ABSTRACT
The interdisciplinary and structured integration of subsystems into a functioning whole is at the root of Systems Engineering. Until recently in the automotive market, much of this has been specific to an automotive sub-domain such as Telematics, Infotainment, Chassis Control, or Engine Management Systems. In the realm of Telematics and Connected Vehicles, the recent trend has been outward from the vehicle, focusing on expanding connectivity and data sources. Systems Engineering for Telematics now includes multiple transports spanning PAN, WLAN, and WAN communications, and beyond that has grown to include entities on the far side of the network link, including data servers, aggregation portals, and network security.

Although it was not trivial for Continental to develop the embedded Telematics connectivity subsystems for products such as GM/OnStar®, Ford SYNC®, BMW Assist™, and Mercedes Tele Aid®, consumer and regulatory expectations are rendering inadequate the artificial boundary of an embedded connectivity domain for new automotive systems. For example, reducing vehicle weight is a common approach in the effort to improve fuel efficiency, and weight targets have been cascaded down to each subsystem and module. However, for each 100 pound weight reduction for passenger vehicles (and without corresponding changes to other vehicles or additional safety technologies), NHTSA and other studies have indicated the effect of hundreds of additional fatalities per year \([1.1 \cdot 2.3]\) in the United States. With both safety goals and US CAFE fuel efficiency goals to meet, the design and interaction of many previously unrelated subsystems in the vehicle become key factors, and in particular, the new interaction between vehicle connectivity subsystems with vehicle safety and performance subsystems.

For this discussion, we take a systems view of the evolving field of vehicle connectivity, review the historical trends, introduce a framework to analyze several human constraints, and use the framework to identify ideal characteristics in a modern vehicle system.

INTRODUCTION
Basic engineering theory begins with the concept of drawing a system boundary. Everything within this boundary is the subject of calculation, and the external interfaces provide sources and sinks, such as for mechanical forces or data.

FIRST GENERATION
For Telematics, a subset of the overall vehicular field of Connectivity, the line has traditionally been drawn around the realm of an embedded cellular device (Network Access Device, NAD), satellite positioning (for example, GPS), and a Telematics Service Provider (TSP). Such First Generation Telematics systems were feature-limited, offering non-driving-related features such as Information Call (I-Call), Breakdown/Diagnostics Call (B-Call), and manual Emergency Call (E-Call) during normal vehicle operation. The Telematics features did not directly affect vehicle safety and performance, and only in the event of a crash did the system exhibit an increased level of integration, whereupon the airbag deployment would trigger an automatic emergency call on behalf of the vehicle occupants. Although this first generation system was end-to-end with both a specific TSP and embedded vehicle system, the over-the-air protocol was fixed and well known before product shipment, and the in-vehicle functions generally did not change over time.

SECOND GENERATION
Second Generation systems introduced what began to be called Connectivity, adding infotainment features such as Bluetooth® interfaces for hands free calling and media...
streaming, radio data services like traffic, video and Rear Seat Entertainment (RSE), and other information. Thus for the Second Generation, the system boundary encircling the consumer-oriented use cases and some Connectivity- and Infotainment-related hardware systems grew larger, but the system still focused on features oriented toward the vehicle occupants and less so the act of driving.

THIRD GENERATION

Today, Third Generation systems are being introduced. They are growing the boundary surrounding what is connected to the vehicle, whether wirelessly or by wire. Mobile devices are now a lasting part of the mix, sharing applications with the vehicle and in some instances becoming part of the vehicle Human-Machine Interface (HMI). Content providers, data aggregators, application stores, network carriers, and service providers are adjusting their market positions to solidify their roles in the value stream, adding more back-end hardware and cloud-based services. As a result, more information choices are available to vehicle occupants than ever before.

Third Generation systems have driven an interesting expansion of automotive Systems Engineering. Systems Engineering grew out of the traditional need for cross-disciplinary engineering to design the hardware and software, in order to ensure the success of a system. Initially, OEMs defined the feature set of the system, but as the key product features become driven by updateable software and services, and in particular open services accessible across different market segments, it has become increasingly important that the system be designed with human interfaces in mind, specifically accounting for human needs, desires, and capabilities. For example, fundamental human needs include transportation, communication, and safety. Human desires, on the other hand, often work as a detrimental factor - compelling the use of mobile devices with non-driving-related services in the vehicle, in some cases resulting in unsafe practices. Finally, human capabilities restrict what can be performed by one person, reducing the potential benefits of the many available features.

EXPANDING THE ROLE

Systems engineers have often had a supporting role in technical marketing and product conception. The shift toward services, though, increasingly adds the cross-disciplinary aspects of business and marketing to the systems skill set, whereupon the systems engineer will need to have strong capabilities in marrying the areas of market trend analysis, business case development, partnership coordination, and customer roadmaps, in addition to his traditional knowledge of hardware and software engineering. Those who believe that the architecture of a successful, distributed system can rely solely on technical engineering skills run the risk of inappropriate consideration of consumer needs and market trends, thus ill-designing the current system and limiting desired growth in the unanticipated directions. Therefore, Systems Engineering must necessarily consider both business and technical aspects when designing a modern, connected system.

TRANSPORTATION

There is a singular reason that consumers need vehicles: transportation. We define transportation as the act of carrying passengers and cargo from Point A to Point B. Infotainment subsystems have improved the comfort of the experience by providing features like navigation, traffic advisories, a mobile phone book, and points of interest (POIs). Improved engine and chassis subsystems have increased vehicle reliability and agility, increasing the likelihood of reaching the destination without a breakdown and allowing the vehicle to be guided deftly away from potential hazards.

However, the separate development of these trends is not without its consequences. Expanding and ever more compelling options for infotainment carry the risk of driver distraction, while increased engine power and smoother suspensions create nimbler cars that require higher levels of driver attention than before.

The time has come for a new generation of Connectivity systems. The need exists to redraw the system boundary past the vehicle data bus that links a vehicle Connectivity system with the rest of the vehicle subsystems, in order to find a way to balance consumer interests with safety and performance.

HUMAN CONSTRAINTS

As a means for understanding human behaviour in relation to vehicular products, we have developed and used a “Four Corners” conceptual framework that can aid in the discussion of human constraints. The reason behind such a framework is that it is not sufficient to merely create an item of interest to a consumer, but such an item must satisfy what a consumer can and will choose to use, as well as account for limitations of which the consumer is not aware. Comprising this Four Corners framework, the first three corners are the limitations of time, money, and attention. The fourth corner is the added factor of aging and its effects on the first three.

“Green field” Systems Engineering, in which there is no single, omniscient customer defining the requirements, may benefit from use of this framework to help optimize key characteristics of the system, in order to enhance the likelihood of product acceptance and success.
THE TIME ELEMENT

First, the Four Corners framework considers the effects of time on product perception and value. There are only 24 hours in a day, and of these, only a limited number are available for discretionary activities once one accounts for sleeping, eating, and other necessary activities. Some time will be spent at home, some watching television, a large portion may be spent at work, some exercising, and about an hour will be spent in the car each day[4] or on other transportation. As some services are now mobile and easily accessible via smart portable devices, it is also interesting to consider those times spent shortly traveling from one point to another, such as walking from the office to the car.

The value of a product, as affected by time, is related to the benefit attained over a period of time. Under this paradigm, the ideal product would be one of high benefit that is available at all times and under all circumstances, although few use cases would support such an ideal configuration. As noted earlier, communications is one such core need, and thus of high benefit. Small, affordable mobile phones have enabled that benefit to be used at any time of the day, resulting in an industry where 1 in 2 persons worldwide has a mobile phone[5,6], with annual unit volumes around 15 times that of the automotive market[6,7].

Some other features, such as navigation which may also incorporate traffic information and points of interest, have a high enough benefit and so are considered valuable even if they are used for only limited amounts of time. This allows for successful products like Portable Navigation Devices (PNDs) that might be used for just one or two trips per week[8]. The Four Corners framework time element may also help to explain the prevailing interest in PNDs relative to vehicle-embedded navigation systems: PNDs are perceived to be accessible nearly any time of the day and in any mode of transportation, while embedded systems are only operational during the typical daily hour the consumer is in a specific vehicle. Furthermore, a person can perform searches and route planning anywhere, including away from a vehicle and without requiring access to a personal computer. Therefore, the problem for many features that are embedded in vehicles is that they are inherently available for less time than their equivalent counterparts on non-vehicular devices.

Nevertheless, the average consumer chooses to spend one hour each day in their car due to the need for transportation. Transportation, being the primary function of a vehicle, is also the one thing a well-designed vehicular system can affect in ways that cannot be performed when the consumer is outside of their car. Therefore, it could be expected that the value of embedded transportation-related functions should not suffer the same detrimental business effects as embedded navigation due to the short time that those functions are available within the vehicle.

THE MONEY ELEMENT

The second element in the Four Corners framework is money. As another personal resource, we may consider a person's available money in the same way as the hours in a day: for most people, there is a limited amount, reduced by both necessary and optional expenditures. If we postulate that many people spend as much on discretionary items as they can afford[9], then in order to achieve an additional, ongoing revenue flow from consumers for a new product, the
perceived value of that new product must be enough to displace a different option that the consumer has previously selected.

Using this consideration, the value for a duplicated feature (both embedded in the vehicle and available from other devices) is lower than if the feature were not duplicated, as consumers would likely want to optimize their free cash for as many distinct features as possible. A product that offers similar features to another, but is more readily available for a longer period of time, may be expected to have a higher perceived value based on the Four Corners time consideration.

Further, we can postulate from this framework that while there may be additional value to tailoring functions for safer or more convenient operation in the vehicle, the end the consumer will analyze his limited time and limited financial resources to determine which he would select: either the function available for more time during the day, or tailored for more safety in the vehicle. It would certainly work to the detriment of the in-vehicle system if the in-vehicle function offers only moderately enhanced functions or HMI, particularly if offered at a higher price for shorter periods of time than a comparable portable option.

There is, however, a more efficient solution by combining the business models for both in-vehicle and extravehicular services. This would ideally keep the total cost similar to a single instantiation of the feature, but allow the consumer to benefit from both instantiations. Doing this in a way that is tailored for use in both in-vehicle and extra-vehicular environments could be the ideal situation for enabling replicated features within the vehicle. Being tailored for in-vehicle use may also mean using those services to improve transportation, particularly where the service performs differently when driving in the vehicle.

Therefore, the primary lesson learned from the money element of the Four Corners framework is that with an increasing number of choices for discretionary spending, there is an increased need to combine business models from the automotive domain with extra-vehicular features, thus reducing the competition for scarce income. Furthermore, this trend need not be the slippery slope of ever-decreasing product prices, but the value may be increased by finding a means to incorporate this service in a transportation-enhancing manner while in the vehicle.

THE ATTENTION ELEMENT
For the automotive industry, the third and most critical element of the Four Corners framework is attention. Time and money are important for the selection of services and features as described above, but after a driver starts the engine and during the time his car is moving, the driver will primarily avail himself of the services and features previously selected. Attention, then, is a limited human resource that has the greatest impact on the transportation activity as it directly affects safety.

Driver workload is a commonly-used term, but for the purposes of this discussion, we will consider driver workload to be a subset of the attention element. While driver workload focuses on how many things a driver may perform concurrently, and the effects of these ongoing actions on any additional activity or changing situation, the concept of attention also takes into consideration elements that may be mutually exclusive. An example of the difference can be illustrated by the multiple audio choices available in vehicles today.

In a moderately-equipped vehicle, the choices may include all of the following: AM radio, FM radio, satellite radio or digital radio, iPod® or other audio player, USB memory stick with audio files, embedded storage with music, and CD player. With only a single vehicle occupant in 80% of the cases, it is clear that only one of these seven options would command the driver's attention at any given moment, and we have not even considered that persons sometimes prefer to drive without any such audio. This illustrates the concept of attention, whereby a person can only pay attention to, and thereby benefit from, a limited number of things at a particular time. Referring back to the Four Corners framework, the value of each of these audio options to the end consumer would increase if the benefit could be applied for longer periods of time. A non-automotive example would be the hundreds of television channels available from cable and satellite providers. With so many choices available, the average incremental value for each of these infotainment channel options is relatively low as the consumer surfs between so many selections.

But there are even more available features: in addition to audio entertainment, the driver may be on a telephone call, navigating to a destination, receiving news and information alerts, searching for points of interest, reading or listening to their e-mail or text messages, listening to an audio book, or talking with another vehicle occupant. Because some of these tasks may be concurrent with other activities, cognitive workload becomes an issue as driver attention is further divided and shifted away from the primary task of driving.

THE FOURTH ELEMENT
Aging, the fourth element of the Four Corners framework, tends to influence the other three elements in nonlinear ways, and we have found that this element suggests several characteristics for successful automotive products. As a person ages, the element of time can be either relaxed or constricted, depending on a person's changing position and responsibilities in their job, the myriad tasks when raising a
family, and the course workload when getting an education - each of these will directly affect the amount of time spent in the car and the number of demands on a person's attention. Money may be short for the youngest drivers, more plentiful near middle age as salaries expand the discretionary options, and may again be restricted in retirement when on a fixed income. For the youngest drivers, aging can help to improve mental maturity and experience\textsuperscript{[10,11]}. However, aging after physical maturity will result in an ongoing and increasing detrimental effect on the capability to handle a cognitive work load. First, as new features continue to be added because of advancing technologies, the aging driver faces more difficulty in learning those features. In the prime years of their job, the consumer may find themselves with spare money to buy additional infotainment features, thereby adding to the driver's cognitive work load. As the years go by, a person's reaction times will decrease, and thus distraction may become more apparent when multitasking across non-driving-related tasks.

Attention and aging may thereby suggest an increasing need for intelligently interconnected services that provide their benefits with a minimum amount of driver attention and manual intervention. Examples of such interconnected services include zero or one click applications, appropriate sharing of data between applications without additional manual steps, and “intuitive” services requiring little or no training or memorization.

**PREFERRED CHARACTERISTICS**

Overall, the Four Corners framework suggests that the ideal automotive product would be one with high benefit over most of the time a user is in the vehicle, would relate to benefits outside of the vehicle, would avoid monetary budget contention by leveraging existing consumer spending decisions, and would minimize its presence in the ongoing competition for driver attention. Adding the aging constraint to broaden the audience to multiple age levels, it would be further suggested that such a system should minimize or eliminate the learning curve (such as being usable without instructions, memorization, or training), minimize discretionary costs, and offer a graduated range of support for drivers who are already overburdened with other available activities.

However, merely listing the ideal characteristics of a product, which could be determined through other means, is not the primary reason for using the framework. Instead, we use Four Corners to provoke the necessary conversations when analyzing the value and viability of a proposed new product.

**CONSEQUENCES OF AN INTERCONNECTED WHOLE**

Understanding the historical evolution of connected vehicle systems\textsuperscript{[12]} and with a framework to assist in analyzing human behaviour in relation to such systems, we can now apply this information to the modern in-vehicle experience. By 2013 in the US market, the typical vehicle is expected not only to have a bevy of broadcast and local infotainment features, but forecasts indicate that over half of the new vehicles will include wireless connectivity, whether via connection through mobile devices or embedded NADs, WiFi, or other transceivers\textsuperscript{[13,14]}. This high connectivity adoption rate provides expanded options for linking the vehicle with external data sources.

**INFOTAINMENT DIRECTIONS**

Consumers are anticipated to pay for enhanced vehicle HMI elements, via speech recognition, large center-stack displays, reconfigurable cluster modules, screen-based tactile interfaces (including resistive, capacitive, and force feedback mechanisms), and other HMI devices. While all of these HMI elements are primarily used to control applications, they can also be used as sensors, giving vehicle a better sense of where a person's hands are, and where their eyes are likely to be looking, by detecting the activation of the various interfaces.

**SAFETY TRENDS**

The number and capability of vehicle sensors and actuators is increasing year over year, as an effect of the improvement of safety and driving systems. Some are by mandate as with stability control, which brings information about wheel rotation and gyroscopic data while enabling autonomous brake control over individual wheels. Others are by choice as with full speed range adaptive cruise control (ACC), which adds forward-facing sensors and can control both the vehicle's accelerator and the braking systems in response to dynamic traffic conditions. Lane-keeping assist (LKA) adds side sensors and steering actuators, which can be used to help the driver keep the vehicle within the marked lane. Aiding the actuators is a range of supporting sensors, including RADAR, cameras, LIDAR, et al, resulting in a large amount of available data from these vehicle sensors.

**ENGINE SYSTEMS**

Vehicle engine power and nimble high-speed driving performance seem to be on the rise in US consumer preferences again; even so, there is also a burgeoning undercurrent of eco-awareness tempering consumer decisions, supported by ever more restrictive emissions and fuel economy standards. It is this combination of trends - eco-awareness and increased engine performance - that raises the
level of instrumentation and electronic management over the engine systems.

MINIMAL CONNECTIONS
While each of these subsystems has shown ongoing improvements in its specific area, most deployed systems have not been optimized for the vehicle system characteristics suggested by the Four Corners framework. The reason is that each subsystem has evolved in a typically safe engineering way: by limiting the system boundary to only closely-related functions (for example, the embedded infotainment subsystem, which includes HMI, links external mobile devices, and data from servers), and by minimizing the interactions with elements beyond that boundary (limited CAN, LIN, and MOST® bus functions). However, by model year 2013, the year for which many vehicle electronics modules are now being designed, the basis of each of these connectivity, safety, and performance subsystems will be well-proven, resulting in the possibility for expansion of the system boundaries in order to create a more coordinated vehicle.

If we temporarily do not consider external connectivity, the vehicle is almost an archetype for the concept of an interconnected whole. Each element in this closed system affects the characteristics of the whole, whether by changing weight or balance, consuming energy, affecting EMC, or providing functionality. The question is whether the tightly-woven subsystems are intentionally designed to draw the maximum benefits out of such interconnectivity, or whether the design is merely an allocation of weight, space, and power consumption across modules.

We can already observe some results of the unintended influence of these design approaches on the driving experience:
• Consumers buy faster, more-responsive vehicles, but they also buy and use new and additional distracting features while driving, whether on mobile devices or embedded with their infotainment subsystems. However, when all such devices are in the same vehicle and are concurrently active, there is typically no coordination across those different subsystems to offset the dangerous combination of speed/power and driver distraction.
• To be most effective, active safety subsystems need to have information about two things: driving situation and driver intent. However, those active safety subsystems with the power to intervene cannot do so in many cases, because driver intent and activities are not well known.
• Safety subsystems, such as for lane departure and forward proximity, often provide an HMI separate from the infotainment HMI, thus increasing the number of visual, audible, and haptic elements presented to the driver. This also applies to many diagnostics subsystems (the “Check Engine” light or other dedicated warning symbols).

• Despite a bevy of vehicle sensors and available data, infotainment subsystems do not understand and account for the dynamic status of the vehicle, environment, and driver.
• While navigation and infotainment subsystems may use map and server-based data to inform the driver of the road ahead, the rest of the vehicle is typically blind to this knowledge.

Excluding external connectivity, we can see that even rudimentary coordination between safety, engine, and user-oriented interior electronics subsystems can result in benefits for all such intelligent subsystems.

Revisiting the forecast that over half of all vehicles will have wireless connections to external data sources, and with transportation being the linchpin that enables the entire automotive industry, the question to be asked is what can and should vehicle systems do to improve transportation in accordance with the Four Corners framework.

DRIVER ADVOCATE®
To tailor and improve the driving experience, the vehicle must first gather relevant data and then act upon it on behalf of the driver. We call this concept Driver Advocate. This approach is one in which the vehicle actively works to improve safety and drivability, acting as a partner to the driver, and neither only as a substitute (autonomous driving) nor relegated to the role of an assistant (either warnings only or action when commanded).

In the first through third generations of Telematics and Connectivity, such relevant data was in most use cases limited to information sourced within the boundary of each vehicle subsystem and was not available from server-based sources.

Illustrating Driver Advocate in these early generational systems: in the infotainment realm, radio volume might be reduced or muted when a turn-by-turn instruction is announced, or when the user begins a hands-free phone call. For collision avoidance systems, the brake controller might only apply partial braking until a user signals his intent by touching the brake pedal, whereupon the system might autonomously perform maximum braking if a collision is imminent. The same applies to stability control, which may use the wheel angle as an indicator of desired direction, then control each wheel to achieve that path. Powertrain systems shift gears based on sensor data from the engine and transmission, as affected by the driver's use of the accelerator pedal.

While each of these functions are useful, they are but a small set of what is possible with today's available information and electronics systems.
ENOUGH TIME
Using the Four Corners framework to help the analysis, we take each of the four elements in turn and look for system-wide improvements. We start with time. The framework postulates that the user will perceive maximum value when a beneficial function is available for the longest possible period of time. For driving-related functions, this means at least the typical 1 hour per day in the vehicle.

Traditional Telematics includes E-Call, B-Call, and I-Call. While some of these features can have a very high benefit, statistics suggest that the usage rate is very low - for instance, an airbag-triggered E-Call occurs, on average, less than once for each vehicle[15]. For the maximum value, the improved functions need to be ones that are beneficial and active during the periods that the passengers are in the vehicle. The features that would be nearly always active are ones that affect how the vehicle moves over the road, how efficiently the engine runs, and what actions the vehicle can perform to actively take a defensive driving posture relative to all surrounding objects and road regulations.

SAVING MONEY
Next, we look for synergies in business models to account for the money element. Designing each subsystem individually results in features that are only paid through the cost of the subsystem itself; i.e., the capability of a chassis control subsystem to maintain vehicle stability or avoid a collision is not affected by the money spent on the infotainment subsystem. So in order to gain a new feature, a consumer must traditionally pay for more hardware.

However, because an increasing number of users are voluntarily choosing to spend money for data connectivity, that particular funding battle need not be fought by the automotive industry. For example, many smartphone users today have access to up to 5 gigabytes of data per month, which includes traffic and incident information, recent roadway segment speeds, map data, traffic cameras, and more. Thus, the question becomes how to leverage that data connectivity to additionally improve the performance of the powertrain and safety subsystems.

STAYING FOCUSED
In the ongoing contest for driver attention, it is imperative to recognize that vehicular improvements, particularly ones that are utilized throughout the driving period, must not add to the driver's workload. Such additional or enhanced functions should add no new HMI, and in the ideal case, would result in a simplification or reduction of the HMI cognitive load as perceived by the driver.

A driver need not necessarily know when a Driver Advocate function intervenes on his behalf. A zero HMI example is when the powertrain system uses Electronic Horizon (eHorizon) map data in a way completely invisible to the user, but potentially resulting in fuel efficiency improvements of 3 to 5%. Another example is deferring the notification to a driver of an incoming call or message when the system detects a potentially unsafe driving situation - driver notification of the message would occur only when the critical situation, which may include blind spot status or unsafe distance to the vehicle ahead, has abated.

Examples of near-zero HMI include slight, corrective resistance in the steering wheel when a driver begins to drift out of a marked lane, or using an accelerator force feedback pedal (AFFP) to provide slight upward pressure on the driver's foot when the driver should slow down. A well-known example of near-zero HMI is the Antilock Braking System (ABS): the driver has signaled his intent to stop, the vehicle detects wheel slippage, and the system's only responsibility is to maximize friction by reducing the slippage.

To reduce driver workload, one must first consider what is essential to the HMI, and then work to eliminate non-essential elements. A screen is needed for navigation, and on the latest vehicles, for control of many interior functions. A cluster module is needed for key driving data such as speed and diagnostics alerts, and in some cases as a quick-glance aid for other functions (odometer, navigation turn indicator). There are, of course, many other necessary HMI elements such as accelerator and brake pedals, steering wheel, discrete knobs, buttons, and levers. Non-essential elements should be eliminated, much as the current generation of smart phones has fewer buttons than ever before.

For any new driving feature, the question is whether the HMI can be almost entirely hidden, as is the case with ABS activation. If a feature must involve the driver, it should make use of an existing, essential HMI element, such as warning notifications using existing displays or spoken warnings rather than adding new lights, unintelligible sounds, or vibrations where no other HMI exists.

BETTER FOR AGE
To accommodate the aging element, we look for zero or near-zero cognitive workload when using any of these advanced functions. This means near-zero training requirements, no memorization, and seamlessly intuitive transitions across multiple active functions without user annoyance or confusion.

An example of this would be integrating an accelerator force feedback pedal with other vehicle systems. An AFFP was added to the prototype ContiGuard® C2X connected safety vehicles, which have been driven by over two thousand drivers without special training. Most of the drivers were not
told that an AFFP system was installed. Instead, they were typically given the instructions, “Just drive and follow the rules of the road.” In every case, the drivers responded appropriately by automatically reducing the pressure on the accelerator pedal when prompted by the vehicle. Most interesting and surprising, though, was the user feedback. Even with all of the safety and communications mechanisms built into those C2X vehicles and demonstrated using everyday driving scenarios, users were most delighted because the vehicle simply “helped me to slow down at the right time” via the AFFP. The complex technology was distilled down to a simple HMI, so in the end, it was the users' perception that the vehicle was helping them to drive better that was most memorable.

**TWO AREAS FOR IMPROVEMENT**

However, we have noted that for the vehicle to become a full-time partner and advocate for the human driver, two areas are of essential importance: situational awareness and interpretation of driver intent. The reason is that in order to take action, the vehicle must understand as much as possible about its precise environment, including changes therein, and also about what the driver wants to do. This is different than autonomous driving, wherein the vehicle is solely in control of the driving task, and where there may not be an active human driver. This is also different than traditional, non-autonomous vehicular systems, in which nearly every action is directly initiated by the driver so the vehicle would need less knowledge of its surroundings. Acting as the driver's partner, the vehicle must be strong in both areas, thereby knowing better when to assist the driver and when to assume control.

The approach for a system designed to address these two problem areas becomes the definition for the next generation of Connected Vehicle Systems (CVS).

**4TH GENERATION CONNECTED VEHICLE SYSTEMS**

Where 3rd Generation Connectivity expanded the systems boundary to actors outside of the vehicle, we define 4th Generation Connected Vehicle Systems by the removal of the artificial boundaries between internal vehicle subsystems. Therefore, automotive products can benefit from coordinated feature development using all of the vehicle's capabilities.

**AVAILABLE VEHICLE KNOWLEDGE**

We begin with the assumption that information known by one vehicle subsystem can be shared with other vehicle subsystems. Such information could be:

**Infotainment**

- Activation of the infotainment HMI, including use of buttons, dials, and touch screens, to detect occupant activity and as indicators of driver attention
- Higher-workload moments in infotainment applications (dialing the phone as compared to just hands free conversation, verbally responding to a text message as compared to having a message read to the driver, selecting a particular audio playlist instead of just listening to the music, entering a navigation destination as compared to navigation guidance, etc.)
- Satellite positioning (such as GPS) and Dead Reckoning using vehicle sensors
- Map matching
- eHorizon map and dynamic data about the upcoming road details
- Passenger position and categorization

**Powertrain and Driving HMI**

- Changes in the position of accelerator and brake pedals including trend analysis
- Changes in the position of the steering wheel and other controls including trend analysis
- Dynamic engine and transmission status
- Fuel usage

**Active Safety and Vehicle Sensor Systems**

- Use of ACC, including specific system settings (set speed, adjustable following distance, and autonomous braking settings) and distance to object ahead
- Nearby objects detected, categorized, and tracked
- Lane markings and relative vehicle position
- Wheel slippage
- Street signs detected and signage information recognized and understood (construction zone speed limit, school zone active)

**REMOTE DATA**

Connectivity data from outside of the vehicle can also be leveraged:

- eHorizon and ADAS map data, particularly data from remote navigation and map servers
- Dynamic map information (additional data layers), such as real-time road segment speeds and construction zone data
• Local warnings and incident data such as disabled vehicles, road condition hazards, weather warnings, and approaching emergency vehicles
• Dynamically-changing speed limits
• Car-to-Car alerts (such as via RKE or DSRC)
• Other data via broadcast, multicast, or point-to-point (FM RDS, DARS/SDARS, cellular packet data)

**IMPROVING TRANSPORTATION**

Using this “sensor fusion” of shared information across vehicle subsystems, new use cases can be enabled to improve everyday driving experiences. In keeping with the goal of minimal cost, these enhanced features could be performed with the technologies and systems available to production vehicles in 2013 - no new hardware would need to be created. Of course, the specific use cases would differ, depending on the subsystems installed on each particular vehicle.

**Improving Navigation**

• Using a vehicle's LKA function, the vehicle can count the number of lanes traversed to determine in which lane the vehicle is driving, allowing the navigation system to provide a more accurate display of the vehicle on the road.
• Lane traversal may also be determined using a vehicle's backup camera or forward-facing camera.
• Local construction data received over-the-air can provide information on the number of open lanes.
• Sign recognition from the forward-facing sensors can provide updated information for the navigation display, including overriding the speed limit data in the map database or changing the road color to indicate a construction zone.
• Sign recognition indicating start of a construction zone can be correlated with local regulations for maximum speeds in construction zones (received over-the-air) to provide guidance to the driver.
• Approaching train information could be provided before the train crossing is visible, allowing the navigation system to calculate the fastest route around a long train.

**Improving Fuel Efficiency and Safety with Map Data**

• Prototype systems with OEMs have shown that eHorizon or ADAS map data, provided via the navigation system, connectivity system, or eHorizon device to the powertrain system, can reduce fuel usage by 3-5%. eHorizon systems are now shipping in commercial vehicles, and can save thousands of dollars per truck per year.
• Map data can be also be used by the vehicle safety systems. For example, knowledge of blind driveways, low-visibility intersections, and pedestrian crossings could be used to help optimize visibility and detection of objects (such as directing some light from the headlights toward a blind driveway to increase visibility, or toward the side of a country road where deer crossings are common).
• Speed limit changes, gathered from multiple sources including sign recognition, the on-board map database, and over-the-air data, can be used by an AFFP to more reliably prompt a driver to slow down, even if all data sources are not available.
• When approaching a neighborhood or school zone, an AFFP could prompt the driver to slow slightly before the signs are visible.
• A combination of engine management system and safety system could be used to bring a vehicle closer to the recommended speed when entering a dangerous curve.

**Improving Active Safety**

• By comparing digital map data with a camera (forward or rear) and/or lane detection sensors, the vehicle can better determine the position of the vehicle relative to the multiple lanes on the road.
• The vehicle could use lane position information to confirm whether an object detected on the side is another vehicle or a side barrier.
• Knowing whether the vehicle is beside the edge of the road or in the middle of a multi-lane roadway may be useful during evasive maneuvers, particularly where the vehicle provides assistance in swerving and braking.
• Information from forward-looking sensors can be combined with map data and dynamic incident data to better estimate whether an object directly ahead is just the center median on a curving road, or whether the object might be in the vehicle's lane.

**Improving HMI**

• The vehicle can act as a sixth sense for the driver, extending beyond the capabilities of human senses.
• The vehicle can automatically start to slow and provide notifications when approaching hazards or stopped traffic, before such hazards are visible, and take actions to alert the driver.
• Because modern vehicles are well-insulated for sound, making it harder to hear nearby sirens, the system can provide notification of approaching emergency vehicles and school buses, as well as information on local regulations when nearby such vehicles (for example, some regulations require drivers to stop under certain situations).
• The vehicle can adapt its HMI to the driver, depending on both the driving situation and what the driver is currently
doing. For example, automatically slowing the vehicle earlier and providing spoken warnings, if the system detects the driver is adjusting the infotainment system in a risky situation.

- Using the infotainment HMI (cluster displays, center stack displays, audio system) as a coordinated part of the overall vehicle driving and safety HMI, the vehicle could reduce/blank the infotainment HMI during quick reaction situations, or use the infotainment system to provide active safety notifications and messages.

Improving Over-the-Air Data

- Roadway data has traditionally been sourced from roadside sensors and manually-activated user reports (including applications for which a user presses a button to submit a report).
- However, each vehicle that passes by a hazard, whether a disabled vehicle on the road, a large pothole, or a construction zone lane shift, can automatically provide this data as an exception report to a server (detection of swerving or departure from a lane, suspension force detection, RADAR target of immobile object, or camera image recognition of a stopped vehicle that is blocking a lane).
- As additional vehicles pass by the same hazard and provide corroborating reports using their own sensors, servers can process and release the information to other vehicles approaching the same location.
- The reports from the various vehicles could contain different but complementary information, depending on which sensors were installed on each vehicle. These use cases, and many others, show features that could be improved or implemented by linking the vehicle sensors and actuation systems with the myriad data sources available to cars today.

By using a sensor fusion approach of merging data across multiple subsystems, situational awareness and understanding of driver intent are improved. For situational awareness, data from multiple sources could be correlated to increase the likelihood of the correct interpretation. For driver intent, the vehicle could determine whether a driver might be manipulating infotainment functions and thus not paying attention when a high-risk situation is imminent.

SUMMARY/CONCLUSIONS

When we began some years ago to analyze what could be performed by combining the different automotive domains of connectivity, infotainment, safety, and powertrain subsystems, we had not anticipated the number of additional and useful features that could be enabled. At that time, it was still a matter of waiting for many of the OEMs to install the next generation of safety and powertrain subsystems, and for there to be available data for the connectivity subsystem to receive.

Today, we see many of these subsystems being installed on vehicles, from RADAR to cameras to electronic braking systems. Connectivity capabilities are anticipated on over 50% of vehicles, and the percentage of vehicles that can access navigation and map data is increasing year-over-year. The externally-generated data sets are also improved, with availability of ADAS and eHorizon map data for many countries. A delaying factor has been the testing and deployment of each of these individual subsystems, but by 2013, OEMs will have had years of experience with these products.

Given the potential improvements to safety, powertrain efficiency, and comfort, now is the time to consider the implementation of these cross-subsystem vehicle features. Not only would it help the first OEMs to differentiate themselves as leaders in improving transportation, but the Four Corners framework suggests that the value to consumers could be very high, thus driving consumer interest for those vehicles so-equipped.

The last barrier, the open and active coordination across the planning and engineering teams of each of the different vehicle domains, is already starting to fall as the automotive industry strives to improve the parameters of cost, quality, and architectural modularity. What started as an exercise to improve each subsystem to benefit the overall vehicle is expanding as the discussion shifts to consider how cooperation across domains could create value by improving the vehicle's performance.

We therefore propose the next steps: working with each of the OEMs, but in joint technology sessions that combine safety, powertrain, and infotainment/connectivity organizations, in order to optimize what could be done with each OEM's system architecture, installed equipment, and service providers. We have already been meeting and working with some of the OEMs to help drive these topics. However, it is clear that there are many potential improvements to transportation that are now technologically feasible, so the goal would be to examine and redouble those activities in the quest to provide not only subsystems, but safe, efficient cars.

By redrawing the internal system boundaries, Fourth Generation Connected Vehicle Systems can help to make the vehicle much more than just the sum of its parts.

REFERENCES

CONTACT INFORMATION

Robert Gee is a Product Line Manager within Continental's Infotainment and Connectivity Business Unit. Gee works with automotive OEMs, partner companies, and Continental's Chassis & Safety and Powertrain Division's to develop the next generation of connected vehicle systems to better enable safe transportation, sustainable resource usage, and consumer information needs.

Gee's previous experience at IBM, Motorola, and other companies includes satellite mission control center architecture, military safety system process development, systems/software process definition and quality assurance to develop an SEI CMM® Level 5 organization, proposal negotiations and contract management, network communications architecture, and engineering on over 40 commercial and government product development efforts.

Gee is a television Emmy Award recipient for his work as a producer for CNN. He is based in Deer Park, Illinois, and may be reached at Robert.Gee@Continental-Corporation.com.

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DEFINITIONS/ABBREVIATIONS

ACC
Adaptive Cruise Control

ADAS
Advanced Driver Assistance Systems

AFFP
Accelerator Force Feedback Pedal

C2X
Car-to-Car and Car-to-infrastructure (Car-to-X), also known as Vehicle-to-X (V2X)

CAFÉ
Corporate Average Fuel Economy

CAN
Controller-Area Network, a vehicle data bus

CVS
Connected Vehicle Systems
DARS/SDARS
Digital Audio Radio Service, Satellite Digital Audio Radio Service

DSRC
Dedicated Short Range Communications, a radio system designed to enable vehicle-to-vehicle and vehicle-to-infrastructure communications

E-Call
Emergency Call

eHorizon
Electronic Horizon, which is map-based data that provides driving-oriented information such as road curvature and slope, in order to provide a look-ahead capability to the vehicle

EMC
 Electromagnetic Compatibility

GPS
Global Positioning System

HMI
Human-Machine Interface

I-Call
Information (or Concierge) Call

Infotainment
Information and Entertainment

LIDAR
Light Detection and Ranging, a technology similar in function to RADAR

LIN
Local Interconnect Network, a vehicle data bus

LKA
Lane Keep Assist

MOST
Media Oriented Systems Transport, a vehicle data bus

NAD
Network Access Device, embedded cellular communications

NHTSA
National Highway Traffic Safety Administration

OEM
Original Equipment Manufacturer

PAN
Personal Area Network

PND
Portable Navigation Device

POI
Point of Interest

RADAR
Radio Detection and Ranging

RDS
Radio Data System

RKE
Remote Keyless Entry

SEI CMM
Software Engineering Institute Capability Maturity Model

TSP
Telematics Service Provider

WAN
Wide Area Network

WLAN
Wireless Local Area Network

Telematics
The combination of telecommunications and computing systems, and in particular for vehicles