DRIVER DISTRACTION WHILE PERFORMING A SECONDARY TASK EVALUATION APPROACH BASED ON FUZZY EXPERT SYSTEM

Smartphone usage as a driver’s secondary activity: Case study

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InTErdisciplinary training network in Multi-actiated ground vehicles (ITEAM): Consortium

• 9 European countries
• 5 partner organizations
• 11 beneficiaries

• 7 nonacademic organizations
• 7 universities
• 2 research centers

https://iteam-project.net/
Driver Distraction: Definition

“Driver distraction occurs when a driver is delayed in the recognition of information needed to safety accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver’s shifting attention away from the driving task” – J.R. Treat. [1]

“Driver distraction is the diversion of attention away from activities critical for safe driving towards a competing activity” – M.A. Regan. [2]


# Driver Distraction: Secondary and primary tasks

<table>
<thead>
<tr>
<th>Primary Task</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Performing maneuver</td>
</tr>
<tr>
<td></td>
<td>Reading traffic signs</td>
</tr>
<tr>
<td></td>
<td>Monitoring traffic</td>
</tr>
<tr>
<td></td>
<td>Overcoming weather</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary task</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>In-vehicle features</td>
<td>Managing vehicle driving functions</td>
</tr>
<tr>
<td></td>
<td>Managing non-driving functions</td>
</tr>
<tr>
<td></td>
<td>Controlling comfort</td>
</tr>
<tr>
<td></td>
<td>Entertainment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items brought into the vehicle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Using electronic devices</td>
</tr>
<tr>
<td></td>
<td>Personal hygiene</td>
</tr>
<tr>
<td></td>
<td>Interaction with passengers</td>
</tr>
</tbody>
</table>

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Driver Distraction: Modes\(^{[1]}\)

Visual  
Auditory  
Manual  
Cognitive

---

Driver Distraction: Evaluation methods

Off-line
- Questionnaire survey
- Comparative driving
- Note taking
- NASA Task Load Index
- Situation Awareness Global Assessment Technique

On-line
- Psychomotor
  - Longitudinal dynamics
  - Lateral dynamics
- Psychologic
  - Hearth rate
  - Skin electric potential
  - Brain waves
- Visual
  - Head movement
  - Eye tracking
Human-Machine Interface (HMI)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 675999.
HMI: Vehicle control loop

**User control**
- Steering wheel buttons
- Switches around steering wheel
- Dash panel buttons and knobs
- Voice recognition
- Multifunctional haptic controllers

**User feedback**
- Haptic
- Visual
- Audible

**Actuators**
- Brake pedal
- Steering wheel
- Throttle pedal

**Vehicle**

**Sensors**
- Wheel speed
- Lateral / longitudinal acceleration
- Yaw rate
- Brake pressure
- Steering wheel angle

**Environment**
- Camera
- Radar
- Laser
- GPS

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HMI: Driver distraction detection and evaluation algorithm

Diagram showing the interactions between Driver, Vehicle, Environment, Actuation, Dynamics, Performance, Distraction detection, Secondary task, and Road.
Fuzzy Logic Controller (FLC): Conventional controller

\[ r_1(t), r_2(t), r_{\ldots}(t), r_n(t) \rightarrow \text{Fuzzification} \rightarrow \text{Inference mechanism} \rightarrow \text{Rule-base} \rightarrow \text{Defuzzification} \rightarrow u(t) \rightarrow \text{Process} \rightarrow y(t) \]

Numbers ↓ fuzzy sets

Modus ponens form expert knowledge

Fuzzy sets ↓ numbers
FLC: Fuzzification

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\[ C = b \otimes a = b^T a \]

\[ a = \begin{bmatrix} \mu_{dx}^{close} \\ \mu_{dx}^{far} \\ \mu_{dx}^{out} \end{bmatrix} \]

\[ b = \begin{bmatrix} \mu_{dv}^{good} \\ \mu_{dv}^{bad} \\ \mu_{dv}^{awful} \end{bmatrix} \]
**FLC: Rule-base**

If $a$ is $MF_1$ and $b$ is $MF_1$ Then $R$ is $r_{11}$

If $a$ is $MF_1$ and $b$ is $MF_2$ Then $R$ is $r_{21}$

... 

Where:

$$R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}$$
FLC: Inference mechanism and defuzzification

\[
R = \begin{bmatrix}
  r_1 & r_2 & r_3 \\
  r_1 & r_3 & r_4 \\
  r_2 & r_4 & r_5 
\end{bmatrix}
\]

\[
C = \begin{bmatrix}
  0 & \mu_{dx} \cdot \mu_{good} & \mu_{dx} \cdot \mu_{good} \\
  0 & \mu_{far} \cdot \mu_{bad} & \mu_{out} \cdot \mu_{bad} \\
  0 & 0 & 0 
\end{bmatrix}
\]

\[
D = C \circ R = \begin{bmatrix}
  0 & \mu_{dx} \cdot \mu_{good} \cdot r_2 & \mu_{dx} \cdot \mu_{good} \cdot r_3 \\
  0 & \mu_{far} \cdot \mu_{bad} \cdot r_3 & \mu_{dx} \cdot \mu_{bad} \cdot r_4 \\
  0 & 0 & 0 
\end{bmatrix}
\]

Hadamard product*

\[
\sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij} \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m
\]

\[
u = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m
\]

* \(D = C \circ R = \begin{bmatrix}
  c_{11} \cdot r_{11} & c_{12} \cdot r_{12} & \cdots & c_{1n} \cdot r_{1n} \\
  c_{21} \cdot r_{21} & c_{22} \cdot r_{22} & \cdots & c_{2n} \cdot r_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  c_{m1} \cdot r_{m1} & c_{m2} \cdot r_{m2} & \cdots & c_{mn} \cdot r_{mn} 
\end{bmatrix}\)
### FLC: Outlook

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fuzzy evaluator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td>MISO</td>
</tr>
<tr>
<td><strong>Crisp input</strong></td>
<td>$dx$ (3 MFs)</td>
</tr>
<tr>
<td></td>
<td>$dv$ (3 MFs)</td>
</tr>
<tr>
<td><strong>Crisp output</strong></td>
<td>$DD$ (8 MFs)</td>
</tr>
<tr>
<td><strong>MFs</strong></td>
<td>Linear Symmetric</td>
</tr>
<tr>
<td><strong>Inference method</strong></td>
<td>Matrix (Sugeno’s)</td>
</tr>
<tr>
<td><strong>Rule-base</strong></td>
<td>9 Modus Ponens</td>
</tr>
<tr>
<td><strong>Defuzzification</strong></td>
<td>Geometric center</td>
</tr>
</tbody>
</table>

**Inference method**
- Matrix (Sugeno’s)

**Defuzzification**
- Geometric center

**DD**

<table>
<thead>
<tr>
<th>$dx = [0 \ 1.5]$</th>
<th>close</th>
<th>far</th>
<th>out</th>
</tr>
</thead>
<tbody>
<tr>
<td>good</td>
<td>0</td>
<td>14.3</td>
<td>42.9</td>
</tr>
<tr>
<td>bad</td>
<td>0</td>
<td>57.2</td>
<td>85.8</td>
</tr>
<tr>
<td>awful</td>
<td>28.6</td>
<td>71.5</td>
<td>100</td>
</tr>
</tbody>
</table>

**3-D Surface**

- $dx = [0 \ 1.5]$
- $dv = [0 \ 12]$

- close: 0, far: 14.3, out: 42.9
- close: 0, far: 57.2, out: 85.8
- close: 28.6, far: 71.5, out: 100

- **Driver Distraction**
  - $dv$ range: 0 to 12
  - $dx$ range: 0 to 1.5

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Case Study: Participants

18 participants

Age ϵ [24 39]
- Mean 30

Experience ϵ [1 21]
- Mean 11

- 72.2% male
- 27.8% female
- 50.0% ≥ 30
- 61.1% < 30
- 50.0% ≥ 11
- 50.0% < 11

Special thanks to the volunteers from IPG Automotive GmbH (Karlsruhe, Germany) for participating in the driver-in-the-loop experiments.
Case Study: Apparatus

- Gas pedal
- Break pedal
- Steering wheel
- 2 LCDs

- Real-time driver-in-the-loop simulation
- Head-up display
- MATLAB®/Simulink® integration with IPG CarMaker®
Case Study: Task and procedure

- Length 10626 m
- 2 lines
- Line width 3.5 m
- Sample frequency 50Hz (0.02 s sample period)
Results: Driver performance

\[ dx \] [m]  \[ dv \] [km/h]

\[ t \] [cs]

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**Results:** Fuzzy logic evaluation
Results: Resultative level of distraction calculation

\[ A_i = (y_1 + y_2) \cdot \frac{(t_2 - t_1)}{2} \]

\[ A_n = \sum_{i=1}^{n} A_i \]

\[ DD_{level} = \frac{A_n}{t_{total}} \% \]
Results: Resultative level of distraction surface

\[ DD_{level} = 28.56\% \]
Results: Driver-in-the-loop experiment outlook

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD [level [%]]</td>
<td>32.29</td>
<td>46.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>&lt;30</th>
<th>≥30</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD [level [%]]</td>
<td>34.87</td>
<td>38.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experience</th>
<th>&lt;11</th>
<th>≥11</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD [level [%]]</td>
<td>42.11</td>
<td>30.45</td>
</tr>
</tbody>
</table>

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Conclusion and Discussions

✓ Evaluation mechanism development based on Fuzzy Set theory;
✓ Real-time driver-in-the-loop experimentation;
✓ Smartphone usage while driving case study.

- Male driver handles the secondary task distraction better than female drivers;
- Drivers younger than 30 years old performed the secondary task better than older ones;
- Drivers with driving experience longer than 11 years deal with the distraction situation better than novice drivers.
Future Research: Driver performance prediction model

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Questions

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THANK YOU FOR YOUR ATTENTION

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