Hazard Analysis of Concept Heavy Truck Platooning Systems

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Research Objectives

- Explore how safety hazards can be assessed and how they vary based on different levels of implementation.
- Identify various strategies and types in truck platooning systems (current and future concepts).
- Develop an understanding of heavy truck platooning concepts.
- Perform hazard analyses on generic heavy truck platooning system concepts and identify cross-cutting and unique items.
Hazard Analysis of Concept Heavy Truck Platooning Systems

Project Team: Battelle, The Volvo Group, WABCO, and SAE International

Research Tasks:
• Market study to identify current and future concept systems
• Conduct hazard analysis and risk assessment
• Select representative, “generic,” platooning system concepts for functional safety analyses
• Safety of the Intended Functionality Analysis (SOTIF)
• Fault Tree Analysis (FTA) for selected hazards
Identifying Hazards

- **Hazard** – an event that poses a danger to people, the system, or the environment. Caused by:
  - Human error
  - Failure of hardware
  - Software issues
  - Limitations of the system design

- **Risk Assessment** – to identify:
  - **Severity**
    - Cost of the hazard, in terms of injuries or fatalities to users and the public
    - System repair costs or environmental damage
  - **Frequency**
    - Measures likelihood of occurrence, per unit of time or usage
  - **Controllability**
    - Ability of an operator to mitigate a hazardous situation

ISO 26262 Road Vehicles – Functional Safety standard
## Platooning System Concepts

### Operational Design Domain (ODD) and System Assumptions:

- Platoon is already in formation
- Operating on a freeway
- Platoon is cruising at a nominal steady-state speed
- No hazardous materials are being transported
- Inter-vehicle communications
- Environmental conditions, such as weather and traffic were included as appropriate

<table>
<thead>
<tr>
<th>System</th>
<th>Truck Configuration</th>
<th># of Vehicles in Platoon</th>
<th>Driver Present in Each Vehicle</th>
<th>Lead Vehicle Driver Responsibilities</th>
<th>Following Vehicle Driver Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2VL1</td>
<td>Single tractor-semitrailer</td>
<td>2</td>
<td>Yes</td>
<td>Speed and steering control, and managing the platoon</td>
<td>Steering control only</td>
</tr>
<tr>
<td>3VL2</td>
<td>Single tractor-semitrailer</td>
<td>3</td>
<td>Yes</td>
<td>Speed and steering control, and managing the platoon</td>
<td>Neither steering nor speed control</td>
</tr>
</tbody>
</table>
3VL2 Concept Platooning System

External Factors

On-board Sensors (Radar, Cameras, LiDAR)
Other Traffic
Roadway Features
Environment (Weather, etc.)

Engine Management System
Electronic Control Unit

Engine Management System Software
Digital Map file

Engine Management System

Driver Monitoring System

Intervehcle Communications
Position Information (GPS)

Driver

Speed Control
Steering Control

Throttle Actuator
Engine Management System
Steering Actuator

Platooning System Boundary

CAN

Other Drivers in Platoon
Other Platoon Vehicles

Platooning Vehicle
Determination of Hazards and Risks

- List of 57 hazards was identified
  - Categorized by: equipment failures, operational environmental hazards and human factors.
  - Classified by: severity, probability of exposure, and controllability.
  - Assigned ASIL to each hazard.
  - Safety Mitigations were developed.
  - Risk Analysis was conducted using input from industry stakeholders.
### Example Hazards

<table>
<thead>
<tr>
<th>Hazard ID</th>
<th>Description</th>
<th>System Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>There is an unexpected stoppage in traffic.</td>
<td>2VL1 and 3VL2</td>
</tr>
<tr>
<td>18</td>
<td>There is unexpected road debris.</td>
<td>2VL1 and 3VL2</td>
</tr>
<tr>
<td>28</td>
<td>There is a difference in tire wear (e.g. traction, tread depth, grip, etc.)</td>
<td>2VL1 and 3VL2</td>
</tr>
<tr>
<td></td>
<td>between the Lead and Following Vehicles.</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>There is a loss in steering control in the Lead Vehicle.</td>
<td>2VL1</td>
</tr>
<tr>
<td>34</td>
<td>There is a loss in steering control in the Following Vehicle.</td>
<td>3VL2</td>
</tr>
<tr>
<td>41</td>
<td>There is a cyber-attack on the Following Vehicle’s communication subsystem.</td>
<td>2VL1 and 3VL2</td>
</tr>
<tr>
<td>53</td>
<td>A motorcycle performs a cut-in between two platooning vehicles.</td>
<td>2VL1 and 3VL2</td>
</tr>
<tr>
<td>57</td>
<td>The driver of the Lead Vehicle performs an evasive steering maneuver.</td>
<td>3VL2</td>
</tr>
</tbody>
</table>
Safety of the Intended Functionality Analysis

- Safety of the Intended Functionality (SOTIF) Analysis
- Performed using ISO 21448 Standard
- Purpose: Reducing the unknown unsafe scenarios is done iteratively as the SOTIF Process proceeds.

**Key**

1. known safe scenarios (Area 1)
2. known unsafe scenarios (Area 2)
3. unknown unsafe scenarios (Area 3)
4. unknown safe scenarios (Area 4)

**Example of an Initial Starting Point of Development**

**Goal for the Finished Development**

*Source: ISO26262 Standard*
Findings from the SOTIF Analysis

- Not having a functional system specification was challenging.
  - SOTIF completed with available information and estimated (or assumed) design details as an example of the process.
- Known unsafe conditions identified as a baseline for establishing list of example verification tasks.
  - In actual SOTIF, validation use case scenarios are developed to identify unknown unsafe scenarios.
  - Unexpected scenarios add to the list of known unsafe conditions.
  - Iterative process of SOTIF increases the safety and reliability of the platooning system.
# Fault Tree Analysis (FTA)

1. Identify undesired events
2. Understand the system
3. Construct the fault tree
4. Evaluate the fault tree
5. Control the hazard

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Symbol Description</th>
<th>Symbol Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Or Gate" /></td>
<td>Or Gate</td>
<td>Illustrates the output occurs if at least a single event occurs.</td>
</tr>
<tr>
<td><img src="image2" alt="And Gate" /></td>
<td>And Gate</td>
<td>Illustrates the output occurs if and only if all inputs occur.</td>
</tr>
<tr>
<td><img src="image3" alt="Transfer Gate" /></td>
<td>Transfer Gate</td>
<td>Illustrates a transfer continuation from a different part within the fault tree that this was developed.</td>
</tr>
<tr>
<td><img src="image4" alt="Basic Event" /></td>
<td>Basic Event</td>
<td>Identifies a basic initiating System or Subsystem fault.</td>
</tr>
<tr>
<td><img src="image5" alt="Undeveloped Event" /></td>
<td>Undeveloped Event</td>
<td>Identifies an event that does not need to be further developed or resolved.</td>
</tr>
</tbody>
</table>
Example Fault Tree Analysis

- There is a loss of steering in the Following Vehicle (FV)

```
  LOSS OF STEERING IN FV
    2
   /\    /\    /\  
  VEHICLE SYSTEM LV PLATOONING SYSTEM FV PLATOONING SYSTEM
  FAILURE  FAILURE  FAILURE
      2.1              2.2              2.3
```
Study Findings

- All but a few of the hazards described in the hazard analysis could be mitigated to an the lowest ASIL level during the risk assessment:
  - An unexpected stoppage in traffic.
  - Unexpected road debris.
  - Difference in tire wear (e.g., traction, tread depth, grip, etc.) between the LV and FV(s).
  - Loss in steering control in the LV.
  - Loss in steering control in the FV.
  - Cyber-attack on the FV’s communication subsystem.
  - A motorcycle performs a cut-in between two platooning vehicles.
  - Driver of the LV performs an evasive steering maneuver.

- Remaining hazards were analyzed in SOTIF and FTA analyses to determine safety countermeasures.
Study Findings (Cont.)

- SOTIF analysis methodology is a useful analysis tool for truck platooning systems.
  - The feedback loop inherent in the SOTIF analysis can help to increase the safety and reliability of a platooning system.

- Based on the FTA results, systems with a human-in-the-loop could benefit from safety mitigations such as training and operating procedures that are fully dependent upon the human complying.
Final Report Available at:

National Transportation Library

https://ntl.bts.gov/
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