# A 'State Map' Architecture for Safe Intelligent Intersections


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## *Abstract*

The frequency and the severity of the crashes at intersections as well as the introduction of new cheap and precise sensing and communication technology led to the development of new smart safety systems at intersection. Any such system must have an architecture in order to work; moreover, to work generally, with a variety of alignments, traffic conditions and traffic types, the need for such an architecture is paramount.

In this paper we introduce a system architecture general enough to encompass all intersection collision warning and gap advisory scenarios. We propose to use our architecture along with standardization of the subsystem interfaces in order to achieve efficiency, fast design and development, high subsystem reusability and high upgradeability.

The kernel of the proposed architecture is a “State Map”, a data base of knowledge of all the dynamic components within and, to a reasonable range, approaching the intersection. A “state map generator” processes the inputs from a heterogeneous set of sensors into a standardized “state map”. The introduction of this subsystem makes faster and easier the development of safety application programs. At the same time it makes easier to reuse and upgrade applications.

# 1. Introduction

We introduce and describe an "intelligent intersection", equipped with sensing, processing and warning systems – which allows intersection crashes to be avoided. These intelligent intersections will enable a broad class of safety applications, where infrastructure- or vehicle-based warnings or advisories can be given to drivers about to execute turning movements.

In such an application, the intersection may be regarded as a system comprised of the infrastructure, the vehicle, the driver and additional technological components to make the intersection truly intelligent. To work, any such system must have a governing architecture; moreover, to work generally, with a variety of alignments, traffic conditions and traffic types, the need for such an architecture is paramount. In this paper we describe such architecture.

The basis of the proposed architecture is a "State Map", conceived to be a data base of knowledge of all dynamic components within and, to a reasonable range, approaching the intersection: vehicle movements, traffic signal timing, and even driver intent. It can be manifested graphically, likened to an all-knowing "safety manager in a helicopter". However, its implementation can be considerably less complex, perhaps as simple as the already deployed loop-actuated signal where presence indicators in an approach leg may elicit a phase change.

## 2. Background

According to the 1998 General Estimates System, crossing path crashes accounted for about 27.3% of police-reported crashes in the United States – a total of 1.72 million crashes (1). Moreover, about one in every four fatal crashes occurs at or near an intersection, one-third of which are signalized. The Infrastructure Consortium – comprised of US DOT, California DOT, Minnesota DOT and Virginia DOT – recognizes the dire problem within our States and across the nation. To that end, they have formed the Intersection Decision Support (IDS) program to investigate application of innovative technologies toward intersection safety. The IDS investigators include members of the Infrastructure Consortium, as well as researchers from the University of California, Berkeley (PATH Program), University of Minnesota (ITS Institute) and Virginia Polytechnic Institute (Virginia Tech Transportation Institute). Each institution and State brings its own expertise and focus to the national problem: California on systems integration, and the left turn problem, particularly in urban areas; Minnesota on lateral direction crashes when minor roads intersect major arterials, particularly in rural areas; and Virginia on near-term deployable approach warning for traffic signals and signs.

Also, while the focus of the Infrastructure Consortium is infrastructure-based warnings and advisories, the IDS program also addresses cooperative elements that rely on wireless communication, most probably the incipient Dedicated Short Range Communications (DSRC). While not explicitly addressing issues of in-vehicle warnings, the flow of information between the intersection and vehicle is an important topic, as the content, timing and format will comprise the intersection-vehicle interface, *should* IDS be implemented in the vehicle. It is important to note, however, that the proposed architecture is designed to be relevant in any instantiation of IDS – with all ITS components completely within vehicles, completely within the intersection, or distributed between these two.

## 3. Enabling Technologies

Today the development of new technologies, the increasing precision of the sensors and the introduction of affordable wireless technology make IDS possible. With the wide proliferation of 170 traffic controllers and the emergent 2070 advanced traffic controller, semi-actuated and fully-actuated traffic signal controllers are deployed through many intersections. The introduction of simple sensors such as loops, video surveillance and radar has further enabled these controllers.

Also, new sensor technologies have been introduced in the market, with increasingly higher precision and update rate. Examples abound: GPS, rapid promulgation of 802.11a and 802.11b radios, and increasingly more capable lidar, radar and video sensors. These technologies make to track of the vehicles approaching the intersection with a high precision.

Processing technologies have developed similarly. It is today possible to buy cheap processors that compute millions of operations in a second; moreover, through standard application programming interface to the 2070 controller, these processors can be deployed to work at intersections. Whether vehicle- or intersection-based, it is possible to compute vehicle trajectories and detect possible hazards (e.g. collisions, traffic signal violations) in real time, given sensor inputs.

This gives rise to the State Map concept, the basis of an intelligent intersection that can sense the approaching vehicle using a combination of sensor technologies and communication, compute crash likelihood and warn the drivers of the hazard in order to avoid collisions. These intelligent intersections may also aid the driver in taking their decision. For example, the intelligent intersection can help the driver in judging the size of a gap between cars when he or she is trying to turn.

A variety of intersection collision avoidance and decision support applications have been proposed and investigated (see for example the Intersection Collision Avoidance system proposed in (2) and (3)). They usually focus on a particular problem and they develop a smart intersection to address the problem using a particular approach. They use disparate hardware and software technologies and different models, but their approaches have commonality, which can be channeled with State Map-based architectures.

## 4. State Map Architecture

The architecture we will describe may be a logical approach that can be used to describe IDS, or for that matter, any intersection collision warning/avoidance application. This approach has four basic arguments: efficient, faster design and development, high subsystem reuse, high upgradeability.

The state map architecture has logical definitions for interfaces and subsystem services. Every system can be developed using different technologies, but the overall logical structure is always the same. Since the interfaces are standard a subsystem can be easily re-used or upgraded. Additionally, since the overall design is ready yet and every subsystem can be re-used the length of the design and development phases are drastically reduced. The interface standardization may reduce the training duration as well.

The systems hitherto proposed can be simplified and logically described using the architecture in Figure 1(a). These applications usually focus on a particular problem and they are not been developed thinking about sub-system re-use. The architecture we propose, described in figure 1(b) has been developed for high reusability.

System reuse is an important issue. In the end, an intelligent intersection should address, at a minimum, a wide variety of crossing path crash types and perhaps other intersection-related crashes such as rear-end crashes. Thus, the components must be applicable or shared by a variety of safety applications. They must be interchangeable and address multiple crash type.

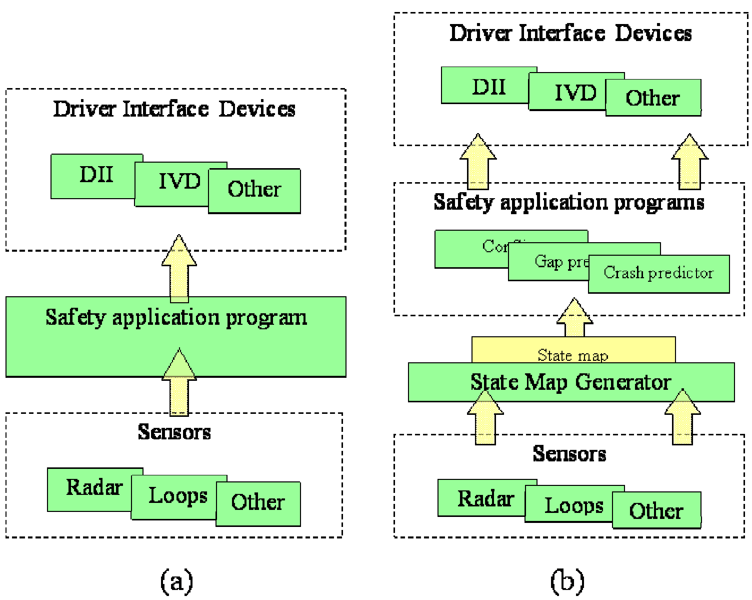


**Figure 1: Typical (a) and proposed (b) intelligent intersection logical architecture**

Intelligent intersections are so because they are aware of the surrounding environment; they are equipped with sensors. These applications gather information of the surrounding environment using different sensor devices (e.g. radar, inductive loops, vision), but the information is similar: approaching vehicle positions and speeds and perhaps acceleration, the traffic signal phase and status (e.g. amber, two-seconds to red) and the road condition (e.g. icy or slippery).

The format and the nature of this sensor input data is different from system to system (e.g. it may be a list of returns or a presence acknowledgement) but the information that these systems want to gather are really similar: the system need to acquire a similar dataset. The sensor data (return, inductive signature, and signal controller feedback) is then fused and transformed into something meaningful for the safety application programs (e.g. vehicles and signal phase) that are going to assess threats and aid the drivers. Based upon this dataset, the safety application program computes a set of information to be communicated to the drivers to aid or to warn.

For example the Intersection Collision Avoidance System described in (2) the input of the traffic control, Doppler radar and communication are fused together to establish if there are vehicles in the intersection, where they are and what's their speed. These vehicles are placed on a GIS map of the intersection that is then processed by the Collision Avoidance Program to determine if there is any collision threat.

We observe that many these safety applications work similarly and base their intent (e.g. gap judging support, collision avoidance, signal warning feedback) on a similar set of data.  As such, Figure 1(a) could be extended to Figure 1(b).

The idea behind the proposed architecture is simple and powerful: many applications may share the same sensors and interfaces. Since all the intelligent intersection applications may base their decision on the same dataset, or at least on a subset of it, the architecture can reduce the complexity of processing the sensor input into a logical description of the environment from the safety programs. It does not make sense to process the sensor input inside every program block. The "state map generator" subsystem takes care of the sensor fusion and processing. Also, the sensor raw dataset is processed and turned into a logical description of the intersection. The returns detected by sensors became vehicles. The distances of the objects from the sensor devices became position on the intersection (e.g. leftmost lane, 45 meters from the center of the intersection). We call this processed standard dataset in a standard format a State Map.

Similar to web-based TCP/IP protocols, the IDS State Map can build safety applications for intelligent intersections without dealing with the complexity of the sensor device technologies. Since the format of the State Map can be standardized, new applications can be built on top of it without dealing with detailed interfaces to sensor signal processing. This would significantly reduce the design and development time needed to build the application. At the same time, safety application programmers do not need to be trained on using a particular set of sensor every time a new system is developed.

Similarly, the systems developed using this approach area may be easily upgradeable; a sensor can be replaced without touching or adjusting the algorithms. In the same way, an algorithm can be added or replaced with a better one without adapt it to the existing sensor (or without adding new sensors).

## Conclusion

About one in every four fatal crashes occurs at or near an intersection. Today the development of new technologies, the increasing precision of the sensors and the introduction of affordable wireless technology make possible to address this problem with smart intersections that are aware of the surrounding traffic. We propose a new logical architecture and the use of interface standardization to develop this kind of intersection in order to achieve efficiency, faster design and development, high subsystem reusability and high upgradeability.

The kernel of the proposed architecture is the "State Map", conceived to be a data base of knowledge of all dynamic components within and, to a reasonable range, approaching the intersection:  vehicle movements, traffic signal timing, and even driver intent. It is going to be used by the safety application programs to take their decisions.

To work, any such system must have an architecture; moreover, to work generally, with a variety of alignments, traffic conditions and traffic types, the need for such an architecture is paramount.  The State Map concept defines this type of architecture.

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