The five ECU car

If we're to keep adding functionalities to cars, reducing the cost and complexity of the electronics is essential. But we're going to need a different approach to development. **Automotive Engineer** asked the industry's experts to share their thoughts

Lennart Lundh, head of electric systems design, Volvo Cars

"There's enormous potential to reduce cost by putting more processing power into bigger controllers. A lot depends on where you start from. There is often a very good business case for a central body module and the infotainment area tends to be a master node too – at Volvo it acts a gateway between the body CANbus and the MOST network.

In the high-speed CANbus network it's harder to talk about a specific master node because you have the brake, chassis and powertrain controls. Each is fairly powerful, so right now at Volvo, we're not talking about a specific master in that area.

If you go for an architecture with five domains, you need a top-down design process in place. You must start by designing the functional architecture before the technical architecture. In the car, you need a reliable communication network. FlexRay could be the solution.

You'll then need a standardised layered solution in each node, such as Autosar, so all the suppliers have the same basic software and interfaces. You probably need a standardised meta-model between the OEM and the Tier Ones and a powerful, shared process chain.

'Today we have sub-system suppliers supplying both high-level and low-level functionality. That will change'
Lennart Lundh

The business interface between OEMs and Tier Ones will change. If you adopt a top-down approach, you'll probably use software from different suppliers in one specific node, while the OEM takes care of some of the high-level functionalities. Today the systems suppliers provide a mixture of high-level and low-level functionalities.

The real aim is to handle the growing complexity in cars. We're working at the functional architecture level to achieve this, but whether we'll implement a five ECU architecture with a master ECU handling the active safety, say, is a big question mark.

There's no consensus that a five-ECU architecture is the best way to handle complexity because it comes close to the areas where OEMs compete. We've achieved a consensus around the basic software and low- and high-level interfaces but the difficulty comes when we talk about application interfaces. These are about functionality and that's what premium OEMs compete on.

It's also hard to define the car as the sum of five well-defined domains. You need information from the engine ECU in other domains to build functionality, especially when it comes to active safety. If, like Volvo, you were focusing on active safety, your choice of master nodes would reflect this. I doubt that BMW would choose the same set.

All OEMs work differently. Architectures are a mix of bottom-up and top-down design and it propagates differently through each department. It's essential to have a thorough centralised team, setting the rules and deciding which processes,

methods and tools to use. You need a single model-based environment in which all parts of the organisation work. At Volvo a central department handles all the electronics outside of the powertrain.

To cope with the complexity of high-level functionality, you'll have OEMs designing the master nodes maybe have Tier Ones working on software very closely linked to the hardware – the actuators. That's where we should focus in the next generation – trying to design these different interfaces better. Today we have sub-system suppliers supplying both high-level and low-level functionality. That will change.

It will take a change of mindset for OEMs to collaborate more. We'll need to come to a common understanding that we're trying to remove the waste in the development process that's linked to our relationship with Tier Ones. By adjusting that interface, you release resources at OEMs and suppliers to develop new functionalities. The trouble when it comes to systems architectures is that premium OEMs have one way of doing that, volume OEMs another.

Car-to-x projects could be a model for future development. Because they are still at the pre-competitve research level, cooperation's easier. But to cope with the growing need for functionality, we need a more harmonised meta-model between OEMs and also between OEMs and Tier Ones – that's key. This can only be done top-down; we can't do this bottom-up anymore.

Colm Boran, director of electronic systems integration, Autoliv

"The architectures we've been thinking about for the very long term will be closer to just three main domains: powertrain, chassis and entertainment. But we won't get there in a single step, it will come down from several dozen, to 10, then five, three, down to two, or whatever.

We've been monitoring the industry, discussing this with several carmakers and developing our portfolio so that it fits. When you get to a high enough level in car companies, you do find a push for this kind of thing. The departments responsible for specific functions don't see it that way, however.

If you look at it from a high enough level, I'd say most vehicles are similar in the structure of their electronic architecture, the kinds of functions contained in each ECU.

Electronic features have typically been added to mechanical functions piece by piece. They started off with small micro-controllers with just a few kilobytes of memory, and then built up in isolation. Individuals, even at Autoliv, concentrated on improving their function, without paying enough attention to what's happening in the rest of the car.

We've created a bit of a monster. Trying to get these ECUs to communicate with one another over various networks is quite complicated, especially since developments are done by different companies in different parts of the world. Until you start plugging them together at the prototype stage, you don't find all the issues.

There's still a little mistrust by some mechanically-minded people about electronics.

Processing power: a lot of control is already centralised in engine ECUs

They have stories about how some small electronic part failed and the vehicle wouldn't move, but it's changing. Most realise the benefits far outweigh the occasional disadvantages.

The thing that generally gets engineers at OEMs moving is if there's a chance to reduce cost. Then management forces them to focus on it. There is room for significant savings and quality improvements by bringing more ECUs together.

The chassis and safety domains may each have up to seven different ECUs, with a 16- or 32-bit microcontroller, which come with between 100 and 300 pins. Each pin must be soldered to the circuit board and these mechanical connections are typically where the quality problems show. It's not usually the silicon that fails.

So by combining several ECUs into a single, smart ECU, you can reduce the amount of electronics needed in the actuator. It could be just an eight-bit machine with maybe just a few dozen pins.

'Brakes and suspension people need to discuss integration opportunities with their colleagues that do airbags and seatbelt controls'
Colm Boran

But if you want to group four or five ECUs together, how do you make the two or three different specialised suppliers play well together inside one ECU? The car industry isn't well prepared for that yet, especially when it comes to developing software in different organizations.

Companies like Bosch could make a single ECU that covers four or five traditional ECUs today and they could do it all in-house, but we think OEMs want to pick and choose from different suppliers. Suppliers will have to open their architectures to allow third-party software in.

Autosar, which promises the idea of a standard operating system, is the right trend, but isn't a cure-all. Some of the bigger electronics companies are »

specifying things for Autosar that they already have in production and that doesn't necessarily make it easier to combine things into one ECU.

Like in nature, things generally get organised in the most efficient way. You have 50 or 60 different brains in your body, you have one that is internally divided with specialised functions in different areas. We think that's the way it'll happen in the car too.

Given that we're a safety company and see a lot of overlap between the safety-related functions and many of the chassis-related functions. And if if you have a pure electric vehicle with a motor at each wheel, the powertrain could easily become part of the electronic stability control.

We're positioning ourselves to be a player in a market that combines safety and chassis. We launched a system last year that uses the inertial sensors for restraint control for stability control as well. So with a single gyro we can detect a crash or roll-over event and through some signal processing and careful mechanical design, we can use the same sensor to measure subtle events that lead to vehicle instability and then send signals to the brake ECU.

There are other ways to do the integration of course. Some of our competitors are trying to integrate sensors into the brake ECU.

We think there will be more and more of this kind of conglomeration of sensors, designing gyros or accelerometers to measure things for several systems. The sensors in a vehicle typically add up to between five and ten times more than the micro-processors, so this is where most of the cost savings will come from in a more integrated architecture.

To make it work the most efficiently, car makers may need to reorganise their engineering and purchasing departments to get different groups working together on the integration. The brakes or suspension people need to be able to discuss opportunities with their colleagues that do airbags and seatbelt controls.

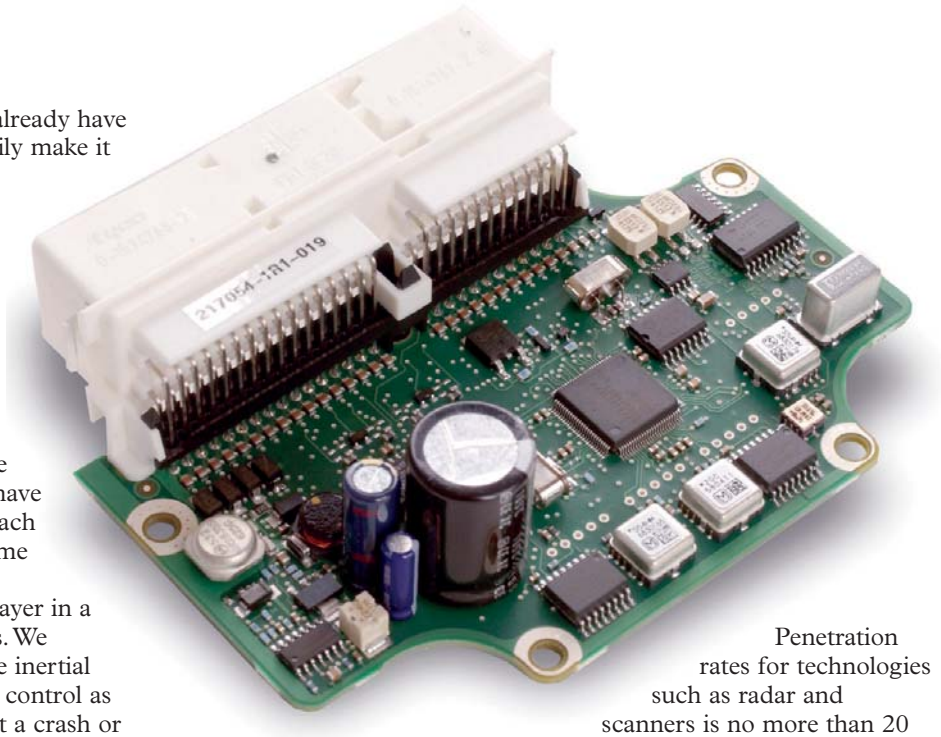
Hans-Gerd Krekels, strategy director for integrated electronics, TRW

"When the industry talks about a five ECU concept, is it really more a five domain concept? If we're really talking about five ECUs, it'll take ten to 20 years. At TRW, reducing the number of ECUs is the focus of my work, but we're also reducing them with respect to domains.

You need to be very careful which way you integrate. With each step, you reduce the number of components, housings and electronics, but you increase the complexity of your product.

Integration in the infotainment domain has been underway for years. A decade ago, you had a lot of stable radios and stable navigation systems. If you find a stable in-vehicle infotainment system today, you're a lucky man. You can't take such risks in the chassis and safety domains.

Everybody talks about the integration of passive and active safety, but you must take into account that passive safety now is merely a commodity with a high penetration rate; active safety is not.



Centralising control: TRW says integrating active and passive safety ECUs is attractive, but adds cost to basic airbag systems

Penetration rates for technologies such as radar and scanners is no more than 20 per cent. Combining an airbag system with a radar system, running everything on one processor is easily done, but then you lose the cost benefit of a basic airbag.

In the ideal world, there'd be only one ECU linked to complete environment sensing, getting all the information from the outside world and then calculating what needs to be done with the chassis. The actuators could be made much simpler and you limit the intelligence of the ECUs on the airbag to just firing.

If you wanted this to happen by 2015, then the whole industry would need to be working on these actuators now. But they're not. It's more likely to happen in the decade's second half.

'In the ideal world, there'd be only one ECU linked to complete environment sensing, calculating what needs to be done with the chassis'
Hans-Gerd Krekels

The first step is to combine more sensors. The next level is to find out what better information you can derive by combining the information from the sensors. And then you start thinking about the kind of vehicle dynamics software you can integrate into such a unit without changing the actuators for stability control or steering too much. That's what we're doing.

The next step would be to think about how to combine digital maps or other sensor elements like communication into it. You add intelligence step by step until you have a system that finds a good penetration rate. Then we can start limiting the ECU content in the actuators.

The vehicle dynamics software is something like the human-machine interface (HMI); it's the car's DNA. The OEMs want to own it. In recent years, they've retaken responsibility for the HMI and we see the same trend emerging for the dynamics software. The BMW 7 Series is an example of this.

Being able to do it for mid- and low-end cars is another thing. We're developing concepts and evaluating to do the same thing, but not necessarily using a dedicated controller.

We're starting by combining the yaw rate and the lateral and longitudinal accelerometers for the ESC with the load and other crash sensors you need in the airbag. It makes sense to do this in the centre of the car; it's a protected environment. And it's a first step towards a safety domain controller.

We'll have two controllers in one ECU first and then in the next step, reduce it to one controller. We can't afford to take big steps that might produce something unstable.

Marco Nassi, head of vehicle body and lighting electronics, Magneti Marelli

❝ Magneti Marelli is one of the leading suppliers of automotive ECUs for all parts of the drivetrain and vehicle. And we have an inter-divisional team working on this idea of reducing the number of ECUs in the car.

The number of ECUs in a car varies a lot, but it's clearly growing because electronics account for 90 per cent or more of the innovation in our field. The time it'll take to reduce the number of ECUs is linked partly to their penetration rate.

To benefit from integration, you need a stable function with a high penetration rate. Parking sensors, say, are available as an option on most mid-segment cars. They're usually sold with a standalone ECU and this is probably the most convenient approach in terms of architecture and cost if the penetration rate is 10 per cent. Once it becomes a standard feature, you'll no longer need a dedicated ECU for the ultrasound sensor, and it'll make sense to integrate it into any of the others.

It's possible to limit the standard functions to five ECUs. But if innovation is still alive and you have new proposals for customers, my feeling is that it will be difficult to put them all onto five ECUs.

We're already integrating functions onto domain controllers. Our body computer module provides hundreds of functionalities. The issue is that adding new ones isn't just about software, you need memory and wiring, you need to plan for future expansion by leaving pin connectors available.

To remain open and flexible, you need to over-design at the outset and this has an additional cost. It's a long term strategy that needs the right tools and standardised features. To be effective, it needs to be widespread and everybody should use the same standards, protocols, validation techniques and so on. The entire industry needs to align on certain standards and this requires time.

Autosar is helping. Several European car makers are migrating to Autosar applications. It's the winning solution at the moment and will be applied with success to higher segment cars where you need to integrate a lot of functionalities. But for low- and medium-level cars, it's not cost-competitive yet with vertical solutions. That will change though.

Our vision for the five-ECU car is that you can find a different way of putting together functionalities using geographical approaches, financial approaches. One will cover the entire

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THE SILICON SUPPLIER

Marc Osajda, in charge of global automotive strategy at Freescale

❝ We're the car industry's biggest supplier of semiconductors. OEMs don't buy silicon from us, but we talk to them, just as we talk to the Tier Ones.

Vehicles' architectures are becoming very complicated. There are 60 to 70 ECUs in a car, little black boxes with a micro-controller inside and some sort of electronics for sensing, computing or actuating.

Some need to be at a specific location. The front light needs to go in the front, the rear light at the back. Some things just go where there is enough space and where the wiring makes sense.

Having 70 is definitely too much. It's too complicated and the wiring adds weight. We've seen our customers present the idea of the five ECU car. The OEMs would like to concentrate some of the functionality into big, brainy domain controllers. That's realistic because with increasing computing power, you can do a lot of computation out of one relatively sophisticated ECU.

Actually, we see the ideal architecture as four plus one: a domain controller for powertrain; active and passive safety; comfort features; and one for infotainment and telematics.

The plus one would be a gateway that connects the four, passing sensor information from one domain to another, and where data crosses from one network to another, from FlexRay to CANbus to LINbus, whatever's relevant.

It would also be a secure point of entry or exit to the outside world for car to car, or car to infrastructure communication. Putting the main computing power into a domain controller would simplify things, but you'd still have a lot of satellite ECUs, sensors and actuators.

For safety, the controller could run the algorithms, but you'd need some electronics on the brake's hydraulic pump to actuate it. You'd also need sensors around the car for airbags and the ESC system.

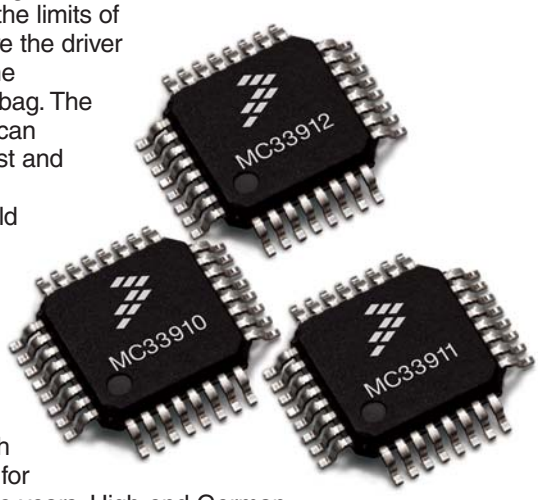
People are serious about implementing a central gateway and rethinking the architecture of the car. Many already have a central body controller that takes care of all the comfort features: lighting, switches, HVAC and things like that. But the real consolidation will start with safety. There'll be consolidation of active and passive safety into one domain.

'The people we're talking to are serious about implementing a central gateway and rethinking the architecture of the car'

Marc Osajda

You'd to try to prevent the crash as much as possible by activating the brakes, but once you reach the limits of the physics, then you prepare the driver for the crash by tightening the seatbelts, pre-arming the airbag. The other advantage is that you can combine sensors, cutting cost and providing better data.

Standardisation could could help some of the compatibility issues. It makes sense to run Autosar on big ECUs, but not the small ones because you need too much memory and silicon.



We expect to see cars with new electronic architectures for safety in the next three to five years. High-end German platforms will be first, but the French OEMs are watching closely.

» powertrain sector, the second will cover safety, chassis and driver assistance, one will relate to the chassis with braking, steering, suspension and so on. One will be for the human-machine interface and comfort and will include the body, climate control, lighting, instruments, navigation and entertainment. The last one could be for connectivity inside and outside the vehicle.

It makes sense to use FlexRay to link the powertrain, chassis and safety domains. Others will manage with leaner networks.

Moving to a five ECU architecture would require a complete redesign of the supply chain. Currently, if you supply a specific function, you provide the actuators and the ECU that controls them. In the future, you'd ask them to ship the actuators and perhaps provide the control strategy to be integrated by somebody else.

'Car makers will push for integration as long as they have a benefit in terms of overall system costs'
Marco Nassi

Car makers like to have competition among suppliers. I think they'll push for integration as long as they have a benefit in terms of overall system costs. If they integrated too far – to a single master ECU, say – then they'd lose this advantage and the Tier One would have too much power in the negotiation.

To make an ECU more reliable, it's not enough just to be a good mechanical engineer. It's a global approach to the safety. You have to identify in an analytical way, what the safety integrity levels of each undesirable effect are and then you have to provide a target to the design in order to achieve this. It's a different way of working and you need to organise your company, so that you're not designing for cost reduction, you're designing for safety. When you're dealing with hundreds and thousands of functionalities, you have to understand the system requirement, how they interact and how you manage the change.

You also have to think about building up an architecture of different smart sensors, controlled by a limited number of ECUs. They need to collect more data and do more of the filtering and low-level processing locally. This will allow you to use different protocols for data transmission. Without smart sensors, there's no way to simplify the cabling and wire harness.

Peter Laier, head of chassis components, Continental

"We all see a move towards higher integration of the car's domain controllers. The idea of a five ECU car is going around as a way of making people aware of the trend. The question for me is: how many ECUs are needed in these domains?

It depends on the OEMs, but we see no clear indication that everybody is going in the same direction. In the chassis domain, there is a differentiation between dynamics and safety, and then between active and passive safety.

The discussion starts with the question of whether it makes sense to concentrate dynamics and safety functionalities on one ECU or to separate them. Is it then sensible to keep active and passive safety separate?

You must also consider how OEMs organise their R&D. The divisions will need to work together and harmonise their development schedules and the milestones for different technologies.

There's a clear trend towards a chassis and safety domain controller. Such a controller makes sense. It means not only adding a chassis and safety controller, it means reducing the content of other ECUs or it will never play.

That's a big change. The first customers are moving in this direction. BMW is working on its Integrated Chassis Management strategy. Audi is working on something similar and Toyota has an idea for a four ECU strategy. They want to learn about it first. They see the difficulties in changing existing architectures with one giant leap, so they're doing it step by step.

A chassis and safety domain controller would make a lot of sense. There are more and more vehicles with more functionality onboard; even C-segment cars are introducing damping control.

The main ECUs in the chassis area are now 100 per cent loaded. Additional functions need a new home. This could be the start of a new domain that will grow, step by step. But if such a controller is standard, then your base vehicles have to carry an expensive architecture.

The biggest issue is that every OEM has its own agenda, direction and ideas. We're developing different technologies for different OEMs and this limits the possibility for economies of scale. If there could be a standard approach, that reduces the cost of platforms and would make breaking-even on a domain controller easier.

It would be helpful to organise a common discussion to decide on a better direction together on the style of platform OEMs want to implement.

Information networks: Integrating the infotainment and the communication functions into a single domain makes sense

The key issue is harmonising the first steps, so that the next generation of vehicles could integrate active safety and then passive safety. It's more about living together than sharing functionalities.

We need to agree that the platform will be home to OEM and suppliers' software and we need to define the interfaces. OEMs can decide individually on processors and memory, but if it could also be harmonised, it would help economies of scale.

We don't need a standard, but an idea of an architecture that is accepted throughout the automotive industry would be very fine.

Peter Rieth, in charge of technology in Conti's chassis and safety division

❝ Car manufacturers are already organised into three big domains: chassis, powertrain and interior. Powertrain takes care of fuel consumption, emissions and torque. Chassis cares for the vehicle's stability, turning the engine torque into real torque, controlling the forces at the tyre.

At times the chassis makes demands of the engine controller for more or less torque. When we overrule it, the emissions could suffer a little because safety has priority.

'It would be sensible, not only to put the control tasks in one place, but also to integrate the different smart actuators' sensors, to reduce their total number'

Peter Rieth

The interior is another domain, covering all communication functions. There could be a multimedia domain for audio and video and body functions such as window closing; it could be a sub-domain of interior. Beyond these, you'd need another substructure of ECUs.

A nice architecture is good, but in the end cost rules the game. That's how we got where we are today. We have an ESC controller with the yaw rate and lateral acceleration sensors integrated into its printed circuit board. That's fine unless you keep adding more and more functions. There's a need for new domains.

But there can't just be five big ECUs and nothing else. We'll also need smart actuators with a local control unit.

For electronic stability control, you'd make its controller a smart actuator with a smaller ECU that cares for the braking forces at the wheels. These could also take care of any limp-home mode, so that you never lose basic brake functions, say. The same approach could work throughout the car.

It would also be sensible, not only to put the control tasks in one place, but also to integrate the different smart actuators' sensors, to reduce the total number of sensors in the car.

There will more networking between functions so there's a need to introduce a higher speed databus such as FlexRay. If you're going to do that, you need to discuss how you'll organise the architecture in any case.

THE INDEPENDENT EXPERT

Dr Frédéric Holzmann, functional design manager, E/E architecture firm Intedis

❝ Right now you can find about 45 ECUs in a B-segment car. The figure goes up to 150 for high-end vehicles. There's no perfect topology, but there are some patterns. Most have gateways that split the body from the powertrain, chassis, and safety.

Some old fashioned architectures use a big backbone upon which they put everything. These face limitation on their bandwith and capacity for integration. Other OEMs have already re-organised their network, using head units with dedicated networks. The first like this was in the powertrain domain because of the need to synchronise gears, clutch, engine and hybrid components.

We are now seeing by some OEMs, an advanced driver assistance (ADAS) network where the image processing platform is used as head-unit most of the time. A car with just five ECUs isn't feasible because of thermal, safety and packaging issues, but having five domain controllers, with 50 to 100 electronic satellites to acquire data from the sensors or drive the loads, is. You centralise the software, not so much the hardware.

'The next generation of sensors need to have their own intelligence and power management'

Dr Frédéric Holzmann

This could work in all segments, adapting the size of the domain controllers to suit. Ultra low-cost cars could be the exception. Body electronics and driver information would have so little content that one ECU would suffice for both domains.

For an OEM, the first challenge is to split its vehicle portfolio into platforms that maximise the volumes while minimising the number of variants. The second is to define a generic structure for the platform that balances cost with a degree of freedom.

For the suppliers, the challenge will be to define generic platforms. You already find them for engine control, brakes, and slowly for ADAS. The last domain is the interior body controller. In my opinion you'll never find a standard because this part of the car is where you have the most competitive differentiation.

Between domains, you transfer only very high level data. The backbone can still be with CAN, but FlexRay networks will come in the future. Within the domains, the different solutions depend on the bandwith you need and the way to transfer to data. FlexRay for powertrain and chassis is already coming and is planned for ADAS. In the interior, high-speed CAN with LIN is the trend, but it could go from MOST directly to Ethernet.

The next generation of sensors need to have their own intelligence and power management to outsource these from the head units. A powertrain ECU now has more than 350 pins. We're reaching the maximum size and saving hard wired pins and power is a must.

We should perhaps wait for the introduction of full electric vehicles. When you remove the combustion engine and all the mechanical parts, changes to the electronic architecture will not seem like such a major issue anymore.

Powertrain is probably the logical place to start because of CO_2 and hybridisation. Such mega-trends drive development. In safety, it's the EU's aim to reduce the number of road deaths. In the body structure, it's the development of infotainment and communication technologies.

We need some enablers so the ECUs can communicate freely. At the moment they are independent of each other. The Autosar initiative will help to make ECUs more open and make it easier to exchange software blocks.