GPS clock)					x		
	Signal Timing	Check/input time-of-day and coordination plans in controller once per month (time-based systems)						x	
		Synchronize frequency of retiming with traffic growth						x	

Table 1 Resource Allocation Strategies (continued)

Type	Improvement	Actions	Reduce Passive Downtime	Reduce Discretional Downtime	Reduce Waiting Downtime	Reduce Repair Downtime	Increase Uptime	Reduce Timing Degradation	Increase Monitoring Capabilities
Short-Term	Detection	Provide adequate training to maintenance staff					x		
		Run system reports for detection failures checking at critical intersections every other day (including pedestrian detection)	x						
		Closely inspect new installations of detectors, especially inductive loop					x		
	Communication	Provide adequate training to maintenance staff					x		
		Run system reports for communication channels once per week	x						
	Signal Timing	Check/input time-of-day and coordination plans in controller once per month (time-based systems)						x	
		Broadcast time-of-day plans to local controllers at least once per day						x	
		Fine-tune signal timing as needed						x	

Research Findings

- In general, traffic signal systems under distributed architectures are less sensitive to communication failures than those under centralized architectures. Adaptive traffic control systems, which are mostly under centralized architectures, are especially sensitive to detection failures.

- The results of a traffic agency survey in Florida indicated that most traffic agencies rank themselves slightly better on communication and detection system maintenance than on keeping their signal timing up to date.

- The result of the traffic agency survey showed that the top three suggestions to improve traffic signal system performance were (1) well-trained engineers, (2) well-trained technicians, and (3) increased budget.

- A practical traffic signal performance assessment should measure the performance of the traffic signal system itself, considering the status of system degradation. The signal system degradation index developed in this study provides a simple way to measure traffic signal system performance.

- For a typical control section with 8 – 10 coordinated signals, according to sensitivity analyses, the average travel time on the corridor can increase up to 40 percent depending on the degree of detection degradations.

- This study also found that failure of opposing left-turn detectors on the major street generally has more impact on the travel time on the major street than those of side-street detectors and requires a higher priority of response.

- For a typical control section with 8 – 10 coordinated signals, according to sensitivity analyses, the average travel time on the corridor can increase up to 22 percent depending on the degree of communication degradations.

- Detection failures have more effect at low-to-moderate traffic volumes. At higher volumes, the green times tend to be consumed in their entirety. In this situation, the coordinated directions take less advantage of unused green times in other phases.

- Communication failures have more effect at higher traffic volumes. This is mainly because communication failures directly affect the progression of a larger number of vehicles on the major street, which results in increased travel times on the major street.

- Detection degradations are built up over time as individual components fail. On the other hand, communication degradations can affect the system performance at a faster pace. The control section can experience dramatic increases in travel time when detection and communication failures occur simultaneously.

- For a typical control section with 8 – 10 coordinated signals, signal retiming can reduce the average travel time on the corridor up to 16 percent for a 15 – 25 percent growth of traffic volume since the last signal retiming. It is most beneficial to retime traffic signal systems when significant growth occurs on a control section with median traffic volumes.

- The recommended short-term, mid-term, and long-term resource allocation strategies are very beneficial for helping transportation agencies to reduce the impact of communication and detection degradations and outdated traffic signal timing and to improve system monitoring capabilities.

- Any transportation agency can use the process presented in this study to compute the percent improvement per dollar invested in the improvement strategy. After ranking the considered strategies, the agency can select the strategies with the highest ranking matching its needs.

Research Recommendations

- To provide substantial benefits to transportation agencies, it is recommended that further research be conducted to expand the results of the current research to cover city- and county-wide signal systems, conduct case studies with local transportation agencies, and document benefits and findings.

- It would be beneficial for future research to develop a user-friendly software or spreadsheet application that traffic agencies can easily use as a tool to effectively improve or enhance their traffic signal systems within their jurisdictions.