Vehicle-Infrastructure Integration (VII) and Safety: Rubber and Radio Meets the Road in California

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Emerging active safety systems such as forward collision warning, lane departure warning, curve overspeed warning and the like offer potential and significant benefits in transportation safety. Through the years there has been much research and development with these systems, field operational tests have been conducted or are underway, and a host of products are now available to drivers [1-6]. In the United States, the government focus in this area was primarily the Intelligent Vehicle Initiative (IVI) [7].

To date, a hallmark of active safety systems has been autonomous operation. A notable exception was the relatively small "sensor friendly vehicles and roadways" study sponsored by US Department of Transportation, with PATH as a significant participant. With this project, sensed (but not communicated) information from the infrastructure or other vehicles was studied for use in tandem with on-board driver-assist systems in a cooperative manner — with significant increases, potentially, in driver-assist system reliability and thus, effectiveness [8].

In recent years the concept of cooperative systems has gained further acceptance, as the revolution and proliferation of wireless communications has captured the attention and interest of infrastructure owner-operators, as well as vehicle manufacturers. With the allocation of Dedicated Short Range Communications (DSRC) bandwidth and the present IEEE effort in establishing standards [9], the concept of vehicle-roadside cooperative systems, recently dubbed in the United States as Vehicle-Infrastructure Integration (VII) is generating significant attention [10]. The idea that vehicles, these days equipped with several hundred sensors, the real possibility of Global Positioning System (GPS) becoming an additional and ubiquitous sensor, and a means to send sensed information off the Controller Area Network (CAN) bus to the infrastructure (and also from the infrastructure to the CAN bus) has manifold, revolutionary applications in Intelligent Transportation Systems.

Promising applications abound: with traffic and highway management (e.g., use of probe vehicles for traffic, weather and road surface condition), with in-vehicle travel information (e.g., dynamic route advisories), with crash and incident response (for immediate response and automated situational assessment), and central to this article, with cooperative active safety warning systems. There are bounds to such applications: a nominal DSRC radio range of about 300 meters, and importantly, the need for a great many of these radios to exist on the roadside, as continued on next page
well as within vehicles, in order for VII to work. Moreover, an indeterminate subset of roadside units (RSU), as these DSRC-equipped stations are often called, must communicate via some also indeterminate means to processing centers, and for larger scale applications, they must be processed.

**COOPERATIVE ACTIVE SAFETY SYSTEMS**

With cooperative active safety, vehicle-vehicle and vehicle-roadside communications could in principle aid in intersection warning where conflicting vehicles could “talk” others or the intersection could transmit its sensed or traffic signal phase information to vehicles (see article on IDS and CICAS in this issue of Intellimotion). Aid in curve overspeed could be given, also, where activation of stability control or tire slip differential systems could indicate poor road conditions for given vehicle state (which encompass dynamics and would uniquely include speed and weight). To use cooperative active safety in this application, vehicles could inform other vehicles or the infrastructure and the infrastructure could message vehicles wirelessly and/or direct to drivers via a roadside changeable message sign. Other applications include forward collision warning, where instead of reliance on a fused system of Doppler radar and perhaps other sensors, DSRC could transmit forward vehicle state to the following vehicles. This information would include braking rates and braking capacity, resulting in a more reliable rear-end collision warning system. Yet another application is in highway-rail intersection safety, where rail vehicles, the rail and road systems and crossing traffic could communicate. Undoubtedly, many other cooperative safety applications can be determined with DSRC as the principle enabling technology.

**CURRENT EFFORTS**

Where does California fit in? California is at the nexus of VII need and innovation. The same reasons to create a national VII program are acutely recognized in California: an obligation to better manage the safety and productivity of our highway system, and the understanding that a fusion of public, automotive and other private sector innovations can make this a reality. There are also significant, and in some instances, very applied needs. Indeed, there are two Caltrans sponsored efforts underway at PATH:

1. **Expedited VII (EVII)**

Caltrans has funded PATH and its DaimlerChrysler subcontractor to pave the way for VII, jump-starting research and development with a project called “Expedited VII”. The aim of the project is to create two RSU, consisting primarily of a DSRC radio and processor, plus provision of backhaul to processing center, installed in Type 332 cabinets, most likely at the Berkeley Highway Laboratory (BHL), then to develop two applications, one dealing with traffic and another dealing with safety:

- **Vehicles as Traffic Probes** – The vehicles shall send raw location, time, speed and direction information to RSU, which will pass the data to a processing or Traffic Management Center (TMC) where it will be used to create timely and accurate real-time traveler information.

- **Slippery Road Warning** – An application demonstrating low latency safety-critical messaging would be show road surface conditions at curves, where a vehicle would travel over a section of slippery road, then using its sensors would transmit that its tractive state was sensed (and possibly corrected), along with the GPS location of where this occurred.

As part of EVII, we will also investigate scalability issues by analysis.

In February, a PATH, DaimlerChrysler and Caltrans team installed and tested two prototype RSU at the BHL between the Ashby and University Ave exits. These prototypes did not have backhaul communications, but they were in every other way a functioning set of RSU. A simple application was run, where the RSU broadcasted the GPS location of Ashby and University Ave exits, and a car traveling on Interstate 80, upon detecting this radio signal, calculated the distance to these exits through its own GPS location. An in-car
annunciator provided an “Exit ahead” message to the driver, and an in-car display showed a countdown every 50 meters until the exit is passed. This simple application may point the way toward the more significant VII applications described earlier.

2. VII California
Caltrans and Metropolitan Transportation Commission (MTC) are working with PATH to define a three-year project to develop, demonstrate and deploy VII testbed in a key corridor in Northern California, most likely in ten-mile segments of two routes North of Palo Alto and South of the San Francisco Airport, along State Route 82 and US 101.

In support of this, a relatively nearer term phase of the project will:

- Define the concept of operations, locations and applications for this testbed
- Develop, test a prototype RSU suitable for replication and installation along this testbed
- Provide, as necessary, installation assistance for 40 RSU within this testbed.

Overall, Caltrans, MTC (along with its Parsons Brinkerhoff Farradyne partner) and PATH aim to:

- Evaluate exemplar public use cases from which we can generalize VII feasibility;
- Evaluate institutional, policy and public benefit issues;
- Explore wireless communication deployment issues and options;
- Resolve key technical issues involving implementation and operation;
- Assess implementations of the VII infrastructure, architecture and operations; and
- Support private sector evaluation interests.

The aim of VII California is to provide a framework to first assemble the best multi-modal, multi-application testbed possible. The objective is to build this testbed, then bring together every interested automobile manufacturer, initially with only a few vehicles and a common agreed-upon roadside interface. With this, Caltrans and MTC can address vehicle-to-roadside and roadside-to-TMC landside implementation and operations. This will be done by implementing from a limited set of VII use cases, those that are both acceptable and challenging to our stakeholder community. Then there will be an evaluation of these use cases in the context of whether VII makes sense by providing travel benefits for California and by gauging how well it works, technically, operationally and institutionally. In the end, at least for this modest scale, the chicken and egg problem of RSU, will be addressed, and multiple scalability and architectural issues can then be considered. Ultimately, safety and convenience for the entire traveling public just might be addressed with this VII revolution.

Indeed the radio may meet the road, a new and significant alchemy in transportation.

REFERENCES
Intersections are the most complicated part of the roadway environment, so it should not be surprising that they are also the most dangerous. Even though intersections represent only a tiny fraction of the entire roadway infrastructure in the country, about 44% of all crashes occur at or in the immediate vicinity of intersections, and the majority of these are crossing-path crashes. Traditionally, the safety of intersection driving has been governed by the use of traffic control devices, ranging from stop signs to traffic signals, and a variety of geometric design principles have been codified in order to improve visibility and ease of maneuvering vehicles through intersections.

However, there are limits to the effectiveness of these traditional approaches, primarily because drivers may be either unable or unwilling to make complete use of the information available from the intersection traffic control devices (TCDs). Examples of these driver behavior challenges include:

- inattention or distraction interfering with perception of the TCDs;
- impatience tempting them to willfully violate a TCD if they do not perceive a threat from crossing traffic;
- failure to scan all directions for potentially threatening approaching vehicles;
- failure to perceive approaching vehicles even when looking in their direction;
- limited ability to detect the speeds of approaching vehicles and therefore the length of the gaps available for completing turns;
- social pressure to complete a turn through an insufficient gap if multiple vehicles are queued behind them.

The first two challenges are associated with conflicts involving violations of TCDs, while the latter four do not involve any violations, but rather gap acceptance for legal, but unprotected, turning movements. All of these are amenable to support through use of ITS technologies, which have been explored in the Intersection Decision Support (IDS) project, under the sponsorship of the U.S. Department of Transportation. PATH researchers have been focusing especially on the gap acceptance challenges for unprotected left turns at signalized intersections, in cooperation with Caltrans DRI. In parallel with this research, research teams at the University of Minnesota and the Virginia Tech Transportation Institute have been working on the gap acceptance issues for unprotected left turns at rural stop signs and the violations of TCDs respectively. Together, these three university research teams and their sponsoring state departments of transportation have formed the Intelligent Vehicle Initiative’s Infrastructure Consortium.

ITS technologies can implement several functions that extend beyond the capabilities of traditional TCDs in order to help drivers overcome intersection safety problems:

Figure 1: West Coast Intelligent Intersection
- tracking the locations and speeds of all vehicles approaching an intersection;
- computing the available gaps (or the potential imminent violations), with frequent updates (10 per second) in order to identify impending hazardous situations;
- illuminating dynamic roadside displays to alert drivers to impending hazards;
- communicating hazard information to vehicles so that drivers can be alerted by in-vehicle displays.

A large team of PATH researchers has been working on development of IDS for the past three years, and are now nearing completion of the first phase of that program. This work has increased our depth of understanding of turning behavior in general, and of the safety problems it creates, as well as producing some promising intelligent crash countermeasures and measurements of driver responses to some of them. These have provided a solid foundation for the next phase of research that will be needed on experimental verification and field testing of the new systems.

**Highlights of the recent work include:**

**Analysis of intersection crash data in order to refine the problem definition**

The U.C. Berkeley Traffic Safety Center led this analysis of national and state traffic safety databases, seeking the best available information that could shed light on the causal factors that contribute to intersection crashes.

**Definition of a general architecture to accommodate IDS implementations with both vehicle and infrastructure elements.**

This architecture enables data to be collected by sensors in the vehicles and in the intersection infrastructure, and alerts to be displayed to drivers by means of both roadside and in-vehicle displays. The concept of an intersection "state map" was defined to represent the repository of all the relevant information regarding the state of the traffic signal and all vehicles in the vicinity of the intersection, so that hazard conditions can be assessed by processors residing in the infrastructure, the vehicles, or both.

**Development of the West Coast Intelligent Intersection at the Richmond Field Station,**

as an environment for testing IDS technologies and systems. (Figure 1) This experimental intersection includes a variety of traffic detection systems, connected to a 2070 traffic controller installed in a state-of-the-art Model 340 cabinet. It has been used for tests of the effectiveness of alternative detection technologies, and of wireless communications between the intersection and approaching vehicles, as well as for tests of driver responses to alerts under various potential hazard conditions.

**Figure 1: Intelligent Intersection at the Richmond Field Station.**

**Development and evaluation of a dynamic driver-infrastructure interface (DII) as the means of displaying alerts to approaching drivers (Figure 2).** Through the efforts of researchers at the U.C. Berkeley Visual Detection Laboratory, a very conspicuous “looming” no left turn sign has been designed and built, and its effectiveness has been evaluated in the laboratory.

**Evaluation of commercial-off-the-shelf traffic detectors.**

Because the traffic detection requirements for IDS purposes are more demanding than for conventional traffic control applications (in which it is only necessary to know vehicle presence or occupancy, and latencies are not critical), the capabilities of detectors to identify vehicle location and speed have been tested. The detectors under evaluation include conventional inductive loops as well as the 3M Canoga micro-loops, Sensys Networks magnetic detectors embedded in Botts Dots, (Figure 3) the EIS RTMS radar systems and three video image processing detectors (from Traficon, Iteris and Econolite).

**Field measurements of baseline intersection driving.**

In order to ensure that intersection hazard alerts are compatible with normal intersection driving and do not generate an excess of nuisance alerts, it has been necessary to quantify aspects of intersection turning behavior that have
not been previously documented. This led to two parallel field data collection activities. The first of these relied on portable roadside-mounted radar and video detectors to sample the behavior of all drivers turning at several selected intersections, so that the effects of intersection design and operational characteristics on aggregate turning behavior could be identified. (Figure 4) The second relied on use of PATH’s instrumented Ford Taurus to collect detailed in-vehicle data regarding the turning behavior of specific drivers in three age groups, as they passed through four intersections in downtown Berkeley (Figure 5).

**Design and implementation of an IDS alert system**

to help left turning drivers make better gap acceptance decisions when making a permissive left turn (on a green traffic signal) into a gap in oncoming traffic. This work involved using the field observation data to select threshold values of the duration of gaps in opposing traffic that should be sufficient for turns, and then simulating the effects on the alerts of imperfections in the available detector data (voids in detector coverage, errors in speed measurements). The dynamic DII display was installed at the Intelligent Intersection and was illuminated according to several different criteria for turning drivers in three different age groups so that their reactions to the alerts could be assessed.

**Development of infrastructure-vehicle wireless communication capabilities.**

Early in the program, the PATH research team recognized the importance of exchanging data between the intersection and the approaching vehicles in order that each could have the best available information about the state map of the intersection. The information to be exchanged was identified, and initial estimates were made of the maximum burden this could place on a DSRC (Dedicated Short-Range Communication) wireless channel under worst-case traffic conditions. Experiments were conducted in cooperation with DaimlerChrysler Research and Technology North America, to show that indeed the information could be exchanged between the intersection and the approaching vehicle over a real-time wireless link emulating DSRC. (Figure 6)

The PATH research team has already produced technical reports and papers regarding many aspects of this research, including four papers at the 2005 TRB Annual Meeting, and they are currently documenting the results for the final project report. While this is in progress, the U.S. DOT is sponsoring the planning for the follow-on program to IDS, which is known as Cooperative Intersection Collision Avoidance Systems (CICAS). In this new program, the efforts of the Infrastructure Consortium are being integrated with parallel efforts by the CAMP (Crash Avoidance Metrics Partnership) consortium of seven automotive manufacturers to develop in-vehicle systems. The new program explicitly recognizes the importance of cooperation between vehicle and infrastructure systems (the first C in CICAS) in trying to reduce intersection crashes in the future.
PATH is participating in the creation of CICAS, which should be the means of advancing the current IDS research to the stage that it will be ready for field testing on public intersections, where drivers from the general public will first be able to receive dynamic displays advising them against turning when the traffic conditions are measured to be unsuitable (insufficient gaps available).

Figure 5: Specially Instrumented Ford Taurus

Figure 6: Equipment for DSRC experiments.
  a) Instrumented cabinet
  b) Wireless antenna on vehicle
Changeable Message Signs (CMS), also called Variable Message Signs (VMS) have become a predictable fixture on the roadway in 2005. Such signs come in a number of distinct varieties, and we studied two of these. Fixed signs installed adjacent to, or over the roadway, usually are capable of delivering three lines of 16 characters each. Portable signs mounted on trailers, and often deployed in work zones or at construction sites, exhibit three lines of eight characters. Fixed signs can be accessed and programmed remotely. CMS adds capability for traffic control and for driver information that has been decisive in a variety of circumstances. One circumstance occurs in a child abduction cases. The Amber Alert network causes CMS signs throughout a region to display the identity, if known, of a vehicle bearing the abducted child.

The sign might read, for example:

And it might be followed in rapid succession by a second frame reading:

AMBER ALERT
CALL CHP
510-555-3336

Other common messages relate to road closures, detours, accidents that lead to traffic tie-ups and the need for detour, and extreme weather-related matters. CMS characters (the letters and numbers that can be presented) are constructed on a 5x7 matrix, and are usually 18 inches high. These can be seen at a distance of just under 1/10 mile by licensed drivers who have 20/40 or better acuity. Motorists traveling at the speed limit therefore have a finite amount of time, a few seconds, during which to apprehend the message.

Because of the ubiquity of CMS signs, it is natural to ask: “What is their effect?”

One effect that is direct, laudable, and clear, is that CMS signs have played a decisive role in the apprehension of child abductors and in bringing to safety the abducted victim. Motorists are familiar with advisories warning that delays will be encountered on roadways under repair, and other needed information. But few motorists have failed to encounter one profound effect: wherever the CMS is delivering a message, there is the risk of increased congestion, presumably because motorists slow to try to take in the content. Likewise it is not uncommon to find motorists who simply didn’t have time to absorb the CMS message, either because they noticed it too late, because their attention was diverted by the need to attend to driving tasks, or because the sign may have been partially obscured by another vehicle. If any of the foregoing is the reason for CMS-caused congestion, then it makes sense to ask, as Dudek [1] did whether there are avenues to optimization of the structure of the message. Message designers have many choices, and some are made according to guidelines that accompany the CMS. One example is that in two-screen messages, messages that require more than one frame of content, the message designer can pick from a range of possible ‘off’ frame durations. Off frames are those for which no content
is delivered. One might think that the best ‘off’ frame duration would be zero because the blank frame would merely delay the presentation of the next frame and delay would require motorists to slow down to wait for the message.

We have recently received support from Caltrans to find means of optimizing the presentation of CMS messages. Our purpose has been to achieve the best possible intelligibility of the sign since optimum intelligibility may have two beneficial outcomes:
- motorists can appreciate more of the message being delivered if it has been optimized,
- the tendency for congestion at or near a CMS can be lessened.

Our studies have been laboratory-based examinations of how message structure can impact its intelligibility. We have employed what human factors scientists term a ‘low fidelity’ simulation. Simulated CMS images are presented on a computer screen to an observer who is engaged in a task comparable in its visual requirements to steering. Our results, of course, cannot be extrapolated beyond the laboratory without subsequent study. Our ultimate aim is to move some of our insights into domains where tests are more applicable to real world use.

In this paper we describe several such insights and we close by describing plausible real-world tests of the concepts that we have developed.

**Low-fidelity simulation**

The rational for our study has been that we can match the CMS content to the visual needs of drivers in testing situations where the visuals are tested. In such tests we merely want to know how much of the message has gotten through we are not interested in either cognition (what the message implies to the observer) or message interpretation followed by subsequent action. The structure of our test facility is shown to the right. A driving scene appears above with the simulated vehicle guidance task depicted below.

**Guidance task**

What it simulates is the need to maintain constant eye contact on the road. The ‘road’ in this case is two parallel line segments. These move randomly left and right relative to a mean location on the screen. By moving the mouse, the observer can keep the blue disk, simulating his vehicle, safely between the lines. If the disk should stray across a line it turns red, signaling that the observer has erred. We instruct our observers to do their best at avoiding this error, while they also engage in the additional task.

**CMS message task**

At a random time after the observer pushes a ‘start’ button, his progress through the simulated environment shown on the upper screen will include passing by a simulated CMS. That CMS appears to the side of the road and enlarges as it passes by to the right edge of the screen, just as if it were being overtaken on the highway. The observer has limited time during which to ‘see’ the message, and she/he must maintain to safely drive and stay on simulated roadway.

Factors that separate this task from the task of real driving are: the field of view is far smaller than the field seen through the windshield and, the size and brightness of the CMS are quite close to what occurs in the real world. Another difference is that there is little cost for making errors – while in the real world, one’s life is at stake. Cues, other than the visual, are not present in our simulation, while in the real world, and in high fidelity simulators, motion of the observers simulating acceleration forces, sound and fully realistic vehicle controls can all be present. Accordingly, our low level simulation should not be counted on for insights beyond those that relate to visual detection. Nonetheless, the parameters that govern detection such as brightness, size, and temporal factors are the same as those in the real world.

**What do we test?**

We present messages to our observers with driving-relevant content. Their job is to recall the message while doing a good job of steering the blue disk. We pay observers for correct recall of messages but only if they exceed a criterion performance score in the ongoing guidance task. The idea here is to make that guidance task ‘important’ to them, just as it would be in real driving. CMS messages tested were selected from a CMS archive taken from Caltrans District IV for the second and third quarters of the 2002-2003 fiscal year. The archive was broken down into 17 categories and messages were selected from the categories based on their frequency within the archive. The digital images of the signs

Simulated driving scene showing CMS and the vehicle guidance task below
Distributed Surveillance and Control on Freeways, Benjamin Coifman, 129 pp UCB-ITS-PRR-2004-43
Optimization and Microsimulation of On-ramp Metering for Congested Freeways, Gabriel C.Gomes, 169 pp UCB-ITS-PRR-2004-44
Field Investigation of Advanced Vehicle Reidentification Techniques and Detector Technologies - Phase 2, Stephen G. Ritchie, Seri Park, Cheol Oh, Shin-Ting (Cindy) Jeng, Andre Tok, 88 pp UCB-ITS-PRR-2005-8
Berkeley Highway Lab Video Data Collection System, Chao Chen, Daniel Lyddy, Baris Dundar, 18 pp UCB-ITS-PWP-2004-08
Initial Scoping of Bay Area Smart Mobility Corridors and ITS World Congress, Susan Shaheen, Rachel S. Finson, Cynthia McCormick, 70 pp UCB-ITS-PWP-2004-09
Effects of Traffic Density on Communication Requirements for Cooperative Intersection Collision Avoidance Systems (CICAS), Steven E. Shladover, 12 pp UCB-ITS-PWP-2005-1
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were made using SIGNView\textsuperscript{TM}, a software package used to construct CMS messages. The research was restricted to simulated signs displaying 16 characters in three lines, representing permanent CMS displays, or in some cases signs containing only 8 characters in three lines, as is the case in portable CMS displays. We then find out how much of the content was retained by asking the observer, right after the CMS message has been presented. The experimenter makes note of what was recalled by the observer and enters this into a file that contains the actual content. Testing is repeated as many as 36 times for each of six young and three older observers. We then cumulate the percentage of words correctly recalled and the percentage of numbers.

**What have we learned?**

One test, alluded to above, sought an answer to the nuts and bolts question of how long one leaves an ‘off’ frame present when there are two frames in the message. The ‘off’ separates the content frames from each other. Guidelines followed by Caltrans in California make the ‘off’ frame nonexistent. In California, there is no ‘off’ frame. Our tests reveal that this isn’t the best approach and the results were not anticipated. Delaying the second frame by 300 MSEC resulted in both better word (84.3\% vs. 71.5\%) and number (73.1\% vs. 62.2\%) retention scores as compared with the 0 MSEC ‘off’ frame presently used in California. 100 and 200 MSEC delays improvements were not as good. We can construct a reason for this finding, but only further testing will be able to confidently assign a cause. In any case, the route to a field test of the concept is clear. In currently deployed CMS devices, it is straightforward to effect a 300 MSEC off frame between content containing frames, at the time the message is constructed.

We have also studied the layout of the message. Presently in California, messages are center justified as shown in the example in Figure 1. We wondered whether performance, which was not perfect for such messages (around 77.6\% for words), could be improved by changing the layout of the message. We were a little surprised to find that both left justification and a staircase configuration in which the top line started at the left, the middle line was centered, and the bottom line was aligned at the right, gave an improved word score (86.8 and 86.7\% respectively). This layout too could be readily implemented in presently deployed CMS apparatus.

We also tried some ideas that didn’t lead to improved outcomes. One such idea was to enable the text of a message to expand in size beyond the rate at which fixed-dimension letters would appear to enlarge. Such a looming signature, it was thought, would signal more importance to the observer and thus enable better recall. Such was not the case. In fact word recall performance declined when the message was caused to loom faster than approach to the CMS would have caused. Another surprising failure was that common abbreviations (e.g. E for east) made messages less intelligible. Abbreviations constitute a crucial tool for the traffic engineer who is trying to develop a clear message in the constrained structure of the CMS. The cost of using abbreviations has to be weighed against the cost of reduced message content, or the cost of going to multiple frame messages.

**Where do we go from here?**

Our results appear to suggest at least two ways of improving message intelligibility. One has to do with the duration of a blank screen (off frame) between multiple screen messages. The other has to do with the geometric layout of the message. Both can be implemented on present-day CMS apparatus. Our plan is to seek a field test in which messages with identical informational content, but different geometry or timing, are placed on two CMS devices but on different roadways. Measuring congestion is one approach. Measuring recall of message content is another. We are also pursuing other approaches in our laboratory.

**Conclusion**

CMS signs bring new, timely information to the driving public. They have already proven their worth in this task and it can be anticipated that they will be fixtures on our roadways for the foreseeable future. We have found through laboratory testing that conventional approaches to how they are used can be improved. We are thus of the optimistic view that field testing of one or more of improvement strategies that we have devised are warranted and should be attempted.

**Reference**


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