CAPLOS
Compressed Air Powered Lateral Obstacle Simulator

Marc Schneider, Markus Sieber and Berthold Färber

Human Factors Institute, Universitaet der Bundeswehr Muenchen, Werner-Heisenberg-Weg 39, Neubiberg, Germany

Abstract: The development process of advanced driver assistance systems (ADAS) should include user studies in order to ensure optimal human-machine-interaction. Relevant active safety test scenarios must be based on appropriate use-cases, i.e. critical traffic situations. In order to avoid endangering subjects' physical well-being, test equipment is required that reliably simulates obstacles with realistic appearance that are also safe to crash. For cross-traffic scenarios and the examination of lateral driving behavior, existing test equipment, such as driving simulators, exhibit certain deficits. The authors present a compressed air powered lateral obstacle simulator (CAPLOS), a low-cost system for the creation of incursion-based critical situations. This paper describes the setup of CAPLOS and demonstrates its suitability for use in active safety ADAS user studies with exemplary driving study data.

1 INTRODUCTION

Advanced driver assistance systems (ADAS) that provide active safety functions reduce the danger posed by critical situations, e.g. by helping prevent collisions. During an intervention, these systems cooperate or compete with the driver for control over the vehicle and thus have high requirements regarding the design of the human-machine-interaction. To ensure that these requirements are met, the ADAS development process must include user studies (Koenig, 2012). For these driving experiments, the critical situation in which the ADAS is designed to intervene must be reproduced in a way that appears realistic to the driver in order to elicit realistic driver behavior. At the same time, the situation must be reproduced in a manner that does not expose the test subject and test equipment to any real danger.

2 STATE OF THE ART

Several different approaches have been put forward to provide ADAS developers with the possibility to test systems in early development stages.

One such approach is the use of driving simulators. Being virtual test beds, driving simulators naturally provide the possibility to expose test subjects to critical traffic scenarios in the absence of any real physical threat. They suffer, however, from serious limitations regarding the simulation of prolonged or intense vehicle dynamics and are therefore unable to provide fully realistic kinesthetic force feedback for highly dynamic maneuvers that are usually inherent to active safety scenarios. While having severally advantages, driving simulators are therefore not deemed appropriate for a conclusive evaluation of driver behavior, see e.g. (Schmitt et al., 2006).

Another approach is the use of safe to crash obstacles in field studies. With test subjects driving a real car, vehicle dynamics need not be simulated and are fully realistic. The challenges with this approach are the reliable reproduction of obstacle placement as well as the realistic appearance of the obstacle. Several studies report the use of foam cuboids or balloon cars, e.g. (Eckert et al., 2011), but do not mention how the obstacle was reliably placed in the correct position at the correct time regardless of external influences such as wind, or which measures were employed for the obstacle to have the appearance of a solid object with which a crash must be avoided.

A more elaborate and expensive piece of test equipment for the use in field studies is EVITA (Hoffmann and Winner, 2008), a system designed for use on a test track in order to investigate critical scenarios in longitudinal traffic. It consists of a towed dummy car that can be released and then perform an intense braking maneuver, creating a critical situation for the

71

Figure 1: CAPLOS main body.

following car, while being constructed in a way that cushions a potential collision in order to avoid any physical harm. EVITA keeps test subjects safe while simultaneously making a very realistic impression. Unfortunately, it is not designed for cross-traffic scenarios. Test subjects driving behind EVITA are aware of the possible source of danger in front of them at all times.

Similarly, other previously existing solutions are equally expensive designs and/or are based on constructions that make test subjects aware of possible danger, such as rope or cable constructions on or above the road. The authors desired an easy to construct and inexpensive piece of test equipment for the use in field studies that can be reliably placed, has realistic appearance while being safe to crash, and can easily be hidden from sight behind a wide variety of roadside structures in order to elicit realistic driving behavior with real vehicle dynamics in cross-traffic scenarios with unsuspecting drivers.

3 CAPLOS

The authors designed CAPLOS as a low-cost solution to safely, validly and reliably test realistic driver behavior to avoid collisions in cross-traffic scenarios.

3.1 Objectives

CAPLOS was designed as a system to help examine driver behavior in reaction to suddenly appear-ing obstacles. The objective was to build a system that can create a critical situation by making an obstacle appear suddenly, while being low-cost, easy to set up, easy to hide behind cover or camouflage, that is safe for drivers and the test vehicle, provides reliable obstacle placement, is able to fit different types of dummy obstacles, makes a realistic impression on drivers, and provide different triggering options. It was a requirement that the length of stroke for the suddenly appearing dummy obstacle be more than 1m and that there are multiple safety mechanisms: the system should provide the ability to pull the dummy obstacle out of harm's way in the last possible instant, while the dummy obstacle should also be risklessly crashable.

3.2 Solution

The proposed solution named CAPLOS (compressed air powered lateral obstacle simulator, Fig. 1 + 2) consists of 2 pneumatic pistons, a lever-construction, a pushing rod with fitting bearings, a frame to direct and stabilize the translation, an air compressor to provide power, an associated control unit and a mobile and crashable dummy at the front. A vehicle approaching and falling below a certain time-to-collision (TTC) to CAPLOS triggers the system, causing the movement of the dummy obstacle into the road. In the last instant before a possible collision or in case of electrical shutdown the pneumatic mechanism automatically retracts the dummy obstacle for safety reasons.
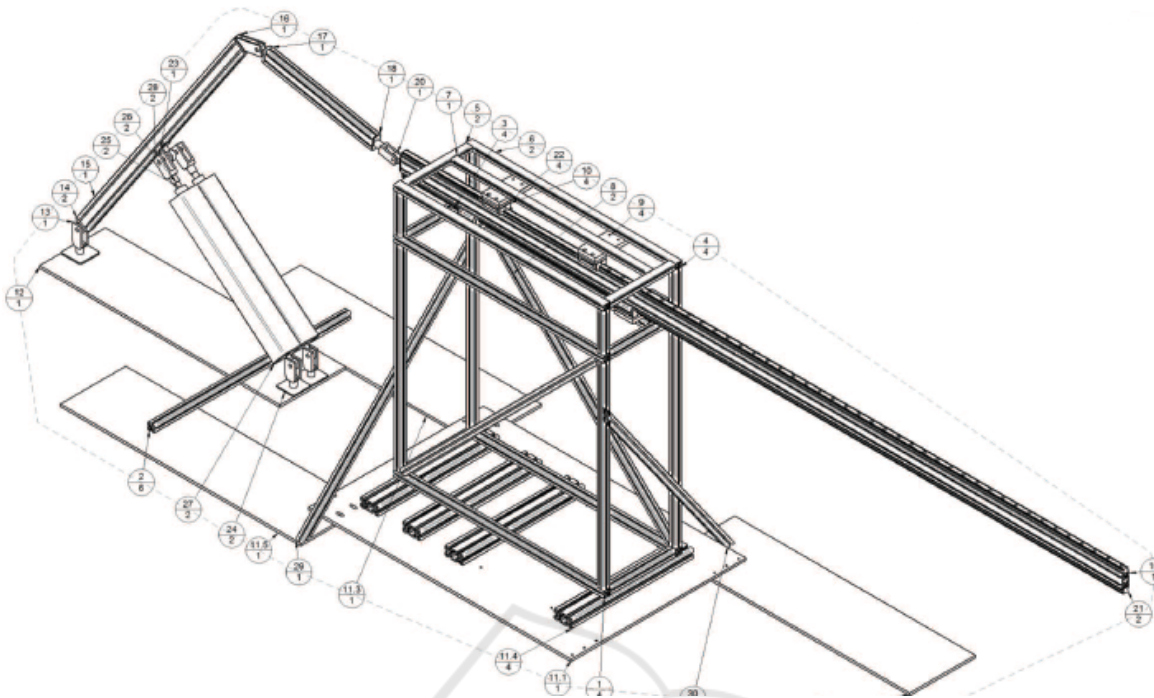
Figure 2: Construction drawing of CAPLOS (Schreiber, 2015).

3.3 CAPLOS - Structure

3.3.1 CAPLOS - Frame

The frame (Fig. 3) is connected to a steel base-plate, which provides stability and weight for the system while at the same time it can be separated into more easily manageable parts for transportation. The frame itself, built from aluminum profiles, ensures the straight and controlled translation of the pushing rod through the exact positioning of the required bearings. The rigid construction guarantees functionality even in the hypothetical case of a clamp in the linear movements or the dummy getting hit by a vehicle, ensuring the safety of test subjects, bystanders, the vehicle and CAPLOS itself.
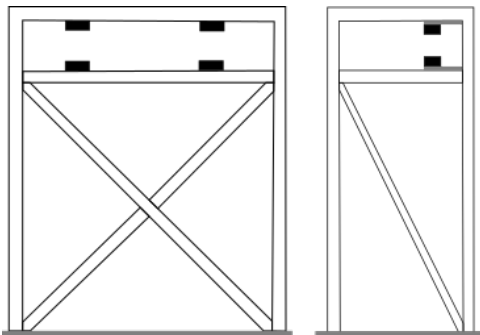

Figure 3: Schematic diagram of the CAPLOS frame.

3.3.2 CAPLOS - Power Unit

An off-the-shelf air compressor with 10 bar maximum pressure is connected to the pistons through control valves and serves as the power source. In order to reach the required speed when pushing out the dummy or pulling it in again, a work-principle consisting of linear pneumatic pistons was selected. Through a conversion of the translation's length and speed via the lever construction (Fig. 4 + 5) the required speed dimensions can be reached even with low-cost pneumatic machinery. The adjustable connection of the pistons to the lever enables mechanical regulation of length of stroke and movement speed.

This lever construction is connected to the pushing rod with a guiding rod. In combination with the basic frame and rigid implementation of the joints in the construction, straight friction-reduced movements are ensured. At the opposite end of the main pushing rod a dummy of arbitrary dimensions (car silhouette, pedestrian, ...) can be equipped.

3.3.3 CAPLOS - Control Unit

CAPLOS is controlled by electronic and pneumatic components built into a case (Fig. 6). In order to regulate the position of both pneumatic pistons a 5/3-way-valve (to switch between pushing and pulling) and a 3/2-way-valve (to convert an electrical trigger signal to a pneumatic signal) were used in the control
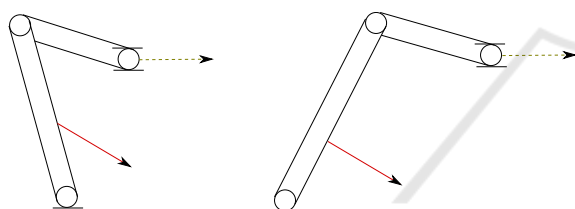
Figure 4: CAPLOS lever construction.

Figure 5: Schematic diagram of the CAPLOS lever construction.

Figure 6: Control case of CAPLOS.

Figure 7: Schematic diagram of activation via WiFi.
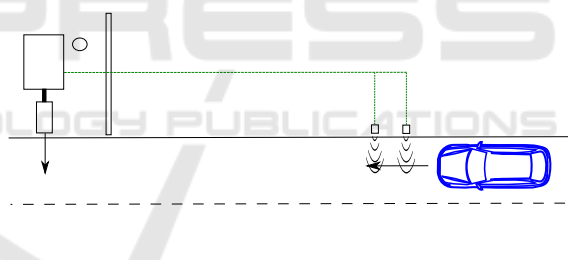
Figure 8: Schematic diagram of activation via light barriers.

unit of CAPLOS. An electric signal activating the 3/2-valve causes the 5/3-valve to switch to push out mode. To switch the state of the 3/2-way-valve a voltage of 12V to 24V is provided by the built-in power supply unit, which also supplies the additional light barriers. With the electric signal dropping out, caused either by CAPLOS receiving the signal to pull back or by the failing of the electrical power source, CAPLOS automatically returns to pull-in mode by default, thereby preventing possible harm from system breakdown.

The electrical trigger signal is provided by a RaspberryPi minicomputer's GPIO-pins or USB-port. The control unit continually monitors whether the trigger conditions are met. The required data can be transmitted to the RaspberryPi in several ways, two of which have so far been implemented for CAPLOS:

- via a WiFi signal sent by the test vehicle (Fig. 7)

- via light barriers and speed-calculation within the RaspberryPi (Fig. 8)

The system's activation via WiFi signal is realized with high-range antennas. The light barriers can be connected to the RaspberryPi directly with a 5 wire cable. The experimenter defines the desired trigger criteria, for example a certain time-to-collision (TTC) or distance of the ego vehicle to CAPLOS.
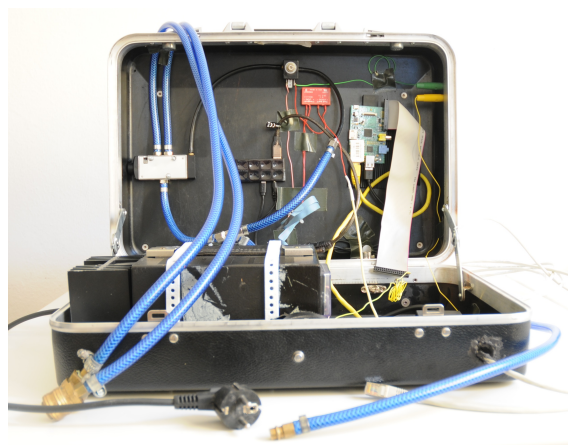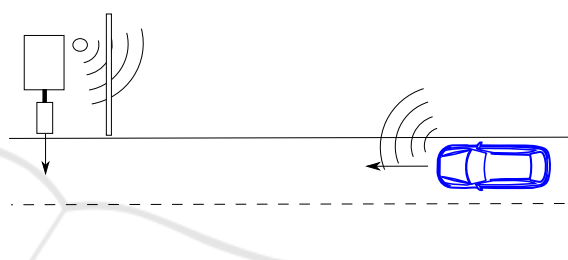
3.3.4 CAPLOS - Dummy

The dummy obstacle, which is positioned at the front end of CAPLOS's pushing rod, enables the machine to carry multiple types of dummies like car silhouettes (Fig. 9) or pedestrian puppets (Fig. 10). In order to prevent damage to the test vehicle or CAPLOS in case of the vehicle hitting the dummy, it is comprised of two distinctive parts linked by hinges, enabling the obstacle to fold away when hit, thereby significantly reducing the force on the dummy as well as the test vehicle. Hook-and-loop fasteners ensure stable cohesion of the dummy parts until a collision occurs.

Guidance of the dummy obstacle in lateral and vertical direction is realized through three attached wheels and the use of a hinge-construction (Fig. 11). The wheels provide the required stability while the

Figure 9: Exemplary CAPLOS dummy obstacle: passenger car.

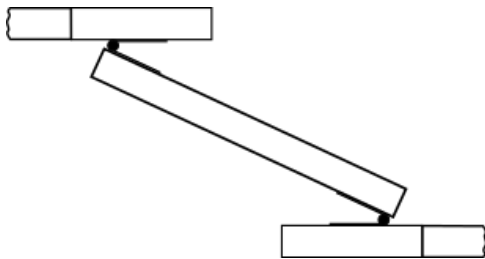Figure 10: Exemplary CAPLOS dummy obstacle: pedestrian.

Figure 11: Schematic diagram of the hinge-construction between pushing rod and dummy obstacle.

hinge-construction compensates for unevenness of the ground.

Table 1 shows mechanical property data based on static and dynamic simulations of the facility.

Table 1: Performance data from simulation.

mean speed	$3\ m/s$
maximum speed	$10\ m/s$
minimum distance	$0.8\ m$
maximum distance	$1.3\ m$
minimum piston power	$1120\ N\ (2\ bar)$
maximum piston power	$5600\ N\ (10\ bar)$

4 SUITABILITY OF CAPLOS

Suitability of CAPLOS for the simulation of lateral incursion-based critical scenarios was evaluated using data collected in a driving study that was conducted on the test track of the Universitaet der Bundeswehr Muenchen.

4.1 Driving Experiment

60 test subjects were instructed to drive along a straight rural road with two lanes at 50 km/h. They were told that the object of the study was to examine differences in lane keeping between right-hand and left-hand traffic with a left-handed vehicle. CAPLOS was hidden from sight behind a stationary car parking perpendicularly at the side of the road approximately 100m from the exit of the double lane change traffic cone corridor. The subject car was instrumented with an inertial measurement unit fed with GPS as well as dGPS correction data from a nearby base station, ensuring an accuracy of at least 0.02m in positional tracking. When the combination of the car's distance to the known position of CAPLOS and its current speed yielded a TTC of 1.6s or less, CAPLOS was activated via a WiFi connection. Once CAPLOS was activated, a fotorealistic silhouette of a passenger car was pushed out into the road, partly blocking the subject car's lane and forcing the driver to react to the suddenly appearing obstacle in order to avoid collision (Fig. 12). Four groups of 12 test subjects each experienced different system-induced warnings in reaction to the obstacle, the remaining 12 test subjects were left unassisted.

Figure 12: CAPLOS in action.

The test subjects experienced this situation a second time after a series of uneventful laps. Data from both expositions was used to evaluate CAPLOS's suitability for the simulation of critical cross-traffic scenarios in test subject driving studies.

4.2 Suitability Measures and Results

Reliability regarding the positioning of the dummy obstacle is assumed to be near perfect, as it is held firmly in place by the mechanical build of CAPLOS and the length of stroke is set to a fixed value by the length of the cylinder pistons and the transformation ratio within the lever construction.

As a first measure of suitability, the machine's reliability was ascertained using video data from a car-mounted camera capturing the scene in front of the subject car from 60 experimental trials with different temperature and weather conditions. Frame-by-frame analysis was used to determine when the dummy car first started moving and when it reached its furthermost position, yielding the machine's reaction time (time between the subject car falling below a TTC of 1.6s and first movement of the CAPLOS dummy obstacle) and its expansion time (time between first movement of the dummy obstacle and its reaching the fully expanded position) respectively.

Both reaction time (n=60, M=0.406s, SD=0.040s) and expansion time (n=60, M=0.726s, SD=0.066s) were found to be highly reliable despite variance caused by differences in latencies of the WiFi signal (which can not be controlled), differences in air pressure (pressure in the pressure tank was only replenished to its nominal value once it fell below a certain threshold, allowing for some variance), low data frequency (frame rate of the video feed was 25 frames per second, resulting in 0.04s steps of analysis) and possible observer imprecision (especially regarding first movement of the CAPLOS dummy obstacle).

No such data were publicly available from similar existing machines for comparison. Performance was therefore compared to previous preliminary tests. The setup used mere positional triggering (not accounting for the exact subject car speed) and a lab assistant to tip over a rubber foam obstacle onto the road. After an extensive training phase, twenty sets of five trials each were performed over the course of two days. Only the third to fifth trials from each set were used for comparison. Four of these sixty trials failed. In the remaining, 'reaction time' (time between subject car dropping below desired TTC and first obstacle movement) was, unsurprisingly, found to vary to a much greater extent (n=56, SD=0.284s). Also, 'expansion time' (time between first movement of the

obstacle and its reaching the final position) was found to be similar on average, but also more varied (n=56, M=0.753s, SD=0.172s).

As a second measure of suitability, it was ascertained whether the situation induced by the sudden appearance of the CAPLOS dummy obstacle was perceived as critical by the test subjects. Drivers were asked to judge the criticality of the experienced situation using the scale for criticality assessment of driving and traffic scenarios (Neukum et al., 2008), where test subjects first classify the situation as either imperceptible, harmless, unpleasant, dangerous, or uncontrollable and, in a second step, indicate possible tendencies towards a lower or higher category within the three middle categories, resulting in a 11-point scale (Fig. 13).
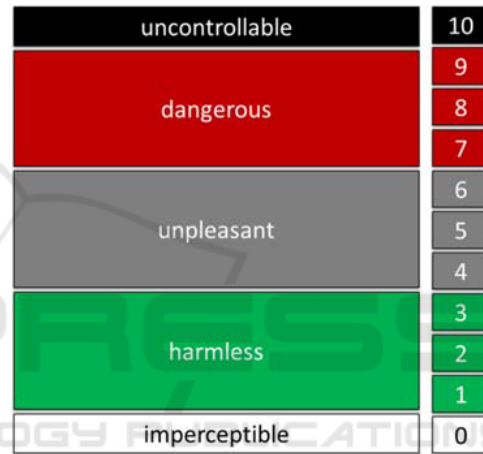

Figure 13: Scale for criticality assessment of driving and traffic scenarios (Neukum et al., 2008).

In total, less than 5% of the test subjects rated the experienced situation as harmless. Almost two thirds (63%) rated the situation as dangerous or uncontrollable. Fig. 14 shows the test subjects' ratings for each exposition to CAPLOS in a box plot.
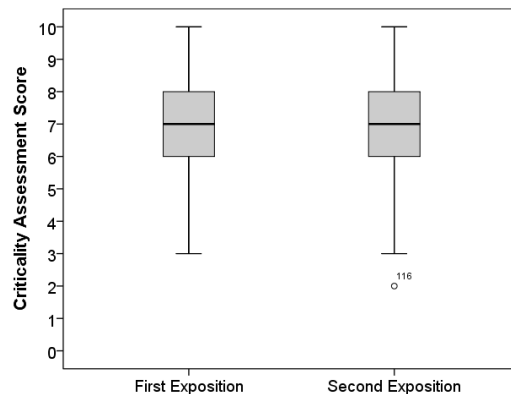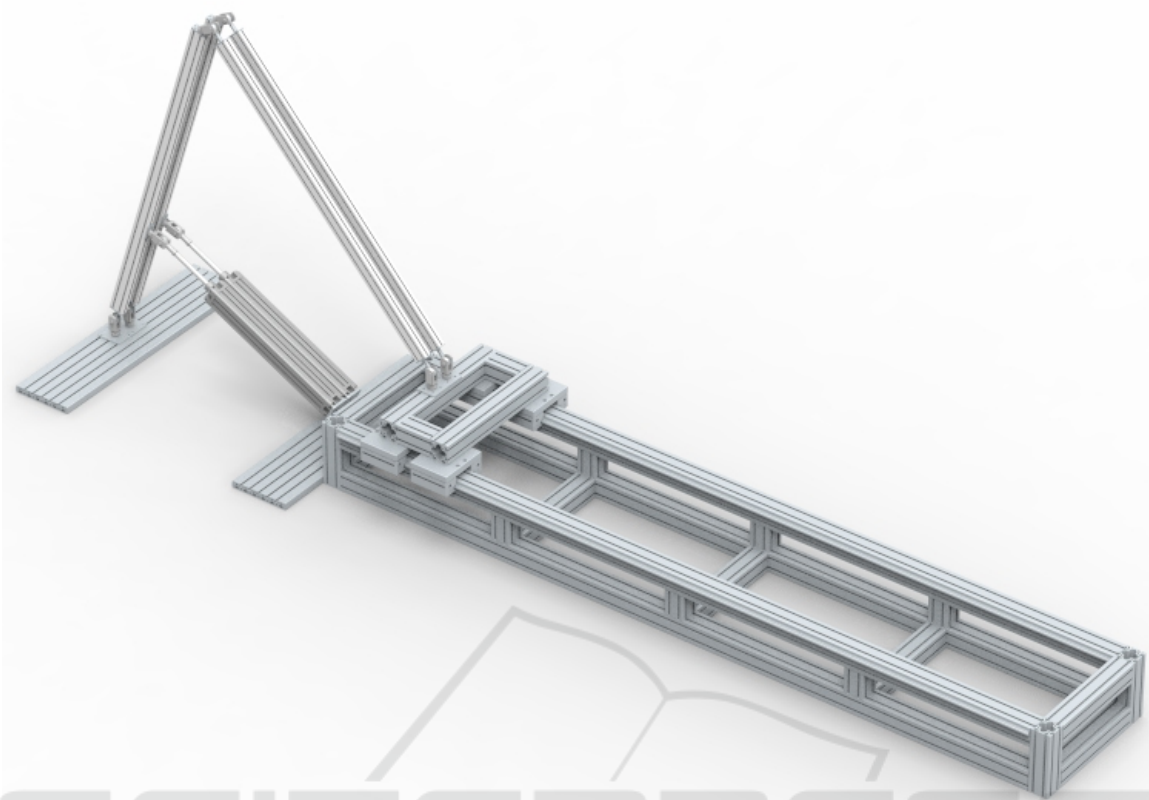

Figure 14: Criticality ratings.

Figure 16: CAD-model of the improved CAPLOSm (Walter, 2015).

As a third measure of suitability it was ascertained whether the test subjects were surprised by the critical situation induced by CAPLOS. The Facial Action Code (Ekman and Friesen, 1976) is a system developed for measuring all facial movement using anatomically based 'action units'. Noticeable raising of the inner as well as the outer eye-brows, widening of the eyes by raising of the upper eye-lid, and dropping of the jaw (corresponding to action units 1, 2, 5, and 26 in the Facial Action Coding System (Ekman et al., 2002) respectively) were regarded as signs of surprise (or fear) in subjects' facial expressions (Fig. 15) in response to the CAPLOS dummy obstacle's moving into the road. Facial expressions were recorded by a camera aimed at the driver with a frequency of 25 frames per second and were analyzed in slow motion (50% speed).

Even in the second exposition to CAPLOS 49 out of 60 test subjects were found to show perceivable signs of surprise in facial expression. The relative amount was even higher (11 out of 12) for the unassisted group, providing evidence that the surprise was in response to the critical situation elicited by CAPLOS and not to the sudden intervention of an assistance system.

Figure 15: Exemplary subject facial expression in reaction to CAPLOS exposition.

5 CONCLUSION

The presented setup for CAPLOS constitutes a low-cost test facility that permits reliable sudden positioning of different types of safe-to-crash dummy obstacles with different triggering options. The data collected in a driving study featuring CAPLOS further provide evidence, that CAPLOS is able to create traffic scenarios which test subjects view as critical and surprising. Bearing in mind that these data are based

on multiple expositions to CAPLOS without active distraction of the drivers, the authors conclude that CAPLOS can be regarded as a valuable instrument suitable for user studies in active safety ADAS development and evaluation.

This setup of CAPLOS was, however, built partly from scrap materials and parts scavenged from other machinery and was therefore restricted in regard to optimal design. The authors' newest work includes the construction of a new mobile version of CAPLOS (CAPLOSm Fig. 16) mounted on top of a trailer. This allows for a more efficient and more robust base design (Fig. 17) as well as further significant improvement concerning ease of deployment. A change in the leverarm design (Fig. 18) allows for greater variation in extension length. Moreover, the authors intend to include a mobile power source with CAPLOSm for independent operation in any location.
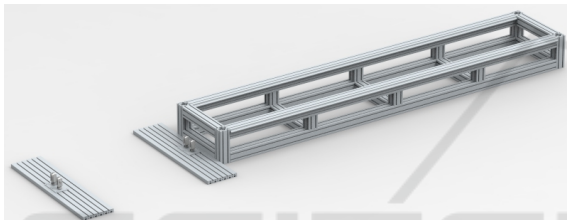

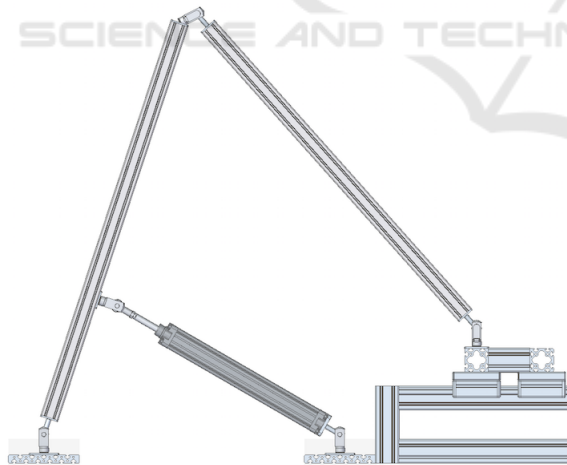Figure 17: New robust base design of CAPLOSm (Walter, 2015).

Figure 18: CAPLOSm - leverarm and piston mechanism (Walter, 2015).

REFERENCES

Eckert, A., Hartmann, B., Sevenich, M., and Rieth, P. (2011). Emergency steer & brake assist: a systematic approach for system integration of two complementary driver assistance systems. Washington DC.

International Technical Conference on the Enhanced Safety of Vehicles.

Ekman, P. and Friesen, W. V. (1976). Measuring facial movement. pages 56–75. *Environmental Psychology and Nonverbal Behavior.*

Ekman, P., Friesen, W. V., and Hager, J. C. (2002). Facial action coding system: The manual on cd rom. Salt Lake City.

Hoffmann, J. and Winner, H. (2008). Evita - Das Untersuchungswerkzeug fuer Gefahrensituationen. Garching. Aktive Sicherheit durch Fahrerassistenz.

Koenig, W. (2012). Nutzergerechte Entwicklung der Mensch-Maschine-Interaktion von Fahrerassistenzsystemen. In *Handbuch Fahrerassistenzsysteme*, pages 33–42, Wiesbaden. Vieweg+Teubner Verlag.

Neukum, A., Luebbeke, T., Krueger, H.-P., Mayser, C., and Steinle, J. (2008). Acc-stop&go: Fahrerverhalten an funktionalen Systemgrenzen. pages 141–150. Workshop Fahrerassistenzsysteme.

Schmitt, J., Faerber, B., Maurer, M., and Breu, A. (2006). Menschliches und technisches Verhalten an den Systemgrenzen eines FAS. *pages 1960:563–579. VDI-Berichte.*

Schreiber, P. (2015). Entwicklung einer mechanischen Apparatur zur Darstellung ploetzlicher Hindernisse im Rahmen der Fahrerassistenzerprobung (student work). Neubiberg. *Human Factors Institute, Universitaet der Bundeswehr Muenchen.*

Walter, M. (2015). Bau und Dokumentation einer Versuchsapparatur zur Fahrerassistenzssystemerprobung (student work). Neubiberg. *Human Factors Institute, Universitaet der Bundeswehr Muenchen.*