Electronic Vehicle and Vehicle System Knowledge Center
Budapest University of Technology
Hungary

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EVSC Simulation Exercise

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  - Steady-state circular test
  - Single lane change
- Evaluation of the results
- Conclusions

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Motivation

- The classification of available standards from point of view
  - Simplicity, applicability
  - Safety when physically testing
  - Expressiveness of demonstration
- Tractor-semitrailer combination is chosen for simulation
  - None of the members can be tested without the other one
  - Most complex arrangement
  - Involves all elements of single vehicles
  - Suitable for defining environmental parameters (test area, adhesion etc.)
- Basis for later research, establishing of reference parameters

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Partners

- The simulation has been carried out by the Electronic Vehicle and Vehicle System Knowledge Center of the Budapest University of Technology and Economics
- The EVSC control logic has been developed in the frame of the EU5 supported PEIT (Powertrain Equipped with Intelligent Technologies) project
- The control logic has been running on a prototype real time hardware from ETAS
- The simulation setup is a hardware-in-the-loop containing the electronic elements of the brake system
- The vehicle dynamic simulation has been made with a validated software package from SDK

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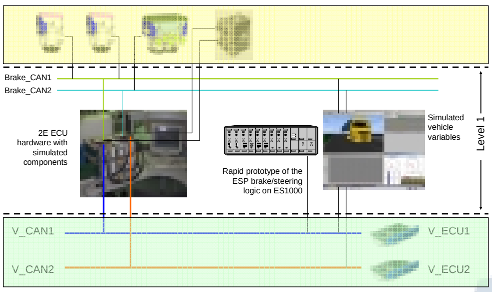
HIL Simulation Setup



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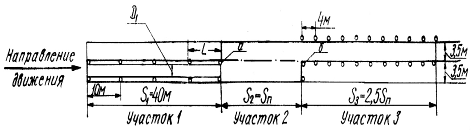
Simulated vehicle tests

- **ISO 14792 Steady state circular test**
  - Quasi static - quasi open-loop test; r1=100 m; r2=36 m
- **GOST R 52302-2004 Single lane change test**
  - Introduced in informal documents GRRF-55-20, GRRF-57-07



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Conditions of simulation

- Vehicle: tractor – semitrailer combination
- Differential lock: on and off
- Load condition:

	Unladen	Laden
• Tractor	7500kg	7500 kg
• Semitrailer	13500 kg	13500 kg
• Payload	5000 kg	19000 kg
• **GVW**	**26000 kg**	**40000 kg**

- Adhesion coefficient: µ=0,4 and µ=0,9
- Speed: gradually increased up to critical situation

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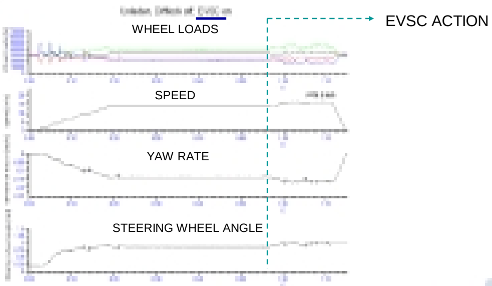
Steady state circular test – tractor simulation results; r = 100 m, µ = 0,9



The EVSC intervenes before the situation becomes critical

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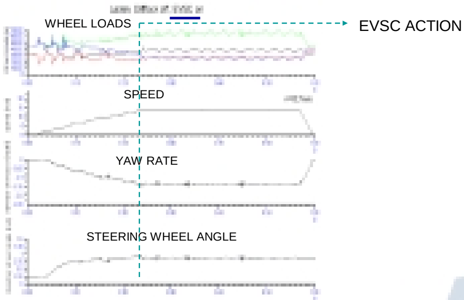
Steady state circular test – tractor simulation results; r = 100 m, µ = 0,9



The EVSC intervenes before the situation becomes critical

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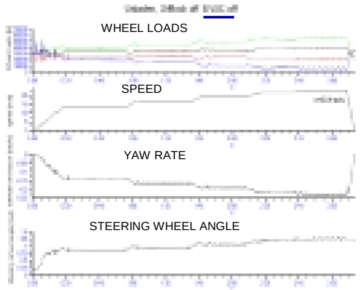
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



STABLE

The disengaged diff.lock prevents reaching critical speed

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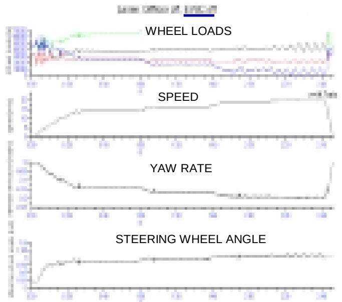
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



STABLE

The front inner wheel is continuously on the ground

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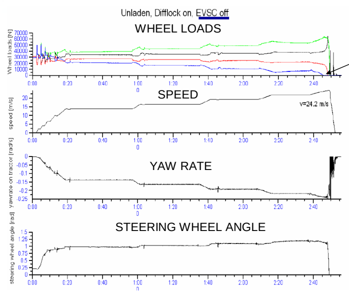
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



ROLLOVER

Engaged diff.lock contibutes to rollover when EVSC is off

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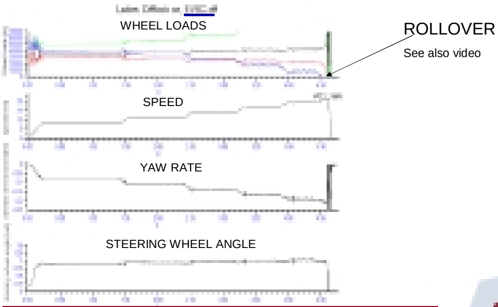
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



The effect of diff.lock is independent of load condition

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Steady state circular test – vehicle combination rollover simulation

LADEN STATE, r=100 m, μ = 0,9, EVSC: OFF, DIFF.LOCK: ON

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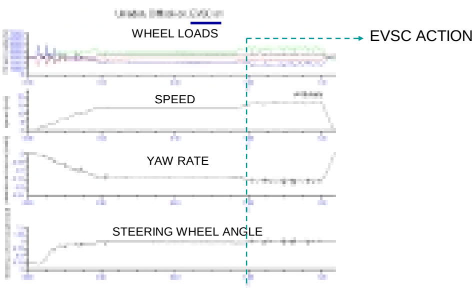
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



The EVSC prevents rollover even if diff.lock is on

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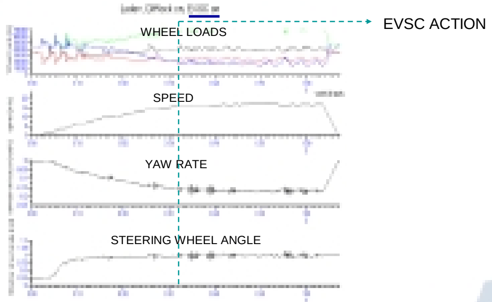
Steady state circular test – tractor simulation results; r = 100 m, μ = 0,9



The EVSC is effective in every load condition

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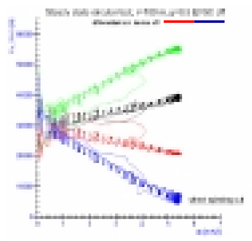
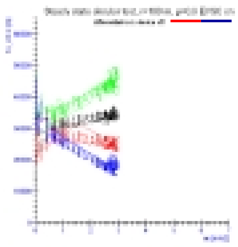
Steady state circular test – relevance when demonstrating roll-over behaviour

Wheel loads vs. centripetal acceleration (unladen raw data)



V_{acmax}=22.9 m/s



V_{acmax}=16.4 m/s

With diff.lock off, EVSC effect can be safely demonstrated

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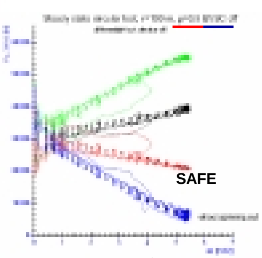
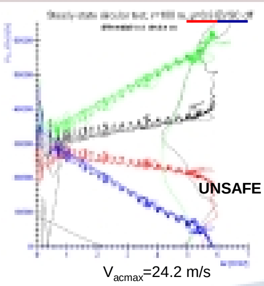
Steady state circular test – effect of differential lock on roll-over



V_{acmax}=22.9 m/s



V_{acmax}=24.2 m/s

Unsufficient traction due to disengaged diff.lock prevents rollover; when diff.lock is on, EVSC has to be on as well

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Steady state circular test
Summary table of results

	μ=0,9		Laden		Unladen	
			EVSC on	EVSC off	EVSC on	EVSC off
High adhesion	Laden	DL on	stable 16.8 m/s	**roll-over 21.1 m/s**		
		DL off	stable 13.7 m/s	stable 19.7 m/s		
	Unladen	DL on			stable 16.4 m/s	**roll-over 24.2 m/s**
		DL off			stable 16.0 m/s	stable 22.9 m/s
	μ=0,4		Laden		Unladen	
			EVSC on	EVSC off	EVSC on	EVSC off
Low adhesion	Laden	DL on	stable 13.5 m/s	**unstable 18.4 m/s**		
		DL off	stable 16.9 m/s	stable 17.4 m/s		
	Unladen	DL on			***controllable 16.4 m/s***	**unstable 16.4 m/s**
		DL off			***controllable 16.4 m/s***	**unstable 16.4 m/s**

Jack-knifing!

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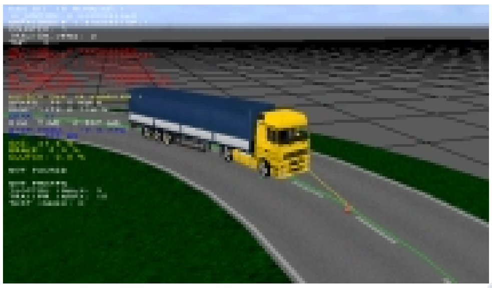
Steady state circular test simulation
R=36 m, μ=0.4, EVSC off



Anti jack-knife device is necessary when testing

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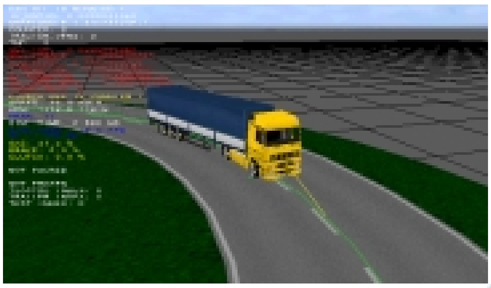
Steady state circular test simulation
R=36 m, μ=0.4, EVSC on



EVSC helps to keep the track

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Steady state circular test
Interpretation of results

- Low adhesion for demonstrating self-steering properties
- High adhesion for demonstrating rollover properties, provided that diff. lock is off
- When no differential locking device or it is off, the inner driven wheel spins over, limiting speed, thus rollover risk is minimal
- If practical test, however, preliminary stability limit assessment (e.g. tilt table test of the combination) is advisable, jack-knife prevention device is necessary
- The semitrailer characteristics (e.g. torsion stiffness) significantly affects the tendency for rollover

The steady state circular test is a safe and applicable demonstration method

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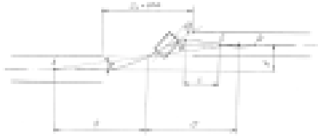
Single lane change manoeuvre
Driver model, desired path

- Complex driver model
  - Variables of this simulation
    - Path preview distance is speed dependent
    - Different continuous steering speeds were defined: max. 5 rad/s (good), max. 10 rad/s (excellent) and max. 15 rad/s (beyond human capabilities)
- A prescribed trajectory must be followed by the driver within predefined tolerance bands



The simulation environment copes with closed loop tests as well

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Single lane change manoeuvre
Simulation: v=60 km/h, 5 rad/s

EVSC is off – use of outrigger is essential

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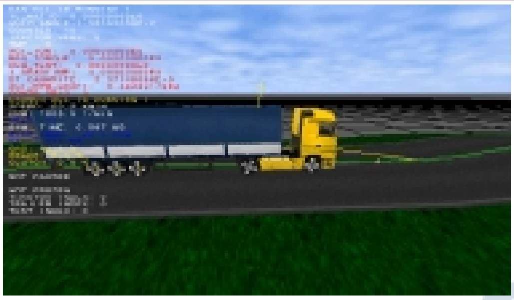
Single lane change manoeuvre
Simulation: v=60 km/h, 5 rad/s



EVSC is on – use of outrigger is essential

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Single lane change manoeuvre
An excellent driver's performance

- The excellent driver reached 70 km/h speed with disengaged EVSC, while the good driver could reach safely only 60 km/h speed with engaged EVSC. To ensure comparable results, steering robot is necessary
- Wheel loads can be decreased to zero even if EVSC engaged
  - Active EVSC results in better performance; the duration is shorter

The driver influence is cruicial in the closed loop test

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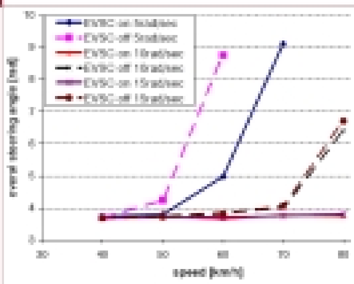
Single lane change manoeuvre
Method of assessment



- If steering speed is high enough, the combination can follow the desired path at any speed, and only physics determines stability; EVSC has a positive effect
- If driver's ability limits the steering speed, he compensates it by over-increasing the steering angle in order to follow the desired trajectory.
- The EVSC always supports driver's intention including overreaction.

The driver influences the test result significantly

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Conclusions

- The demonstration of the EVSC functionality during both steady state and lane change manoeuvre on a high µ-road might be possible in certain configurations without safety installation on the vehicle, since
  - The EVSC will intervene well before the vehicle reaches the roll stability limit - no need for outrigger or anti-jackknifing installation
  - However, a static tilt test for preliminary limit assessment is advisable for the whole combination
- The demonstration of the EVSC functionality during steady-state circular manoeuvre on a low µ-surface of adequate sizes requires an anti-jackknifing installation in truck-trailer combination (nothing in case of solo vehicle), which, however, does not change the vehicle parameters.

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Conclusions

- The determination of the roll-over threshold of the vehicle (combination) during the steady-state manoeuvre with EVSC system off and having a reasonable CoG height is not possible with turned off differential lock, since the vehicle is not able to reach the critical speed
- The roll-over threshold can be determined with switched on differential lock. In this case the vehicle requires outrigger for safety reasons.
- The determined roll-over threshold strongly depends on the vehicle parameters, such as:
  - Suspension design and components, especially their behaviour in the strongly non-linear range

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Conclusions

  - Torsion stiffness of the vehicle body - especially critical in case of trailer
  - The construction of the outrigger strongly influences the mentioned parameters
- At closed loop tests the assessment of the EVSC performance gain will have many subjective elements, and can vary rather significantly
- At closed loop tests the driver's parameters play essential role during the manoeuvre, the performance improvement with EVSC system strongly depends on his/her abilities
- For demonstration with simulation, a common simulation environment should be defined, with validated model parameters
- Further standardised tests should be still studied.

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Thank you for your attention