ANALYSIS OF SHOCKWAVES ON MOTORWAYS AND POSSIBILITY OF DAMPING BY HIGHLY AUTOMATED VEHICLES
AGENDA
1. Definition of Shockwaves
2. Characteristics of Shockwaves
3. Software Environment and Calibration Process
4. Highly Automated Vehicles
5. Results
6. Evaluation Framework
7. Conclusions
DEFINITION OF SHOCKWAVES

- A boundary in traffic stream that demarks a discontinuity in flow-density domain
- Points in space and time at which vehicles change their speed abruptly

http://rsta.royalsocietypublishing.org/content/366/1872/2017
SPEED OF SHOCKWAVE

\[ \omega = \frac{q_2 - q_1}{k_2 - k_1} \]

Vehicles in queue

Shockwave

Vehicles upstream
The entire simTD Test Field Hesse, centred around the Hessian metropolis Frankfurt am Main.

- The motorway sections
- The rural roads
- The inner-city roads
MICROSCOPIC CHARACTERISTICS OF SHOCKWAVES

Trajectory vehicle #500 on 28.11.2012
MACROSCOPIC CHARACTERISTICS OF SHOCKWAVES

Space-time diagram of shocks. Speed contour plots from 11.10.2012 on the A5 South between Friedberg and Bad Homburger Kreuz.
MODEL ENVIRONMENT

Simulation Software: PTV Vissim 7
Psycho-physical car following model

Wiedemann 74:

$$d_{ax} = \frac{\Delta x_0 (1 + CC1 * \sqrt{v})}{1 + TX_{add} + b \cdot x_{mult} * z}$$

$\Delta x$: Minimum desired following distance between stopped cars
$\Delta x_0$: Speed of the slower vehicle [m/s]
$z$: A value of range [0,1] which is normally distributed around 0.5 m with a standard deviation of 0.15 m
$AX$: Average desired distance between two cars in a standstill condition.

Car following logic and driving states (Vissim Manual, 2013)
CALIBRATION PROCESS

1. Base model development
2. Calibration Planning
3. Initial Validation
4. Model Calibration
   - System Calibration
   - Model Calibration
5. Check Simulated via Field Data
6. Validation Target met?
   - Yes: Calibrated and Validated Model
   - No: Return to Model Calibration
CALIBRATION RESULT

Parameter set with minimum root-mean-square deviation:
\[ ax = 1 \quad bx_{\text{add}} = 3 \quad bx_{\text{mult}} = 5 \]
HIGHLY AUTOMATED DRIVING
HIGHLY AUTOMATED VEHICLES

Simulation Parameters:

- Homogenous driving behavior
- Shorter headways than conventional vehicles
- Shorter reaction time to acceleration and deceleration
- Higher desired acceleration and lower desired deceleration
- More cooperative in lane changing

http://next.mercedes-benz.com/
Penetration rate of 5%  

RESULT: AUTONOMOUS DRIVING

- Penetration rate of 50%  

![Speeds](image1.png)  

![Flows](image2.png)
EVALUATION FRAMEWORK

Network Indicator

1. **Average Network Speed**

   1. \[ V_k = \frac{\sum_{i=1}^{180} Speed_i \times flow_i}{\sum_{i=1}^{180} flow_i} \]
   
      - \( V_k \): Weighted average of the detector
      - \( i \): Minute from the beginning of simulation
      - \( Speed_i \): Speed recorded by detector \( k \) at the minute \( i \)
      - \( flow_i \): Flow recorded by detector \( k \) at the minute \( i \)

   2. \[ V_{network} = \frac{\sum_{k=1}^{12} V_k}{12} \]
EVALUATION FRAMEWORK

Shockwave Indicator

I. Propagation Speed: Detection of upstream front of congestion

II. Dissolving Speed: Detection of downstream front of congestion
## PERFORMANCE: AVERAGE NETWORK SPEED

<table>
<thead>
<tr>
<th>Penetration Rate</th>
<th>Average Speed [km/h]</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>83.22</td>
<td>-</td>
</tr>
<tr>
<td>5 %</td>
<td>84.10</td>
<td>1.1 %</td>
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<tr>
<td>10 %</td>
<td>85.92</td>
<td>3.2 %</td>
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<tr>
<td>20 %</td>
<td>90.76</td>
<td>9.1 %</td>
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<tr>
<td>50 %</td>
<td>105.60</td>
<td>26.9 %</td>
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<tr>
<td>100 %</td>
<td>112.30</td>
<td>34.9 %</td>
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## PERFORMANCE: PROPAGATION SPEED

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<thead>
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<th>Penetration Rate</th>
<th>Shockwave Propagation Speed [km/h]</th>
<th>Percentage Change</th>
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<tbody>
<tr>
<td>0 %</td>
<td>-11.17</td>
<td>-</td>
</tr>
<tr>
<td>5 %</td>
<td>-10.49</td>
<td>-6.1 %</td>
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<tr>
<td>10 %</td>
<td>-10.17</td>
<td>-9.0 %</td>
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<tr>
<td>20 %</td>
<td>-8.78</td>
<td>-21.4 %</td>
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<tr>
<td>50 %</td>
<td>-6.26</td>
<td>-44.0 %</td>
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<tr>
<td>100 %</td>
<td>-4.81</td>
<td>-56.9 %</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- Possibility of simulation of the HAVs within the fleet and observe their effect on traffic flow in different traffic situations
- As the penetration rate exceeds 20 %, considerable changes can be observed
- Higher penetration rates lead to the suppression of shockwaves
- The dissolving speed of the congestion was not addressed by highly automated vehicles
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