BMW Group Research and Technology.
Contents.

1. Introduction: BMW Group Forschung und Technik. Safety research and on-board electronics – a vision for the future.

Rising traffic volumes are making increasing demands on drivers. Complicated driving situations demand maximum concentration and fast, well-considered reactions. The BMW Group is committed to developing systems which assist with driving tasks and, as a result, significantly enhance safety for all road users, while also increasing driver convenience and enjoyment. The result of longstanding research projects are innovative driver assistance systems which demonstrate that increasing traffic density and enjoyable driving need not be mutually exclusive. On the contrary – such electronic helpers are already assisting with tasks such as braking, lane-keeping, maintaining a safe distance and changing lanes, not to mention providing parking assistance and improving nighttime vision. The decline in the number and severity of accidents demonstrates the effectiveness of these assistance systems. Between 1970 and 2004 the number of accident fatalities in many European countries dropped significantly. By 61 % in Austria, by 65 % in France, by 45 % in Italy, by 63 % in Sweden and by 57 % in Great Britain. In Germany as well, numbers fell by 73 % in this period, although the total number of kilometres travelled nearly doubled in the last 30 years. From 2005 to 2006, accident rates in Germany dropped again, this time by 0.8 %. More crucial than that, however, is the decrease in the number of personal injuries by 2.6 % and fatalities by a full 5 % (number of fatalities 2006: 5091, i.e. 270 less than 2005). (Source: German Federal Statistical Office in Wiesbaden, 2007). Nevertheless, the research work still continues because every accident is one too many.

Innovations contribute to road safety.

BMW Forschung und Technik GmbH, a wholly owned subsidiary of BMW AG, is an important pillar of this research. All its innovations concerning accident prevention are based on detailed analysis of accident causes and chronology. It is against this background that it develops and tests specifically tailored solutions and systems. The aim is to help drivers handle their driving responsibilities, to inform and/or warn him, and thus avoid accidents through preventive technology or at least mitigate the consequences. Technology is designed to provide people with functions that compensate for physiological limitations (e.g. human response times). However, the decision rests with the driver.

Current developments by BMW Group Research and Technology in the field of driver assistance systems:

- an emergency braking system for protecting pedestrians,
- the intersection assistant,
- the wrong-way driver information system
- and the curve information system.

These systems improve driver anticipation, making use of both autonomous on-board systems and inter-vehicle communication.

Vision of an "automotive Internet Protocol-based on-board electronics network".

BMW Group Research and Technology also carries out research into a new Internet Protocol-based networking technology for on-board electronics systems. This "future on-board electronics" project is based on the vision that all vehicle applications should be able to communicate intelligently and on an equal basis with each other and with their environment. In this way vehicles will become an integral part of the digital telecommunications infrastructure. Connected with this are new functions in the link-up with mobile devices and glimpses inside increasingly "transparent" vehicles.

2. Research into improved road safety.

2.1 Driver assistance systems development by the BMW Group.

The system proposes – the driver decides.
Driver assistance systems are supplementary in-vehicle electronic systems which assist with driving tasks and thus significantly enhance road safety for all road users. The BMW Group, the pioneer in many areas of on-board electronics, works to the principle that ultimate responsibility for using the vehicle lies with the driver, who can override or switch off systems. After all, it is crucial that, as a driver, you can decide not to proceed through a green light if, for example, you hear an ambulance approaching. The driver remains in charge of events at all times.

Whatever the technical system in question, the relationship between driver and vehicle is based on intelligent and efficient task-sharing. By combining the strengths of each, it is possible to achieve the maximum in safety, comfort and driving enjoyment. Complex decisions are handled by the driver, for as a human being he has improvisatory skills and fault tolerance capabilities. Moreover, his sense of responsibility helps him to make decisions. High-speed information processing is dealt with by the on-board electronics. Systems do not suffer from fatigue, are not subjected to stressful situations, and can process a wide range of information at the same time. In concrete terms, this means that vehicles from the BMW Group offer the driver as much information as desired and as is likely to be helpful in a given situation.

Stabilisation, manoeuvring and navigating.
Driver assistance systems fall into three basic categories, depending on the driving task in question: stabilising the vehicle, executing a manoeuvre or navigating. The Anti-lock Braking System (ABS) and Dynamic Traction Control are classic examples of stabilising systems. Active Cruise Control (ACC) and the Lane Departure Warning System assist the driver when performing a manoeuvre. Satellite-based direction-finding and information systems (such as navigation) form a third level of such systems. In all cases, the guiding principle is what information the driver can realistically process when confronted with sometimes difficult situations. In order to attract the driver's attention, the assistance supplied by present-day and future driver assistance systems in a given situation is accompanied by visual, haptic or auditory signals.

2.2 The basis: accident analysis.

An understanding of the "bigger picture" and underlying principles is essential when it comes to developing solutions for accident avoidance systems. What is required, therefore, is a high level of expertise in analysing and interpreting traffic situations, driver behaviour and the behaviour of road users in general.

The human factor – misjudgments and inappropriate responses.
Often, the driver simply doesn't have the necessary information in order to be able to respond correctly in a given situation – for example he can't see round corners or through parked cars. 23 % of accidents involving cross traffic and 16 % involving oncoming traffic at German intersections are to the result of impeded vision. Although passive safety systems like seatbelts and airbags provide high standards of protection, the fact remains that their protection capability has now been taken pretty much as far as it will go. What's more, such systems only make their contribution if an accident has already taken place. The way forward in safety system development therefore lies in the area of active safety features. If these systems assist the driver at the crucial moment, driver errors can be mitigated or corrected and accidents can be anticipated and averted – or their severity can be reduced – at the earliest possible stage. Intelligent electronic driver assistance systems can identify risks at an early stage, provide timely warning of hazards or recommend appropriate action. The driver can then initiate the correct actions and reduce the risk or, ideally, eliminate it altogether.

Basis of development: understanding through analysis.
The BMW Group Research and Technology engineers start by analysing a wide range of accident scenarios as a basis for developing effective solutions. These include single-vehicle accidents, various accident scenarios when turning off, accidents when joining a road or at intersections with different road users, accidents caused by stationary traffic, e.g. at the end of a tailback or in stop-go traffic, etc. etc. In addition to data supplied by the BMW Group accident research team, their work also uses information provided by the German Federal Statistical Office in Wiesbaden, the GIDAS (German In-Depth Accident Study) project and international studies.

Types of accident.

The most frequent type of serious or fatal road accident is the single-vehicle accident (43 %) in which the driver loses control of the vehicle on a straight road. The second most frequent type (approx. 21 %) is that of accidents occurring in same or opposite direction traffic, that is to say conflict scenarios with oncoming, side or preceding traffic. Here the greatest proportion – 37.6 % – is accounted for by rear-end collisions, which frequently result from failure to maintain an adequate safe distance or through inattention. Accidents at intersections (with turning or crossing traffic) account for 17 % of the total and accidents involving a pedestrian crossing the road account for approx. 10 %.

This data, precisely analysed and interpreted, provides the foundation on which the BMW researchers develop assistance systems for enhanced active safety. The emergency braking system for the protection of pedestrians, the intersection assistant, the wrong-way driver information system and the curve information system each address, in reverse order, one of the above-mentioned types of accident, which means that in each case their contribution to road safety is efficiently and effectively focused.

Data on the driving manoeuvres executed or attempted in order to avoid an accident are even more valuable for purposes of analysis and interpretation. Here's an example: a driver approaches an intersection where the cross traffic has right of way. If an accident occurs here, in 33 % of cases it is the result of a misjudgment and in 23 % of cases due to impeded visibility. The worst thing is that 42 % of those responsible for an accident make no attempt at braking and 60 % do not attempt any evasive steering action. A timely indication of the impending hazard would certainly have resulted in different statistics.

2.3 Emergency braking for pedestrians.

State-of-the-art restraint systems, crash-optimised bodywork design and improved road infrastructure mean that in many countries, road deaths have now been steadily falling for many years. Between 1970 and 2004 the number of accident fatalities in many European countries dropped significantly. By 61 % in Austria, by 65 % in France, by 45 % in Italy, by 63 % in Sweden and by 57 % in Great Britain. In Germany as well, numbers fell by 73 % in this period. In the USA as well, numbers fell by 81 % between 1970 and 2001. Innovative driver assistance systems have likewise contributed to this decline, despite the steady increase in the number of vehicles on the road and constantly rising traffic density. Not satisfied with this, however, the BMW Group engineers are working on even more effective systems for the protection of all road users. Pedestrians are particularly at risk should they be involved in a collision with a vehicle. Regrettably, such collisions all-too frequently result in serious injuries. This prompted a BMW Group Research and Technology research project to develop a safety system which detects an imminent pedestrian collision in time to take appropriate action with the aim of minimising the consequences for those involved.

A seventh sense: infrared camera, radar and laser scanner.
All the time drivers are reacting to a situation, valuable time is being lost. One can assume a human reaction time of about one second. Factors such as tiredness or alcohol can easily double that, while inattention or distraction can multiply the response time. This is where the emergency braking system comes in. Using various sensor technologies such as an infrared camera, a radar system and a laser scanner, the system registers the driving environment, distinguishes between pedestrians, vehicles and other objects, and draws on software to calculate whether the driver still has time to avoid an impact. Thus the system recognises objects within the realm of perception of the various sensors, classifies these almost simultaneously with split-second speed, and determines whether or not they are relevant in terms of safety. This is done using sensor measurement values. For example, the sensor recognises legs in motion and, with the aid of a thermal image, a contour comparison and the direction of movement, detects a pedestrian in a collision path. In this way the system ascertains whether a potential accident situation exists – for example if a pedestrian suddenly steps onto the road into the path of an approaching vehicle. Since such a technical system has shorter reaction times than human beings, it is able to shorten the total stopping distance. The normal reaction distance at a speed of 50 km/h is already 15 metres, and to that has to be added the braking distance.

Shorter reaction times.

Within a few hundred milliseconds, the environment-sensing systems supply all this information about detected and classified obstacles ahead of the car to the scene interpretation system, which decides in a matter of milliseconds whether the situation is potentially hazardous. The question is: is a pedestrian moving along the same trajectory as the vehicle and can a collision course be predicted from this? If the answer is affirmative and the pedestrian cannot avoid the hazardous situation by his own means, and nor can the driver respond appropriately, then the system intervenes. The remaining time before the potential collision can then be used for initiating measures designed either to prevent the collision or at least to reduce the impact energy and thus mitigate the consequences of the accident. Such measures can include warning the driver of the collision risk in the most suitable form for the given driving situation, either by a visual or an audible signal. In real life, the driver can often avoid an accident at the last moment by taking swift avoiding action. Also, a reduction in speed by decelerating the vehicle, by preparing the brake system or by supporting driver braking action can also be helpful. Finally, if the driver's options are exhausted, automatic emergency braking can prove a life-saver. Needless to say, such intervention presupposes reliable scene interpretation on the part of the sensor system. The research project is exploring such a braking intervention function using a precisely configured test set-up.

2.4 The new intersection assistant and traffic light assistant – for increased safety at crossroads.

Traffic at intersections is often difficult to see.
The most frequent causes of accidents at intersections include driver misjudgements, inattention or inappropriate driving manoeuvres. BMW Group Research and Technology has therefore developed safety features – the intersection assistant and traffic light assistant – that assist drivers in negotiating crossroads. Using WLAN-based vehicle-to-vehicle communication technology, the intersection assistant acquires information about the current traffic environment and exchanges it with other vehicles. This data concerning vehicle positions and current status is then electronically processed and passed on to the driver in the form of recommendations. For example the intersection assistant detects a vehicle approaching the intersection which has priority over the subject vehicle even if this vehicle is not yet visible. Effectively, this system allows the driver to see round corners – and a little way into the future.

Technology helps drivers cope with stressful everyday situations.
In Germany alone, a third of all personal-injury accidents that take place at an intersection are due to failure to see, or to spot in time, another road user, poor visibility due to obscuring of the intersection by buildings or trees, or insufficient attention to the road and traffic on the part of the driver. The following is a typical hazardous everyday situation: a car driver approaching an intersection and wishing to cross straight over encounters a steady stream of traffic on the intersecting road, which has priority. The driver's view into the intersecting road is obscured by parked vehicles. It is in situations like this that the intersection assistant comes into its own.

It gathers data about the other road users in the area of the intersection and can reduce potential risks. The intersection assistant communicates with other vehicles which are approaching the intersection. The system evaluates the incoming data relating to speed, distance from the intersection and directions of travel, together with the data pertaining to the subject vehicle. If a risk of collision is detected, the driver is warned by means of visual or audible signals and by gentle deceleration of the vehicle. The big advantage here is that even if an accident proves to be unavoidable, the fact that speed is reduced at an early stage will mitigate its consequences. Should the driver be unable to defuse the situation by his own responses, the intersection assistant can prepare the brake system and support driver braking action.

Collisions between a car and a motorcycle pose a particularly dangerous risk. In an accident, motorcyclists sustain serious injuries around three times as frequently as car drivers, and the number of fatalities among bikers is almost four times the figure for motorists. Even between these different types of road user – car and motorcycle – the intersection assistant can set up a communication link. Furthermore, active measures can be triggered on the motorcycle too if a risk situation is identified. If the motorcycle has priority over the car, its headlamp, direction indicators and horn are activated to make it more noticeable. In this way the motorcycle will actively attract the attention of a car driver who is making a dangerous approach to the intersection.

Giving the green light: the traffic light assistant.
If a vehicle is additionally equipped with the traffic light assistant, it is even able to communicate with traffic lights. This system evaluates incoming data such as the current status of upcoming traffic lights and their green/amber/red timing phases, along with intersection-specific and vehicle-specific information. If the traffic light would be red if the driver were to continue approaching the junction at his present speed, the driver receives this information in good time to begin gentle braking. The driver is likewise notified if there is a risk of him ignoring a red light. The system can also advise on a suitable speed at which to approach an intersection in order to catch a green light. Thus the system has benefits both for safety and for convenience. Since the driver is able to "see into the future", so to speak, he can be more confident about matching his driving to the traffic light phases. Feverish acceleration followed by abrupt braking can therefore be avoided, resulting in calmer, safer, more fuel-efficient driving.

Development work on intersection assistance systems.
In testing road user/object/intersection scanning systems, and developing driver assistance systems, BMW Group Research and Technology makes use of both the BMW dynamic driving simulator and real test vehicles. The advantage of the driving simulator is that it allows risk-free and reproducible simulation of critical traffic situations. Later on, real versions of the assistance systems can then be fitted and tested in real vehicles.

Taking into account the current position and driving status of the subject vehicle, the intersection assistance systems use specially developed algorithms to analyse the current traffic situation and extrapolate it into the future – amongst other things allowing the probability of a collision to be estimated. Based on this calculation, the system can warn the driver of potential accident situations. Future systems will also, however, need to be supplied with digital map data containing information about intersections. This will need to include information on priorities and traffic lights.

2.5 "Wrong-way driver" information – advance warning of drivers heading in the wrong direction (including oneself).

It is the nightmare scenario for every driver: a wrong-way driver heading towards you from out of nowhere in the middle of the motorway. Because of the relative speed, the driver has only fractions of a second to react. If a collision is unavoidable, its consequences are often fatal. It doesn't take much imagination to see that a head-on collision between two vehicles both travelling at, say, 120 km/h is going to have very serious consequences, despite sophisticated passive safety systems and well-developed passenger safety cells. Every year, radio stations report some 1,800 wrong-way drivers – or "ghost drivers" – in Germany alone. And, according to transport researchers, the next wrong-way driver on the road could very well be you or I. The reasons for travelling the wrong way down a public highway are more often than not decidedly mundane and have nothing to do with age – indeed, only 10 % of wrong-way drivers are over 65. In a study on this area of road safety, the most frequent causes of such behaviour have been identified as stress and over-exertion, loss of bearings and poor visibility. Alcohol, meanwhile, is a factor with a third of wrong-way drivers. With signposts next to slip roads leading onto motorways having only a limited effect on preventing wrong-way driving, BMW Group Research and Technology has developed a new driver assistance system to help alleviate the situation. Using the car's navigation system as a basis, the wrong-way driver information system automatically recognises when a driver is about to join a road in the wrong direction and triggers a warning made up of audible and visual signals. Beyond this, the wrong-way driver information system can also use vehicle-to-vehicle communication to warn other vehicles when a wrong-way driver is approaching on the same road.

Wrong-way driving: three levels provide fast information.
The aim of this assistance system is first and foremost to prevent people from driving the wrong way down a road in the first place. The system uses navigation data – which could conceivably be complemented by road sign recognition – to identify an instance of the driver potentially heading in the wrong direction. The driver is alerted to the potential danger by audible and visual indications on the instrument cluster or in the Head-up Display.

However, should the driver still join a motorway or one-way street in the wrong direction, the main priority is to warn other road users – which is where Car2X-communication comes in. In the research project, the oncoming wrong-way driver can be pinpointed using the map on the navigation display. The sections

of road on which the offender is currently on the move are highlighted, the system complementing the data from the navigation system with the position, direction and speed of the wrong-way driver. This information can also be viewed in the Head-up Display at regular intervals – and for as long as the wrong-way driver remains on the wrong side of the road. Audible warning signals also help in a critical situation. The frequency of the audible and visual warnings is graded through three levels – from "wrong-way driver is in the area" to "wrong-way driver immediately ahead".

Integrated communications enhance safety.
Wrong-way driver information is transmitted on two communications channels. Fast, but with a current maximum range of 600 metres, the vehicle-to-vehicle channel (Car2Car) is used for close-up identification of the vehicles in the immediate area.

The role of the vehicle infrastructure communications channel (Car2Infrastructure), meanwhile, is to carry the information to other vehicles in the wider area. The vehicle driven by the wrong-way driver sends its position to a service centre, which then passes on the warning to all other vehicles. The service centre can supply both police and media with the data directly. And that can cut the time in which the wrong-way driver has yet to be seen by any road users – or identified as such – by valuable minutes. Wrong-way driver information and precise position data can be accessed at any time on a screen. Just a single vehicle equipped with this technology shortens the "warning chain" and the information transmitted benefits all drivers, whether they receive it through vehicle-to-vehicle communication or radio traffic bulletins.

2.6 Curve information system acts as a personal co-driver.

Country roads hold the greatest danger for road users. It may be the case that only 27 % of all accidents occur on these routes, but most of them are extremely serious. Many such accidents can be attributed to overestimating one's own driving skills or misjudging physical limits such as grip levels and curve radii. BMW Group Research and Technology has developed the curve information system to help drivers think ahead at the wheel. This assistance technology uses the navigation system to provide information, irrespective of individual speed, on the nature of an upcoming curve. This extended horizon makes it easy for the driver to prepare in advance for the characteristics of the road ahead – and that makes the driving experience safer. The BMW Group presented this anticipatory route information system during an Innovation Day back in 2006. In the development stage now being tested, the system tailors this information to the vehicle's current speed. This feasibility study alerts the driver via the Head-up Display or navigation display if they are travelling too fast for an approaching corner. This allows drivers to adjust to the right cornering speed in good time on unfamiliar stretches of road.

Electronic horizon allows anticipatory driving.
The curve information system as selectable driver assistance system acts as a personal co-driver, letting the driver know if he is travelling at excessive speed for upcoming corners. Appropriate danger warnings are projected onto the windscreen's Head-up Display in the form of symbols, and the driver is advised to adjust his speed. If the vehicle's speed drops accordingly, the warning disappears. The faster the car is moving, the further ahead the system casts its gaze. And the better the maps underpinning the system, the more effectively it is able to work. This system is a research prototype. In order for it to be implemented, detailed blanket-coverage navigation data needs to be available.

2.7 Reliable coverage of the area around the vehicle is a job for all the senses.

The BMW Group researchers are developing powerful sensor systems for use in vehicles to enable "machine understanding" of driving situations. This involves the application of new integration methods and the linking up of individual sensors tuned to various purposes. For example, map and position-finding information is brought together in order to increase the reliability of video-based lane recognition and to ensure its applicability in various road, weather and light conditions. Active, i.e. independently transmitting sensors such as radar, lidar, laser or ultrasound can be used to complement camera technology – or as systems in their own right – to increase the performance of (machine-based) obstacle recognition. This data provides advice for the driver which extends perceptive range and raises levels of alertness. The latest driver assistance systems warn drivers in critical situations and lower their stress levels. This has the effect of increasing drivers' competence at the wheel and enabling them to handle complex or hazardous driving situations with greater assurance.

Sensor data fusion for guaranteed system stability.
Correct recording and interpretation of the area around a vehicle provides an important basis for functions such as emergency brake boosting or the intersection assistant system. Conventional driver assistance systems help the driver to carry out individual driving tasks, such as maintaining proximity to the vehicle in front. Using sensor data fusion, future assistance systems, on the other hand, will provide a platform for a host of safety-enhancing and comfort functions to be executed with the required efficiency.

In order to raise the reliability of the area information even further, the assessment of the situation also takes into account all data from other in-vehicle sensors monitoring driving dynamics. Processing the values recorded by several sensors (sensor data fusion) will allow the area around the vehicle to be recorded more reliably and precisely than today. Here, the advantages of radar and laser scanner sensors can be combined with the benefits of visual systems to determine the dynamic characteristics of objects and their precise position and size. In this way, the type (pedestrian or vehicle) and direction of the approaching object, for example, and thus the potential impact angle can be determined precisely and the relative impact speed calculated in advance. In concrete terms, that means that individual sensors such as radar, lidar, video, heat imaging devices, 3D cameras and ultrasound, as well as the GPS system and connected digital maps, each deliver – in the same way

as human sensory organs – individual images of reality. None of these images in isolation is sufficient to create a reliable model of the area around the vehicle. Only when the data from the various sensors – taking into account recording quality – is combined to give values of greater accuracy can a model of the surrounding area be put together which can be used for a range of functions.

The BMW Group combines the strengths of the driver and those of the vehicle's assistance systems. In other words, drivers remain responsible for driving the vehicle, while the assistance systems support them by supplying them with relevant information. This means the drivers' actions need to be interpreted correctly. In the future, processes such as line of vision recognition can help vehicles to understand and recognise what drivers are seeing and how they are intending to act.

3. The vehicle network of the future.
A revolution in on-board network technology enables new comfort and safety functions.

One needn't go back more than a few decades to find electrics in passenger cars decidedly thin on the ground and car electronics to be something of a rarity. In the engine compartment there was the battery, alternator, control unit, starter motor and ignition; on the dashboard the controls, warning lights, indicator controls and locks. But between the dashboard and the rear of the vehicle there were only a small number of lights and the requisite cables. The radio was about as good as it got in terms of in-car electronics up to the mid-1970s.

Today up to 90 % of a vehicle's innovations involve the use of electronics and software, and the number of control units (e.g. for engine control or DSC) has increased significantly over recent years as a result. Up to 70 control units are fitted in premium-class cars nowadays. Indeed, the latest models boast several hundred electric and electronic functions, and up to 125 MB of data volume on board.

The information age in vehicle electronics.
It took the telephone – presented for the first time at the 1876 World Exhibition in Philadelphia – 55 years to notch up 50 million users. Television reached that figure in 13 years and the Internet needed just three years to achieve the same mark. In short, digital data communication – in wired and wireless form – is now an integral element of our everyday lives. Indeed, modern life has long been shaped by the fast and uncomplicated exchange of information regardless of location. E-mails can now be sent to anywhere you care to mention and at any time of any day – using a mobile phone, notebook computer or smartphone. The data, in the form of speech or e-mail, for example, is digitalised and transmitted in Internet Protocol (IP) packages – the language of the global Internet. This standard has provided the key to limitless freedom and independence, making data such as music, pictures, e-mails, documents, addresses and so on accessible and thus available anytime, anywhere.

The automotive on-board network of today.

Up to five different bus systems, such as CAN, LIN, MOST and FlexRay, work side-by-side to transport electronic data around today's vehicles. All are perfectly equipped to meet the demands of their individual areas of application, but all speak their own automotive languages, which – to continue the metaphor – have to be translated every time information needs to be used by various different systems. The thinking of BMW Group Research and Technology, however, is a step ahead, and its experts are conducting research into a standard language for the "networked car". Underpinning this technology is Internet Protocol. In a vehicle this worldwide standard language can be easily transmitted e.g. by a broadband network like Ethernet, thus making the vehicle another participant in the World Wide Web.

One command fits all: practical examples.

The vehicle thus becomes an integral element in the overall network and occupant comfort is further improved. The innovative, IP-based on-board network makes the infrastructure inside the vehicle more flexible. In the future, it will be easier for workshops to integrate control units including new functions into vehicles or for customers to use and operate their new electronic devices in the car thanks to Plug&Play. Not all applications will have to be fitted "permanently" in the vehicle, since the IP-based on-board network will link it up to the Internet.

The engineers are also looking into a range of other possibilities which come into view if a vehicle's electronics all speak a single language. As a prototype has already shown, this makes it simple to listen to entire MP3 collections online or to download videos from the Internet on board and watch them from the back row. It is also much easier for passengers and service engineers alike to see into the vehicle's on-board network and control units.

The on-board network of the future means vehicles will no longer be tied to the entertainment industry's short development cycles, as the latest developments (Blue Ray, HDTV, IPTV, IP Radio etc.) can be used simply via Plug&Play and no longer need plug connectors with special infrastructure requirements. As far as driver assistance systems are concerned, this innovative on-board network technology opens up totally new opportunities, in particular for complex systems which access various types of information from sensors, cameras etc. All these systems and information providers will then speak the same language. The functional security and reliability of IP technology has already allowed it to establish itself in avionics.

4. BMW Group Research and Technology.
Creative power – customer oriented and efficient.

A company can only be successful in the global marketplace if it can display both innovative power and the necessary speed in implementing its ideas. The BMW Group put in place one of the cornerstones of technological leadership with the establishment of its wholly-owned subsidiary BMW Forschung und Technik GmbH in 2003. Indeed, the legally independent limited company allows creative freedom where necessary, combined with short distances to enable maximum flexibility.

Independent thinking – never losing sight of the goal.
The BMW Group Research and Technology specialists have been given a clear brief: to develop pioneering new technologies for automotive use. In order to break new creative ground efficiently – and independently from the daily business of developing series production models – it was essential that the experts were afforded the freedom they needed. BMW Group Research and Technology made this possible, offering a working environment with flat hierarchies coupled with the rapid decision-making capability enabled by its legally independent status. A conscious break from the strict framework of the BMW Group's product development process allows ideas and inventions to be brought to fruition in the shortest time frame possible. In this way, the feasibility and benefits of new developments can be assessed quickly and transferred into initial prototypes. This enables well-founded decisions to be taken on whether to send a development into series development.

Close links to series development – efficient transfer of innovations.
The "cooperative research" concept has turned out to be extremely successful in the rapid assessment of production readiness. A seamless process sees the series development departments, as recipients of research projects, involved in processes and content from the outset and through all phases. This means the research engineers are working with the specialist departments responsible for series development from a very early stage. Requirement recognition is therefore optimised and needs are responded to efficiently. When the research phase is completed, the expert responsible then accompanies his or her project right through to series development. The expertise therefore remains in-house – all the way from the research and pre-development stages to series development. And that helps to avoid "surface friction" from occurring at inter-departmental interfaces.

The research and innovation network of the BMW Group.

The complexity of today's cutting-edge technology – as used in automotive construction – demands multidisciplinary cooperation both in-house and beyond a company's walls.

The BMW Group is represented by research, development and production locations around the world. BMW Forschung und Technik GmbH is part of the international research network. This also includes the California Innovation Triangle, which consists of three offices located in the western US state: the BMW Group Technology Office in Palo Alto, Designworks in Newbury Park and the Engineering and Emission Test Center in Oxnard. The BMW Group also has a Technology Office in Japan, China and France. BMW Car IT GmbH is another subsidiary of the BMW Group to have taken up the cause of research. Based in Munich, its aim is to utilise the potential of software in vehicles intelligently and to open up paths to new ideas for innovative vehicle functions. After all, the BMW Group's Research and Development Network also comprises the Landshut Innovation and Technology Centre, the Diesel Competence Centre at the BMW plant in Steyr, and the heartbeat of the BMW Group's development activities, the Research and Innovation Centre in Munich (also referred to by its German acronym FIZ).

The BMW Group maintains excellent relations with internationally recognised scientific institutions, such as the Fraunhofer Gesellschaft and the Max Planck Society, as well as universities and higher education institutions around the world. Such ties are of high value, especially in terms of basic research before competition becomes an issue, as research alliances enable the company to focus its own resources more efficiently and to spread technical and economic risk. The BMW Group integrates expert suppliers and system developers into research projects through the Virtual Innovation Agency (VIA).