Virtual Driving with Different Motion Characteristics
Braking Manoeuvre Analysis and Validation

DSC Europe 06, 04.10.06

M. Fischer, S. Briest, M. Vollrath
Agenda

- The DLR Dynamic Simulator
- Experiment Design
- Experiment Results
  - Analysing Parameter Effects
  - Analysing Speed Zone Effects
- Conclusion and Future Tasks
The DLR Dynamic Simulator
The Simulator
Simulator Facts

Motion Capabilities

<table>
<thead>
<tr>
<th></th>
<th>Position</th>
<th>Acceleration</th>
<th>Position</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge</td>
<td>±1,5 m</td>
<td>±10 m/s²</td>
<td>Roll</td>
<td>±21 °</td>
</tr>
<tr>
<td>Sway</td>
<td>±1,4 m</td>
<td>±10 m/s²</td>
<td>Pitch</td>
<td>±21 °</td>
</tr>
<tr>
<td>Heave</td>
<td>±1,4 m</td>
<td>±10 m/s²</td>
<td>Yaw</td>
<td>±21 °</td>
</tr>
</tbody>
</table>

Full cockpit
- force feedback steering
- active brake pedal

Visual system
- 270° x 40° field of view
- TFT-displays in outside mirrors
- Large LCD-screen on backseat as rear view mirror

...
Experiment Design
Experiment Design
Track S1, S3 and R

- S1 (virtual) vs. R (real)
- S3 (acceleration/deceleration)

12 Subjects
- 8 male, 4 female
- aged 25 – 50
- average driving experience

12 Subjects
- 8 male, 4 female
- aged 25 – 50
- average driving experience
Experiment Design
Parameter Variation

- Acceleration vector for different manoeuvres
  - Curve driving: $a_y, w_x, w_z$
  - Braking: $a_x, \omega_y$

- Here: no common components (DoF).
  - Different parameters for tuning

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Parameter Set-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve Driving</td>
<td>a</td>
</tr>
<tr>
<td>Braking</td>
<td>a</td>
</tr>
</tbody>
</table>

hypothesis: b is bad for braking
Experiment Design
Effect of Parameter Sets II

Set a and c vs. b – step input response (f_x)
Experiment Results I
Analysing Parameter Effects
Experiment Results
Braking – main effect parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Realistic</th>
<th>Accurate * (p=0.05)</th>
<th>Match Reality ** (p=0.009)</th>
<th>Safe * (p=0.027)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b is worst for braking
Experiment Results
Track Statistics

S1
Average Speed Straight Sections

SD Speed Straight Sections

S3
in virtual driving speed is underestimated
b leads to more speed changes
Braking Manoeuvres
Characteristic Values

- $t_0$ – foot off gas
- $t_1$ – foot on brake
- $t_2$ – car stopped

at $t_0$ and $t_1$
- $v$ – velocity
- $ST$ – stopping time
- $SD$ – stopping distance
- $TTC$ – time to collision

- $TT$ – transition time
- $a_{\text{max}}$ – maximum deceleration
Braking Manoeuvres
Analytic Method

- Analysis of Variance (ANOVA)
  - S3/S1 vs. a/b/c

- T-Test
  - S1a vs. R
  - S1b vs. R
  - S1c vs. R
  - S3a vs. R
  - S3b vs. R
  - S3c vs. R
# Braking Manoeuvres

## Analysis of Variance (ANOVA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>track</th>
<th>track* parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_0$</td>
<td>.060</td>
<td>.134</td>
</tr>
<tr>
<td>ST$_0$</td>
<td>.008</td>
<td>.008</td>
</tr>
<tr>
<td>SD$_0$</td>
<td>.120</td>
<td>.046</td>
</tr>
<tr>
<td>TTC$_0$</td>
<td>.074</td>
<td>.203</td>
</tr>
<tr>
<td>TT</td>
<td>.424</td>
<td>.160</td>
</tr>
<tr>
<td>$a_{\text{max}}$</td>
<td>.000</td>
<td>.000</td>
</tr>
</tbody>
</table>

### ST$_0$  
![Graph](image1.png)

### SD$_0$  
![Graph](image2.png)

### TTC$_0$  
![Graph](image3.png)

### $a_{\text{max}}$  
![Graph](image4.png)
Braking Manoeuvres
Mean Values and T-Test Results I

- **Approaching speed at t₀ (v₀):**

  - S1a, S1b, S1c, S3a, S3b, S3c, R
  - Velocity [kph]

- **Stopping distance at t₀ (SD₀):**

  - S1a, S1b, S1c, S3a, S3b, S3c, R
  - Distance [m]

- **Stopping time at t₀ (ST₀):**

  - S1a, S1b, S1c, S3a, S3b, S3c, R
  - Time [s]

- **Time to collision at t₀ (TTC₀):**

  - S1a, S1b, S1c, S3a, S3b, S3c, R
  - Time [s]

Byer et al.
Braking Manoeuvres
Mean Values and T-Test Results II

**transition time (TT)**

- **underestimation of speed**
  + **overestimation of distance**
  = **overestimation of TTC**

**maximum deceleration (a_{max})**

- Overestimated TTC leads to significantly higher maximum deceleration
Experiment Results II
Analysing Speed Zone Effects
Experiment Results II
Braking (S3) – main effect speed zone

The faster the speed zone, the worse the assessment scale.

- realistic
- accurate** (p=0.005)
- match reality
- safe** (p=0.002)

Note:
- realistic
- accurate** (p=0.005)
- match reality
- safe** (p=0.002)
Experiment Results II
Braking (S3) – interaction effect parameter-speed zone

How realistic is the feeling of driving?

speed zone* [kph]

assessment scale

parameter*

p=0.058

b is equally worse for all driving speeds
Experiment Results II
Analysis of Variance (ANOVA)

<table>
<thead>
<tr>
<th>parameter</th>
<th>speed</th>
<th>parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST(_0)</td>
<td>.000</td>
<td>.631</td>
</tr>
<tr>
<td>ST(_1)</td>
<td>.000</td>
<td>.936</td>
</tr>
<tr>
<td>TTC(_0)</td>
<td>.000</td>
<td>.797</td>
</tr>
<tr>
<td>TTC(_1)</td>
<td>.000</td>
<td>.294</td>
</tr>
<tr>
<td>TT</td>
<td>.725</td>
<td>.271</td>
</tr>
<tr>
<td>a(_{max})</td>
<td>.000</td>
<td>.598</td>
</tr>
</tbody>
</table>

ST\(_0\) vs. TTCC\(_0\) vs. ST1 vs. TTCC\(_1\) vs. a\(_{max}\) vs. TTC\(_0\) vs. TTC\(_1\)
Conclusion & Future Tasks
Conclusion

- Estimation of speed, distance and TTC is difficult in virtual driving

- Subjective ratings and objective driving data analysis results correspond

- Driving behaviour in simulators is repeatable

- Systematically varying speed is not essential for tuning the motion
Future Tasks

- Manoeuvre dependant tuning
  - with experts and normal drivers
  - different manoeuvre (braking, curving, cornering, lane change, ...)

- Adaptive Motion Cueing Algorithm
  - Time variant motion parameters (manoeuvre dependant)

- Manoeuvre prediction
Questions?

Maximum deceleration ($a_{max}$)

<table>
<thead>
<tr>
<th>Curve Driving</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>S3b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E-Mail: m.fischer@dlr.de