Motion planning and control techniques for driver assistance systems and autonomous vehicles

Antoine Tordeux
Forschungszentrum Jülich and Wuppertal University
a.tordeux@fz-juelich.de

November 17, 2016 — Campus Descartes, Champs-sur-Marne
Overview

Introduction

Motion planning techniques
- Functional architecture of automated vehicles
- Sensing and perception
- Motion planning
- Actuation control

Control and safety
- Stability and homogenisation
- Functional safety

Conclusion
Overview

Introduction

Motion planning techniques
  Functional architecture of automated vehicles
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  Stability and homogenisation
  Functional safety

Conclusion
Introduction

Road vehicles are becoming increasingly automated (VDA, 2015).

- Advanced electric and electronic (E/E) driver assistance systems (ADAS)
- Connected and automated vehicles (autonomous car)
Introduction

Road vehicles are becoming increasingly automated (VDA, 2015).

Advanced electric and electronic (E/E) driver assistance systems (ADAS)
Connected and automated vehicles (autonomous car)

Motivations

▶ Safety  More than 90% of road accidents attributed to driver error (with 31% involving legally intoxicated drivers, and 10% from distracted drivers)
▶ Performance  Reduction of driver reaction time (short distance spacing, platooning) and optimal route choice (efficient use of the network)
▶ Mobility  For children, old or disable persons with no driving licence; development of share use models and cost reduction of the road transportation
▶ Environment  Efficient (smooth) driving and routing (less jam) reducing fuel consumption and pollutant emission
### Automation classification

<table>
<thead>
<tr>
<th>Automation level classification for road vehicles (SAE, 2014)</th>
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<tbody>
<tr>
<td><strong>L0</strong> Automated systems have no vehicle control, but may issue warnings</td>
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</table>
<pre><code>| No automation |
</code></pre>
<p>| <strong>L1</strong> Assistance systems (ACC, lane keeping, …) |
| Assisted |
| <strong>L2</strong> Partial longitudinal and lateral controls for specific situations |
| Partial automation |
| <strong>L3</strong> Longitudinal and lateral controls for specific situations |
| Conditional automation |
| <strong>L4</strong> Full automation for all situations in a defined use case |
| High automation |
| <strong>L5</strong> Full automation for all situations of a given journey |
| Full automation |</p>

Under driver supervision

Without supervision
Projections of development

- Manufacturers: L3 level by 2020 (Tesla, Google, Nissan, Volvo, BMW, ...)

- Information services companies
  - Level 3 by 2020, level 4 by 2025 and level 5 by 2030 (IHS Markit)
  - L3, L4 and L5 Penetration rates of 100, 75 and 25% by 2030 (KPMG)
  - 75% of light-duty vehicle sales automated by 2035 (Navigant)

- Insurance institutes
  - All cars may be automated by 2030 (III)
  - Reduction from 30 to 80% of the accidents (PWC Insurance Monitor)

- Research  Survey during the Transportation Research Board Workshops on Road Vehicle Automation (around 500 experts, 2014):

  *When will automated vehicles take children to school?*

  → More than half expect 2030 at the very earliest; 20% said not until 2040; 10% never expect it.
History

Connectivity

- 1965: Radio traffic information
- 1969: Navigation system
- 1991: Cell phone
- 2002: Bluetooth
- 2007: Car-To-Car Consortium
- 2009: Mobile internet
- 2015: WLAN ITS G5
- 2019: 5G network
- 2020: HD map

ADAS

- 1965: Cruise control
- 1966: Power steering
- 1977: ABS
- 1987: Traction control
- 1994: ESP
- 1995: Braking assistant
- 1998: ACC
- 2001: Emergency braking
- 2002: Lane dep. warning
- 2005: Parking assistant
- 2007: Blind-spot
- 2009: Sign recognition
- 2007: Lane keeping
- 2015: Park assist
- 2015: Traffic jam driving
- 2015: Highway driving
- 2002: Lane dep. warning
- 2005: Parking assistant
- 2007: Blind-spot
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- 2007: Lane keeping
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- 2007: Lane keeping
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- 2015: Traffic jam driving
- 2015: Highway driving

Company

- Levels 0 & 1
- Levels 2
- Levels 3, 4, 5?

Research

- 1952: Wardrop’s Equilibria
- 1955: LWR
- 1971: Payne-Whitham
- 1963: Follow-the-leader (Pipes)
- 1988: Lane changing
- 1980: Dynamic traffic assignment (Merchant & Nemhauser)
- 1985: Multi-ant. (Bexelus)
- 1986: Linear stability (Kometani)
- 1990: Optimisation (Papageorgiou)
- 1995: OVM
- 2000: IDM
- 2000: Nonlinear stability (Komatsu, Sasa, Wilson)
- 2002: Micro-Macro derivation (Aw, Rascle)
- 2002: Multi-class LWR (Wong & Wong)
- 2014: Homogenisation (Monneau, Forcadel)
- 2007: GSOM (Lebacque)

Models

- 1985: ALV
- 1997: CYBERCARS
- 2004: DARPA Challenges
- 2010: Google-Car GCDC, VIAC
- 2015: PROUD DELPHI

Projects

- 1950
- 1970
- 1990
- 2000
- 2010
- 2020

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- Safe and performant 2D models?
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Conclusion
Automated vehicles are **mission-based** and have a **functional architecture** (Behere und Torngren, 2015; Paden et al., 2016).

**Classical components** of the autonomous driving:

1. **Perception**  
   Collection, fusion and interpretation of the sensor (radar, camera) and connectivity (V2V, V2I) data  
   → *Building of a virtual world*

2. **Motion planning**  
   Routing choice and determination of continuous and collision-free reference trajectories  
   → *Calculation of short and safe feasible paths*

3. **Actuation**  
   Determination of stable commands to the vehicle to follow the reference trajectory  
   → *Steering, braking and acceleration rate controls*
Functional architecture of automated vehicles

### Perception

**Data collection**
- Radar, Laser, ultrasonic sensor
- Camera, Infrared camera
- Inertial navigation system
- Global positioning system
- V2V & V2I communications

**Interpretation**
- Data fusion (SLAM)
- Objects identification
  - (Machine learning, clustering filter, ...)

### Motion planning

**Local Planning**
- Continuous interpolation (Spline)
- Holonomic condition, Slipness
- Longitudinal Planning

**Behavior planning**
- Maneuver planning, Roadmap
- Collision avoidance technique
- Heuristic (NN, probabilistic)

**Routing**
- Shortest path problem
- Dijkstra’s algorithm
- Heuristic (A*, hierarchical, ...)

### Actuation

**Control planning**
- Stable reference-trajectory
- Feedback mechanisms

**Vehicle’s control**
- Steering
- Braking
- Accelerating

### Time-dependency

**Reference-trajectory**

**Virtual world**
Functional architecture of automated vehicles

**Perception**
- **Data collection**: Radar, Laser, ultrasonic sensor, Camera, Infrared camera, Inertial navigation system, Global positioning system, V2V & V2I communications
  - **Data**
- **Interpretation**: Data fusion (SLAM), Objects identification (Machine learning, clustering, filtering, ...)

**Motion planning**
- **Local Planning**: Continuous interpolation (Spline), Holonomic condition, Slipness, Longitudinal Planning
  - **Path**
- **Behavior planning**: Maneuver planning, Roadmap, Collision avoidance technique, Heuristic (NN, probabilistic)
  - **Route**
- **Routing**: Shortest path problem, Dijkstra’s algorithm, Heuristic (A*, hierarchical, ...)

**Actuation**
- **Control planning**: Stable reference-trajectory, Feedback mechanisms
  - **Regulation**
- **Vehicle’s control**: Steering, Braking, Accelerating

**Virtual world**

**Reference-trajectory**

**Automatisation**
- **Level L1**: ACC, lane keeping
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**Automatisation**
- Level L3-L4-L5
  - Full automation

**Virtual world**

**Time-dependency**
Functional architecture of automated vehicles

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**Virtual world**

**Reference-trajectory**

**Time-dependency**
Sensor and communication technologies

**Communication technology**

- **Vehicle to vehicle (V2V)** communications (own frequency, *Car to Car Communication Consortium*)
- **Vehicle to infrastructure (V2I)** communications (information to the driver/vehicle, centralized regulation)

**Sensor technology**

- **Cameras** coupled to computer vision to monitor traffic signals, road markings or to detect obstacles or turns
- **Radar (LIDAR), sonar, laser and ultrasound** to evaluate distances and relative speed with potential obstacles around the vehicle
- **Global Position System (GPS)** to determine vehicle location
- **Inertial navigation systems** such as accelerometers and gyroscopes to continuously calculate acceleration and rotation
Exteroceptive sensor technologies for automated vehicles

- Long-range radar
- LIDAR
- Camera
- Short/medium-range radar
- Ultrasound

Adaptive
- cruise control
- Emergency braking
- Collision avoidance
- Pedestrian detection
- Traffic sign recognition
- Lane departure warning
- Cross Traffic Alert
- Park assist
- Surround view
- Rear collision warning
- Blind spot
- Surround view

Source: ABI Research
Sensing and perception

**Metric knowledge**: measuring distances and scenes around the vehicle (sensing)

*Small speed*: short-range sensing / *Large speed*: long-range in high resolution (Angular resolution < 0.1° at 130m if speed > 100km/h (Blosseville, 2015))

**Conceptual knowledge**: identifying lanes, infrastructure, neighbor vehicles, pedestrians or obstacles and their evolution (computer vision – filtering, machine learning, ... )

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**Common robotic adage**: « *Sensing is easy, perception is difficult* »

\[
\text{Sensing} \rightarrow \text{Clustering} \rightarrow \text{Identification} \rightarrow \text{Tracking}
\]

*True negative* (ghost objects) vs *false positive* (blindness)

**Dynamic sensor/data fusion**: SLAM (Simultaneous Localisation and Mapping) with geo-referenced maps (single lanes geometry and topology; Thrun et al. 2005)
Example: Map-aided Evidential Grids for Driving Scene Understanding  
Kurdej et al. 2015

**Occupancy grids:** Description of the environment in discrete cells

Three evidential occupancy grids:

- **Prior information** (map)
- **Sensor acquisition**
- **Perception** (fuzzy logic)

Modelling of the world using a **tessellated representation** of objects such as

- Free navigable space
- Free non-navigable space
- Mapped infrastructure (buildings)
- Unmapped infrastructure
- Stopped objects (obstacles)
- Mobile moving objects

(Moras et al. 2011)
Functional architecture of automated vehicles

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Actuation
- Control planning
  - Stable reference-trajectory
  - Feedback mechanisms
  - Regulation
    - Vehicle’s control
      - Steering
      - Braking
      - Accelerating

Virtual world
Time-dependency
Analogy to classical modelling scales in transportation systems

**Strategic**
- Routing
- Departure time

**Tactical**
- Lane choice
- Jam avoidance

**Operational**
- Local motion
- Collision avoidance
Routing

Shortest path problem in a positive real-valued directed graph

- **Static problem**: polynomial complexity
- **Time-dependent formulation**: NP-hard problem (use of heuristics) – Dynamic (numerical) algorithm or reactive algorithm looking for solution at any time

- **Dijkstra’s algorithm**
  - Complexity in $O(V^2)$: not practicable in real time
- **A-Star heuristic**
  - Use of an heuristic cost function guiding the search
- **Decomposition**
  - Network decomposition in subsets or principal components
- **Preprocessed method**
  - Preprocessing of balanced partition of the graph
- **Hierarchical method**
  - Weights according to the hierarchy of road networks
- **Sampling based**
  - Monte-Carlo techniques for the finding of the shortest path
- **Combination**
  - Hybrid algorithms combining different methods

... (see Gonzalez et al. 2016 or Bast et al. 2015 for surveys)
Behavior planning

Finding of an efficient and safe (collision-free) path in a dynamical environment with moving obstacles

- Understanding of the current driving situation $\Rightarrow$ Cognitive Vehicle
- Time-dependent complex problems

- **Manoeuvre-based** Categorical driving situations: following, lane-keeping, overtaking...
- **Variation methods** Formulation of the problem as an optimisation problem
- **Roadmap** Borrowed from robotic: visibility graph, Voronoi diagram...
- **Potential fields** Gradient problems with attractive (dest.) and repulsive (obstacle) fields
- **Velocity obstacle** Determination of collision-free cones over finite time horizons
- **Heuristic** Neuronal networks, Simulated annealing, ant/swarm optimisation...
- . . . (see Masehian 2016, Tang et al. 2012, Kamil 2015 or Paden et al. 2016 for surveys)
Local planning

Determination of the **reference trajectory**: smooth trajectory dynamically-feasible for the vehicle

**Interpolating curve planners** (curvature optimisation)
- Regular interpolation of the reference path
- Clothoid, polynomial, Bézier, spline, ...

**Speed/acceleration planners** $\ddot{x}_i = F(s_i, \dot{x}_i, \dot{x}_{i+1}, ...)$
- Comfortable and safe following model
- Adaptive cruise control (ACC)

**Non-holonomic driving constraints** $m\ddot{p}_c = F_f + F_r$
- Kinematic single track constraints
- Inertial and slipness constraints
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- **Vehicle’s control**
  - Steering
  - Braking
  - Accelerating

**Virtual world**

**Reference-trajectory**

**Time-dependency**
Actuation control in two steps:

1. Calculation of a command to follow the reference trajectory \((x_{\text{ref}}, v_{\text{ref}})(t)\)
   
   → Feedback mechanisms \(fb\) (e.g. relaxation processes)
   
   \[ \ddot{x}(t + T_a) = fb((x, x_{\text{ref}}, \dot{x}, v_{\text{ref}})(t)) \]
   
   with \(T_a\) the mechanical application time

2. Effective mechanical control of the vehicle
   
   → Steering, braking and accelerating controls
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Conclusion
Stability

Motion planning have to describe **comfortable and safe dynamics**

→ **Stable and collision-free dynamics**

- **Stability of the route choice** (Smith, 1984)
  - Route choice robust to perturbation / Non-oscillating route choice
  - Motion planning / Routing step

- **Stability of the reference trajectory**
  - Attractive reference trajectory / Exponential stability $\|x(t) - x_{\text{ref}}(t)\| \leq Ke^{-\kappa t}$
  - Actuation / Control planning

- **Local and global stability of the homogeneous solution**
  - Congested state – Stability of the homogeneous solutions where all vehicle speed $\dot{x}_i(t) = v$ and spacing $x_{i+1}(t) - x_i(t) = d$ are equal
  - Motion planning / Local planning
Stability of the homogeneous solution

Control of the ACC-systems: description of stable and collision-free dynamics

→ Linear stability theory for dynamical systems

▶ Local stability
  – Following behavior behind a vehicle moving at constant speed
  – Stable and collision-free (over-damped convergence)

▶ String-stability
  – Stable homogeneous solutions \((s, v) \in \mathbb{R}^2_+\)
    
    \[
    \begin{align*}
    x_{i+1}(t) - x_i(t) & \to s \\
    \dot{x}_i(t) & \to v
    \end{align*}
    \]
    as \(t \to \infty\) for all \(i\)
  – Consideration of local, convective and advective perturbations
  – Control of the system stationary state

Homogenisation

**Homogenisation:** *Monotone* convergence of the system to the homogeneous solution (Monneau & Forcadel, 2014)

→ Control of the transient and stationary states of the system

→ Bounds of minimal speed and spacing

**Principle:** constraints on the model’s parameters

- Invariance principle for spacing variables
- Comparison principle on the invariant sets
- Convergence of the system to homogeneous solution by up- and down-bounds

**Example:** Optimal velocity model (OVM)

\[
\ddot{x}_i(t) = \frac{1}{\tau} \left( V(s_i(t)) - \dot{x}_i(t) \right)
\]

| Global stability: \( \tau V'(s) < 1/2 \) |
| Homogenisation: \( \tau V'(s) < 1/4 \) |
Stability + Homogenisation

\[ (x_1(t), \ldots, x_n(t)) \]
Stability + Homogenisation

Space $(x_1(t), \ldots, x_n(t))$
Stability + Homogenisation

\[ (x_1(t), \ldots, x_n(t)) \]

Time \( t \)

Space \( (x_1(t), \ldots, x_n(t)) \)
Stability + Homogenisation

\[
\min_{i} x_{i}(t) - x_{i+1}(t) 
\]

Time \( t \)
Safety for automated vehicles

The safety is a central aspect of connected and automated vehicles

**Essential argument**

- **for** the development of automated vehicle (more than 90 % of the accident due to human errors; Singh, 2014),
- **and against**: safety of autonomous vehicles still need to be proven

Biggest risk sources for autonomous vehicles: **collisions** (Lefèvre et al., 2014)

**Potential high severity of the damage** in case of collision (injure, fatality)

→ Depends on the speed and type of collision

**Very low exposure**
Limit of the empirical evaluation

Even if many accidents in road traffic occur, the probability for a accident with injures or fatalities per unit of distance is very low.

→ Example USA:
  - Injure-rate is around 40 per 100M kilometres
  - Fatality-rate is around 0.7 per 100M kilometres

Example (Kalra and Paddock, 2015): we have to observe without accident 100 autonomous vehicles driving 24h a day and 365 days a year during

| 4 months     | 12M km | (injure) | or | 19 years | 658M km | (Fatality) |

...to statistically prove that injure- and fatality-rate of the autonomous vehicles is smaller that the rate of conventional vehicles.

Connected and automated vehicles are technologies in development

→ Empirical evaluation of the safety not suitable
Functional safety from the ISO 26262 standard

**Standardisation** (Schlummer, 2014): IEC 61508 (generic norm), ISO 26262 (automotive area) or companies and associations’ directives, ...

ISO 26262-3 und 26262-4: Functional safety for the concept and development phases of E/E systems in road cars

→ **Completeness and consistence problem**

*For all items and all driving situations:*

- **P1:** Hazards analyse & Risk assessment → **P2:** Functional safety concepts → **P3:** Technical safety concepts

- **Exhaustive listing** of all driving situations and associated potential hazards (AMDEC, dependability, situation classification)

- Risk assessment: **ASIL risk classification scheme** as function of **Severity**, **Exposure**, **Controllability**
Classification of the driving situations

Discrete (categorical) descriptions of the driving situations according to (Warg et al., 2014; Jang et al., 2015; VDA, 2015b):

- **Vehicle**
  - speed, direction, state, mode, manoeuvre, ...
- **Road**
  - road type, surface type, curving, slope, ...
- **Neighborhood**
  - infrastructure, vehicles, pedestrians, obstacles, ...
- **Environment**
  - weather, luminosity, temperature, ...

Driving situations, environment and potential hazards are **numerous and varied**: they can only exhaustively be described in **specific simple conditions**.

→ Example – Driving in **highways**:  *following, lane keeping, lane changing*

Driving situations in **urban** or **peri-urban** are **more complex**.
Safety concepts

**Functional safety concept:** *Collision avoidance systems*
→ *Controllability* part of the ASIL risk classification

**Technical safety concepts**

- **Emergency protocols**
  - System failure: failure detection, emergency breaking
  - Unexpected event: emergency avoidance procedure *(reactive control, Binfet-Kull et al. 1998).*

- **Driving situation analysis**
  - Setting of safe conditions for all manoeuvres
  - (mathematical criteria based on distances, speeds...)

- **Redundancy**
  - Sensing: Sensor/camera/GPS/carte fusion (SLAM)
  - Motion planning: use of several planners
  - Actuation: for instance steering through stereo-breaking
Functional safety for autonomous vehicles: limit

Main difference with autonomous vehicles (Warg et al., 2014):

- **Conventional vehicle:** the driver is responsible for the vehicle control.
- **Autonomous vehicle:** the automated driving system is responsible.

→ Exhaustive listing of all driving situations and hazards with autonomous vehicle at the levels L3, L4 or L5 is **not possible.**

≪ The higher complexity and the partly implicit definition of the tasks [of autonomous vehicles] for the E/E systems will make it harder to argue completeness and correctness of the safety requirements in each phase of the ISO 26262 life-cycle. ≫

(Bergenheim et al., 2015).

≪ Vehicle-level testing won’t be enough to ensure safety. It has long been known that it is infeasible to test systems thoroughly enough to ensure ultra-dependable system operation. [...] Thus, alternate methods of validation are required, potentially including approaches such as simulation or formal proofs ≫

(Koopman und Wagner, 2016).

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2 Warg et al., 2014; Bergenhem et al., 2015; Johansson, 2016; Koopman und Wagner, 2016.
Dynamic safety analysis

Development of **specific tools for the safety** aiming to take into account the **varied dynamical aspect** of the driving

- Working group **safety of the intended function (SoTIF)** in the revision of the ISO 26262 standard

**Examples:**

- **Dynamic evaluation of the safety** with temporal indicators as **Time-to-Collision**, **Time-to-React** or **Time-Gap** (Tamke et al., 2011; Berthelot et al., 2012)
- Dynamic detection of **unusual events** or **conflictual manoeuvres** (Lefèvre, 2014)
- **Mathematical analyse** of the collision possibilities; Development of **robust collision-free models and avoidance techniques** (Zhou und Peng, 2005)
- **Real-time trajectories predictions** by **simulations** (Eidehall und Petersson, 2008; Ammoud et al., 2009; Chen und Chen, 2010; P. Olivares et al., 2016)
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**Advanced driver assistance systems** are growing up equipments proposed by manufacturers or automotive suppliers
- Improvement of the **safety** and the **driving comfort**
- Levels L1 and L2 of automation

**Progressive transition to connected and autonomous vehicles** (Blosseville, 2015)

- **Autonomous Vehicles** Level L3 of automation (autonomous highway driving)
  - High intelligence of the embedded systems (perception, map)

- **Connected vehicles** Autonomy + Connectivity — Level L4
  - Formalisation of the driving in different contexts (highway, peri-urban, urban)
  - Deployment of V2X communications

- **Integrated vehicles** Connected + Cooperation with the infrastructure — Level L5
  - High performances on networks (optimal affectation)
  - Safety solution at high speed and in complex 2D contexts (mixed urban traffic)
Challenges

Full driving automation depends on the advances of intelligent transportation systems, sensor and connectivity technologies, and computational capacity (Blosseville, 2015)

▶ Motion in complex 2D urban environments with mixed traffic
  - Driving situation very varied / Driving behavior few structured (Saad, 1987)
  - Complicated algorithms for the perception and the motion (machine learning, neural networks, ...) for which the reliability is hard to estimate.
  - Long time anticipation

▶ Autonomous vehicles to avoid crashes due to human errors. Yet most of the time, human driving is free of accident.
  → Challenge for automated cars: replicate the crash-free performance of human drivers. New type of crashes may emerge (ITF, OECD).

▶ Full autonomous vehicles (level L5) on personal rapid transit systems
  - Own infrastructure and driving rules
  - Increase of the mobility
References


References


References


References


References


Empirical evaluation of the accident-rate

- $p$ is the probability of accident for autonomous vehicles.
- $p_0$ is the probability of accident in real traffic.

$D$ is the collision-free traveled distance; it has a geometric distribution with parameter $p$. Therefore $P(D \leq n) = 1 - (1 - p)^n$.

We test $H_0 = \{p \geq p_0\}$.

For a given traveled time $n$, we reject $H_0$ if $R_n = \{D > n\}$.

The probability of a false-positive is then

$$P_{H_0}(R_n) = 1 - P_{H_0}(D \leq n) \leq 1 - P_{p=p_0}(D \leq n) = (1 - p_0)^n = \alpha.$$ 

We have $p < p_0$ with confidence-level $1 - \alpha$ if

$$n \geq \frac{\ln(\alpha)}{\ln(1 - p_0)}.$$
## Example of driving situation classification (H. Jang et al., 2015)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sub-factor</th>
<th>Element</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driving Speed</td>
<td>Very Slow, Slow, Normal and Fast</td>
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<tr>
<td></td>
<td>External Attachment</td>
<td>Without/with external attachment</td>
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<tr>
<td></td>
<td>Operational Mode</td>
<td>Driving, Parking, Fuelling, Repairing</td>
<td></td>
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<tr>
<td>Vehicle</td>
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<tr>
<td></td>
<td>Maneuver</td>
<td>Engine On, Off</td>
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<tr>
<td></td>
<td>Velocity</td>
<td>Accelerating, Constant, Decelerating</td>
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<tr>
<td></td>
<td>Direction</td>
<td>Lane Keeping, Lane Changing, Turning</td>
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<tr>
<td></td>
<td>Movement</td>
<td>Stop, Forward, Backward</td>
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<tr>
<td></td>
<td>Linearity</td>
<td>Straight, curved</td>
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<tr>
<td></td>
<td>Slope</td>
<td>Plain, sloped</td>
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<tr>
<td>Road</td>
<td>Layout</td>
<td>Invisible (blocked), Visible (unblocked)</td>
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<tr>
<td></td>
<td>Coarseness</td>
<td>Paved, unpaved, troublesome</td>
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<tr>
<td></td>
<td>Nearby Elements</td>
<td>Obstacle Clean, Obstacle</td>
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<tr>
<td></td>
<td></td>
<td>Traffic Smooth flow, Congestion</td>
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<tr>
<td></td>
<td></td>
<td>Pedestrians No, A few, Many</td>
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<tr>
<td></td>
<td>Surface</td>
<td>Clear, water (by rain etc), snow/ice</td>
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<tr>
<td></td>
<td>Visibility</td>
<td>Dark, bright, foggy</td>
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<tr>
<td></td>
<td>Temperature</td>
<td>Low, medium, high</td>
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</tr>
<tr>
<td></td>
<td>Momentum</td>
<td>Windy, calm</td>
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</tbody>
</table>