Global Chassis Control in Passenger Cars

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1 INTRODUCTION

Full-scale global chassis control systems are being developed by various companies for use in passenger cars. This development started in Europe in 1983 with the Daimler-Benz 4Matic four-wheel drive (4WD) system, which used online calculation of vehicle states. Calculation results from a bicycle model and yaw rate measurement results from the wheel speeds were compared to determine whether to engage the front axle to the drive train using electronically controlled clutches. This system used longitudinal slip and lateral vehicle dynamics for control for the first time (German patent DE 35 05 455 CS, 1985). Other early examples include the integrated active suspension, active rear steer (ARS) system, traction control system (TCS), and antilock brake system (ABS) in the Toyota Soarer in 1991 (Tanaka et al., 1992) and the introduction of an in-vehicle local area network (LAN) with the 4WDi-Four and ARS system in the Toyota Crown Majesta in 1992. In addition, in 1992, BMW offered dynamic stability control (DSC), the first electronic stability control (ESC) in its 850i sports car. This system controlled the throttle and the ignition timing after comparing the vehicle behavior to a bicycle model. Mercedes and Toyota as ESC released additional brake intervention controls in 1995. These were followed in 1997 by the release of the Toyota Hybrid System (THS) in the Prius, which featured the first example of technology that combined braking performance with the recovery of regenerative energy. Subsequently, various companies are now developing global control systems that integrate powertrain, steering, and active braking systems. These include the integrated chassis management (ICM) system developed by BMW, the vehicle dynamics management (VDM) system developed by Bosch, the vehicle dynamics integrated management (VDIM) system developed by Toyota, and so on. Such systems are beginning to be considered as fundamental technology for enhancing safety and environmental performance as well as driving enjoyment. In addition, advances in vehicle environment recognition technology have led to the development of driver assistance systems such as precrash safety (PCS) and the like. This chapter describes an outline of integrated vehicle systems, focusing on global chassis control. It also
presents an overview of the integration of driver assistance systems and global vehicle dynamics controls to enhance safety technology and discusses the value of the regenerative energy recovery and integrated vehicle dynamics control functions of hybrid electric vehicle (HEV) systems in enhancing environmental technology.

2 HIERARCHY OF INTEGRATED VEHICLE SYSTEMS

The process of driving a vehicle consists of three related factors: the driver, the vehicle, and the traffic environment. The component technologies that make up integrated vehicle control must be structured simply and rationally while considering the requirements to enhance the overall value of the vehicle in terms of safety, driving enjoyment, and environmental performance. Figure 1 shows the hierarchical structure of an integrated vehicle system. The system consists of the following five parts.

1. VDM
2. driver assistance management
3. energy management
4. human–machine interface (HMI) management
5. occupant protection management.

Currently, the most important of these parts are VDM and driver assistance management. It is likely that further advances will occur in the field of sensing, such as cooperative communication among vehicle environment recognition systems using autonomous sensors such as radar and camera, navigation systems, and roadside infrastructure. Such advances are particularly likely for integrated safety systems and VDM is a key technology supporting this progress.

2.1 Integrated safety

This section briefly discusses the concept of integrated safety. Figure 2 shows the trends in active and passive safety technology. Advances in the field of passive safety technology include optimized body structures, enhanced restraint systems such as airbags, and measures for various different types of accident formats (i.e., compatibility in crashes with different vehicle types, pedestrian safety, and the like). However, active safety has grown in importance in recent years. The aim of active safety systems such as ESC, VDIM, and PCS is to help reduce the number of accidents that occur. Systems that coordinate with roadside infrastructure using communication technology may also be developed in the future. On the basis of these trends, it is likely that active and passive safety systems will be introduced together as integrated packages rather than as separate technologies. The aim of integrated safety management is to create a simpler overall system that helps to seamlessly operate each function together (Figure 3). For
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Figure 2. Trends in passive and active safety technology.

Figure 3. Integrated safety management.
this reason, VDM will play a fundamental role acting as the muscles and nerve system of the vehicle.

3 EVOLUTION OF CHASSIS CONTROL DEVICES

The development of more advanced chassis control devices that act as the muscles of the car to control the tires is an essential part of enhancing vehicle dynamic performance. This requires expanding the degree of freedom of control over the forces generated at each tire contact point from the longitudinal direction to the lateral and vertical directions. This can only be achieved by smooth and highly responsive control in all directions. The following sections describe recent development trends in chassis control devices and examples of their application.

3.1 Brake control

The development of brake control systems has accelerated because of the adoption of ABS and electronic brake distribution (EBD) systems as standard equipment. In combination with advances in ESC technology, the major effect of integrated brake control systems in helping to reduce accidents has been confirmed in the real world. As a result, the United States and other countries have begun to mandate their usage and such systems are likely to become standard equipment in the future.

The popularization of HEVs in recent years has also contributed to the development of electronically controlled brake (ECB) systems (Figure 4) with the aims of achieving linear hydraulic brake control and improving response (Nakamura, 2002). This is a brake-by-wire system in which the hydraulic brake pressure at each wheel is isolated from the brake pedal and braking control is performed by a high pressure source through linear solenoids. This system facilitates braking force coordination during regenerative braking in an HEV. As its smooth and highly responsive controllability can also be utilized as part of ESC systems, ECB systems are also spreading to other vehicle types in addition to HEVs.

3.2 Drive system control

This field has seen progress in active controls such as systems that transfer torque to the front and rear wheels in a 4WD vehicle, as well as limited slip mechanisms in center, front, and rear differentials. In recent years, systems for distributing driving force to the left and right wheels using a speed-increasing mechanisms installed inside the differential have been developed. The characteristics of these systems are being actively used to improve cornering performance.

In contrast, the electrification of driving forces has started in HEVs and electronically controlled 4WD vehicles to enable smoother and more responsive driving force control. The practical application of motors capable of driving each wheel independently in the future may also help to further enhance dynamic performance.

3.3 Steering control

Electric power steering (EPS) systems are being rapidly adopted to improve fuel efficiency, as well as for use in HEVs and the like. In addition to simply replacing hydraulic power steering, the role of EPS is spreading to new functions that make active use of its capability to freely vary the assistance force.

For example, it has already been introduced in some vehicles to perform the following functions in coordination with ESC. EPS can assist the driver’s steering effort to facilitate countersteering when the rear wheels slip or to prevent understeering when the front wheels slip. It can also be used as an actuator in functions that help the driver keep the vehicle in its lane by assisting the driver’s steering effort. Alternatively, EPS can also function as an actuator in automatic driving systems such as Intelligent Parking Assist.
In addition, variable gear ratio steering (VGRS) systems have been developed that vary the steering response characteristics of the vehicle yaw angular velocity (Figure 5). Conventionally, the steering characteristics of the yaw angular velocity were determined by the specifications of the suspension. VGRS is capable of varying these characteristics to a constant optimum level in accordance with the driving environment. Furthermore, ESC devices are starting to be used, which utilize the capability of VGRS to control the turn angle of the front wheels independently of the steering wheel angle.

ARS has also been adopted on some vehicles, and its enhancement of dynamic performance has been verified. In recent years, vehicles have been released that combine ARS with front-wheel active steering systems to further improve dynamic performance (Katayama, 2007; Kojo, 2002; Ono, 2007).

### 3.4 Suspension control

The suspension of a vehicle consists of springs, shock absorbers, and link mechanisms. However, there is a long history of control technology applied to suspensions to improve both ride comfort and vehicle stability. Examples include the semiactive suspensions introduced in the 1980s for controlling shock absorber damping force. Improvements have continued since then. Recent years have seen the development of electronically controlled active stabilizer suspension systems that actively reduce vehicle roll (Figure 6). Progress is also being made toward the development of electronically controlled fully active suspensions. As a result, the use of actuators in suspension control is spreading, and these are expected to help improve vehicle performance through the active variation of vehicle attitude and vertical load.

### 3.5 Evolution of vehicle environment recognition technology

One current trend is vehicle environment recognition technology that supports the cognitive processes of the driver. The development of environment recognition sensors such as radar and cameras is advancing rapidly.

Forward recognition technology using radar is already used by cruise control systems. PCS systems have been developed that help the driver to avoid accidents through coordinated control with the brakes (Tsuchida, 2007). A more accurate system that combines information from radar with camera images (Figure 7) and a system that coordinates information with a camera that detects the orientation of the driver’s face have also been developed.

Lane Keeping Assist, Intelligent Parking Assist, and other driving assistance systems that use image-recognition technology have already been commercialized. However, the number of systems in this field is likely to grow further as researchers study ways of utilizing information provided by roadside infrastructure.

![Figure 5. (a,b) VGRS actuator.](image)

![Figure 6. Active stabilizer actuator.](image)
4 EVOLUTION OF CONTROL USING VDIM

4.1 Concept of VDIM

Since the 1980s, various attempts have been made to enhance vehicle dynamic performance using active chassis control. In 1986, the Daimler-Benz 4Matic system was the first to use lateral dynamics for control purposes. Direct yaw moment control systems with active braking such as ESC enable good performance in the critical limit region (Shibahata et al., 1993; Koibuchi et al., 1996; Van Zanten, 1996). The aim of the next generation of vehicle dynamic control systems is to provide seamless vehicle maneuverability and stability at all times through the integrated control of driving forces to all four wheels. Figure 8 shows the concept of Toyota’s VDIM system. This illustration is called the ball in a bowl concept (Hattori et al., 2002). The ball corresponds to the state of the vehicle, which is maintained within a bowl constructed by the control. The inside of the bowl is the stable region, and the outside is the unstable region. In conventional systems, the walls of the bowl are constructed from independent functions such as ABS, ESC, and TCS, which form sheer boundaries before an emergency occurs.

As a result, although these functions are capable of stabilizing vehicle motion, the motion may be discontinuous in some cases. In contrast, VDIM realizes smoother behavior because the conventional control systems are restructured to form a continuous and smooth wall.

As vehicle control systems are becoming more diversified, the algorithm is required to perform cooperative control of many systems, such as the drive train, braking, and steering, easily. Accordingly, the compatibility of the algorithm with various system configurations is important. The hierarchical control system structure shown in Figure 9 has been adopted for VDIM (Hattori, 2002; Fukatani, 2005).

The first layer (vehicle dynamics control) calculates the target forces and moments of the vehicle to achieve the desirable vehicle motion corresponding to the driver’s pedal input and steering wheel angle. There are several examples of research for the first layer. In the critical limit region, the determined target resultant force and moment also satisfy robust stability conditions to avoid vehicle spin (Ono et al., 1998). However, in the moderate region, Yamakado et al. (2010) have proposed a target longitudinal acceleration/deceleration model determined by predicted lateral jerk to improve driving enjoyment. The target resultant force and moment of the vehicle motion are distributed to the target tire forces of each wheel based on the friction circle of each wheel in the second layer (force and moment...
The third layer (wheel dynamics control) controls each wheel motion to achieve the target tire force. There are redundant degrees of freedom in the second layer. The vehicle dynamics performance in the critical limit region depends on the force and moment distribution algorithm, which uses these redundant degrees of freedom.

The motion of a vehicle in the three degrees of freedom (longitudinal, lateral, and yaw) is controlled by the steering and traction or braking forces from the four tires. If each tire can be individually steered and operated for traction or braking, the control system has redundancy. Vehicles move using the friction between the tires and the ground. The frictional forces at the tires have limits dependent on the conditions of the road surface. These limits are called the friction circle, and a tire cannot exert force on the road surface in excess of the friction circle. To extend the limits of the performance of vehicle dynamics, it is necessary to ensure that the forces exerted by all tires work efficiently in cooperation with each other. The problem of integrated control of vehicle motion then becomes how to best use the redundant degrees of freedom. As the friction circle has nonlinear constraints because of the limitations on the frictional forces at each wheel, the distribution of the longitudinal and lateral forces and the yaw moment (vehicle forces and moments) to each tire force becomes a nonlinear problem.

Ono et al. (2009) proposed a vehicle dynamics integrated control algorithm using an online nonlinear optimization method for four-wheel-distributed steering and four-wheel-distributed traction and braking systems. The proposed distribution algorithm calculates the magnitude and direction of the tire forces to satisfy constraints corresponding to the target resultant forces and moments of vehicle motion and also to minimize the maximum \( \mu \) rate (=tire force/friction circle) of each tire. This research demonstrated the convexity of this problem and guaranteed the global optimality of the convergent solution of the recursive algorithm. This implies that the theoretical limitation performance of vehicle dynamics integrated control can be reached.

Comparing it with general quadratic programming can show the efficiency of the proposed algorithm, which calculates the theoretical limitations of vehicle forces and moments. The following minimization problem of the sum of squares of the \( \mu \) rate may be considered as a benchmark. This is an extension of the problem described by Mokhimar and Abe (2003). In this simulation, the generated vehicle longitudinal forces are compared for straight-line braking on a split road with different coefficients of friction \( \mu \) (\( \mu = 1.0, 0.2 \)).

Figure 10 shows the tire forces of a vehicle controlled by the proposed method and a vehicle controlled by quadratic programming. Both of the controls achieve the reference braking force within a moderate area when the reference braking force is 7000 N. However, unlike the vehicle controlled by quadratic programming, the vehicle controlled by the proposed method can also achieve the reference braking force in the critical region when the reference braking force is 10,000 N.

### 4.2 Configuration of VDIM

Figure 11 shows the overall configuration of the VDIM system. Using in-vehicle sensors to detect the yaw rate and steering angle, VDIM collects together various items of data for optimally controlling the brakes and front steering to stabilize the vehicle attitude. It achieves a steer-by-wire function using an active front steering (AFS) system with two actuators (VGRS and EPS) to control the steering angle of the front wheels and the reaction torque of steering. It also acts as a wide-ranging safety control function in coordination with the ECB system.
Figure 11. Configuration of VDIM system.

Figure 12 shows the layout of functions for controlling vehicle dynamics and behavior using VDIM. Creating this layout diagram clarifies the role of each function individually and in combination with other functions. VDIM enables true integration of vehicle control by emphasizing the development of each function and its actions.

4.3 Performance of VDIM

Figure 13 shows the outline of control when driving on a road with different coefficients of friction (μ) under the left and right wheels. As shown in the figure, when the driver brakes, spin moment is generated in accordance with the difference between the left and right braking forces, resulting in deflection of the vehicle. On this type of road surface, a vehicle dynamics control system that uses just longitudinal forces cannot achieve a high degree of stability and braking simultaneously with driving performance. In contrast, this can be achieved by an AFS system that is capable of controlling the vehicle in the lateral direction.

Figure 12. Layout of VDIM software functions.

Figure 13. Corrective steering control during braking on split μ road.
Figure 14 shows the test results of straight-line braking on a split $\mu$ road. It shows the normalized steering angle and peak yaw rate after braking (state without control = 1). With the active steering control, the peak yaw rate was reduced by approximately 50% compared to the rate without the control. In addition, the AFS control requires less corrective steering effort from the driver and generates a lower peak yaw rate on the vehicle than conventional ABS.

AFS has a large effect on side slipping of the front wheels. In particular, for a vehicle braking on a road with different coefficients of friction under the left and right wheels, AFS is capable of maintaining both vehicle stability and driving force. It also helps to suppress vehicle spin behavior when the driver performs an evasive maneuver (Figure 15). AFS is more effective at suppressing spin as it can generate moment by controlling the slip angle of the front wheels in addition to the conventional control that generates moment to reduce spin using braking force.

Figure 16 shows the results of a test comparing the effects of VDIM and ESC. In the test, the vehicle was steered mechanically through a slalom using constant steering operations while accelerating on an artificial low friction surface ($\mu = \sim 0.3$) simulating a snowy road. At the limit regions, the slip angle with VDIM was half that of ESC (+TCD), which shows that VDIM is capable of greatly improving the vehicle stability.

4.4 Further evolution in control using VDIM

4.4.1 Enhancement of collision-avoidance performance using environment recognition technology

Toyota developed a collision-avoidance support system in 2006 that aimed to help reduce accidents by assisting evasive maneuvers by the driver. This system uses a forward monitoring function consisting of a millimeter wave radar and stereo camera to judge the risk of a collision with an object and assists the driver to avoid the collision by varying the steering gear ratio and braking. This system consists of a block that detects objects and judges the collision risk, a block that determines the evasive maneuver by the driver, and a block that controls vehicle behavior (Figure 17). The system operates as follows (Figure 18).

1. If a high collision risk is judged, the system warns the driver to take evasive action.
2. The system reduces the VGRS steering gear ratio to assist the driver’s evasive steering maneuver.
3. If a high collision risk is judged, the system begins automatic braking. When the driver performs an evasive steering maneuver, deceleration during the maneuver is achieved by reducing braking force with a gradual gradient. In this event, VDIM controls the steering and brakes appropriately in accordance with the vehicle state.

Figure 19 shows the results of a double lane change test with and without system operation. The system reduces the driver’s steering wheel angle and steering velocity to enhance the object evasion capability of the vehicle.

4.4.2 G-vectoring

VDIM is basically a feedback control that aims to restore the ball to the bottom of the bowl in the ball in a bowl concept. In contrast, G-vectoring control (GVC) is a feed-forward control mechanism that enables the ball to start rolling toward the edge of the bowl in coordination with driver’s maneuvers. In 2008, Yamakado and Abe identified an original trade-off strategy between longitudinal traction and cornering force using jerk information to observe an expert driver’s voluntary braking and turning actions (Yamakado and Abe, 2008). This strategy was used to develop GVC, which is basically a mechanism for achieving automatic longitudinal acceleration control in accordance with vehicle lateral jerk caused by the driver’s steering maneuvers (Yamakado et al., 2010). With GVC, the direction of the resultant acceleration ($G$) changes seamlessly (i.e., by vectoring) in the same way as it does when an expert driver is behind the steering wheel. In this way, ideal vehicle motion can be achieved. The following
Figure 15. Comparison of vehicle behavior when changing lanes.

Figure 16. Vehicle stability with ESC and VDIM.
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Figure 17. Functional configuration of object avoidance assist system.

Figure 18. Control procedure of object avoidance assist.

equation was proposed as the fundamental equation for GVC.

\[ G_{xt} = -\text{sgn}(G_y \cdot \dot{G}_y) \frac{C_{xy}}{1 + \frac{1}{Ts}} |\dot{G}_y| \]  \hspace{1cm} (1)

where \( G_{xt} \) is the longitudinal acceleration command, \( C_{xy} \) the gain, and \( G_y \) the lateral jerk.

Figure 20 illustrates the GVC concept. When the vehicle starts turning a corner, it starts braking simultaneously as lateral jerk increases (vehicle positions 1–3). After that, the braking stops during steady-state cornering (vehicle positions 4 and 5) because the lateral jerk becomes zero. The vehicle begins to accelerate when it begins to return to straight-ahead driving (vehicle positions 6 and 7). If a bowl were fixed to the vehicle, a ball in the bowl would move smoothly along the level curve as shown at the top of the figure (ball positions 3–5) because of the change in inertial force caused by the acceleration of the vehicle. Considering the shift in wheel vertical load between the front and rear wheels (which is caused by the acceleration and deceleration of the vehicle), the handling of the vehicle when entering a corner and its stability when leaving a corner will be improved.

Figures 21–23 show the measurement results obtained for cases with and without GVC. These results show that applying GVC makes it quite possible to emulate expert driving.
5 METHODS OF DESIGNING INTEGRATED CONTROLS

The previous sections have described how integrated controls have a large potential to enhance vehicle dynamic performance. However, the integration of controls increases the complexity of the systems, substantially increases the scale of development and the work hours required, and makes it more difficult to secure reliability. Consequently, the original goal of improving performance also becomes more difficult to achieve. For this reason, the key concepts for designing integrated control are to create a hierarchy and to mask and abstract information.

5.1 Creating a hierarchy of function and application levels

When constructing a control, it is important to consider the failsafe conditions and other operations in the event of an abnormality, in addition to approaching the control from the standpoint of the normal targeted performance and operation. This is particularly important for integrated controls. The control has to be constructed on a layered hierarchical basis, categorizing the functions to be integrated and the functions that operate independently and autonomously. In creating the hierarchy, it is convenient to envision the relationship between the actions of a person’s hands and feet and the reflexes of the brain and spinal column. Actions that require fast reactions and actions with a fixed pattern are achieved by spinal column reflex and the situation is reported to the brain. The brain directs overall actions by sending commands to the hands and feet. VDIM was created based on this concept (Figure 24). The roles are determined in sequence from the control devices equivalent to the lower order muscles, and the configuration is
designed as much as possible to allow independent action and the selection of functional operation.

### 5.2 Masking and abstracting information

When constructing various functions in a hierarchical structure, another key point is the masking and abstracting of information when collecting information and transmitting commands. From this standpoint, it is simple to envision the relationship between a team manager and the team members in a corporate organization. Normally, the team members perform work based on instructions from the manager. However, the manager does not have a detailed grasp of each specific aspect of the work of the team members and the manager does not give specific detailed instructions about that work. Therefore, if the manager is ill or in another abnormal situation, the team members can operate autonomously to a certain level. In addition, the manager above the team manager is capable of running the organization without knowing the last detail of the work of the team members. Therefore, this manager can produce results that would not be possible individually. A simple and highly reliable system can be constructed by making use of this type of information collection and command transmission system.

Figure 21. Trajectory evaluation.

Figure 22. Steering angle versus yaw rate.

Figure 23. “g–g” diagram.
If the upper level system relies on detailed information from the lower level system, it becomes difficult to change the system configuration or add new functions. For example, in the case of brake control, the upper level system can simply control the total braking force even when in combination with a motor or another device. This is carried out by masking internal operations based on an abstraction and normalization concept. This concept positions braking force and braking $G$ above hydraulic pressure and hydraulic pressure above the solenoid current of the actuator. Furthermore, if a theoretically different brake actuator is added into the system, there is only very little impact on the upper level system.

5.3 Creating packaging level hierarchies

The adoption of software platforms and operating systems (OS) is advancing to absorb differences in inputs and outputs, as well as in the communication between hardware and software, and to create freedom in application package locations for integration into ECUs. Conventional software structures are constructed differently based on the approach of each automaker and software supplier. However, standardization efforts are under way to achieve integration. Future development will also have to consider these trends.

5.4 AUTOSAR activities

AUTOSAR (automotive open system architecture) is an enabling technology for integrating systems in a vehicle. As mentioned in Section 5.3, AUTOSAR defines the basic software architecture, which consists of a hardware abstraction layer (HAL), system/communication services, and a runtime environment (RTE). RTE is an embodiment of a virtual functional bus (VFB) that enables the integration of application software and the physical allocation of applications into each ECU (Figure 25).

The system/communication services provide standard functions such as communication and OS. HAL absorbs the differences between microcontrollers, sensors, and the like. Figure 26 shows the basic AUTOSAR architecture. AUTOSAR is being advanced by a development partnership, in which many global automotive companies are participating in AUTOSAR activities to develop AUTOSAR specifications as a worldwide de-facto standard (Figure 27).

6 FUTURE TRENDS OF INTEGRATED SYSTEMS

6.1 Expansion of active safety and driver assistance

The previous sections have highlighted the significant contribution of integrated control technology in active safety systems. The systems are likely to grow even more important in the future. Normally, the driving process consists of cognition, judgment, and action phases. An error in even one of these driving processes may result in an
accident. Consequently, active safety technology is being developed to support each phase (Figure 28).

Figure 29 shows the technological areas of the various control systems that have already been commercialized. The direction of brake technology has already changed from brake assist (BA) type systems to PCS and other automatic braking systems. However, there are still many undeveloped areas on the horizontal axis, which is likely to be the direction of development in the future.

Although the physical limits are determined by the performance of the tires, brakes, and the like, technologies such as ESC have been developed that support driver operations at these limits. These technologies are now also being integrated with steering controls. In the future, it is likely that development will continue toward the commercialization of vehicle dynamic control that can stretch the possibilities at the physical limits. This development will be based on research such as the verification of theoretical limits when four-wheel independent steering and four-wheel independent braking and traction systems are combined with force control technology through suspension control.

In addition, technology to assist the cognition and judgment phases is likely to become more sophisticated as recognition technology advances. Coordination between dynamics control to enable automatic evasive maneuvering in the lateral direction will probably progress. In preparation for these developments, vehicle dynamics control must have the capability to freely control vehicle behavior. Integrated control technology will play a major role in accomplishing this aim.

6.2 Future trends

Figure 31 shows a matrix depicting the concept for total vehicle system integration. In addition to the integration of energy within the vehicle, further integrated controls are being considered that incorporate the vehicle, driver, and the traffic environment in the same way as active safety. Possible methods of helping to improve the environment

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**Figure 25.** Integration of applications.

**Figure 26.** Basic AUTOSAR architecture.
include the shift lever indictor and CO₂ reduction control using ACC. Integrated functions based on traffic signal controls and ITS (information technology services) that also factor in the traffic environment may be developed that help to alleviate congestion.

From the standpoint of active safety, the evolution from integrated vehicle dynamics controls to integrated active safety controls will focus on the development of driver monitoring functions in PCS systems. In the future, these technologies will develop into systems that provide assistance to individual drivers as appropriate in coordination with the driver and integrated safety systems that are coordinated with the traffic environment and infrastructure.

The matrix in Figure 30 is also related to the achievement of sustainable mobility in terms of vehicle safety, the environment, and comfort. In addition to the autonomous and infrastructure-coordinated driving environment detection technologies shown in Figure 31, an area of growing importance will be individual applications designed in accordance with navigation system and traffic control ITS information and the state and personal characteristics of the driver. Therefore, an integrated HMI that incorporates individual information, instructions, alerts, and warnings will be the key for creating an integrated control that helps to enhance safety, the environment, and comfort.

Figure 27. AUTOSAR partnership and members (2010).

Figure 28. Future trends in active safety technology.

Figure 29. Current control systems and future development areas.
Figure 30. Total integrated vehicle system concept.

Figure 31. Integrated driver assistance concept.

7 CONCLUSION

Dynamic control technology for controls related to the suspension, steering, braking, driving forces, and the like is advancing relentlessly. At the same time, cognition and judgment functions equivalent to the eyes and brain are also being rapidly developed. However, the number of people hurt or killed in traffic accidents remains at a high level. Therefore, this technology has to be consolidated and applied properly to fulfill the responsibility of automakers to develop vehicles that do not cause accidents. Control systems are required that are highly reliable, flexible, and
have the potential for widespread use. This chapter has described the trends and configurations of these systems. Comfort and driving enjoyment are essential parts of a vehicle and these must not be sacrificed. For this reason, the development of these systems will continue while enhancing basic vehicle performance.

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REFERENCES


German patent DE 35 05 455 CS (1985) Vorrichtung zur automatischen Zu- oder Abschaltung von Antriebelementen eines Kraftfahrzeuges.


