# Classification for traffic related inter-vehicle messaging

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## ABSTRACT

One major use of vehicular ad hoc networks is the distribution of traffic related information. For a scalable and robust system it is crucial to evaluate the content at every forwarding node. But successful evaluation of information depends on a number of aspects, which we are discussing in this paper. We explain how detection and distribution of traffic related information is affected and point out the implications on system design.

***Keywords***: Inter-Vehicle Communications, Ad-Hoc Networks, Local Danger Warning, Classifications

## 1. INTRODUCTION

Inter-vehicle communications (IVC) is widely considered as paradigm shift in automobile telematics, preparing ground for sophisticated traffic management, advanced driver assistance systems and situation dependent information services. Consequently, IVC is a fast emerging field of interest in the automobile industry. Many research projects and consortia ([1], [2], [3], [4]) have been initiated during the past few years, aiming at developing and standardizing both communication issues and telematics services.

Among all targeted services, we consider situation dependent services as most beneficial for today's road users. In order to achieve effective cooperative situation awareness, it is critical to recognize situations adequately. Unfortunately, there is a huge variety of real world road situations and they differ in many aspects. It is therefore crucial to elaborate the key characteristics and group situations accordingly, in order to be able to design an efficient, robust and secure system.

So far, services are mostly classified according to their application domain or the requirements they have on the communication system ([1], [2], [3]). In addition, Ward and Jesty [5] introduced a classification scheme for moving vehicle hazards. Their main focus is on hazard and risk assessment in order to support the development of safety-related systems standards. However, such classification is not sufficient since most of the targeted services are situation dependent. They have different requirements in different situations. In addition, as we will show up, the type of sensor that measures a specific context parameter[1] has great impact on the overall system design, too.

1 Or the method a specific context parameters is derived from specific sensors.

In the following section we will introduce the key aspects of real world situations that are relevant for such a system. In each case, we will shortly explain the issue, provide a definition and give an example where appropriate. At the end of this section we give an overview using example applications.

In section three we will point out the main implications on overall system design and conclude in section four

We distinguish between *situations* and *events*. Situations describe the environment during a period of time. They usually reflect the occurrence of specific circumstances. A real-life example would be a lateral wind area or a construction site. There are also short-lived situations such as a car doing an emergency braking. In contrast, events are snapshots of a situation at a distinct point in time.

Cars, being parts of a traffic situation messaging system, generate events after detecting specific situations, create messages resembling that information and distribute them. Cars' on-board systems receiving these messages calculate their relevance and the confidence in the information to decide about driver notification and further distribution.

## 2. CLASSIFICATION

### 2.1. Situation Dynamics

The real world is continuously changing. However, we recognize that there are only three parameters in which a specific situation may change over time: its position, its shape / dimensions and its intensity[2]. Moreover, the dynamic in which those parameters change are typically similar for different complex situations. While an oil spot on the road will typically neither move, nor change its intensity or shape, a fog bank may change in all these parameters over time. We therefore distinguish between the following three generic classes:

- **Static**. Situations that have constant size, no movement or no changes in intensity. (An accident for example, once happened, will not change its location, size or intensity.)
- **Continuous**. Situations that have varying size, continuous movement or continuous change of intensity.

2 Note, that intensity is usually a function of position

- **Chaotic**. Situations that behave chaotic (uncontinuous) in terms of changing their size, movement or intensity, but stay within pre-defined limits.

## 2.2. Driver Related Determinism

In a vehicle messaging system, especially in a local danger warning scenario, messages will most likely have an effect on driving behaviour, since most of the messages contain driving related information. Unfortunately, the driver's reaction can also have an effect on a situation's detectability. A prominent example is the detection of aquaplaning:

A car at normal speed will experience some slippery road condition and can, together with other environmental data, conclude aquaplaning and generate a warning message accordingly. However, a following car receiving this warning may eventually reduce its speed and would therefore not be able to experience slippery conditions.

We call this case non-deterministic detection. This case requires two things. First, there must exist a certain threshold in the sensor fusion function where an event can be detected. Second, the average driver will act upon a notification in such a way, that he will stay below the threshold.

- **Deterministic Detection** Events that can be detected independently from driving behaviour[3].
- **Non-deterministic Detection** Events that may be experienced differently, according to the specific behaviour or action of a driver upon receiving warning messages.

## 2.3. Configuration Dependency

In some cases, the relevance of a situation to vehicles receiving a message depends on a number of settings. Cars have specific properties, such as the model of the car, the type and make of tires, etc. If a specific car sends out an icy-section warning message, what information would a receiving node need in order to assess the effects properly?

Other messages, such as a traffic accident warning may be more trivial, because the receiving car does not have to know the sender's configuration. We therefore distinguish between

- **Objective Events** Events that are characterized by a specific situation, but are not related to specific vehicle parameters.
- **Subjective Events** Events that are related to specific individual vehicle parameters in addition to situative settings.

When receiving message, it is important to know whether an event is objective or subjective in order to calculate their relevance and confidence properly. In the case of a subjective event, information about the sender's configuration improves the quality of a receiver's relevance and confidence decisions.

[3] Note that in a mathematical sense this is not exactly true, because a car that does not move will probably fail to detect certain events.

## 2.4. Aggregation Locality

We distinguish between two ways of event detection. Every single car that meets the system's specifications can detect the first class of events, such as an accident where airbags have been fired. The second class of events requires the interworking of different cars in order to detect events, such as traffic jams. These considerations lead to the following distinction:

- **Single Node Detection** Vehicles are able to detect events individually using only their own sensors[4].
- **Multi Node Detection** Events that can only be detected by aggregating information from more than one vehicle.

## 2.5. Data Collection

The data that leads to the detection of an event can generally be collected in three different ways:

- **On-board Sensors** Readings of various sensors are monitored and if defined patterns are detected or specific thresholds are exceeded, an event is generated.
  There is a special case: in some applications, such as approaching emergency vehicles or post-crash warning all vehicles receive a message originating at a single device, that cannot be directly measured or verified by others[5].
- **Driving Dynamics** Cars have multiple motion sensors that may indicate certain road conditions or specific situations[6].
- **Location Traces** If multiple cars move around a certain area and everyone is avoiding a particular spot, one may conclude that there is some kind of local hazard / obstacle. The same principle could be applied if cars collectively change their driving parameters in a certain area (e.g. reduce speed).

System designers can, for those applications where multiple methods are possible, choose the most appropriate one. An intelligent on-board system could even pick the best method according to its environment (e.g. number of neighbouring cars).

## 2.6. Impact

The impact a specific event may have to the current driving condition or the driver's behaviour will affect its overall design, especially with regard to security issues and possible inference mechanisms. We thereby distinguish between the following four categories:

- **Autonomous** Vehicles act autonomously, i.e. certain vehicle functions or driving dynamics are controlled automatically without driver interaction.
- **Action** Applications that notify the driver about nearby critical conditions or situations (e.g.

[4] Basic sensors have to be defined for every event class. Information from other sources is used to refine the inference process.
[5] This case will be marked as "1" in Table 1
[6] E.g. a hazard may be concluded after an evasion maneuver

imminent dangers) that require immediate reaction in order to avoid an accident.

- **Attention** Applications providing information about traffic-safety related situations that require no immediate intervention.
- **Awareness** Applications providing information about situations that should be recognized by the driver in order to be aware of traffic and/or road related information.

Note that action is closely related with attention, since driver action is only necessary if the car is already very close to the reported event.

This classification determines the requirements concerning acceptable delay. It may also require the use of dedicated frequency bands reserved for traffic safety for some applications, while others may also be distributed with sufficient reliability on shared frequencies.

| | Situation Dynamics | | | Driver related Determinism | | Configuration Dependency | | Aggregation Locality | | Data Collection | | | Impact | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Static | Continuous | Chaotic | Deterministic | Non-deterministic | Objective | Subjective | Single-Node | Multi-Node | On-board Sensors | Driving Dynamics | Trace Analysis | Autonomous | Action | Attention | Awareness |
| Approaching emergency vehicle | | ✓ | | ✓ | | ✓ | | ✓ | | 1 | | | | | ✓ | |
| Post-crash warning | ✓ | | | ✓ | | ✓ | | ✓ | | 1 | | | | ✓ | | |
| Emergency electronic brake lights | | ✓ | | ✓ | | ✓ | | ✓ | | 1 | | | | ✓ | | |
| Work zone warning | ✓ | ✓ | | ✓ | | ✓ | | ✓ | | 1 | | | | | | ✓ |
| Vehicle-to-vehicle anti-crash warning: Lane change, blind spot, merge, wrong way | | ✓ | | ✓ | | ✓ | | | ✓ | ✓ | | ✓ | | ✓ | | |
| Road feature notification: Curve speed, friction, grade | ✓ | | | ✓ | | | ✓ | ✓ | | ✓ | | | | ✓ | | |
| Cooperative dynamic cruise control | | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | | | |
| Cooperative collision warning | | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Cooperative glare reduction | | ✓ | | | ✓ | | ✓ | | ✓ | | | ✓ | ✓ | | | |
| Aquaplaning | ✓ | | | | ✓ | | ✓ | ✓ | | | ✓ | | | | ✓ | |
| End of traffic jam | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | | ✓ | |
| Traffic jam | | ✓ | | ✓ | | ✓ | | | ✓ | | ✓ | ✓ | | | ✓ | |
| Gusts of wind / side wind | | | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | | | | ✓ | |
| Reduced friction | | | ✓ | | ✓ | | ✓ | ✓ | | | ✓ | | | | ✓ | |
| Reduced visibility | | ✓ | | ✓ | | ✓ | | ✓ | | ✓ | | | | | ✓ | |
| Obstacles | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | | ✓ | |

**Table 1: Application Characteristics**

Legend:
✓: This characteristic applies here
1: This is the special case discussed in 2.5 On-board sensors

# 3. EFFECTS ON SYSTEM DESIGN

In this section we want to point out the different characteristics' implications on overall system design.

## 3.1. Communication System

The communication system will be heavily influenced by the way a traffic messaging system works. The communication effort largely depends on whether the event can be detected by a single node or only by multiple nodes. This characteristic has a significant impact on the communication effort, especially with regard to the required bandwidth, latency, and for the question whether distribution logic is implemented on application level or on a network level (See also [5]). In addition, single-node detection can handle fragmented networks (intermittent connectivity) using store-and-forward mechanisms, while multi-node detection typically requires sufficient connectivity among the vehicles in the detection area.

The average packet size is affected by appending configuration information (see 2.3).

Latency is a requirement relevant for the impact classification. An “autonomous” or “action” application will only work effectively if information distribution is fast enough, while “attention” and “awareness” applications will accept much larger delays[7].

We should also note here, that the data collection by evaluation of traces would require the unsolicited sending of periodic beacons that include current position and time by every vehicle.

## 3.2. Security and Privacy

Concerning security, we believe it is essential to evaluate the content in order to evaluate the level of confidence and relevance of received messages (Golle et al. wrote a great paper about this topic [7]).

In general, non-deterministic detection impairs the verification of an event, since it reduces the number of cars that can actually confirm that event.

Another factor that makes it difficult to evaluate information is the time available before notifying the driver. Autonomous applications are the most challenging, since there is no human evaluation in the process, which could potentially identify wrong information. Even in action type applications a driver will be required to act upon a message immediately and does not have time to evaluate the content in detail. In opposition to that, attention and awareness type applications can usually aggregate information from independent sources before notifying the driver. Therefore, the system can make better suggestions.

Privacy is a critical requirement for a traffic-related system (see [8] for details). In order to meet these requirements, vehicles may not use everlasting, globally unique identifiers in the system. It also means that the messages must not contain information that uniquely identifies a sender. Adding configuration details would require some thoughts in this context.

## 3.3. Complexity

The computational complexity to evaluate and verify certain events greatly increases if an event is subjective and affected by driver behaviour (non-deterministic). In addition, more equipped vehicles are necessary to conclude situations realistically. In order to calculate the relevance and confidence of a received message properly, subjective events require that the original sender adds information about its configuration. Of course, this additional information has to be evaluated as well. Note, that this also stresses the necessary in-vehicle storage capacities.

Moreover, the confidence in events that change over time (continuously or chaotic) are much more difficult to determine than static events, because the potential change or movement has to be taken into account as well. Consequently, whether a situation (which may trigger a specific event) is static, continuous or chaotic has great impact on the complexity of calculating the level of confidence in a received event message.

# 4. CONCLUSION

In this paper we proposed a classification for inter-vehicle safety and information services. Such a classification is the basis for categorizing certain application profiles, which in turn is essential for security, efficient forwarding and evaluation algorithms.

We pointed out that the requirements on these issues do not only depend on the targeted service, but also on the intended detection method. Moreover, the requirements e.g. of a hazard warning application are as different as the hazards that should be handled. However, applications or services can only be implemented efficiently if all dependencies and requirements are well known.

The proposed classification should help to get a deeper understanding of the different characteristics of ITS services based on inter-vehicle communication that are currently under discussion in a variety of research projects and standardisation efforts. We think that those aiming to increase a drivers particular attention to certain situations that can be detected objectively and deterministically (following the term we introduced in this paper) are the most promising to be successfully realised within a couple of years. This is due to the fact, that for a reliable service it is critical to verify the information artefacts that are received. For these services this can be done most efficiently.

# REFERENCES


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[7] Note that the distribution area of the latter applications can also be very large, which in turn makes them less susceptible to minor delays in communication.