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A conceptual framework for dynamic extension of the red clearance interval as a countermeasure for red-light-running

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ABSTRACT

This manuscript describes the development and evaluation of a conceptual framework for real-time operation of dynamic on-demand extension of the red clearance interval as a countermeasure for red-light-running. The framework includes a decision process for determining, based on the real-time status of vehicles arriving at the intersection, when extension of the red clearance interval should occur and the duration of each extension. A zonal classification scheme was devised to assess whether an approaching vehicle requires additional time to safely clear the intersection based on the remaining phase time, type of vehicle, current speed, and current distance from the intersection. Expected performance of the conceptual framework was evaluated through modeling of replicated field operations using vehicular event data collected as part of this research. The results showed highly accurate classification of red-light-running vehicles needing additional clearance time and relatively few false extension calls from stopping vehicles, thereby minimizing the expected impacts to signal and traffic operations. Based on the recommended parameters, extension calls were predicted to occur once every 26.5 cycles. Assuming a 90 s cycle, 1.5 extensions per hour were expected per approach, with an estimated extension time of 2.30 s/h. Although field implementation was not performed, it is anticipated that long-term reductions in targeted red-light-running conflicts and crashes will likely occur if red clearance interval extension systems are implemented at locations where start-up delay on the conflicting approach is generally minimal, such as intersections with lag left-turn phasing.

1. Background and objectives

Red-light-running (RLR) at signalized intersections is a serious safety problem in the United States, contributing to right-angle, left turn head-on, and rear end crashes. Enforcement strategies (human and automated) are often used to reduce the occurrence of red-light-running by imposing the threat of a citation. However, enforcement is only effective in deterring RLR events where the driver could safely stop in time, but instead chooses to proceed through the intersection. Enforcement strategies will not reduce RLR events where the driver entered the intersection shortly after the red, but was either unable or unaware of the need to stop. Such events are more effectively treated by engineering countermeasures, including traffic signal phase extension systems.

Various detection and control strategies have been developed and implemented to provide on-demand extension of the traffic signal phase timings upon the detection of vehicles that will not likely clear the intersection prior to the start of the next conflicting phase. Such systems utilize one or more sensors to detect vehicular characteristics, such as speed, location, and classification, and include algorithms to predict when approaching vehicles will not likely clear the intersection prior to the impending conflicting green phase. Detection of a probable RLR event will inform the signal controller to extend a particular interval for either a preset or calculated amount of time. Until recently, the majority of such systems have been designed to estimate the optimal time to end the green interval based on consideration of both of RLR prevention and delay to vehicles waiting on other approaches (Kronborg and Davidsson, 1993; Bonneson et al., 2002a; Zimmerman, 2003; Middleton et al., 2011; Du et al., 2012). These systems have typically utilized point-detection from in-pavement loop sensors or side-firing microwave or radar, which afford a single predictive measurement of intersection arrival times at the intersection.

Prior to 2009, implementation of red clearance extension systems in the United States was prohibited by the Manual on

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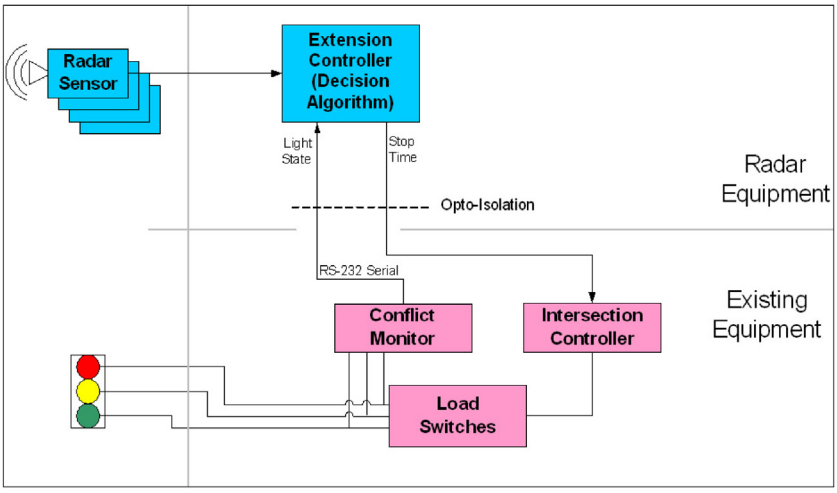

Fig. 1. Basic detection and control for radar-based interval extension system.

Uniform Traffic Control Devices (2003, 2009), as red clearance intervals were required to be of a preset fixed time (2003). However, the 2009 MUTCD included language allowing for on-demand extension of the red clearance interval on a cycle-by-cycle basis (2009). Such provisions, coupled with further advancements in vehicular detection technology, have facilitated development and testing of systems for extension of the red clearance interval (Zhang et al., 2011; Wang et al., 2012; Park et al., 2015), including for use within a connected vehicle environment (Chen et al., 2013).

Extension of the red-clearance interval relies on the ability to obtain and analyze dynamic, real-time data for vehicles on the subject approach, including speed, distance, and classification, and send the appropriate message to the traffic signal controller. Recent advancements in radar-based vehicular detection technology allows for real-time tracking of the trajectories for multiple vehicles approaching an intersection, which is relayed to the corresponding extension controller several times per second. A decision algorithm programmed into the extension controller software instantaneously analyzes the trajectory information based on a pre-programmed set of operating procedures and parameters. Fig. 1 depicts a basic schematic of the detection and control process for an interval extension system using radar detection.

An interval extension call is placed to the signal controller only if the algorithm determines that an oncoming vehicle can neither comfortably stop nor safely clear the intersection prior to the start of the conflicting green phase. The duration of the interval extension is based on the time needed for the vehicle to clear the intersection before the onset of the conflicting green, and is updated dynamically as the status of the approaching vehicle(s) changes. Fig. 2 displays a basic time diagram of the extension process for the red clearance interval.

Dynamic extension of the red clearance interval is a relatively new concept with only limited implementation. Furthermore, the operating parameters and procedures have not been broadly researched, and little is known about the potential impacts on safety, traffic operations, and signal operations. It was hypothesized that a properly defined dynamic red clearance interval extension system with appropriately specified operating parameters may potentially reduce conflicts and crashes caused by red-light running events, while having only minimal impacts on traffic operations and signal operations. The primary objective of this research was to develop and evaluate a conceptual framework describing the procedures and operating parameters for real-time extension of the red clearance interval, including determination of when to provide extension of the red clearance interval based on real-time vehicle trajectory data for vehicles approaching at the end of the signal phase, and the duration of such an extension.

2. Interval extension process

2.1. General concepts

The primary objective of a red extension algorithm is to identify vehicles approaching at the end of the phase vehicles that may potentially commit a red-light-running event and extend the red-clearance interval in real-time based on the maximum necessary amount of time needed for all potential red-light-running vehicles to clear. The basic flow of information for this process is shown in the following flowchart (Fig. 3).

2.2. Event classification

The detection procedure for interval extension is described as a means of classifying approaching vehicles into respective zones, based on whether it is predicted that a vehicle will:

- Stop prior to entering the intersection (Zone 1);
- Clear the intersection prior to the start of the conflicting green phase (Zone 3); or
- Not clear the intersection prior to the start of the conflicting green phase and also not stop prior to entering the intersection (Zone 2).

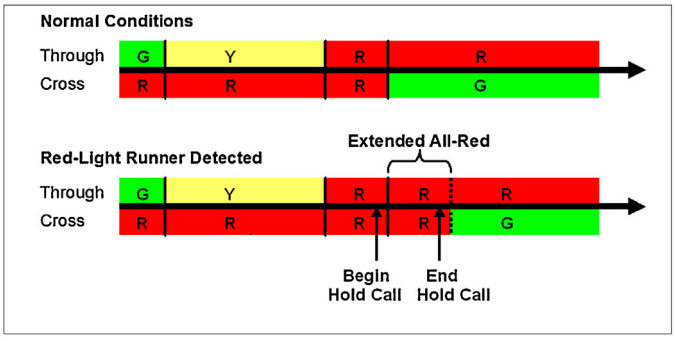

Fig. 2. Time diagram for extension of red clearance interval.

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