Vehicle Dynamics and Control

Fall 2010

Professor Kyongsu Yi

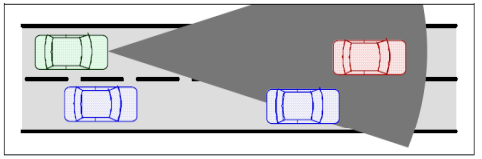
Lecture 1: Introduction

Instructor: Professor Kyongsu Yi
301-1502
Tel: 1941 Email:kyi@snu.ac.kr
http://vdcl.snu.ac.kr

Lectures: Mo/We 11:00-12:15 @301-1512
Office hours: Tue 10:30 to 11:30 or by appointment

Objective: To provide an overview of ground vehicle dynamics through the development, analysis and interpretation of engine, powertrain, automotive chassis and vehicle models.
Analysis and prediction of the dynamics of ground vehicles. Chassis control systems, Vehicle control systems, Human driver model, vehicle-driver closed loop systems, etc.

Lecture 1:

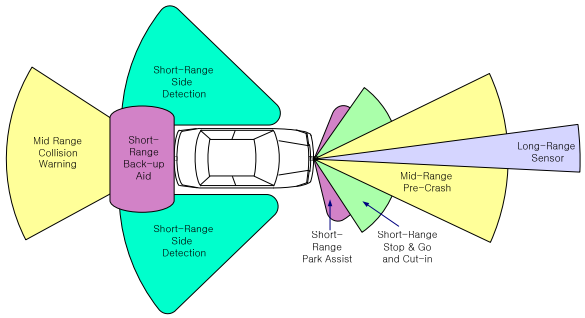


Grading: Homework 60%
Final exam 40%
Students absent in a class without instructor's permission prior to the class would be failed.

Homework: Students will turn in before the end of the class on the due date. Late homework will not be accepted. All homework assignments are to be completed on your own. You are allowed to consult with other students during the conceptualization of a problem nut all written and programming work are to be generated by yourself.

Lecture 1:

Exam: **90-minute final exam**
on December 13 (Mo) in class, 11:00-12:30



References

1. “Vehicle Dynamics and Control”, Rajesh Rajamani, Springer, 2006.
2. “Fundamentals of Vehicle Dynamics”, Thomas D. Gillespie, SAE, 1992.
3. “Theory of Ground Vehicles”, 3rd Ed., J.Y. Wong, Wiley Interscience, 2001.
4. “Vehicle Handling Dynamics”, 1st Ed., Masato Abe, Elsevier, 2009.
5. “Tire and Vehicle Dynamics”, Hans B. Pacejka, SAE, 2002.

The Car and The Future

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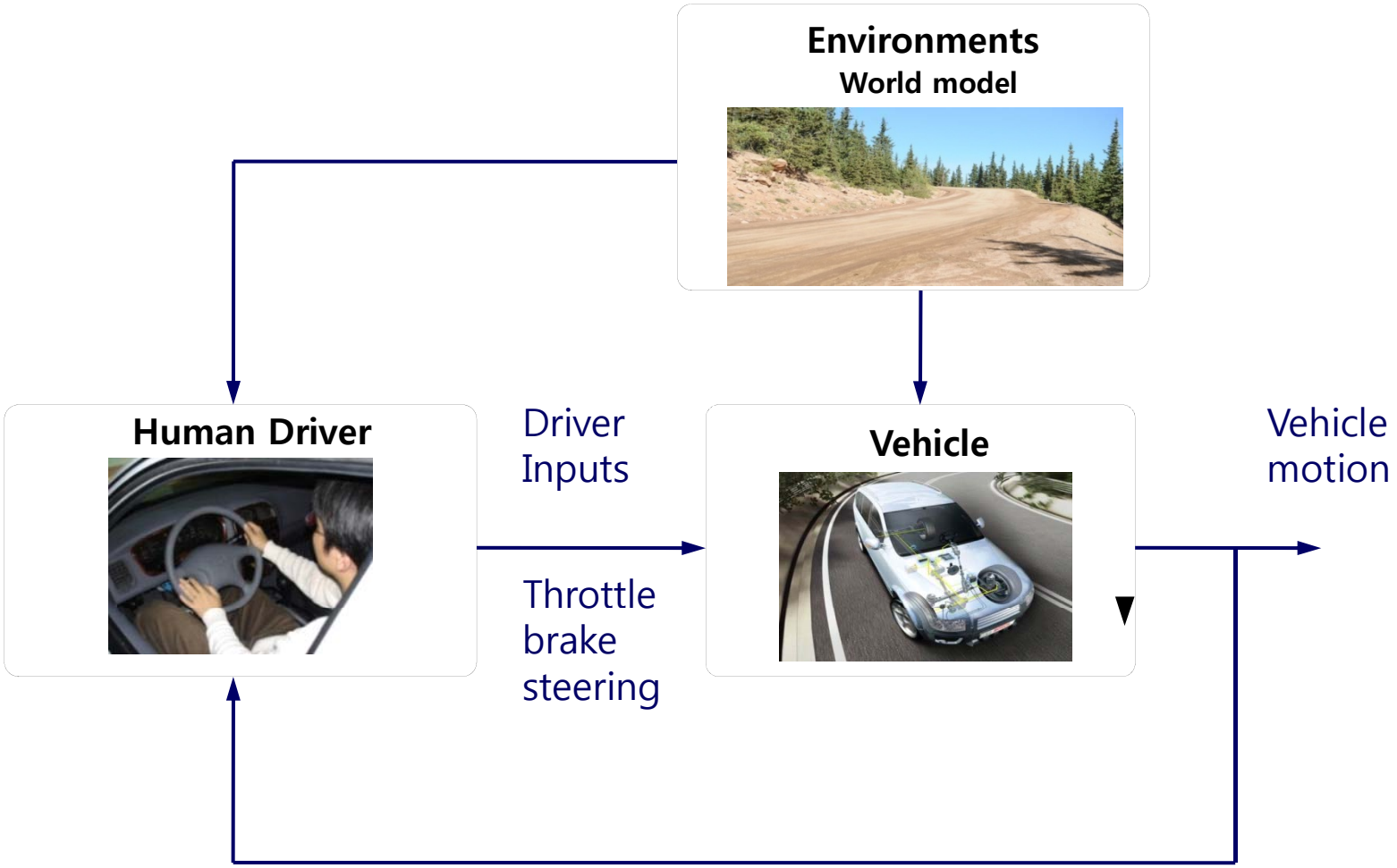
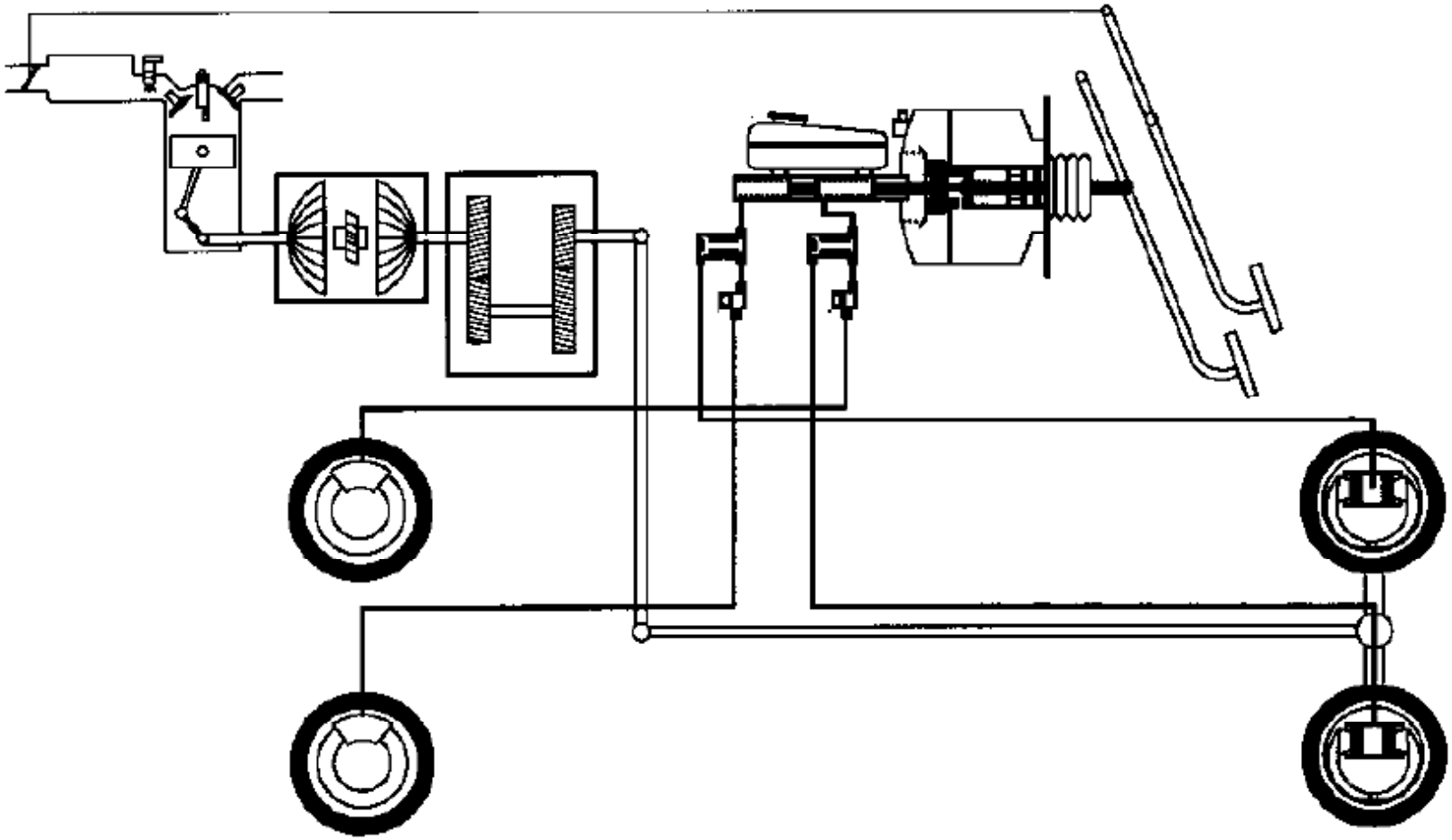
Vehicle

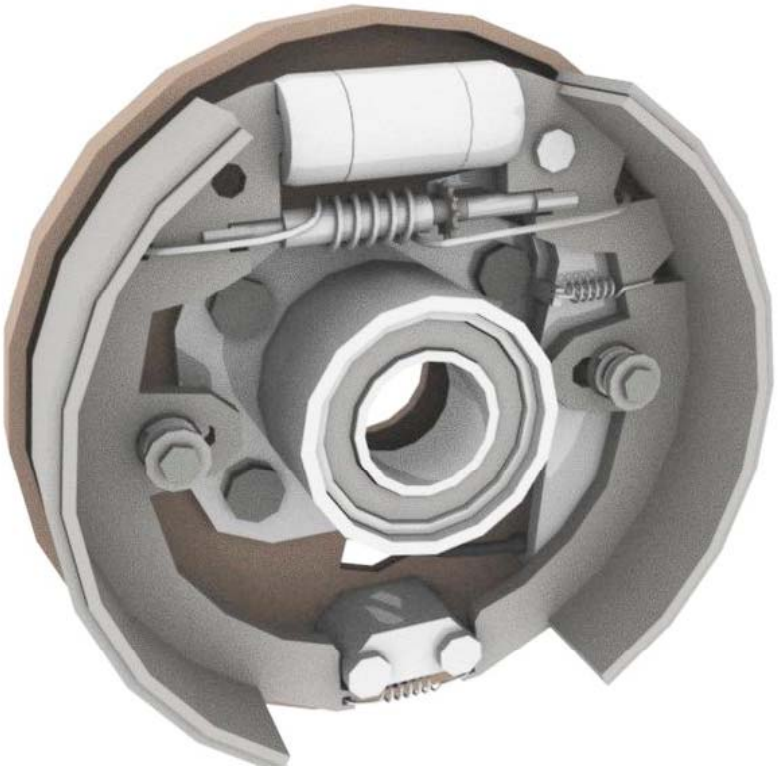
Engine, Brake, Suspension and Steering

Vehicle-Driver Systems

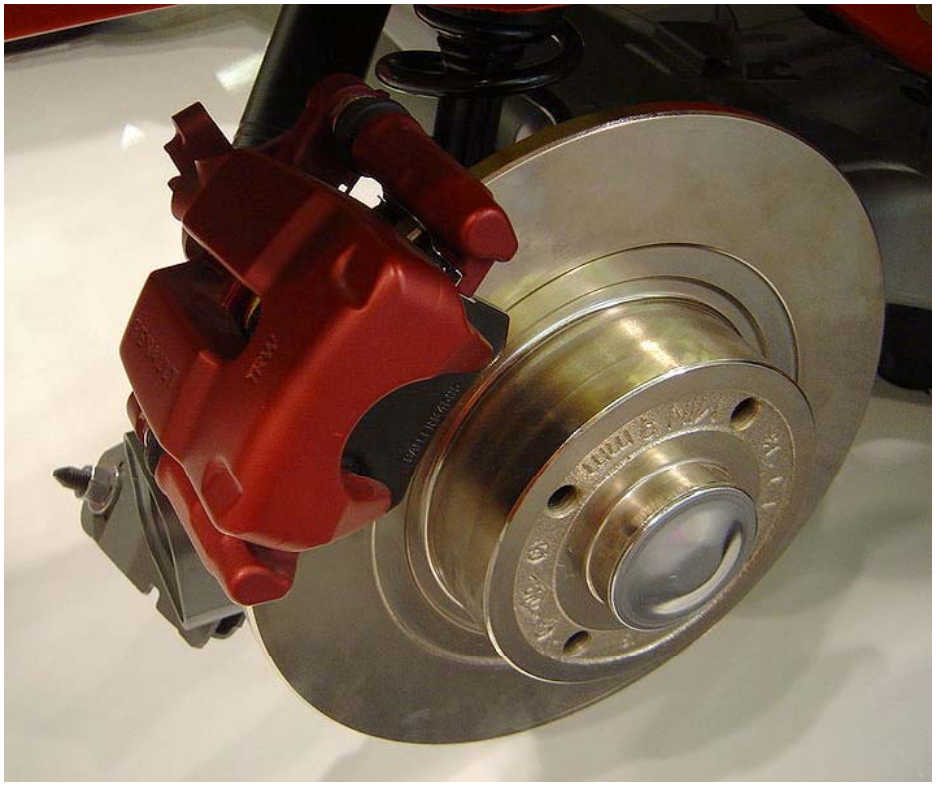


Powertrain and Brake System





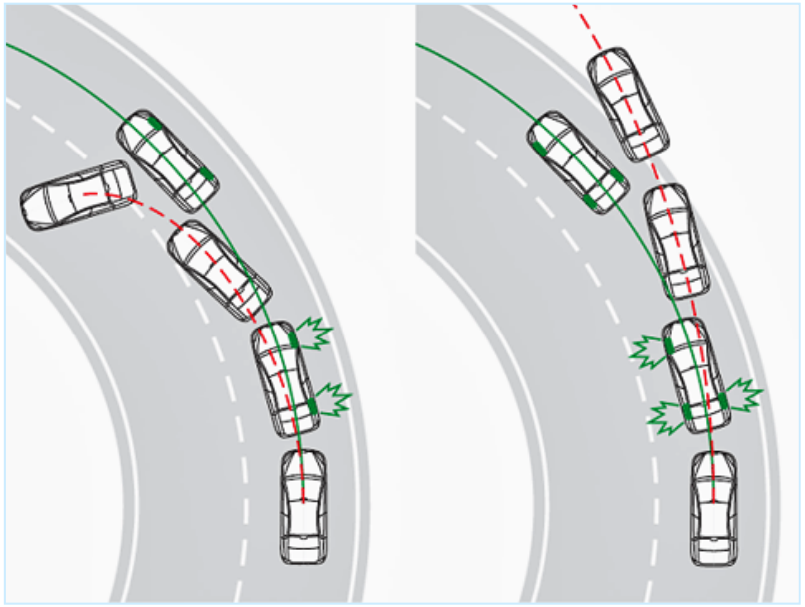
Drum Brake



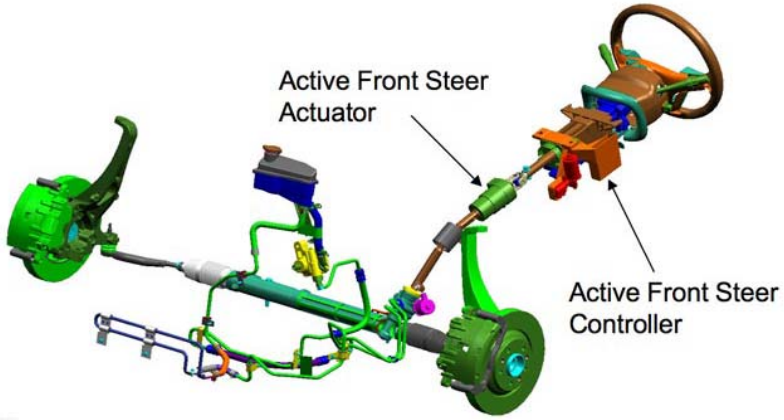
Disk Brake

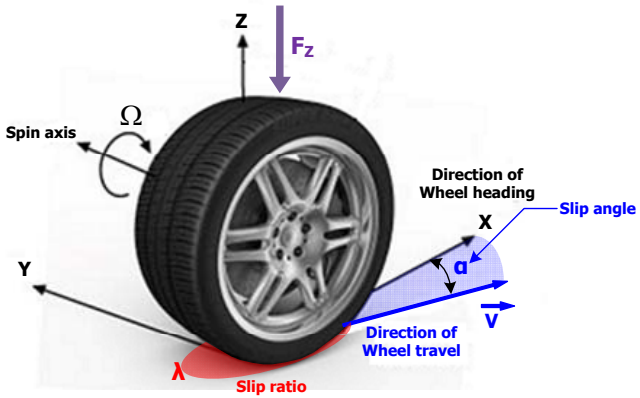
http://en.wikipedia.org/

Steering Systems



Cadillac STS – Active Front Steer System Diagram





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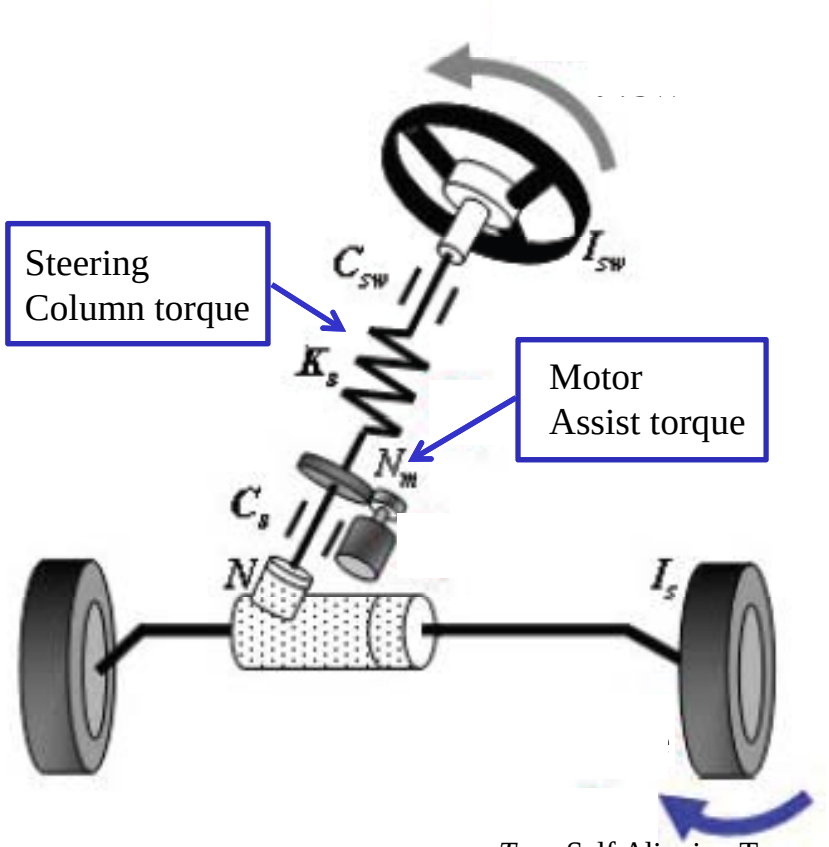
Motor Driven Power Steering Systems



T_{SAT} : Self Aligning Torque

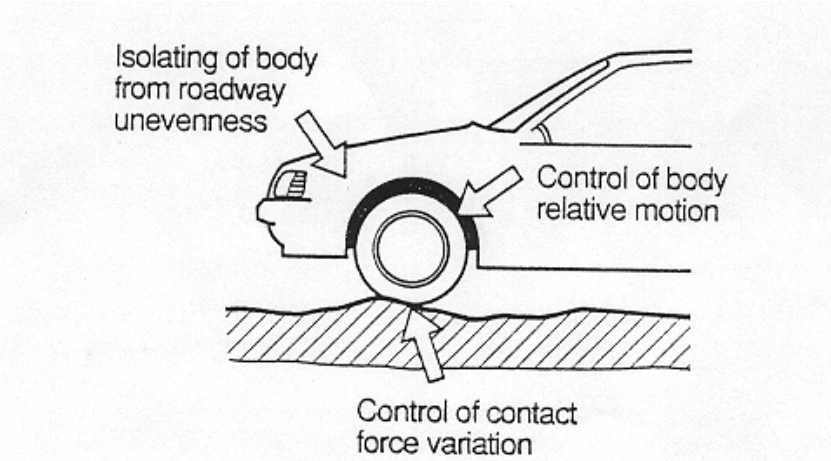
$$N \cdot (T_{column} + T_{mot,assist}) = T_{SAT}$$

$$N : Steering\ \ wheel\ \ gear\ \ ratio$$

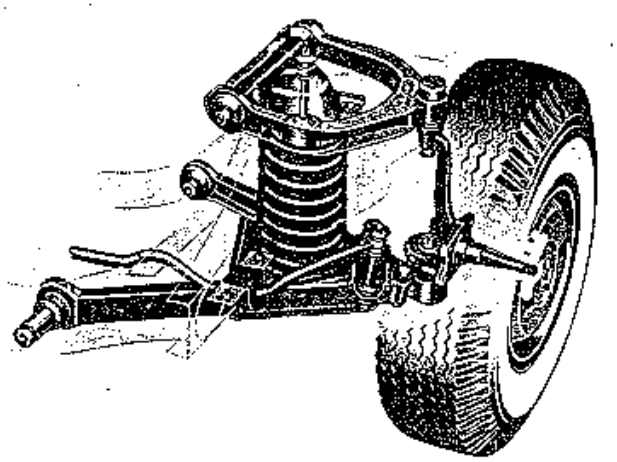
Excitation from road (inputs from environment)

Suspension Functions

- Support the vehicle static weight
- Isolate a car body from road disturbances
- Keep road holding on a rough, bumpy, and winding road for improved traction, braking and cornering

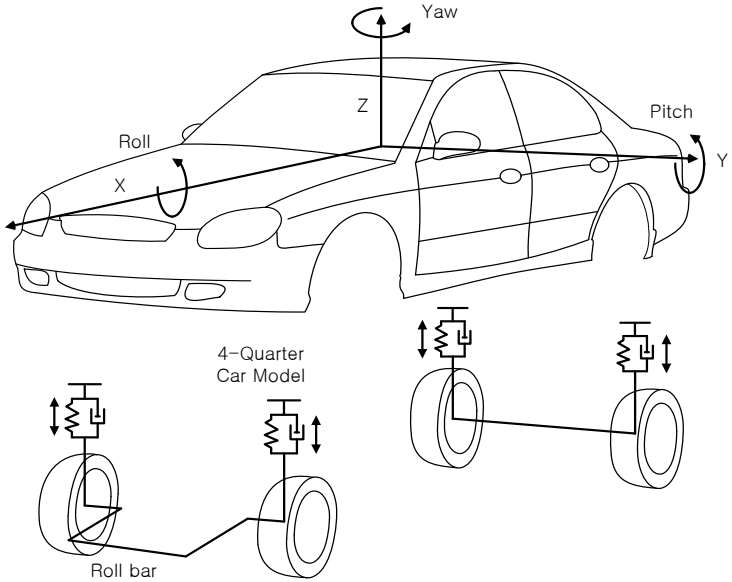


Functions of vehicle suspension systems.



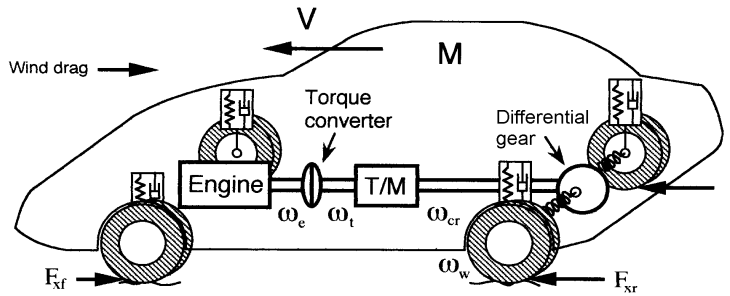
Vehicle Dynamic Model

3D Vehicle Model



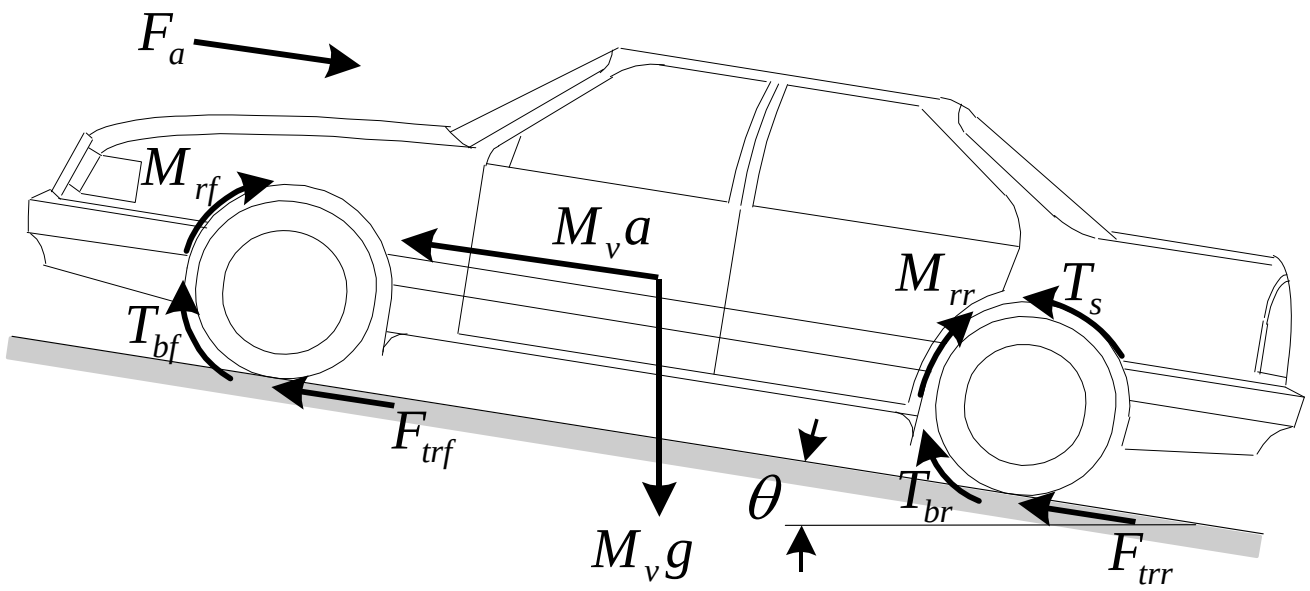
- 6-DOF Vehicle Body
- 4-Quarter Car Model
- Tire Model

Powertrain Model



- Engine Model
  - Torque Converter
  - Transmission
  - Axle Shaft
  - Differential Gear

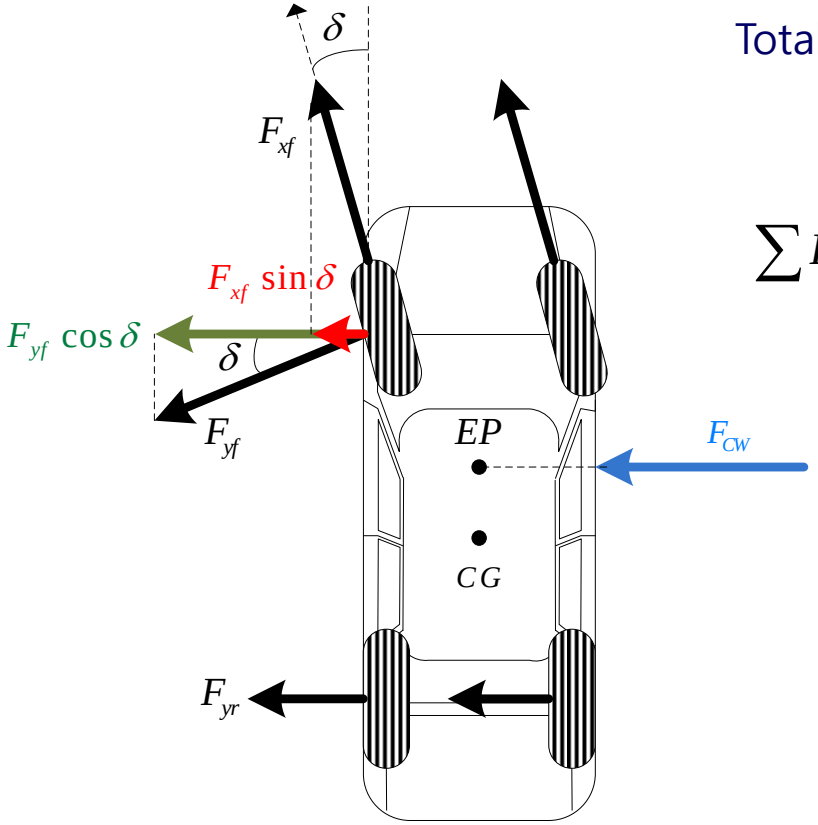
Vehicle Longitudinal Dynamics Model



Free Body Diagram of Vehicle Body

Lateral Dynamics

Crosswind Disturbance : Crosswind force



Total lateral force including crosswind disturbance

$$\sum F_y = F_{yf1}\cos\delta + F_{yf2}\cos\delta + F_{yr3} + F_{yr4} + F_{xf}\sin\delta + F_{xf}\sin\delta + F_{cw} + F_{BANK}$$

$EP = \text{equivalent point}$

$F_{xfi/yfi} = \text{longitudinal/lateral force of front i-th tire}$

$F_{yri} = \text{lateral force of rear i-th tire}$

$\delta = \text{steering angle}$

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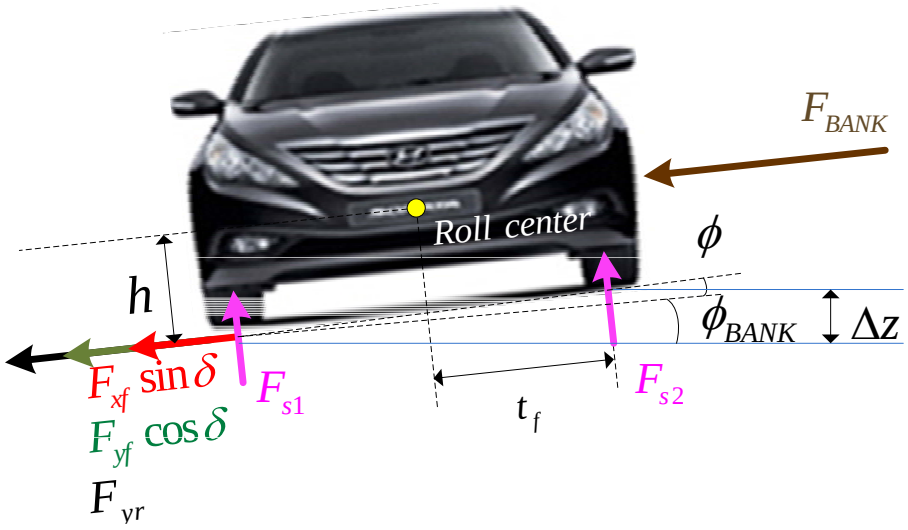
Lateral Dynamics

Bank angle

Total lateral force including crosswind disturbance



$$\phi_{BANK} = \sin^{-1}\frac{\Delta z}{2t_f}$$

$$F_{BANK} = mg\sin(\sin^{-1}\frac{\Delta z}{2t_f}) + m_u g\sin\phi$$

$$(m_u = unsprung\ \ mass,\ \phi = roll\ \ angle)$$

$F_{txi/tyi}$ = longitudinal/lateral force of i-th tire

δ_i = steering angle, $\delta_1 = \delta_2 = \delta,\ \delta_3 = \delta_4 = 0$

$$\sum F_y = F_{ty1}\cos\delta_1 + F_{ty2}\cos\delta_2 + F_{ty3} + F_{ty4} + F_{tx1}\sin\delta_1 + F_{tx2}\sin\delta_2 + F_{BANK} + F_{CW}$$

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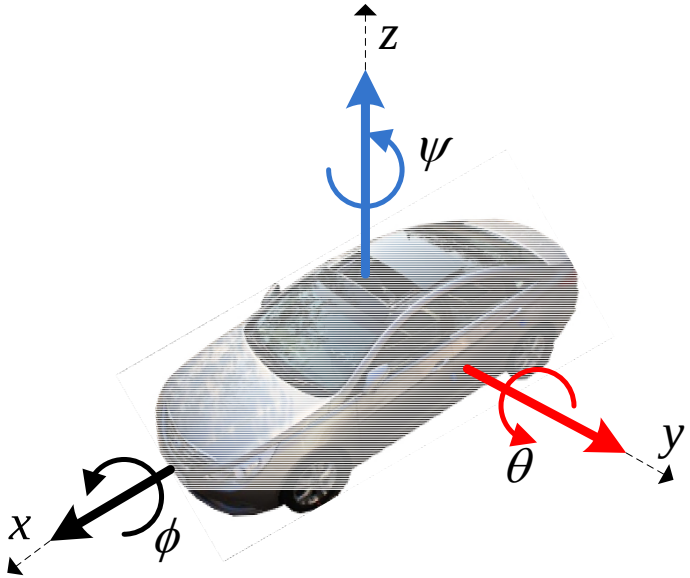
Roll/Pitch/Yaw dynamics



$$\ddot{\psi} = \frac{\sum M_z - (I_y - I_x)\cdot\dot{\theta}\cdot\dot{\phi}}{I_z}$$

$$\ddot{\phi} = \frac{\sum M_x - (I_z - I_y)\cdot\dot{\theta}\cdot\dot{\psi}}{I_x}$$

$$\ddot{\theta} = \frac{\sum M_y - (I_x - I_z)\cdot\dot{\phi}\cdot\dot{\psi}}{I_y}$$

각각의 각가속도로부터 velocity, angle 계산

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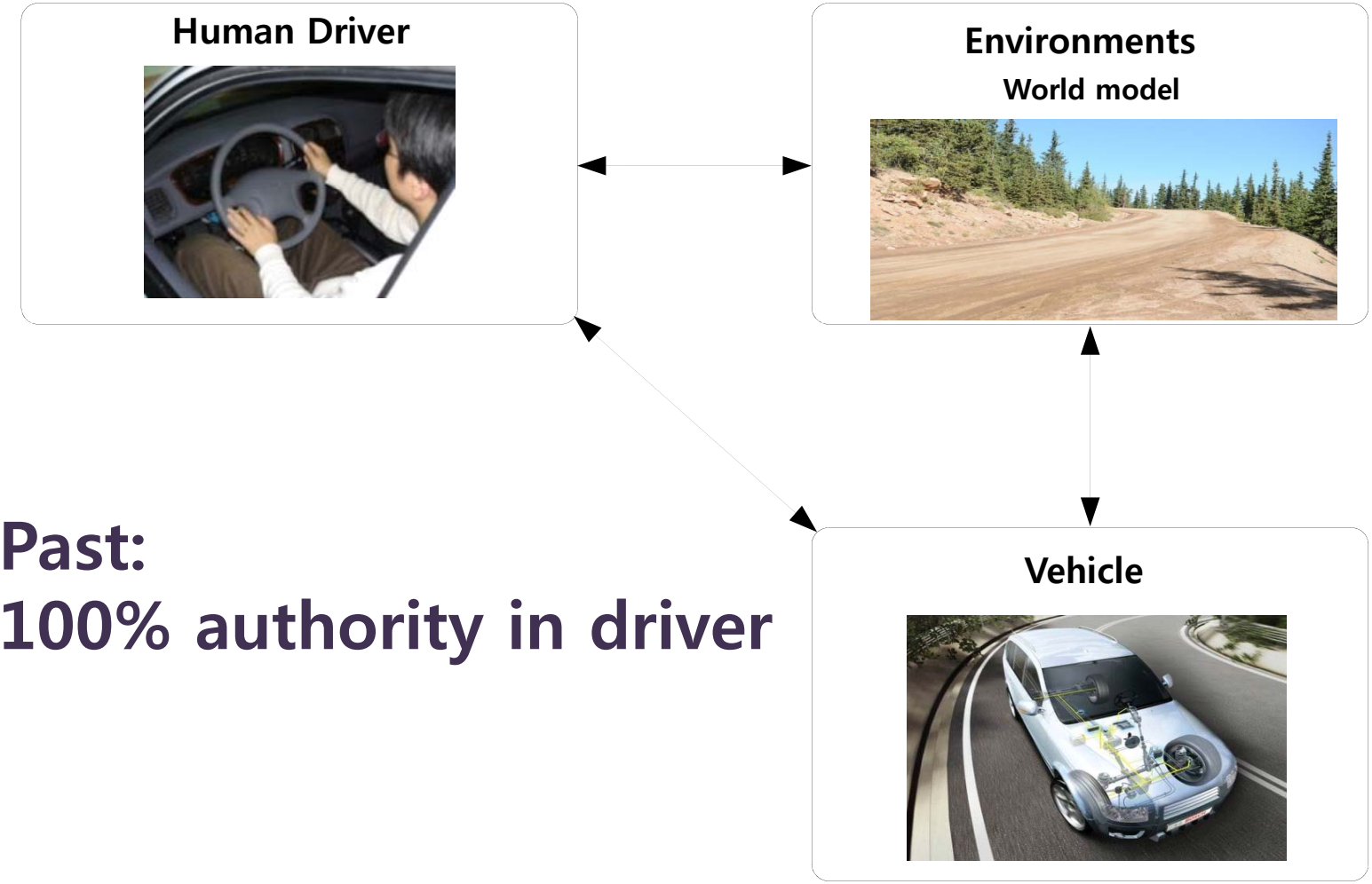
Transition from Driver Assistance Systems to IVSS



Past:
100% authority in driver

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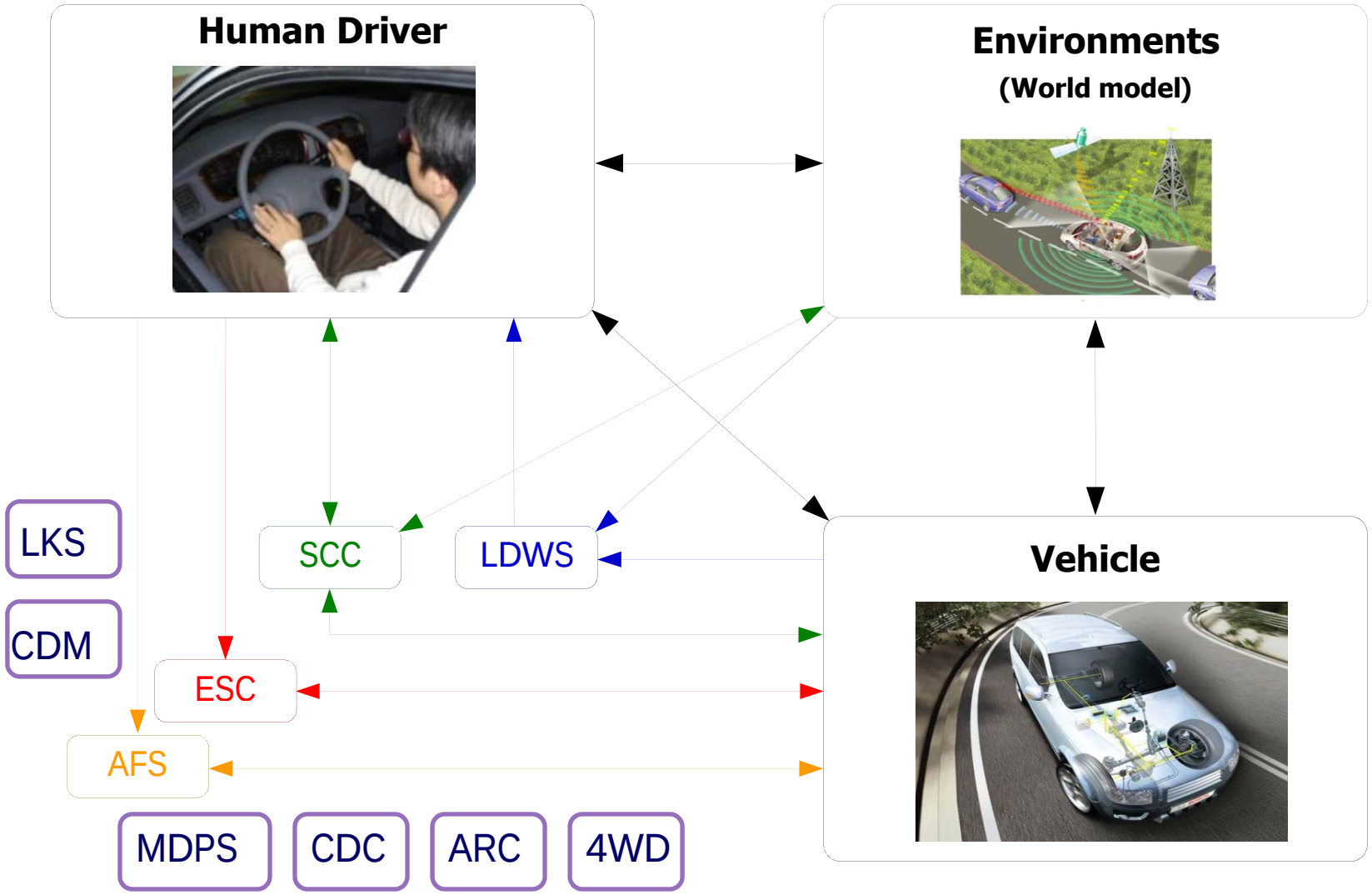
Present: Assist by Driver Assistance Systems



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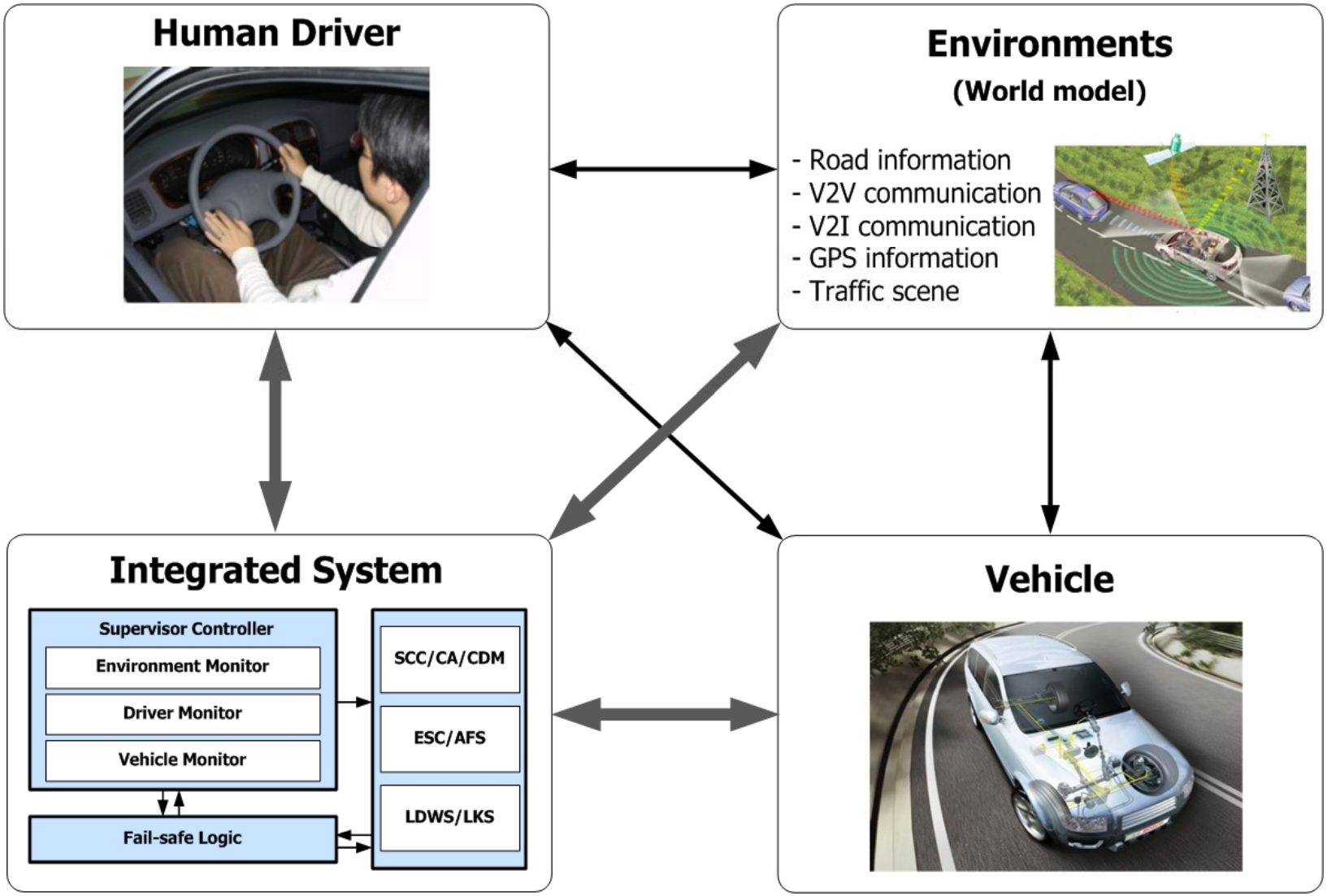
Future: Smart support by IVSS



Total Number of Control Module=76

Complete structure network V240 maximum equipment

CAN CLASS B

(1) Driver-side SAM c. m. with fuse and relay m.
(2) Passenger-side SAM c. m. with fuse and relay m.
(3) Rear SAM c. m. with fuse and relay m. 1
(4) Rear SAM c. m. with fuse and relay m. 2
(5) Left front seat c. m.
(6) Right front seat c. m.
(7) Left rear seat c. m.
(8) Right rear seat c.m.
(9) Left front door c. m.
(10) Right front door c. m.
(11) Left rear door c. m.
(12) Right rear door c. m.
(13) Partition wall c. m.
(14) Front overhead control panel c. m.
(15) Center roof node c. m.
(16) FCP (VBF) c. m.
(17) RCP (HBF) c. m.
(18) EIS (EZS) control m.
(19) Instrument cluster
(20) Steering- column m.
(21) AAC (KLA) pushbutton c. m.
(22) Rear AC control and operating m.
(24) Audio gateway c. m.
(25) PTS c. m.
(27) TPC (RDK) c. m.
(28) PSE c. m. (combined)
(29) TLC (HDS) c. m.
(30) Central gateway c. m.
(31) Airbag c. m. (Armada 20)
(32) Special vehicle multifunction c. m. (SVMCM [MSS])
(33) Vehicle power supply c. m.
(34) Steering wheel heating converter
(35) Independent car heater
(36) Left rear closing assist c. m.
(37) Right rear closing assist c. m.

CAN CLASS C

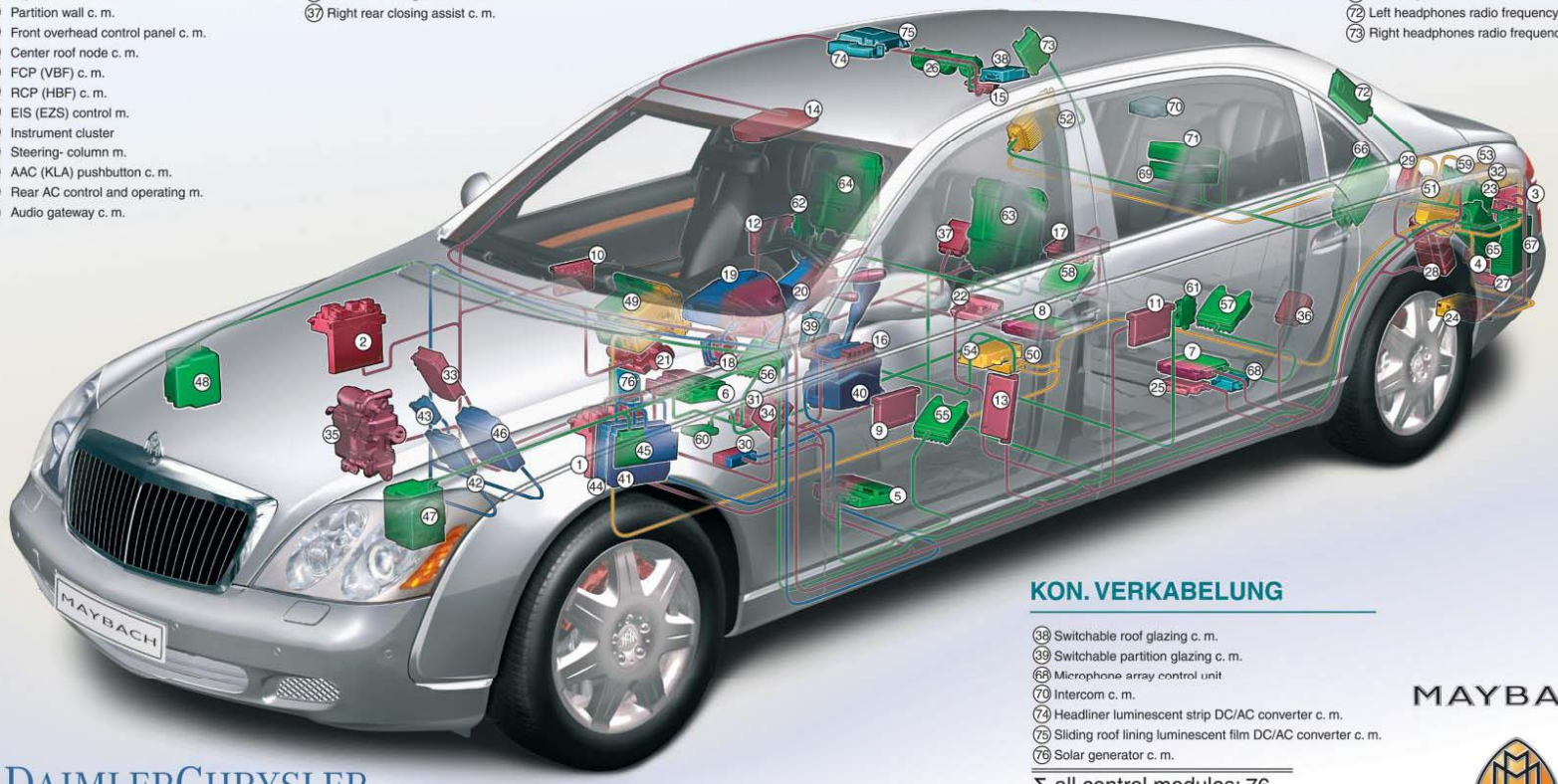
(18) EIS (EZS) c. m.
(19) Instrument cluster
(20) Steering- column m.
(30) Central gateway c. m.
(40) Electronic selector lever module c. m.
(41) AIRmatic with ADS c. m. (SLF)
(42) DTR c. m.
(43) Headlamp range adjustment c. m.
(44) ME-SFI (ME) c. m.
(45) Twin- Sensotronic Brake System (FSG)
(46) ETC (EGS) c. m.

MOST-BUS

(24) Audio gateway c. m.
(49) Headunit
(50) Voice control system control unit
(51) TV-Tuner MOST
(52) Sound amplifier
(53) Navigation processor
(54) Front telecom. control m. (CP1)

PRIVATE-BUS

(5) Left front seat c. m.
(6) Right front seat c. m.
(7) Left rear seat c. m.
(8) Right rear seat c. m.
(23) TV-Tuner CAN
(26) Roof instument
(45) Twin- Sensotronic Brake System (FSG)
(47) Twin- Sensotronic Brake System (ASG 1)
(48) Twin- Sensotronic Brake System (ASG 2)
(55) Left front multicontour backrest c. m.
(56) Right front multicontour backrest c. m.
(57) Left rear multicontour backrest c. m.
(58) Right rear multicontour backrest c. m.
(59) Rear m. Keyless Go c. m.
(60) Interior m. Keyless Go c. m.
(61) Left rear door Keyless Go c. m.
(62) Right rear door Keyless Go c. m.
(63) Left rear display
(64) Right rear display
(65) Rear telecommunications c. m. (CP2)
(66) Surround amplifier c. m.
(67) Audio/video controller c. m.
(69) CD player with changer
(71) DVD player
(72) Left headphones radio frequency transmitter
(73) Right headphones radio frequency transmitter



KON. VERKABELUNG

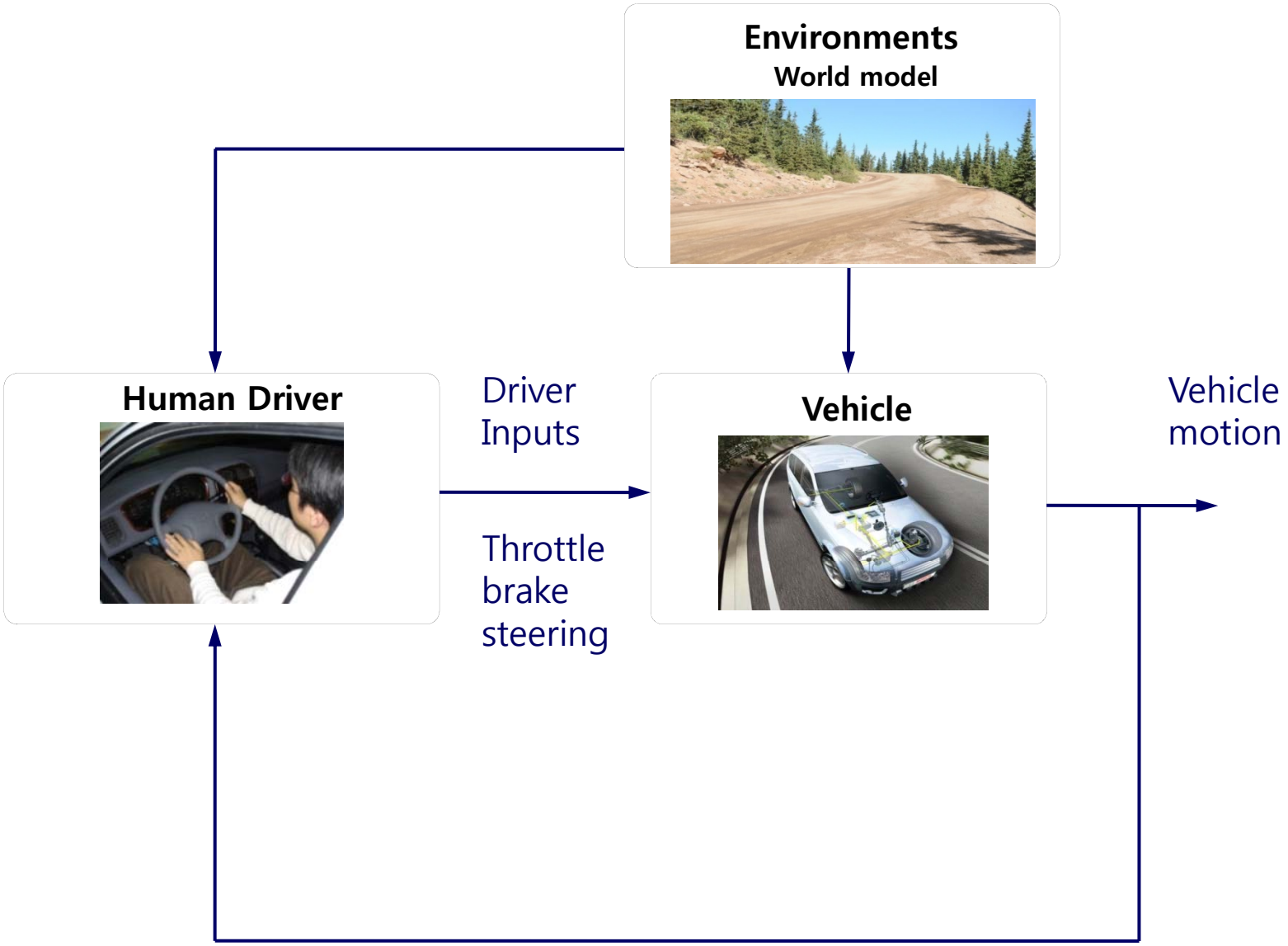
(38) Switchable roof glazing c. m.
(39) Switchable partition glazing c. m.
(68) Microphone array control unit
(70) Intercom c. m.
(74) Headliner luminescent strip DC/AC converter c. m.
(75) Sliding roof lining luminescent film DC/AC converter c. m.
(76) Solar generator c. m.

Σ all control modules: 76

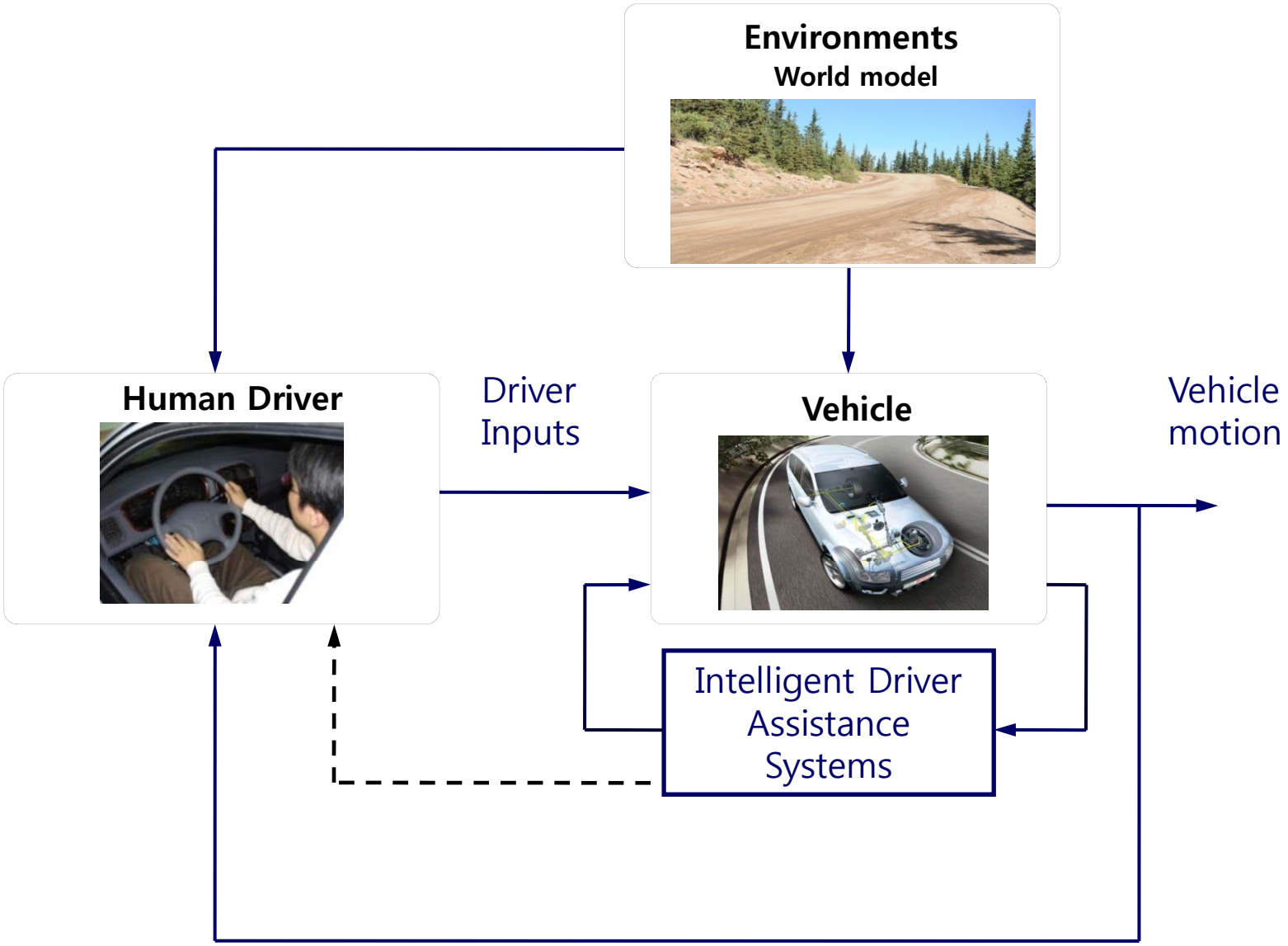
c. m. = control module

MAYBACH

Vehicle-Driver Systems



Vehicle-Driver-IDAS Systems



Major Course Contents

Part 1: Lateral Vehicle Dynamics

- 1.1 Vehicle Dynamic Model
- 1.2 Planar Model
- 1.3 Bicycle Model
  - Bank angle/crosswind
- 1.4 Tire Models
- 1.5 Understeer/oversteer
- 1.6 Dynamic model interms of error wrt road
- 1.7 lane keeping model
- 1.8 Lateral stability Control

Part 2: Longitudinal Vehicle Dynamics

Part 3: Vehicle Control Systems

Part 4: Suspensions

Part 5: Three-dimensional rigid body model of a vehicle

Major Course Contents

Part 2: Longitudinal Vehicle Dynamics

- 2.1 Longitudinal Dynamic Model
- 2.2 Engine model
- 2.3 Transmission
- 2.4 Tire models
- 2.5 Brake

Part 3: Vehicle Control Systems

- 3.1 Driver Model
- 3.2 Lateral Stability Control
- 3.3 Lane Keeping Systems
- 3.4 Adaptive Cruise Control
- 3.5 Autonomous Driving Systems

Major Course Contents (contd.)

(tentative, Optional)

Part 4: Suspensions

- 3.1 Fundamental properties of suspensions
- 3.2 Invariant properties
- 3.3 Ride quality
- 3.4 Active/semi-active suspensions

Part 5: Three-dimensional rigid body model of a vehicle

- 5.1 Newton/Euler formulation –review
- 5.2 14 DOF vehicle model (6+4+4)

Understand the underlying physics and being able to construct models to analyze and predict vehicle behavior

Control system design for safety and maneuverability

End of Introduction

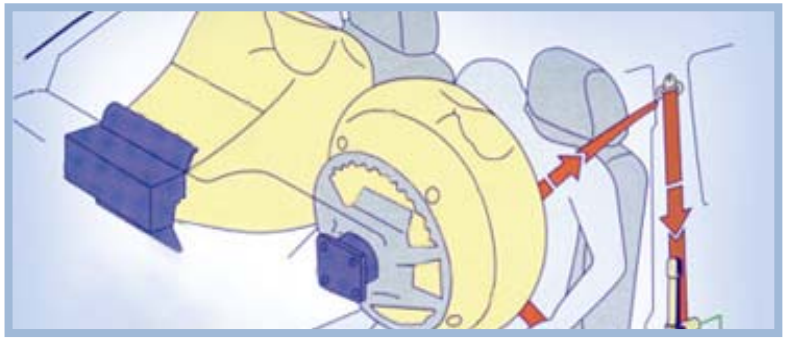
October 6, 2010

안전한 자동차

지능형 안전 자동차
Intelligent Safety Vehicle

주행 안전 장치

수동적 안전 장치
사고 완화



- 에어백
- 안전벨트
- 목받침

능동적 안전 장치
사고 방지

- ABS Anti-lock Braking System
- TCS Traction Control System
- ESP 전자식 주행안정 프로그램
- Brake Assist 제동 보조 장치
- 자동주행 (Smart Cruise Control)
- 충돌방지 (Collision Avoidance)
- 차선 이탈 방지 (Lane Departure Avoidance)

Vehicle Stability Control (VSC)
Electronic Stability Control (ESC)
Electronic Stability Program (ESP)

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1 ESP 동영상 bosch esp exp motor_C

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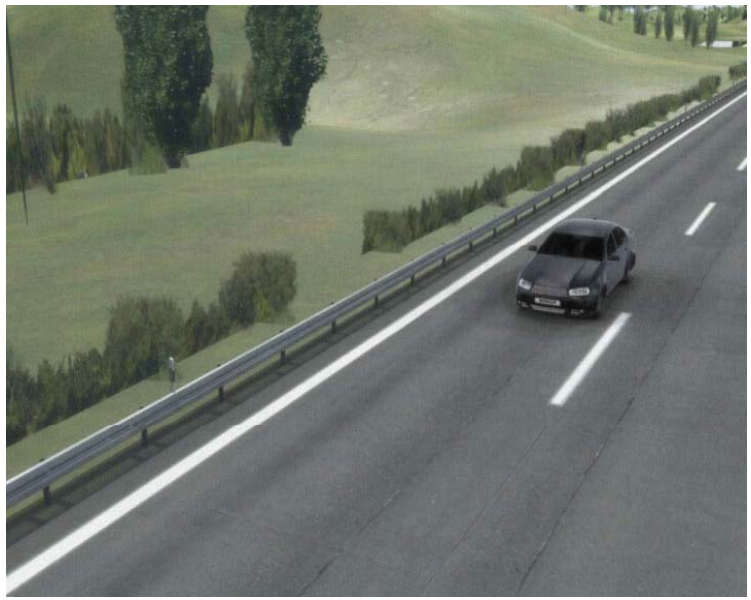
VSC 작동 원리

ESP는 어떻게 작동하는가?



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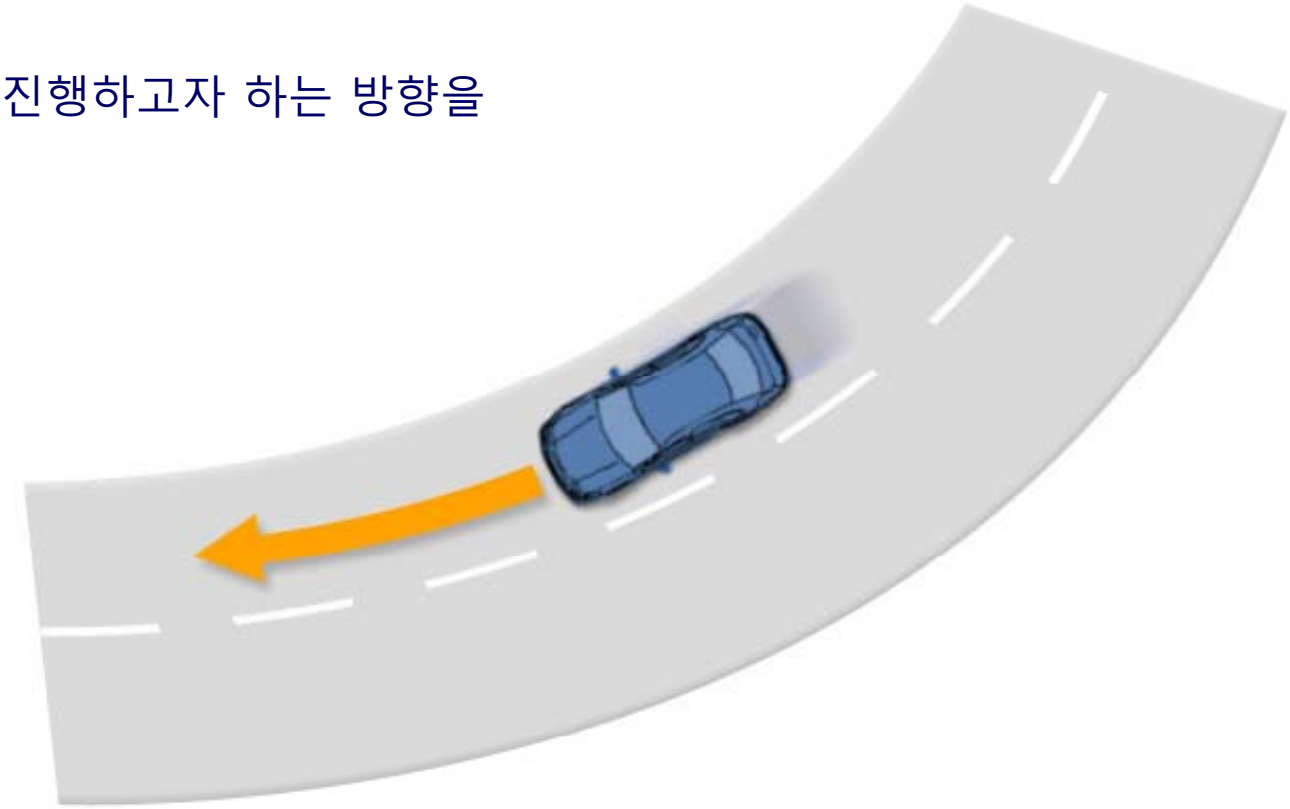
ESP는 어떻게 작동하는가?

ESP는

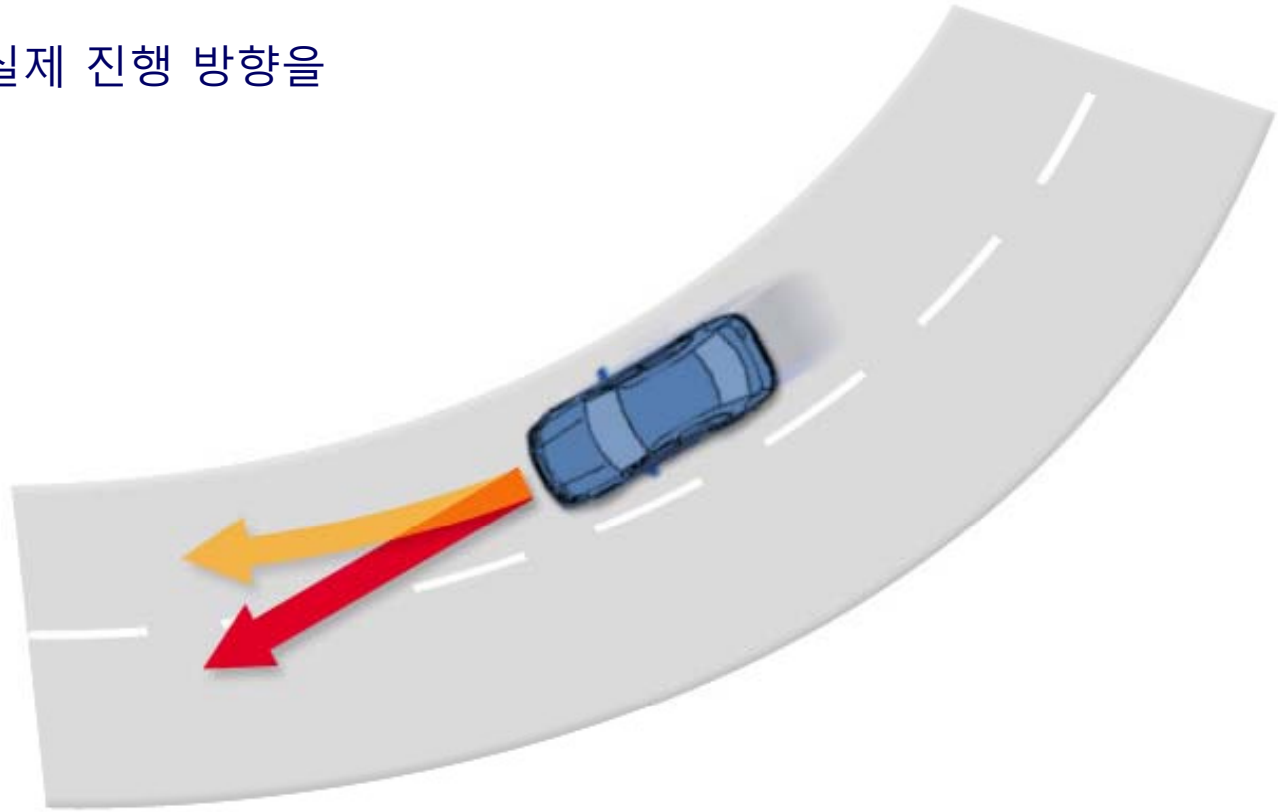
- 운전자가 진행하고자 하는 방향을 인식한다



ESP는 어떻게 작동하는가?

ESP는

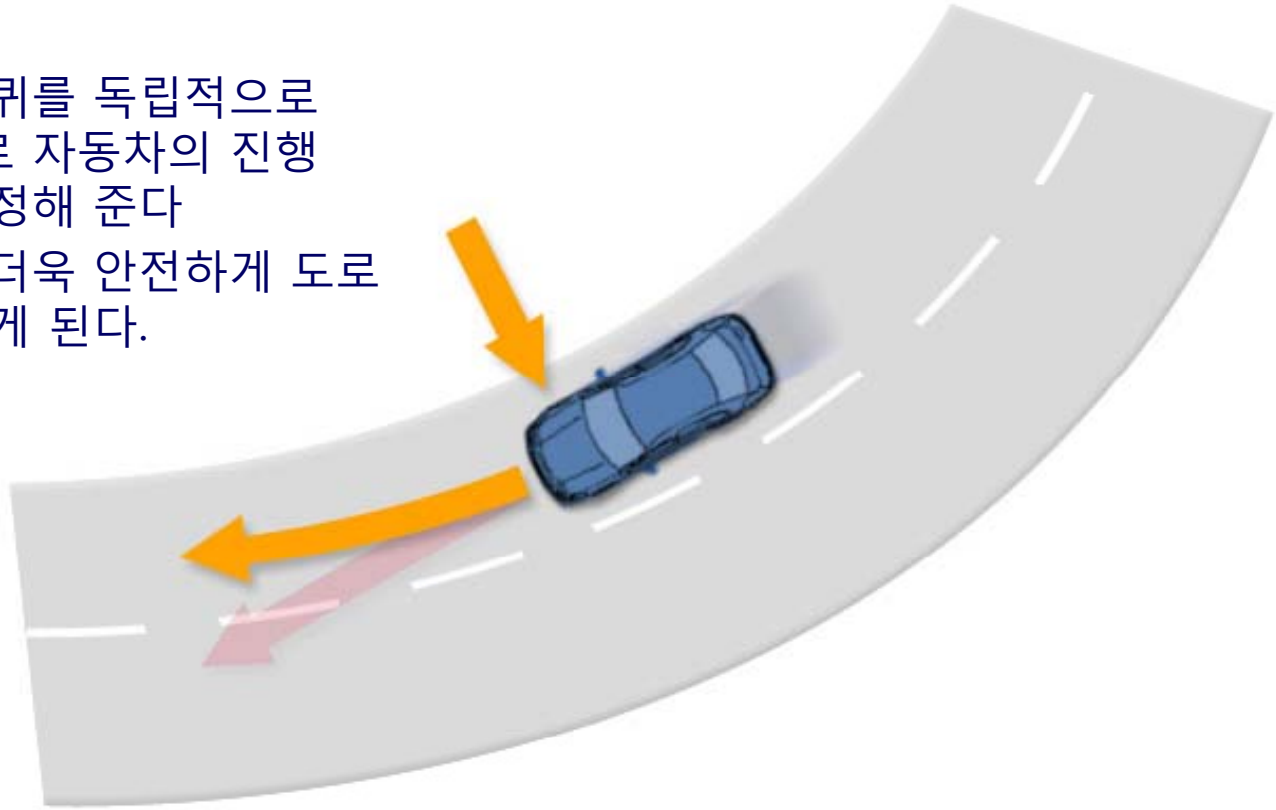
- 자동차의 실제 진행 방향을 감지한다.



ESP는 어떻게 작동하는가?

ESP는

- 각각의 바퀴를 독립적으로 제어함으로 자동차의 진행 방향을 조정해 준다
- 자동차는 더욱 안전하게 도로 위에 머물게 된다.



ESP: 4 wheel independent braking

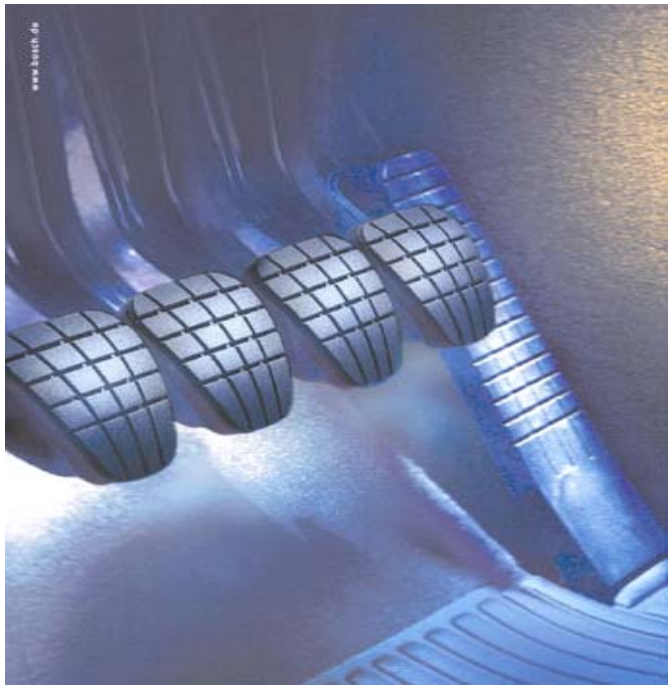
Can you brake hard on the front wheel, softly on the back left wheel and, at the same time, accelerate the back right wheel to stop the rear of your car losing control in a bend?

1995년 독일 보쉬 개발

2002년부터 Benz 모든 차량에 장착

2011년부터 미국 수출 모든 자동차 장착 의무화

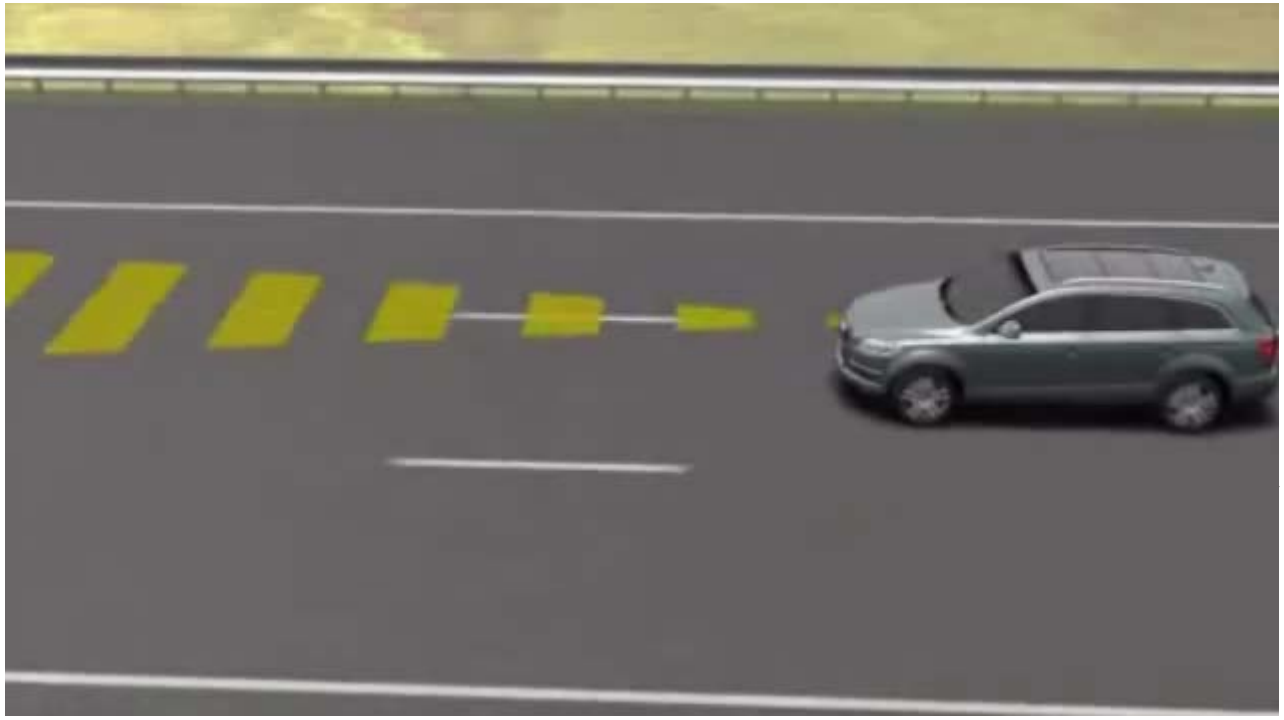
2012년 부터 미국에서 생산되는 모든 자동차에 장착 의무화

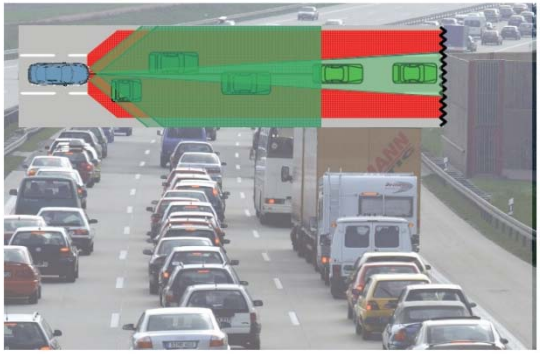


현대자동차 제네시스 2008년

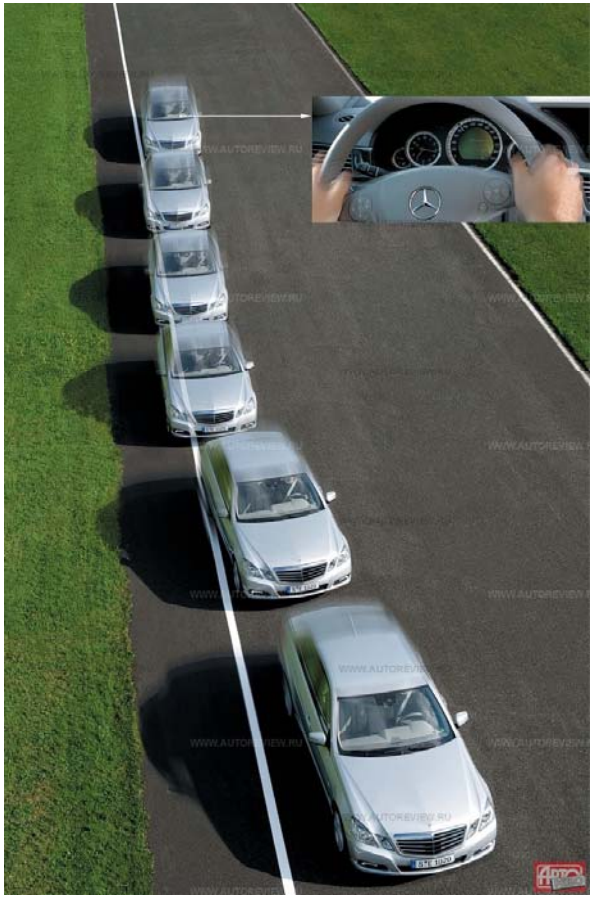
그랜저 2010년

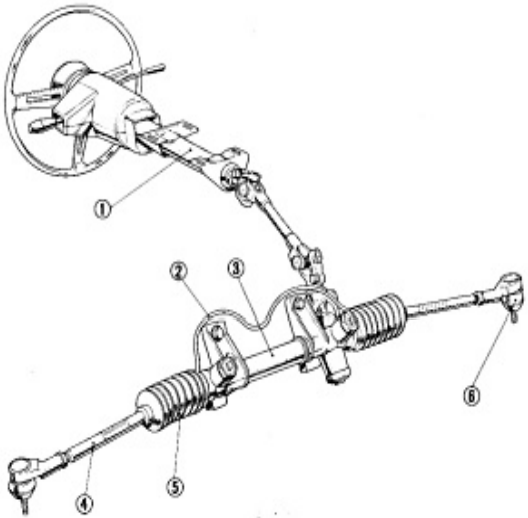
아반테 2012년





Lane Departure Warning
Lane Keeping Systems
Lane Departure Avoidance Systems





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미래의 자동차

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Future Vehicles

Hyundai Blue Will – Chicago Auto Show 2010

Toyota Concept Car– 2009 Tokyo Motor Show

Kia Venga– 2010 제네바 모터쇼

Mercedes Benz – New York Auto Show 2007

Honda Puyo– 2007 도쿄 모터

Chevrolet Aveo RS Show Car – Chicago Auto Show 2010

Future Vehicles: Small and Smart

Dreaming … *"the car for the 2 kW society"*

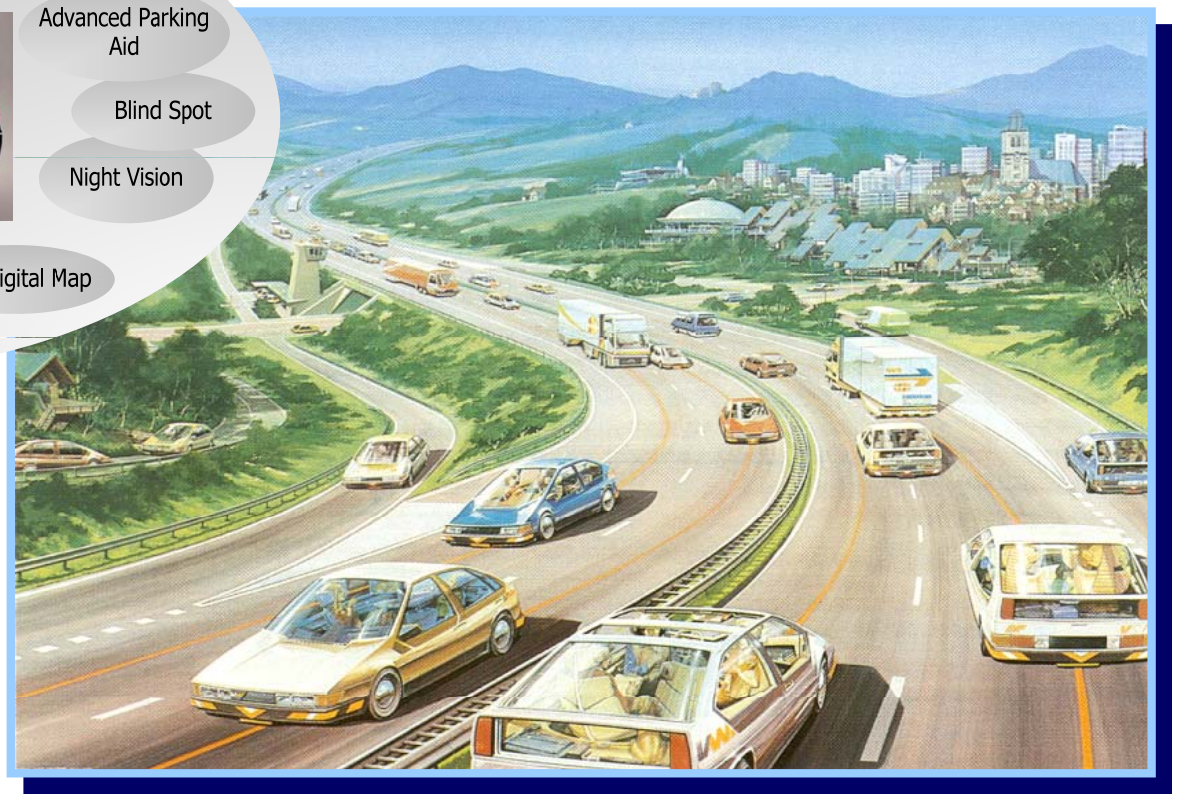
m	1‘600 kg	700 kg
$A_f c_w$	0.70 m^2	0.40 m^2
c_r	0.013	0.010
η	0.2	0.30
⇒	**7.6 l/100km** (EU cycle)	**2.0 l/100km** (117 mpg)

1600 kg/70kg = 23

700kg/70kg = 10

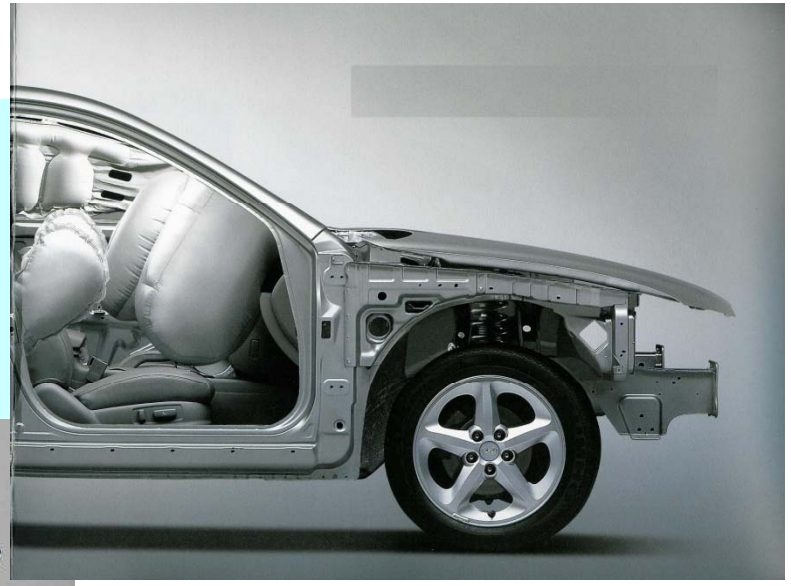
Future Vehicle

지능형 안전 자동차 기술
100% 사고없는 안전하고 편안하고 효율적인 자동차
Clean, Safe, Convenient Crash-free Vehicle



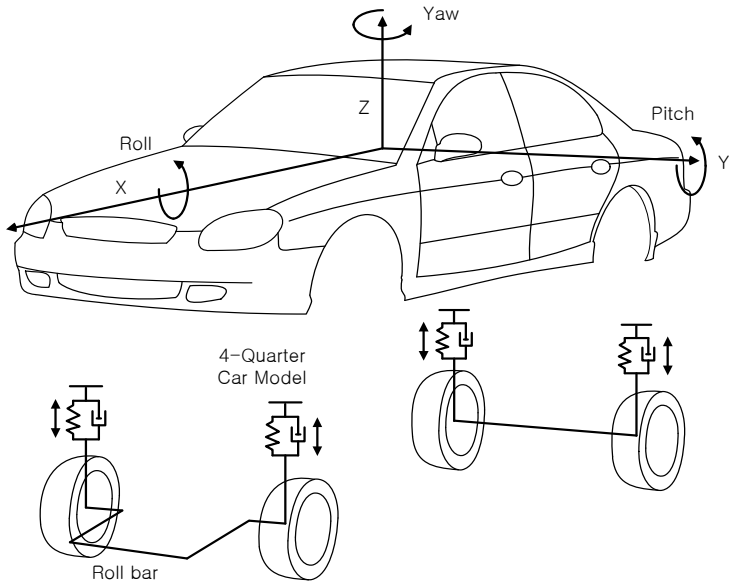
NF Sonata 2004

NF Sonata 2004



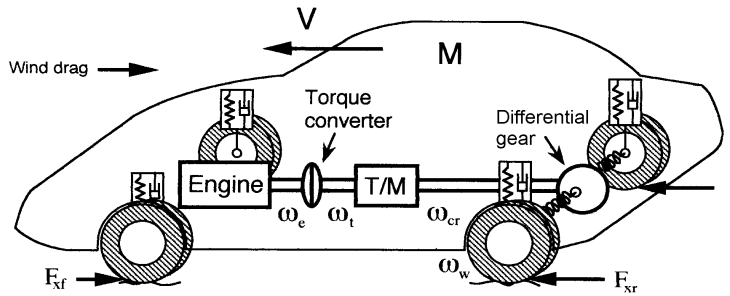
1. Vehicle Model

3D Vehicle Model



- 6-DOF vehicle body
- 4-Quarter Car Model
- Tire Model

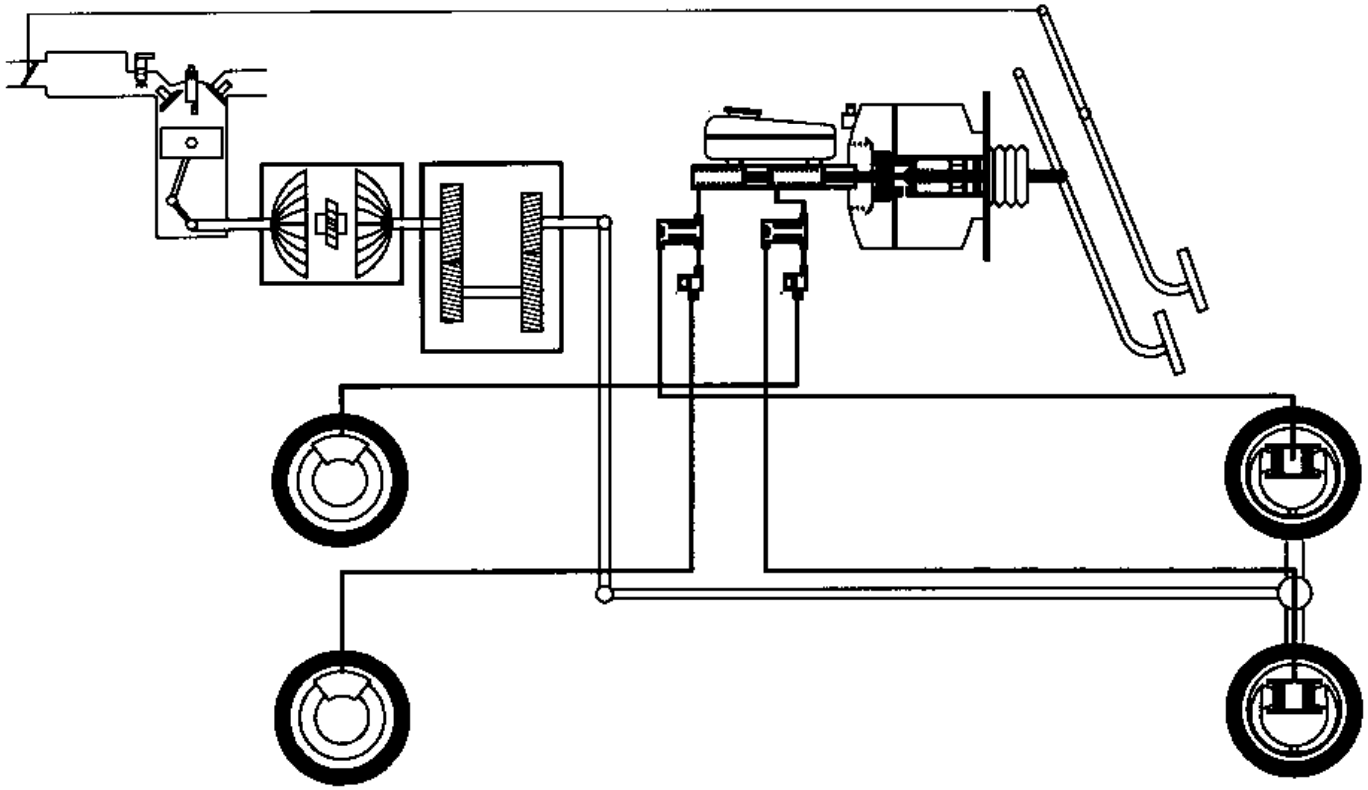
Powertrain Model



- Engine Model
  - Torque Converter
  - Transmission
  - Axle Shaft
  - Differential Gear

1. Vehicle Model

Powertrain and Brake System



3 DOF Vehicle Planar Motion Model

■ **3 DOF linear vehicle model을 위한 가정**

1) Roll, Pitch Motion 무시 $\left(\phi = 0,\ \psi = 0 \right)$

2) Suspension Dynamics 무시 $\left(F_{z1} = F_{z2} = F_{z3} = F_{z4} \right)$

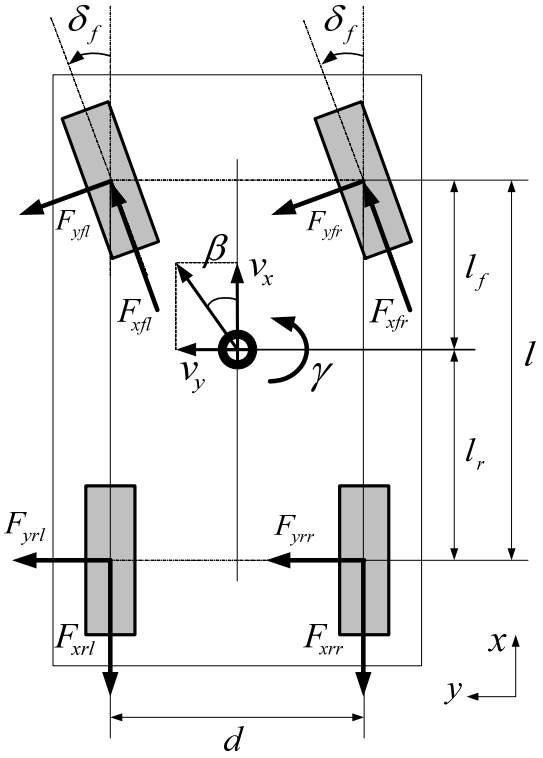
운동방정식

$$m(\dot{v}_x - \gamma v_y) = F_{xr} + F_{xf}\cos\delta_f - F_{yf}\sin\delta_f \qquad (1)$$

$$m(\dot{v}_y + \gamma v_x) = F_{yr} + F_{yf}\cos\delta_f - F_{xf}\sin\delta_f \qquad (2)$$

$$I_z\dot{\gamma} = l_f F_{yf}\cos\delta_f - l_r F_{yr} - l_f F_{xf}\sin\delta_f \ldots$$

$$+\frac{d}{2}(\Delta F_{xr} + \Delta F_{xf}\cos\delta_f) \qquad (3)$$



Motivation and Auto Industry

Korean Automotive Industries

(1) Volume – No. 5 in the World (3.2 Million, 2001)
(2) 10% of GNP
(3) Export $2.33 billion,
balance in the black: $1.96 billion
99% of parts are home products
(4) Manufacturer 50,000.
Suppliers 100,000.
Auto Related Service 250,000.

TOTAL: 400,000 Jobs and 1,600,000 peoples

(5) Technology – Not Competitive

Motivation and Auto Industry

Technology Trends

(1) Environment-Friendly Vehicles

(2) Intelligent Vehicles

Transition of Vehicles

Transportation → "Safe", "Comfort", "Convenient" and "Entertaining" Mobile Office

Automobile Engineering

1. Body

2. Engine
3. Transmission

4. Chassis
   - Suspension
   - Brake
   - Steering
   - Wheel assembly

5. Automotive Electronics