Intersection Safety Application
Introduction to INTERSAFE [1]

- **The main objective**
  To improve safety and to reduce (in long term avoid) fatal collisions at intersections.

- **Period**

- **Participants**
  - Vehicle manufacturers: BMW, VW, PSA, RENAULT
  - Automotive suppliers: TRW, IBEO
  - Institute/SME: INRIA/FCS

Introduction to INTERSAFE [1]

The core technologies

- Sensors for detection of vehicles and all other objects present at the intersection
- Sensors for localization of the host vehicle when approaching and traversing the intersection
- Communication between the host vehicle and the infrastructure (traffic lights) to exchange additional information including status of the traffic light, weather, traffic and road conditions

Schematic view on INTERSAFE
INTERSAFE: System Architecture [1]
The following inputs are required:

- (High-Level-)Map of the intersection (e.g. geometry of the intersection, number of lanes, priorities, turning lanes or traffic signs/lights)
- Location, path and classification of other road users within the intersection
- Exact location and path of the host vehicle with respect to the intersection
- Bidirectional Communication with the traffic management (e.g. Status of the traffic lights, traffic light timings or information of other road users and road conditions)
INTERSAFE: System Architecture [1]

Accurate feature matching
Complementary information
(GPS or GALILEO)

High-Level Map
Intersection geometry and other information like lane details, user priorities, pedestrian crossings, turning lanes, traffic signs/lights and other functional features

Objects detected by Sensors
Road users detected, tracked, and classified
Lane markings
White arrows indicating turning lanes

Matched Result

Bidirectional communication

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INTERSAFE: Approaches [1]

B-ISS (Basic Intersection Safety System)
1) Available sensor
2) Situation analysis, that is feasible with such a sensor
3) Reliability analysis
4) Application deduction

A-ISS (Advanced Intersection Safety System)
1) In-depth accident analysis, which provides characteristics of accidents
2) Relevant scenarios choice
3) Application specification
4) Sensor requirement
INTERSAFE: Concept and Vision [1]

Static World Model
- Where are we (precisely)?
- Who else is on the intersection?
- Does the intersection match our map?

Dynamic Risk Assessment
- Where are we going to?
- What are the others doing?
- Is there a foreseen risk of collision with our vehicle?

Driver Assistance at Intersections
- stop sign assistance
- traffic light assistance
- turning assistance
- right of way assistance
- ...

A-ISS (future applications)
B-ISS (state of the art)

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Accident Analysis [1]

Analyzing Process

Analysis of the national statistics and evaluation of the reachable information

It was mainly used to sketch the importance of intersections compared to other hotspots. As a result it became clear that the informational value is limited.

→ Numbers of intersection accident could be derived, which need further analysis.

Analysis of additional accident databases – scenario selection

In-depth databases provide the needed deeper insight into traffic accidents. The accidents recorded are also assigned to the same accident types, but also to a specified scenario.

→ This allows the understanding what are the main scenarios.

Analysis of additional accident databases – scenario investigation

The scenarios describe the driving manoeuvre which leads to the crash. The main task is to understand why it led to a crash in this particular case. The circumstances are relevant for system development.

→ Driver mistakes and contributing factors were derived.
## Accident Analysis: Frequency and Severity [1]

### At intersection

<table>
<thead>
<tr>
<th></th>
<th>FR 2003</th>
<th>UK 2002</th>
<th>DE 2003</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury accidents</td>
<td>26729</td>
<td>138293</td>
<td>34403</td>
<td>354534</td>
</tr>
<tr>
<td>Fatalities 30 days</td>
<td>975</td>
<td>1287</td>
<td>1403</td>
<td>324</td>
</tr>
<tr>
<td>Serious Injuries</td>
<td>4878</td>
<td>19066</td>
<td>8592</td>
<td>4850</td>
</tr>
</tbody>
</table>

**Figure 2-2: Statistics about injury accidents (source: CARE 2005)**
## Accident Analysis: Frequency and Severity [2]

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>UK</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of all injury accidents</td>
<td>90.220</td>
<td>228.512</td>
<td>354.534</td>
</tr>
<tr>
<td>Rate at intersections</td>
<td>30%</td>
<td>60%</td>
<td>42%</td>
</tr>
<tr>
<td>Number of all fatalities</td>
<td>6.058</td>
<td>3.581</td>
<td>6.613</td>
</tr>
<tr>
<td>Rate at intersections</td>
<td>16%</td>
<td>36%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table 2-1: Selection of national accident statistics from 2002/2003.
The combination of passenger car vs. passenger car is the most dominant one (over 45%).

Intersections are not the major hot spot for pedestrian accident.
Five scenarios represent between 60% and 72% of injury accidents at intersection in France and Germany.
About 80% are even below 50km/h.
Accident Analysis [1]

Common Features
- Urban area (80% vs. 20% in rural areas)
- During the day (70% vs. 20% at night and 10% dusk/dawn)
- No precipitation (85% vs. 15% rain/snow)
- Dry road surface (65% vs. 35% wet/moist)
- Typical X-shaped (56% vs. 28% T/Y-shaped and 16% others)
- One lane (79% vs. 15%)
Accident Analysis: Main Scenario [1]

1st Scenario: Left Turn Across Path
- Misinterpretation of the oncoming vehicles’ speed (directly linked to the distance needed for clearing the area of danger)
- Ambiguity of traffic control (oncoming traffic expected to be stopped for intersection clearance)
- Sun glare

![Figure 2-8: Mistakes assigned to left turn across path (GIDAS)]

![Figure 2-9: Mistakes assigned to left turn across path (LAB)]

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Accident Analysis: Main Scenario [1]

2nd Scenario: Turn Into/Straight Crossing Path

- Misjudging the speed of vehicles coming sideways
- Sight obstruction into the other street
- Overestimated their possible acceleration to pass the intersection
- Inattention is a comparatively frequent mistake (36%)

Surveillance of the immediate neighborhood and traffic detection (e.g. by communication or special sensors) may provide improvements to inform the drivers of perpendicular traffic with right of way.
3rd Scenario: Red Light Crossing

- Drivers recognize a red light at a very late stage and subsequently desperately try to avoid a crash.

The user should be informed early enough and if needed must be warned punctually in order to avoid the critical situation.
User Need [1]

User needs can be described regarding to different aspects:

- Driver behavior
- User awareness
- User acceptance
- Willingness to purchase
User Need: Driver Behavior Determinants [1]

• **Left turning** with oncoming traffic was identified as a complex task.
• **Elderly drivers** make more mistakes.
• The most important difficulties for all drivers were:
  - Keep others in mind especially if they behave unexpectedly
  - The decision who has right of way
  - Sight obstructions and highly subjective complexities of intersections
  - Orientation passing through the intersection
Functionality: Turning Assistance [1]

A Visual and auditory warning shall support the driver in his decision making for turning in an intersection

Figure 4-1: Possible warning information for turning assistance
Functionality: Right-of-Way Assistance [1]

The system will warn the driver if he seems to violate a right-of-way but also if somebody else is expected not to give the right-of-way to the case vehicle.

Figure 4-2: Possible warning information for right-of-way assistance.
Functionality: Traffic Light/Stop Assistance [1]

There will be a visual and acoustic warning as soon as the system identifies a potential hazard. In order that the driver avoids such a conflict a speed recommendation will be given to the driver when approaching an intersection with traffic lights or stop signs depending on the current and intended status of the traffic light or the presence of a stop sign.
Requirements [1]

For the turning and the right-of-way assistance it is of interest to know in which driving lane a vehicle is located in order to predict the possible conflict points on the intersection.

Considering an average vehicle width of about 2m an **overall accuracy of 1m is needed** in order to locate a vehicle in a particular driving lane.

![Figure 5-1: Conflict point dependent of opponents’ driving lane](image)
However, there are multiple possible sources of errors:

- The error of positioning of the vehicle itself
- The error of object detection of nearby vehicles
- The error of map

Splitting the target error equally yields about 0.3m error for each source.

Taking into account an ideal Gaussian distribution for errors, a standard deviation of 0.1m corresponds to a maximum error of 0.3m.

Therefore, the accuracy for each part should be 0.1m.
Requirements: Localization of the Host Vehicle [1]

A resolution of ±0.1m should be reached.

These localization requirements show that the accuracy needed in INTERSAFE is much higher than in any other PReVENT project that deals with this topic.
Requirements: Object Detection and Tracking [1]

Going straight: 180°
Turning right: 252°
Turning left: 252°

Scenario 1: 120 ~ 134m
Scenario 2: 100 ~ 120m
The risk assessment as part of the warning function took advantage of the type of the object and its location with regard to the intersection as well. A car/pedestrian on the road was treated different to a parked car/pedestrian on the pavement, even if the characteristics were quite similar.

It is necessary to classify objects into:
- Parked vehicles
- Potentially moving vehicles
- Pedestrians
## Requirements: Map [1]

<table>
<thead>
<tr>
<th>Fusion Level</th>
<th>Function</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Identification of relevant areas where objects are likely to occur and</td>
<td>General geometry of the intersection. For lane recognition, an estimated accuracy of 1m is needed.</td>
</tr>
<tr>
<td></td>
<td>where not</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identification of restricted lanes to support the classification process</td>
<td>Lane information with classification for which objects they were designed (e.g., bicycle lanes, pedestrian crossings). The map precision for</td>
</tr>
<tr>
<td></td>
<td>of other objects</td>
<td>lane recognition is estimated to be one half to one quarter of the lane width (or crossing width).</td>
</tr>
<tr>
<td></td>
<td>Fusion of the objects into a common reference frame.</td>
<td>An accuracy of 0.1 m is required for the high-level map itself to discriminate between a pedestrian on the pavement and a pedestrian on the road. (see below)</td>
</tr>
<tr>
<td>Application Level</td>
<td>Precise localisation of case vehicle to compute distances and safe-gaps</td>
<td>Precise geometric information of lanes, stop lines and natural landmarks.</td>
</tr>
<tr>
<td></td>
<td>Identification of potential conflicting vehicles (turning assistance and</td>
<td>Design and lay-out of lanes together with allowed and restricted manoeuvres.</td>
</tr>
<tr>
<td></td>
<td>right-of-way assistance)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cope with the problem of occlusion</td>
<td>Classified stationary objects to identify possible occluded field of view.</td>
</tr>
<tr>
<td></td>
<td>Realisation of traffic control at intersection</td>
<td>Traffic lights and signs with assigned directions/lanes.</td>
</tr>
</tbody>
</table>
Requirements: Data Acquisition Rate [1]

For the defined INTERSAFE operating conditions only vision, laser and radar sensor systems (or their complementary assembling) could be considered for the application. These limit the requirements for update rate of the whole system to the most possible value for the slowest of the used sensors.

In consequence the possible update rate is limited to 10 ~ 15 Hz as this is usual for modern vision systems.
**Requirements: Communication [1]**

There are two relevant communication techniques:

1) 5.8 ~ 5.9 GHz–based dedicated short range communication (DSRC): It requires a line-of-sight (LOS) connection between two communication partners.

2) IEEE802.11p–based wireless access in the vehicle environment (WAVE): It is supported by Car-to-Car Communication Consortium.

Two goals of communication:

1) Globally synchronized time: GPS or UTC (Universal Time Coordinated) time signal receiver

2) Minimum latency time: 300ms for low–tech version, 100ms for high–tech version

Minimum communication distance: 300m
System Architecture: B-ISS [2]
System Architecture: Sensor Level [2]

The INTERSAFE demonstrator was equipped with two laser-scanners, one video camera and additional communication devices.

<table>
<thead>
<tr>
<th>Information about…</th>
<th>…is perceived by</th>
</tr>
</thead>
<tbody>
<tr>
<td>lane markings, lane signs</td>
<td>video camera</td>
</tr>
<tr>
<td>objects, road users, landmarks</td>
<td>Laserscanner</td>
</tr>
<tr>
<td>vehicle speed, acceleration, yaw rate</td>
<td>ABS, DSC/ESP</td>
</tr>
<tr>
<td>infrastructure / traffic light information, other vehicle information</td>
<td>communication module</td>
</tr>
</tbody>
</table>

Table 5-1: Sensor level elements.

FLM (feature-level-map): high-level-map represented a consistent overall image of the intersection. It contained the geometry of lanes for vehicles or bicycles and the pavement. In addition the road markings and natural landmarks, such as posts or poles were registered in an additional layer of the digital map.
System Architecture: Perception Level [2]

Relative localization of the host vehicle within the intersection
  → matching detected objects with registered landmarks.

Background elimination

Detection of the road users (dynamic objects)

Tracking and classification of the road users
Scenario interpretation

Risk assessment: The potential conflicts for the current situation were extracted and analyzed in the risk assessment module.

Warning strategy
Sensor Specification [2]

Laser-scanner

![Diagram of laser-scanner](image)

**Figure 5-2: Laserscanner and FLM.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>accuracy</td>
<td>± 0.1 m</td>
</tr>
<tr>
<td>range</td>
<td>0.3 ... 200 m</td>
</tr>
<tr>
<td>horizontal field of view</td>
<td>≤ 240 degree</td>
</tr>
</tbody>
</table>

Table 5-2: Specification of the Laserscanner system.
Sensor Specification [2]

Video Camera

Figure 5-3: Video camera and FLM.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>position accuracy</td>
<td>0.1 m</td>
</tr>
<tr>
<td>heading accuracy</td>
<td>~ 0.1 degree</td>
</tr>
<tr>
<td>range</td>
<td>2.5 ... 50 m</td>
</tr>
<tr>
<td>horizontal field of view</td>
<td>≤ 45 degree</td>
</tr>
</tbody>
</table>

Table 5-3: Specification of video camera.
Communication Module
The current technological basis is IEEE802.11b with DSRC specific adaptations.
HMI Specification [2]

A common technique for showing graduated warnings is a progress bar indicating a rising or falling risk or discrete symbols.

Together with the visual support, acoustic warning was necessary to direct the driver’s attention to the assistance function.

Figure 5-5: HMI graphics in head-up and navigation display.
System Development [2]

Following the two approaches, INTERSAFE realised

- an Intersection Driver Warning System following the bottom-up-approach (B-ISS) in
  - a VW Phaeton demonstrator based on on-board sensors and communication for
    - left turn,
    - turning/crossing and
    - traffic light assistance,
  - a BMW 5 series demonstrator based on communication for traffic light assistance.

- the improvement of a dynamic driving simulator (top-down approach) to obtain requirements for future Intersection Active Safety Systems (A-ISS) for the following scenarios
  - left turn
  - turning/crossing and
  - traffic light assistance
System Development [2]

Bidirectional V2I (V2I2V) Communication

The advanced traffic light – including bidirectional V2I communication (e.g. position information, speed values and indicator status) to other equipped vehicles. Thus the field of view of the on-board sensors was extended by messages from other road users approaching the intersection relayed by the traffic light.

*Figure 6-1: System Setup for Bidirectional Communication Tests.*
System Development [2]

Scenario Interpretation

a) Possible conflicts
b) Traffic participants
c) Right of way regulation

→ All possible conflicts and the assigned probabilities of the driving behavior of the vehicles omitting the time domain.

Figure 6-2: Computation of conflicts.
**System Development [2]**

**Risk Assessment**

Computing a risk level for each possible conflict in time and space domain. “Whether or not two vehicles were reaching the conflict point in the same time interval.”

The conflict with the highest assigned “risk level” was considered to be the most important one.

This conflict was passed to the **warning strategy level**.

![Diagram](image)

*Figure 6-3: Continuous HMI for visualisation of the risk level.*
System Development [2]

Traffic Light Assistance

The traffic light assistance developed was based on traffic light data transmitted via V2I communication.

The V2I communication was based on IEEE 802.11a standard for transmission – the so called WLAN.

DGPS (Differential GPS)
A-ISS: Simulation–based Probability

The system’s decision whether the left turning maneuver was critical or not due to oncoming traffic had to be make before starting maneuver. So, for the calculation of the collision probability the driver’s future plane had to be predicted.

Figure 7-2: BMW dynamic driving simulator.
Demonstrator [2]

VW Phaeton Demonstrator Vehicle

Camera: lane marking detection
2 laser scanners: landmarks detection
V2I communication module

Figure 7-1: Sensor integration in the VW test vehicle.
Demonstrator [2]

BMW5 Series Demonstrator Vehicle

V2I communication module

D–GPS: accurate positioning

Figure 7-2: BMW demonstrator vehicle.
Cooperative Intelligent Transportation Technology

Nissan Safety Shield with Cooperative ITS

Precise determination of vehicle position based on accurate GPS data

Map information of intersection surroundings from roadside radio

Host vehicle localization from accurate GPS and map data

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Cooperative Intelligent Transportation Technology

Nissan Safety Shield with Cooperative ITS

- **Distance to intersection** and in which lane it is traveling
- **Signal phase** and **timing** pertinent to the current travel lane
- **Position** information from surrounding vehicles
Cooperative Intelligent Transportation Technology

Nissan Safety Shield with Cooperative ITS

Signal Violation Warning

Oncoming Traffic Notification

Prepare to Stop

Oncoming Traffic
Cooperative Intelligent Transportation Technology

Nissan Safety Shield with Cooperative ITS

http://www.youtube.com/watch?v=-DoyfPLSiJs
http://web.yonsei.ac.kr/hgjung
Introduction to INTERSAFE-2

http://www.intersafe-2.eu/

- Total 6.5 M€ / 3.9 M€ funding
- June 2008 – May 2011

The cooperative sensor data fusion is based on:
- State-of-the-art and advanced on-board sensors for object recognition and relative localization
- A standard navigation map
- Information supplied over a communication link from other road users via V2V if the other vehicle is so equipped
- Infrastructure sensors and traffic lights via V2I if the infrastructure is so equipped to observe the complex intersection environment.

Warning and Intervention

Passenger cars and heavy good vehicle
Introduction to INTERSAFE-2

- Left Turn Assistance
- Right Turn Assistance
- Traffic Light / Right-of-Way Assistance
- Crossing Assistance
References