The Future of Transportation

A system of systems perspective on the future of the car

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The future of the car is the future of transportation. What do we mean by that? It is not to say that the car is the future of transportation, rather the future of the car will depend on how the broader transportation system digitally evolves. The digital transformation of transportation infrastructure will have profound influence on how and how quickly the digitalization of the car will play out as will the stitching between the intelligent car and the intelligent infrastructure - connectivity.

Our autonomous aspirations

The idea of the autonomous vehicle has dominated our imagination and hopes for the future of the car especially in the last few years as the state of technology appeared ripe for mass commercialization. Despite significant progress, it remains a technology topic that has been the subject of considerable hype as well as skepticism.

Beyond our aspirations for the technology and dreams of a driverless utopia, why do we believe that driverless vehicles will matter? Safety and reduction of loss are foremost of the issues that we hope to address by putting the operation of road vehicles in the hands of autonomous automation.

In the US alone, over 35,000 people are killed in vehicle related accidents annually with the number topping 38,000 in 2020 according to the NHTSA.[1] The global figure is a staggering 1.35 million killed on roadways around the world each year and growing.[2] In 2010, 13.6 million vehicle crashes are estimated to have resulted in $836 billion in societal harm in the US.[3]

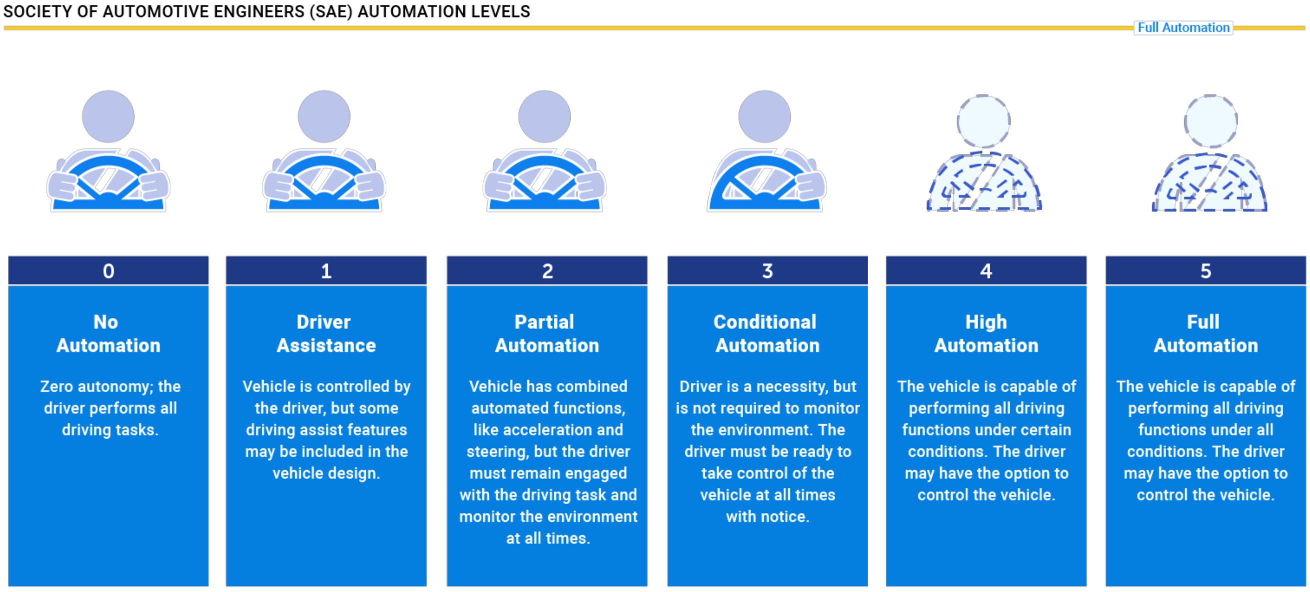
Traffic congestion is another growing problem globally as populations continue their migration to crowded urban centers. In 2018, traffic is estimated to have cost the US economy $87 billion in lost productivity.[4]

$87 Billion

Cost on US economy due to traffic congestion in 2018

Source: INRIX

Then there are the many environmental concerns related to vehicular transportation ranging from noise to air pollution. There is also the matter of the environmental impact of parking lots and parking structures that contribute to the "urban heat island" effect and water pollution that afflict dense urban areas.[5]



SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Figure 1: SAE Automation Levels Reprint: NHTSA

The prevailing thesis suggests that taking “flawed” and distracted humans out of the driving equation will cease the perennial loss of life, and economic and societal harm. Furthermore, fleets of shared, self-driving vehicles would change the economics of vehicular mobility especially in urban areas where parking can be difficult to find and expensive with personally owned vehicles spending 95 percent of their existence in a parking space or garage.[6]

For society and the environment to reap the benefits of the autonomous future of the car, cars at large need to ride up the automation curve which is represented by the Society of Automotive Engineers’ (SAE) automation levels. This framework has become the de facto standard for classifying the progressive levels of automation from purely manual to fully autonomous operation of a vehicle.

The SAE levels of automation are commonly misconstrued as levels of autonomy. Only the top three levels (Levels 3 through 5) of the SAE framework suggest degrees of autonomy with level (Level 5) representing a fully autonomous vehicle that requires no human operation or intervention. Levels 0 through 2 represent degrees of driver assistance capability that passive and active ADAS (Advanced Driver-assistance Systems) can deliver today.

Despite significant technological progress, much improved economics, shrinkage of what used to be bulky sensor systems such as LiDAR, and the massive investments in autonomous vehicle projects such as Waymo, we have a long way to go before we see fully autonomous vehicles on the road in significant numbers.

What might be deemed the most populous “autonomous driving” system - Tesla’s popular Autopilot offering registers at Level 2 on the SAE automation scale; Level 2.5 if you want to be generous. It is likely that Honda will be the first auto brand to put a production Level 3 car on the market, but even so, the vehicle will conditionally operate autonomously at low speeds.

In the meantime, the autonomous future of the car will have to contend with the overwhelmingly dominant installed base of not-so-autonomous vehicles. According to IDC’s 2018 forecast for ADAS, vehicles with Level 0 automation will continue to dominate the share of vehicles produced until 2024.[7] In 2018 IHS Market ambitiously forecasted that autonomous vehicle sales would surpass 33 million units annually in 2040.[8]

Even if IHS Market’s lofty projections are met, the firm estimates that twenty years from now a mere 26 percent of new car sales will be “autonomous vehicles”. This means in no uncertain terms that the dream of a Level 5 fully autonomous utopia is easily more than a decade away if not many more.

This also means that for the foreseeable future, autonomous vehicles will have to deal with less capable peers and roadside elements that are off the grid, offline, and operated largely by people with their varied - and often unpredictable - driving styles.

Autonomous is a team sport

If we consider the broader objectives and aspirational benefits of the autonomous car, they are not solely rooted in the advancement of the vehicle up the SAE levels of automation. This isn’t a bad thing. It merely means that we must look at the progression of autonomy in transportation differently.

Transportation infrastructure has been largely disconnected from the vehicles that operate on it. The key modes of communication between the road and elements on the road such as vehicles and pedestrians have been visual, aural, and haptic. We are all familiar with signs, traffic signals, lane markers, speed bumps, crosswalks, and the blare of a horn or siren.

Despite the presence of vehicles capable of SAE Level 2 automation, the de facto interface between transportation infrastructure and the car has been and largely continues to be the human driver. Vehicles on the road are passively orchestrated and managed by rules expressed by the transportation infrastructure and then followed by human operators and pedestrians with varying consistency and quality.

However, intelligent transportation infrastructure elements such as smart traffic signals, digital signage, and fast-growing array of sensing systems will provide important perception capabilities and contextual information. These sensory functions and information will form a critical foundation for pervasive condition and situational monitoring of the road, its surroundings, and the elements operating on it.

Most importantly, the intelligent transportation infrastructure will be able to address the massive offline, analog world that will persist for the foreseeable future by filling in the gaps in information that most vehicles on the road won't be able to acquire on their own because they are not "intelligent" enough or not active participants in the intelligent transportation system.

The simple step of making non-digital elements visible to the digital realm will bring about a broad scope of enhanced safety and traffic efficiency benefits at scale without the need to wait for most vehicles on the road to achieve an autonomous level of automation (greater than SAE Level 2).

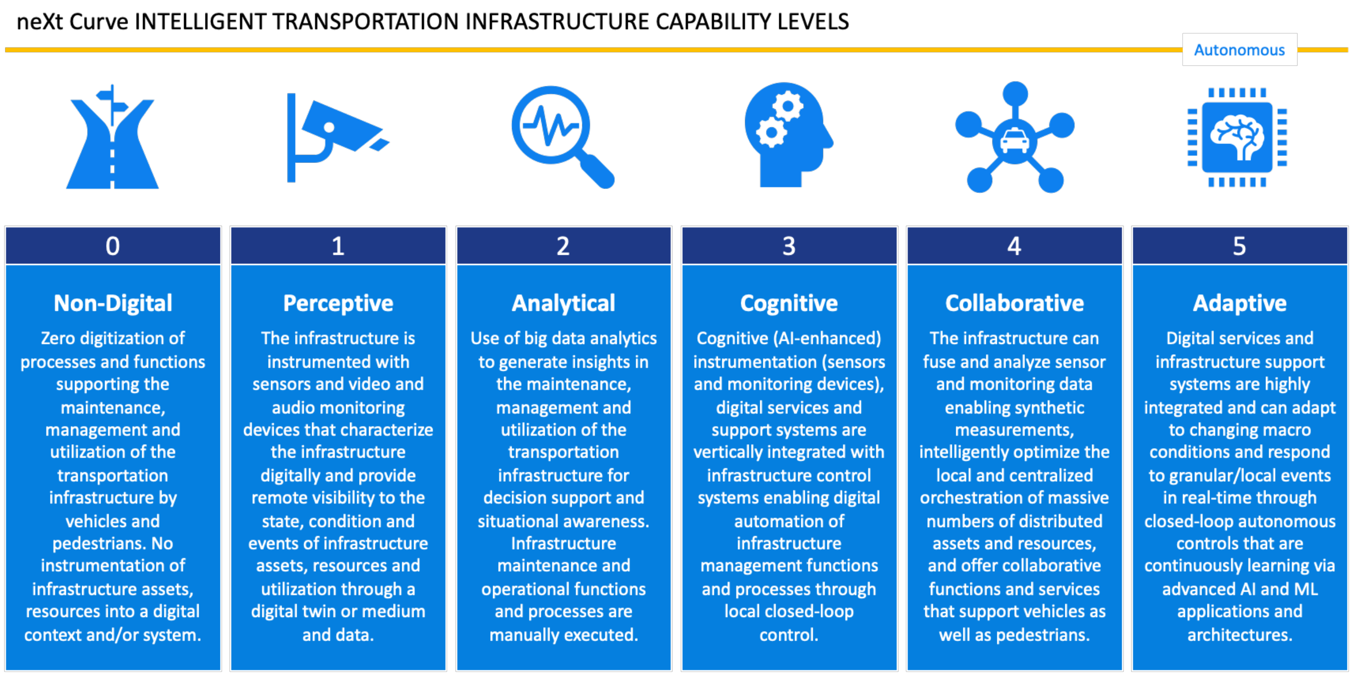
The goal of intelligent transportation infrastructure is to arrive at a set of critical, high value digital services and automations that can be broadly consumed and applied and are able to respond in real time to events and the operational needs of the vehicle and driver in any instance. These services and automations will also be able to adapt intelligently and autonomously to changes in the condition of the infrastructure and the situation of each vehicle and element with all due consideration of the state of their surroundings.

Such an infrastructure could dynamically determine the optimal speed limit for a segment of road based on weather conditions, quality of the road surface and the level of traffic. It would also be able to monitor the behaviors of vehicles traveling on that segment and issue warnings to non-compliant drivers through available digital signage or directly to the ADAS system of a connected car based on the connectivity capabilities and digital maturity of the vehicle.

These shared data services would provide vehicles, autonomous and otherwise, with rich contextual information for safer and more efficient operation in any and every location and condition. Moreover, intelligent infrastructure would enable vehicles to participate in holistic objectives such as dynamic traffic flow optimization regardless of their level of automation and connectivity.

Oddly, there isn't a global industry standard for intelligent transportation infrastructure, or one that suitably describes the development stages of intelligent capabilities and the automation of transportation infrastructure.

To spur thinking, neXt Curve has framed a digital capability model for intelligent transportation infrastructure based on our observation of how Internet of Things (IoT) systems mature over time to achieve adaptive automation; what would be equivalent to a SAE Level 5 fully autonomous vehicle.


neXt Curve INTELLIGENT TRANSPORTATION INFRASTRUCTURE CAPABILITY LEVELS

0	1	2	3	4	5
Non-Digital	**Perceptive**	**Analytical**	**Cognitive**	**Collaborative**	**Adaptive**
Zero digitization of processes and functions supporting the maintenance, management and utilization of the transportation infrastructure by vehicles and pedestrians. No instrumentation of infrastructure assets, resources into a digital context and/or system.	The infrastructure is instrumented with sensors and video and audio monitoring devices that characterize the infrastructure digitally and provide remote visibility to the state, condition and events of infrastructure assets, resources and utilization through a digital twin or medium and data.	Use of big data analytics to generate insights in the maintenance, management and utilization of the transportation infrastructure for decision support and situational awareness. Infrastructure maintenance and operational functions and processes are manually executed.	Cognitive (AI-enhanced) instrumentation (sensors and monitoring devices), digital services and support systems are vertically integrated with infrastructure control systems enabling digital automation of infrastructure management functions and processes through local closed-loop control.	The infrastructure can fuse and analyze sensor and monitoring data enabling synthetic measurements, intelligently optimize the local and centralized orchestration of massive numbers of distributed assets and resources, and offer collaborative functions and services that support vehicles as well as pedestrians.	Digital services and infrastructure support systems are highly integrated and can adapt to changing macro conditions and respond to granular/local events in real-time through closed-loop autonomous controls that are continuously learning via advanced AI and ML applications and architectures.

Source: 5GAA, US DOT, neXt Curve analysis

Figure 2: Intelligent Transportation Infrastructure Capability Levels

As with any IoT system,) the instrumenting of assets, operations and environment is the vital first step (Level 1). The acquisition of digital visibility to things in a system is a prerequisite for condition monitoring, event detection, and location-based services. These perception capabilities allow the intelligent transportation infrastructure to expand and deepen its sensory footprint and enable the collection of telemetry and surveillance data across the infrastructure.

With data from sensors, the Level 2 intelligent transportation infrastructure applies analytics to generate insights. The analytic results can then be used to predictively maintain roads and proactively manage assets while improving operations and traffic efficiency by identifying anomalies and bottlenecks as they occur.

Level 3 on the intelligent infrastructure maturity scale would be analogous to SAE's Level 3 for conditional automation. At this level, which we dub "Cognitive", the intelligent infrastructure begins to apply a broad base of AI techniques on richer sets of contextual data from sensors to passively digitalized "analog" elements operating on the infrastructure and around its surroundings such as pedestrians and buildings. This level of infrastructure capability also entails the application of machine learning and robotics/RPA (Robotic Process Automation) for the intelligent automation of operational functions and tasks.

We envision a Level 4 intelligent infrastructure will achieve integrated analytics and advanced perception capabilities through the fusion of sensor functions and big data sets providing novel insights for deep situational awareness. Data elements such as continually monitored microclimate data can be integrated with high-fidelity road condition data and real-time traffic telemetry to provide granular and situation-driven digital services to support autonomous and non-autonomous vehicles operating in a locale.

At Level 5, infrastructure operators can realize intelligent orchestration and closed-loop control capabilities across the infrastructure that can be applied to operational activities such as traffic management and safety functions. Networks of "orchestration bots" (virtual infrastructure management agents) could adaptively coordinate and optimize infrastructure services, resources, and client vehicles of diverse automation maturity through the application of advanced AI technologies and novel federated computing architectures.

In many ways, intelligent transportation infrastructure is an accelerator for the digitization of transportation and a scalable way of dealing with the "legacy" issue that the auto industry and the transportation systems will have to reckon with for the foreseeable future. In this regard, the intelligent transportation infrastructure will shoulder and raise the lowest common denominator of intelligent capability in any situation and location through the active and passive digitization of the road and everything on it.

As an intelligent transportation infrastructure rides up the maturity curve, the possibilities for novel transportation support services that can augment safety, improve traffic efficiency, and enhance the vehicular mobility experience appear closer than they might have in our imagination.

The role of mobile wireless connectivity – team spirit

The future of transportation is digital and intelligent. Holistically, the intelligent transportation system will be a highly distributed computing environment. Compute and workloads will be distributed across vehicles, traffic lights, digital signs and on sensors that will proliferate across our increasingly intelligent transportation infrastructures. The one thing that will make distributed computing for transportation uniquely challenging is its demanding requirements for mobile computing.

For this reason, mobile wireless connectivity will have an essential role in shaping the future of the car, the infrastructure and vehicular transportation as a whole. For the promises of the autonomous vehicle to be realized, all things that can communicate will need to communicate with one another. Imagine self-organizing, self-managing clusters of digital system of systems in which the car interfaces with other vehicles in proximity and with shared services provided by an intelligent transportation infrastructure.

5G is unique among communications technologies in addressing these requirements. Its DNA is mobile by nature. Features such as CV2X (cellular vehicle-to-everything) communication are geared toward enabling everything in the transportation system to communicate with one another. All connected and intelligent elements in an environment will be able to participate in swarm intelligence that supports localized and macro-scale

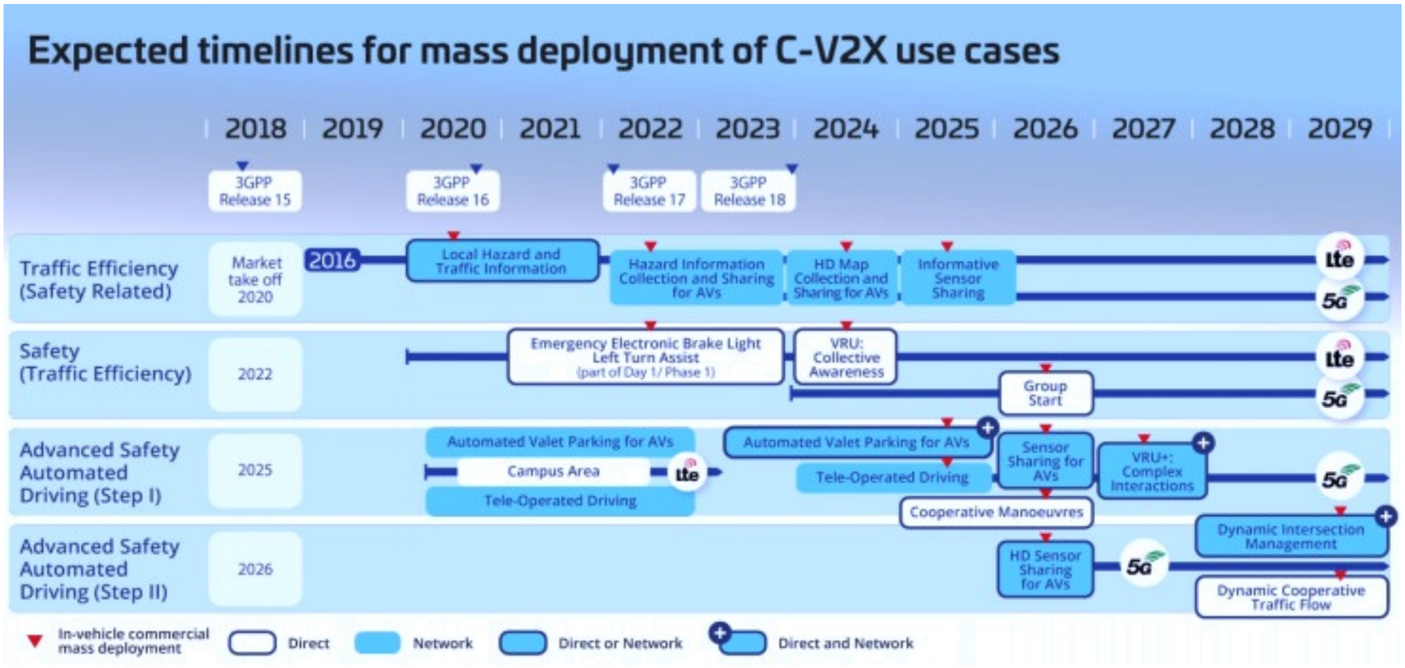


Figure 3: C-V2X Roadmap Source: 5GAA

collaborative functions such as real-time traffic flow optimization and adaptive fleet and resource orchestration.

615,000

Number of motor vehicle crashes that could be prevented using V2V technology

Source: NHTSA

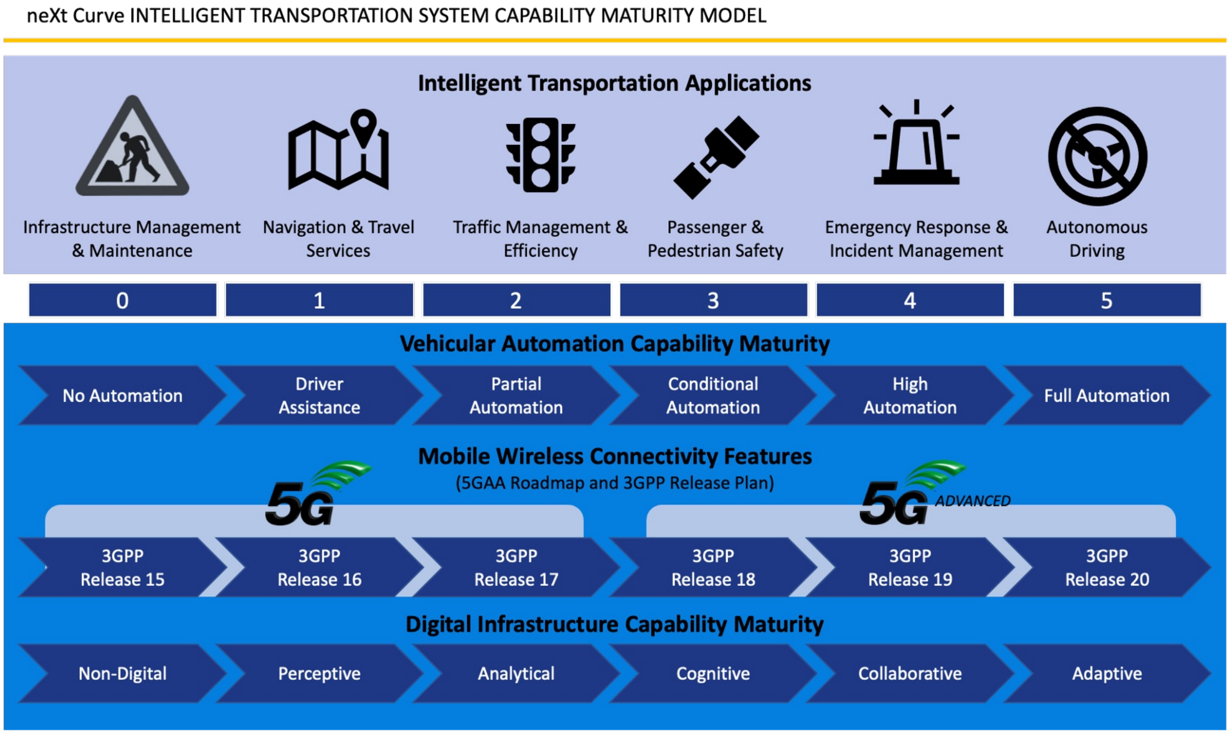
As the 3GPP continues to evolve the global standard for mobile wireless communications, it has and is specifying industry-specific features in collaboration with the auto industry via the 5GAA (5G Automotive Association). Not only is this consortium advancing the CV2X roadmap, it is looking at how the broader 5G feature sets for URLLC (Ultra-Reliable Low-Latency Communications), eMBB (enhanced Mobile Broadband), and mMTC (massive Machine Type Communications) can be leveraged to accelerate the mobile computing model for the various V2X (vehicle-to-everything) distributed computing scenarios which include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P).

The C-V2X roadmap includes important features such as cooperative maneuvers and sensor sharing to catalyze valuable safety enhancing applications. The most common C-V2X safety scenario is one in which a vehicle approaching an intersection equipped with smart connected cameras and sensors can identify oncoming traffic and pedestrians and notify all parties of potential hazards in real time.[9]

While mmWave deployments have taken a bit of a back seat as operators have focused on coverage in the early stage of their 5G network rollouts, the use of high band frequencies will open an exciting frontier of distributed mobile computing applications for transportation that will capitalize on massive bandwidth coupled with sub-5 millisecond latency and industrial-grade reliability.

As 5G continues to advance along the 3GPP roadmap, it will influence how intelligent transportation applications will be architected. It will also factor into how and where compute will be placed along the central and edge cloud continuum and on a multitude of endpoint devices ranging from cars, sensors, and smart cameras that will eventually line thoroughfares around the globe.

Over time, 5G will enable critical capabilities for the intelligent transportation system.



Source: 5GAA, 3GPP, SAE, US DOT, Anas FS Grupo Italiane, neXt Curve analysis

Figure 4: Intelligent Transportation System Capability Maturity Model

- Edge Compute Elasticity – As 5G networks mature and expand coverage, increasingly high-performance shared computing models across the edge and the edge cloud continuum become more technically viable especially with the introduction of mmWave. Examples of emerging shared computing applications include federated learning across cloudlets (edge cloud nodes) at the edge of the network, and new mechanisms for offloading compute-intensive mobile workloads from a vehicle or battery-powered infrastructure element to cloudlets within serviceable proximity.
- Service Extensibility – 5G networks will provide a mobile communications channel for 3rd party service providers to interface with vehicles and the intelligent transportation infrastructure. Examples include an insurance company capturing telemetry data or a weather agency publishing an informational service and content to vehicles or the intelligent infrastructure.
- Resiliency & Deterministic Networking – With the advent of 3GPP Release 16 and the 5G core network comes deterministic and time-sensitive networking. These industrial grade features differentiate 5G from its "best-effort sibling" LTE and any other wireless technology. Mobile networks supporting intelligent transportation will be capable of highly reliable and resilient communications for mission critical applications and collaborative functions needed to advance our march toward the fully autonomous car.
- Improved Distributed Computing Economics – As 5G advances in capability, features and coverage, it will have an outsized influence on the economics of distributed computing. 5G's promise to bring massive communications capacity to mobile computing networks and dramatically reduce the cost per gigabit will make a broader range of workload placement strategies and distributed computing architectures economically viable than they are today and have been in the past. Consequently, progressively favorable economics will provide developers with welcome flexibility for how they can design, deploy and deliver intelligent transportation applications.

The future is here and will be unevenly distributed

Much like broadband access, the availability of intelligent transportation services will be unevenly and unequally distributed. Vehicles on the road will also be a mixed bag of automation capability for a long time to come. These realities lend to a deep fragmentation in digital maturity and connectivity across intelligent transportation systems that will pose daunting challenges for the industry and the engineers designing the transportation systems of today and tomorrow.

For these reasons, the intelligent transportation systems that we are designing for today and the future will need to be able to handle a wide range of service and computing modalities depending on the technical capabilities and compatibility of the elements of the system in any given location. These factors will determine the level and quality of intelligence that can be achieved in aggregate to realize benefits such as improved safety and contextual support for autonomous driving. There will be a lowest common denominator. The intelligent transportation system will need to recognize it while maximizing service levels and benefits that a system can deliver based on available resources and technical maturity in a locale.

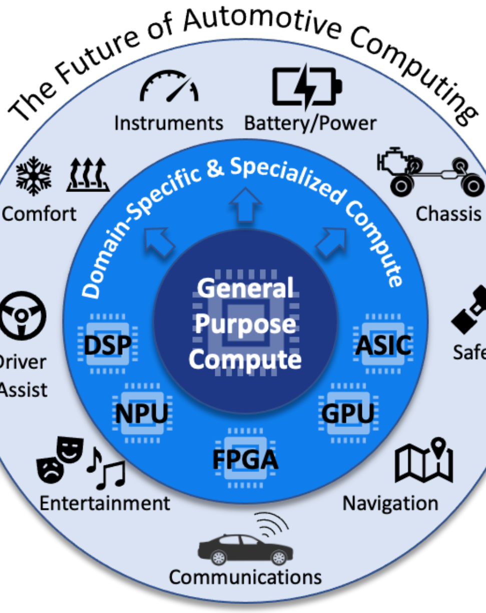
Simply put, no context, situation or location will be the same. The capabilities of an intelligent transportation system will differ from cubic meter to cubic meter depending on the capability of mobile elements passing through an area of service. This lumpiness will matter as many mission-critical functions will require precise spatial and location information possibly down to the cubic inch.

Advanced intelligent transportation systems will have to orchestrate resources and services considering these varying and dynamic constraints. For example, rural areas will likely suffer lower quality of connectivity and infrastructure services than in dense urban centers where the service level and capability requirements are much higher and more economically feasible for transportation infrastructure operators and mobile network operators to provide.

Vehicles operating in these variegated environments will need to be able to adjust their mode of operation based the availability and level of service in a location. The overall system will need to manage the various dependencies in real-time. Not simple stuff.

The next chapter in mobile computing

The future of automotive computing is the next frontier for mobile computing. The automotive and transportation industries can learn much from mobile network operators, mobile device manufacturers and the technology companies that have grappled with similar challenges facing the intelligent transportation system as mobile computing and the networks that support it have evolved from one "G" to the next over the decades.



Source: neXt Curve analysis

Figure 5: The Future of Automotive Computing

With the advent of the electric vehicle, we are seeing the car evolve into a device that shares many characteristics of the smartphone. We are also witnessing the rapid rethinking of the digital and electronic architecture of the car.

Leading semiconductor companies who are partnering closely with automakers are now proposing system reference architectures and designs that amount to what can be considered a "digital chassis".[10] The core of this proposition is to transcend the vehicle's electronics from its current embedded systems architecture to one that is more general-purpose compute based.

With EVs we are witnessing the emergence of novel electronic system architectures that take advantage of newer in-vehicle networking technologies and topologies. Automotive ethernet is one such technology that can provide the super-fast, deterministic communications for handling the massive data bandwidth required of LIDAR sensor systems and ADAS functions with mission critical reliability and latency.[11]

The digital chassis platform architecture also proposes to reduce the number of electronic control units (ECUs) in today's vehicles by enabling more centralized compute architectures. The SoCs (system on chip) at the center of this new vision for vehicular compute architecture are comprised of multiple CPU cores and an expanding range of specialized processors all tightly interconnected using advanced integration and packaging technologies and techniques.

These powerful and versatile chips are fostering the simplification of vehicular control systems and the reduction of the current cost of complexity. At the same time, these SoCs and the novel architectures that they enable provide flexibility in the way that the electronic and digital systems of a vehicle can be designed with the power efficiency and performance of leading-edge silicon.

This flexibility could be a welcome benefit to auto manufacturers who are currently facing persistent electronics supply chain issues. In large part, the "chip shortage" impacts modules and components that use chips manufactured in legacy process nodes. Emerging "digital chassis" architectures are designed around leading-edge chips that are not facing the supply and fab capacity constraints of legacy node devices.

Much like mobile computing of today and of the past, intelligent transportation systems will become increasingly diverse and technologically heterogenous computing environments. It will be a massive digital system of systems with mobile communications serving as a vital overlay that allows all the highly distributed and mobile elements of the intelligent transportation system to interface and collaborate with the real time connectivity, industrial reliability, and massive capacity that 5G will bring over time.

Finally, for the car of the present and future to interoperate with intelligent transportation systems globally, standardization will be essential as it has been for the advancement of the mobile wireless industry and technologies. The intelligent transportation system will also need to deal with the complexities of supporting multiple generations of network, infrastructure and vehicular technologies and services over years and decades.

There is little question that 5G and subsequent Gs will play an essential role in how and how quickly intelligent transportation systems will transform the auto industry, advance autonomous mobility, and enhance our mobile lives. The future of transportation is mobile computing.

Conclusion

The transportation system of our imagination is just an aspiration. Our pursuit of it will be a long journey populated with transformative opportunities for improving safety, traffic efficiency, and many other objectives we have set in our minds for the future of the car and transportation overall.

The automotive industry cannot evolve the car with a myopic lens focused only on the vehicle itself. The objectives and aspirations that we have for the future of the car depend on infrastructure that will be a vital partner in realizing intelligent transportation systems of tomorrow.

The future of transportation systems will be accelerated by catalytic technologies that drive the digital maturity of the car, infrastructure, and connectivity. In large part, those technologies are already in the works in today's mobile computing universe that is anchored on the mobile wireless infrastructures and technologies that have achieved global standardization thanks to 3GPP.

The task now is to engineer intelligent transportation systems that can manage the growing technological complexity that comes with mobile computing and can deliver digitally enhanced transportation services on top of that complexity. This requires holistic design thinking that considers the state of the art and economics of transportation infrastructure, communications, and vehicular technologies.

The Research Team

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Mr. Lee is the founder of the research advisory firm neXt Curve. Drawing upon over twenty-five years as a managing partner, principal consultant, and industry analyst with Gartner, IBM, PwC and EY, Leonard has advised and delivered emerging technology and business solutions to leading enterprises across a broad range of industries. His perspective is shaped by extensive experience helping Global 500 companies drive business innovation and value through digital technologies and assisting top technology vendors with their go-to-market strategies for their digital products and services.

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