# The Driven Hour

## It's time to get more realistic about Connected Cars and the volume of data that they will generate.

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## Executive summary

Connected Vehicles are considered to be one of the major drivers for investment in cellular communications technologies with forecasts projecting every new vehicle produced being 'connected' by 2025[1].

What does this mean with respect to the impact on communications networks? What are the applications driving the growth in data and what data volumes will network operators be expected to transport?

The paper examines today's Connected Cars, to consider the range of applications being used to provide information to the vehicle manufacturers, those designed for the consumer and the data volumes vehicles will generate and consume. The paper looks forward to the next generation of vehicles, past the hype of '4TB per day' to understand what future applications may look like and what data volumes will these produce.

As this paper illustrates, Connected Vehicles will generate significant volumes of data but:

a) most of the data will be consumed within the vehicle

b) only a 'valuable' subset of the data will be transmitted

c) the commuter vehicle duty-cycle data volume will be roughly ~8GB, not the 4TB figure initially suggested.

Transferring data comes at a cost - as the number of Connected Vehicles and data volumes increase, network operators and vehicle manufacturers will need to make certain considerations to support vehicles of a global scale. However, this is only one element of the data transport and processing pipeline between the vehicle and the vehicle manufacturer's data centres. The cost of data needs to be considered in a broader, more holistic context, since the cost of cloud-based computing solutions includes not just the compute but storage and data transmission from the cloud.

[1] https://www.gsma.com/iot//wp-content/uploads/2013/06/cl_ma_forecast_06_13.pdf

## Introduction

Next-generation cellular network technology is on the horizon in the form of 5G. The technology's deployment and the associated use-cases are dominating the agenda for many service providers around the world.

Connected Vehicles are often mentioned as being a major driver for 5G, especially with respect to the provision of low-latency communications for safety-related use-cases. With the 5G capability to provide 'network slicing,' it is likely that automotive manufacturers will be attracted to such offerings with a view to improved security, resource allocation and service differentiation.

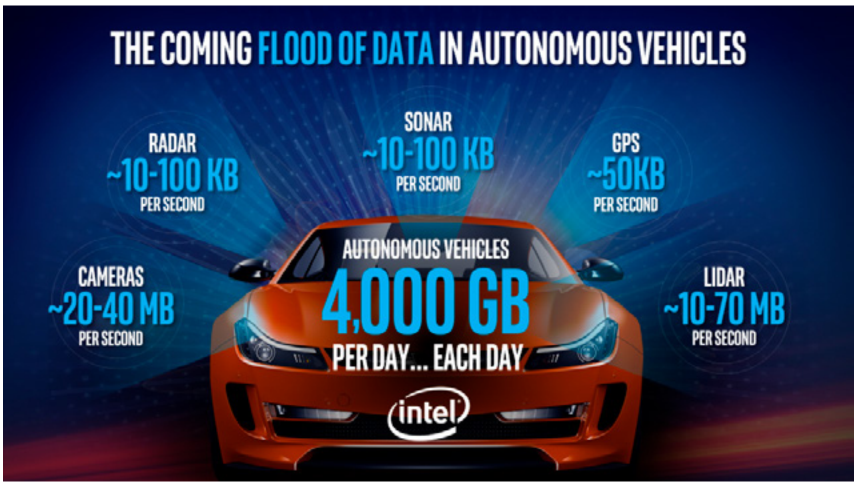
While viable business models for the support of safety-related use-cases are still to be defined, modern vehicles are already connected to service provider networks using cellular technology for a range of applications. This paper will provide a deeper view of 'Connected Vehicles' with the intent to inform the discussion around their impact on 5G architectures by providing an insight into the data volumes that Connected Vehicles generate today and what that might look like in the near future.

## The driven hour

It's time to get more realistic about Connected Cars and the volume of data that they will generate.

In 2016, Intel presented a slide[2], suggesting that autonomous vehicles will generate 4TB of data per day. This was a wonderful 'sticky' number that is still quoted in the press today.

Figure 1: Intel's 4TB picture




[2] https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/

What was lost from the message was that the vast majority of this data never leaves the vehicle. Moreover, the 4TB data volume pertained to research and development vehicles rather than regular production vehicles.

While there is no doubt that future production vehicles will generate increasing amounts of data, what must be remembered is that much of the data generated from an array of sensors and electronic control units within the vehicle will be recorded and processed locally, with the majority of the information being discarded. Only a subset of the overall data, that which is valuable, will be transmitted back toward the vehicle manufacturer.

In this paper, we'll explore the variety of applications that generate the data streams to and from the Connected Car, in order to better understand the load that will be placed on communication networks.

Vehicle telemetry can offer the manufacturer significant insights into the operational behaviour and performance of the vehicle, as well as the ability to understand their customer base in greater detail. The data may also open other business relationships such as vehicle insurance (own or partnered) and shared mobility services. Telemetry can reveal if the windscreen wipers are used, and if so, how often. It can reveal if particular features within the vehicle are being used or not – which may then help the manufacturer to determine if they should continue to develop a particular feature or potentially withdraw it. In addition, to some vehicle manufacturers, the collection of telemetry information combined with data from sensors such as cameras, is extremely valuable in helping to provide 'training data'[3] for Advanced Driver Assistance Services (ADAS) and systems that may offer forms of automated driving (SAE Levels[4] 3, 4 & 5) in the future.

Alongside the use of vehicle data by the vehicle manufacturers is the burgeoning market for this data. The McKinsey report[5] from late 2016 estimated the revenue from vehicle data monetisation could be as high as $750 billion by 2030.

For vehicle manufacturers who are interested in broadening their income streams, this is a significant area of interest.

While vehicle telemetry monitoring may appear to be a valuable service to the owner/user of the vehicle, the greatest value is perhaps to the vehicle manufacturer themselves in the ability to gather information from the vehicle fleet. This information has applications in vehicle manufacture and supply chain. This can be vital in helping manage the number of vehicles impacted by recall notices[6] and the associated warranty costs. According to the study[5], the number of recalls related to electronic and electrical systems has risen nearly 30 percent per year since 2013, compared with 5 percent annual increases from 2007 to 2013. With the increasing 'software-isation' of vehicles, with some vehicles now having well over 100 million lines of code, detecting and mitigating issues that may impact the vehicle fleet is of vital importance to the manufacturers.

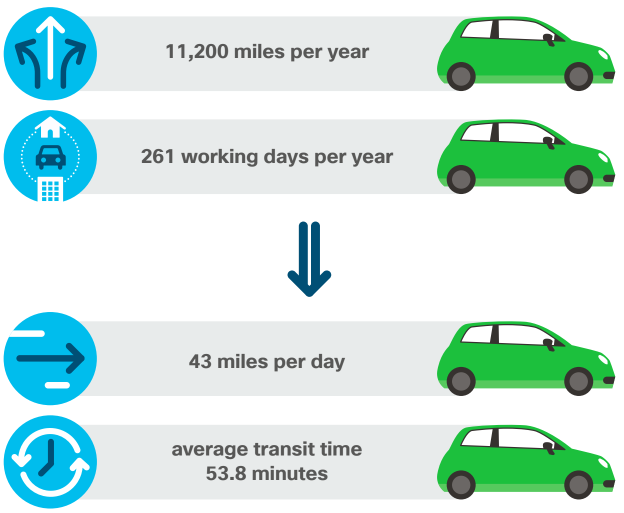
> **"While there is no doubt that future production vehicles will generate increasing amounts of data, only a subset, that which is valuable, will be transmitted back toward the vehicle manufacturer."**

[3] https://www.tesla.com/about/legal
[4] https://blog.ansi.org/2018/09/sae-levels-driving-automation-j-3016-2018/#gref
[5] https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Monetizing%20car%20data/Monetizing-car-data.ashx
[6] https://www.alixpartners.com/insights-impact/insights/the-auto-industrys-growing-recall-problem-and-how-to-fix-it/?press#sm.00008828e18u0dqnzv624pahcttr1

## What is a 'day'?

When considering Intel's slide with the headline figure of 4TB per day, an important question to ask is, what is a 'day'? For the automotive industry, a 'day' is the usage period of that vehicle within a 24-hour period (also known as the 'duty cycle'). In the United States, the average personal light vehicle travels just over 11,200 miles per year[7]. With an average of 261 working days per year, this equates to a distance of approximately 43 miles per day, with an average transit time of 53.8 minutes[8].

Figure 2: Travel data for the average personal light vehicle (US)




In the discussion about how much data vehicles generate, we need to bear in mind that our roads carry a wide variety of vehicles, from heavy-duty freight haulage to public transit services and motorcycles. The duty cycle for these vehicles varies widely, with public transport and freight vehicles needing to be in operation for a significant portion of a 24-hour period. The term 'per-day' therefore needs to be put in perspective. Instead, we need to understand the usage pattern and determine data volume 'per-duty-cycle' of any given vehicle.

## Let me 'infotain' you

In-car entertainment, or what is known as In-Vehicle Infotainment[9] is one of a set of applications that may contribute to the download data stream. As with other forms of consumer entertainment, the methods by which consumers access their entertainment has changed and will continue to change. Not that long ago, many cars were fitted with a CD player as part of the integrated car audio system. That is now relatively rare with that media being replaced by a USB port or a Bluetooth interface to enable the use of media streamed from a paired device. The in-vehicle infotainment unit continues to evolve with many including high-resolution touch-screen capabilities, an automotive navigation system[10], some offering broadcast television receiving functions and more advanced solutions including the ability to run smartphone-like applications.

In the Automotive industry, a debate about the vehicle manufacturers role in the infotainment value-chain is underway. One camp offers the position that the vehicle manufacturer has no real role to play anymore. The car can be considered to be an advanced paired Bluetooth accessory, enabling the user to play media from a connected personal communications device with some infotainment systems offering connection solutions such as Apple Carplay[11] and Android Auto[12]. Further, that navigation services will be delivered to the connected personal device, doing away with the need to offer an integrated navigation service within the vehicle. A key tenant of this approach is that the user pays for their consumption of media and navigation services, using their personal data plan associated with their personal communications device.

The alternative position suggests that the vehicle manufacturer can participate in the infotainment value-chain, offering a variety of integrated and connected experiences, with infotainment systems that include versions of applications such as Spotify[13] and Google Maps.

[7] https://afdc.energy.gov/data/10309
[8] https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_1YR_S0801&prodType=table
[9] https://en.wikipedia.org/wiki/In-car_entertainment
[10] https://en.wikipedia.org/wiki/Automotive_navigation_system
[11] https://www.apple.com/ios/carplay/
[12] https://www.android.com/auto/
[13] https://support.spotify.com/us/article/volvo/

Some vehicle manufacturers include such services as part of cellular data plans that the owner may purchase[14], independent of any personal communications device that they may own, while others include a cellular data plan as part of the initial purchase, with a data plan renewal being offered after an initial period (often 1-3 years). In some cases, the vehicle manufacturer will install a specific cellular modem for these services. Again, the user is paying for the data, directly or indirectly. By being in the value-chain, the vehicle manufacturer may be able to obtain additional revenues by monetising their customer base.

In respect to the data volume to and from the vehicle, with infotainment being delivered via the user's communication device, the data stream is from the cellular service providers to the communications device. As a result, this does not contribute to the vehicle data volume. If the media is delivered via an integrated infotainment system, the data-flow is often from the infotainment service provider (such as Spotify) via the vehicle manufacturers digital real-estate, through the cellular service provider and on to the vehicle. In some cases, the data stream may be from the infotainment service provider through the cellular service provider and on to the vehicle. In the latter approach, the vehicle manufacturer is out of the chain and therefore unable to monetise the data stream.

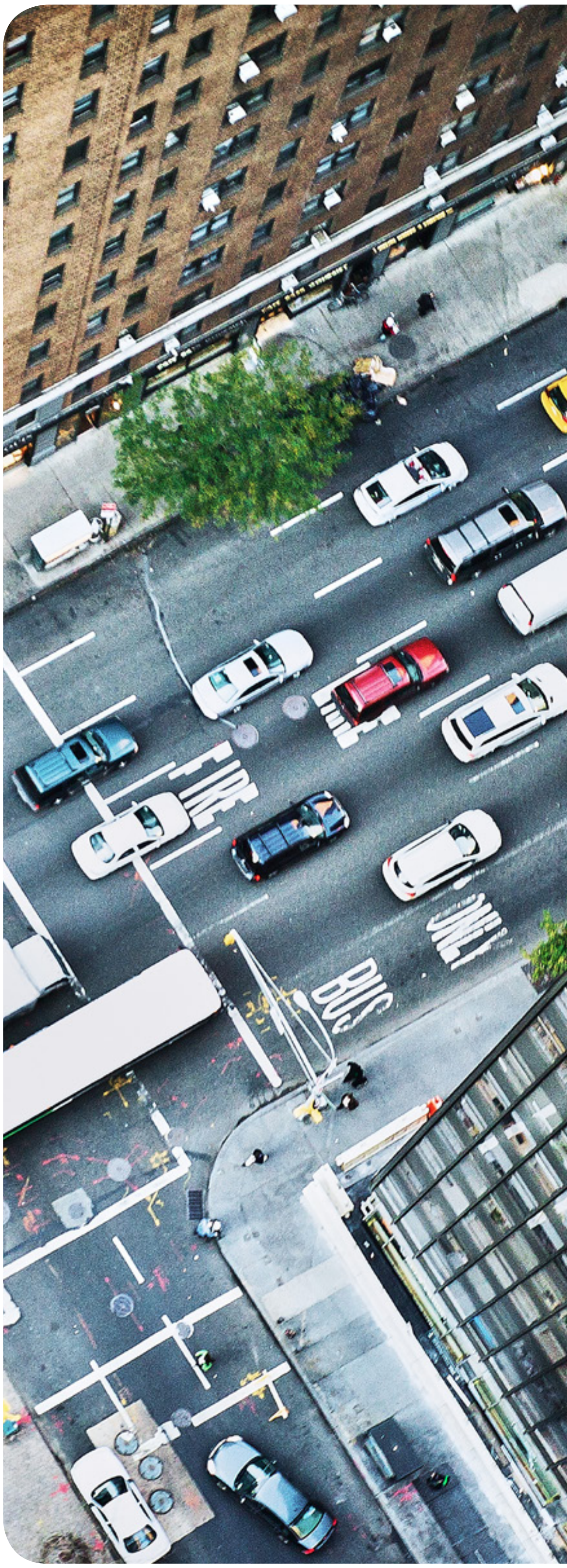
So, what does the data stream volume for these services look like? Spotify offers a good example of a popular music platform that offers adaptive streams where the 'quality' of the stream can change based on the quality and bandwidth of the network connection. With streams ranging from 96kbps to 320kbps, the data volume being sent to the vehicle (or connected communications device) equates to 40MB/hour to 150MB/hour[15]. It is key to note that the primary direction is from the cloud to the streaming client application.

Companies like Spotify[16] are rumoured to be investing in a 'connected' media experience, however, is cellular coverage sufficient to support mass usage of streaming media on the move? Will consumers need to change their data-plans and potentially pay more per month to support this, or will they download content (via WiFi) for use in the vehicle and listen 'offline'?

When considering navigation services, one must consider that many integrated solutions retain map information on local storage within the vehicle (such as a flash drive). Periodic map updates may be provided to the vehicle over a cellular connection. Others rely on the vehicle being serviced, with a garage technician performing an update operation. However, 'layer information' such as live traffic congestion updates and road construction notifications are received by the vehicle over the integrated cellular interface. According to TomTom[17], such layer information updates constitute ~7MB of data per month (233KB per day). Vehicles (and smartphones) also contribute to the collection of traffic information not only through vehicle telemetry (discussed later in this paper) but also through methods such as 'Floating Car data'[18], that use the integrated cellular connection to determine location, speed and direction of travel.

'Live' navigation services may be included in the vehicle's infotainment system or operate on a personal communications device. Google Maps, as an example, uses about 0.67MB of data every 10 miles and 0.73MB of mobile data for every 20 minutes[19]. With the average one-way commute in the United States taking ~26 minutes[20] with a distance of 21.5 miles, the result is a download of ~2.419MB. Live traffic information is derived from the GPS-determined location of the devices using the Google Maps application[21].

[14] https://www.att.com/plans/connected-car/volvo.html
[15] https://www.whistleout.com/CellPhones/Guides/How-Much-Data-Does-Spotify-Use
[16] https://www.theverge.com/2019/1/18/18188523/spotify-in-car-music-player-release-date-price
[17] http://us.support.tomtom.com/app/answers/detail/a_id/4355/~/how-much-data-usage-does-tomtom-traffic-generate%3F
[18] https://en.wikipedia.org/wiki/Floating_car_data
[19] https://www.whistleout.com/CellPhones/Guides/How-Much-Data-Does-Google-Maps-Use
[20] https://storage.googleapis.com/titlemax-media/2018/03/average-commute-to-work-by-state-city-9_compressed.jpg
[21] https://en.wikipedia.org/wiki/Google_Traffic



# Vehicle services

Alongside the infotainment services that driver and passengers may make use of, are an increasing range of applications that the vehicle manufacturers offer. These also contribute to the overall data volume that a vehicle will generate.

Some vehicle manufacturers such as Jaguar, provide additional information services to the vehicle owner/user. For example, the InControl[22] service includes the ability to report completed journeys. This function[23] provides the customer with information about their journeys using data sent from the vehicle including the journey distance, real-time location, the duration of the journey, the average speed and data about the efficiency of the journey.

The information required to offer this function is derived from existing vehicle telemetry that is collected by the vehicle manufacturer. Such information forms a small part of the overall vehicle telemetry that is sent over a cellular connection to the vehicle manufacturer.

A growing number of manufacturers offer ‘remote-control functions’ using a cellular connection, enabling users to perform such functions as enable the heating/air-conditioning, lock or unlock the vehicle, sound the horn, flash the headlamps, check the fuel level or battery charge and effective range, check current location etc. More advanced functions include ‘summoning’[24] the vehicle, however, these services require a relatively small data exchange between the vehicle and the vehicle manufacturer’s data centre.

Some vehicle manufacturers such as Tesla[25] are known to use software and firmware update over-the-air today, with companies such as Ford and GM[26] expected to follow suit in the near future. In some cases, these updates are delivered via a cellular connection. In others, WiFi can be used as an alternative delivery method. Anecdotal reports from various driver forums suggest that for Tesla vehicles, the full version updates take place roughly every 6 months, with the version 9.0 update required a download of approximately 1GB. Periodic firmware updates also occur but these are unannounced and are much smaller in size (100-150MB). Over-the-air updates are of significant value to vehicle manufacturers in addressing potential defects or in delivering new capabilities to a vehicle, post-sale. Discussions with a small sample of vehicle manufacturers have identified that some are currently reluctant to use over-the-air updates for anything other than updates to non-safety related software such as infotainment services due to concerns about managing the associated risk.

[22] https://d3370ejym0x8p5.cloudfront.net/static/docs/manuals/owner/MyJaguarLandRoverInControlManual_en_GB.pdf

[23] https://incontrol.jaguar.com/jaguar-portal-owner-web/about/privacy-policy/GBR

[24] https://www.tesla.com/en_GB/blog/summon-your-Tesla-your-phone?redirect=no

[25] https://www.tesla.com/en_GB/support/software-updates?redirect=no

[26] https://www.consumerreports.org/automotive-technology/automakers-embrace-over-the-air-updates-can-we-trust-digital-car-repair/

# What is your vehicle reporting?

Vehicle manufacturers are increasingly building their vehicles to be 'connected', meaning that they are able to report information back to the manufacturer once the vehicle is in operation. Some manufacturers will gather such information for a limited period of time (typically covering the warranty period) but some intend to gather information throughout the lifetime of the vehicle.

In the case of Jaguar[27], such vehicle telemetry includes information relating to the vehicle being involved in an accident such as the fact that the airbags have been deployed or the sensors have been activated. Further data includes the fuel amount, the distance to empty status, the odometer value, the distance to service status, the coolant level, the washer fluid level, the brake fluid status, the brake pad wear, the tyre pressure, tyre pressure sensor failure, engine malfunction, the oil level, the door and window status, if seatbelts are buckled or not, and information from any sensors, for example in the car, on the steering wheel, or from camera information, including if the cab is open, boot open, bonnet open status, battery information including voltage, emissions information and whether the alarm is armed or sounding.

In cases such as a detected fault condition, the information including Diagnostic Trouble Codes[29] (DTC) will be recorded to local storage within the vehicle. This can subsequently be used by service engineers to determine the fault condition that was encountered. Some vehicles will send a summary fault report to the vehicle manufacturer, as well. As more sensors are added to vehicles, not only will vehicle manufacturers gather information about the performance and operation of the vehicle itself but may also gather data generated from the sensors themselves[30]. This does not mean that such data is gathered continuously but rather that vehicle systems may transmit a form of the sensor data in cases of 'interest' such as an accident or an unexpected set of telemetry data being recorded. Such information is of interest to not only the vehicle makers but potentially to organisations such as insurance companies.

As one can see from the information collection details, the manufacturers are collecting far more information than just fault conditions. The position and movement information can include details such as braking and acceleration styles. Traction-control indications can help determine road conditions at a location. Some vehicle makers and mapping service providers are starting to use such information to identify roadway hazards such as potholes[31].

Table 1: Data sets gathered by BMW[28]

| Type of data | Examples of information collected |
|---|---|
| **Vehicle status** | Mileage, battery voltage, door and hatch status |
| **Position and movement** | Time, position, speed |
| **Vehicle service** | Due date of next service visit, oil level, brake wear |
| **Dynamic traffic** | Traffic jams, obstacles, signs, parking spaces |
| **Environmental** | Temperature, rain |
| **User profile** | Personal profile picture/avatar, settings as navigation, media, communication, driver's position, climate/light, driver assistance |
| **Sensor** | Radar, ultrasonic devices, gestures, voice |

27 https://d3370ejym0x8p5.cloudfront.net/static/docs/manuals/owner/MyJaguarLandRoverInControlManual_en_GB.pdf

28 https://btcapiwebappeu.azurewebsites.net/api/gateway/contentserver/staticcontent/Angular/gdpr/v2/?target=bmw-browser#/legal-docs-content?version=2018.11.08-2&fileName=Bmw_cd_pp_gb-en.json

29 https://en.wikipedia.org/wiki/On-board_diagnostics#EOBD_fault_codes

30 https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/

31 https://360.here.com/2015/06/23/here-sensor-data-ingestion/

Such services are designed of course, on the premise of having cellular connectivity coverage. However, very few countries are able to provide ubiquitous coverages. A 2017 report[32] noted that the United Kingdom had 91% coverage of national highways but a much lower 58% coverage of non-highway classed roadways. A 2017 report[33] indicates that most major urban areas in the United States have good cellular coverage but with the large geography covered by the US highway system, there are still many locations where cellular services are patchy at best.

From a vehicle manufacturer's perspective, one cannot rely on universal cellular coverage. As a result, applications need to be designed to operate on the premise that connectivity may or may not be available and therefore vehicle systems need to include the ability to store critical data locally, transmitting valuable information when connectivity is restored.

# Data volume today

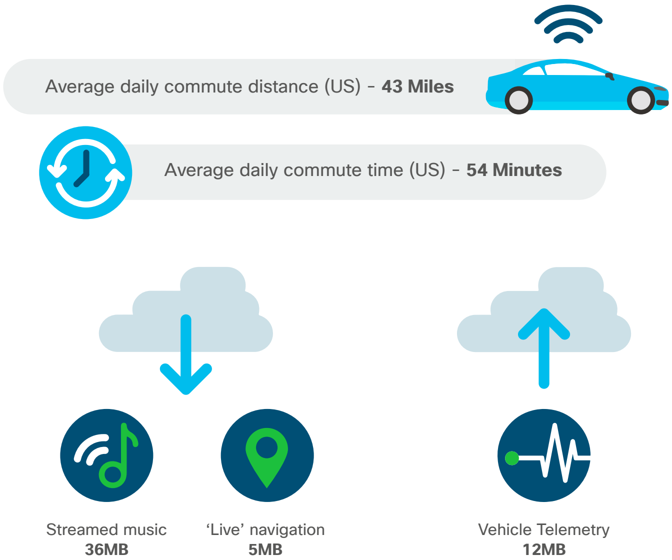
How much information is the vehicle transmitting to the vehicle manufacturer and when is it taking place? The data volume varies from manufacturer to manufacturer and will also depend on the type and model of the vehicle.

A study performed by ADAC[34] in 2016 identified that the BMW i3 electric vehicle transmits the 'Last State Call' automatically every time the driver switches off the car and locks the doors (vehicle is not in motion). This call includes the content of the error memory, battery details including cell temperatures and charge level, the driving mode (eco, eco plus, sport), operational data of the range extender, the mileage at various driving operations, quality of the charging point including malfunctions and the position of the last 16 charging points used.

Key to note in the BMW case is that some information is obtained while the vehicle is in motion, with other information being collected at the end of the journey. Information provided by OEM A (a Japanese auto-maker) indicates that their personal light vehicles generate a report of ~10-15MB per duty-cycle.

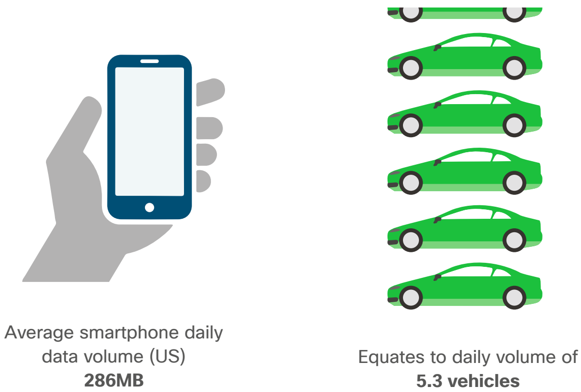
This is collected on a monthly basis in an upload over a cellular LTE connection. Information from OEM B (a Japanese auto-maker) indicates a volume of 15-20MB per duty-cycle collected while the vehicle is in operation where the average 'driven-day' in Japan is ~90 minutes, equating to a US duty-cycle volume of ~12MB.

Figure 3: The daily commute




How does this compare to the typical smartphone users? According to a 2018 report[35], monthly mobile data traffic per smartphone in North America reached 8.6GB (286MB per day) by the end of 2018.

Figure 4: Smartphone vs Car




[32] https://www.ofcom.org.uk/__data/assets/pdf_file/0018/108513/connected-nations-mobile-2017.pdf
[33] https://opensignal.com/reports/2017/02/usa/state-of-the-mobile-network
[34] http://www.eenewsautomotive.com/news/which-data-do-oems-collect-connected-cars
[35] https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-november-2018.pdf

# What will the data consist of tomorrow?

As vehicle manufacturers increase the number of models within their vehicle fleets that are a) connected and b) carrying more data gathering capabilities from a range of different sensor types, one should expect that the data volumes that the manufacturers will gather will increase. In addition, new features and functionality will be added that will make use of network connectivity.

One of the major focus areas is safety – vehicle-to-vehicle, vehicle-to-infrastructure as well as vehicle-to-vulnerable road users, such as cyclists and pedestrians. There are many safety use-cases detailed by bodies such as the US NHTSA[36]. The onboard sensor sets in the vehicle will certainly contribute to the vehicle's own ability to detect and (potentially) avoid risk scenarios. The current technologies to support communication-based safety applications such as 'forward-collision warning' and 'blind intersection warning'[37], are centred on the use of Dedicated Short-Range Communications[38] (DSRC) and the emerging Cellular-Vehicle-to-Everything[39] (C-V2X). In such use-cases, latency is a vital component. In the case of DSRC, dedicated hardware is used for data communications to and from the vehicle. It is likely that C-V2X will also require a dedicated modem rather than trying to share bandwidth with a modem that is supporting infotainment services or vehicle telemetry. From the perspective of data-volume to the vehicle manufacturer, the safety data is exchanged over a different connectivity interface, however, it is very likely that indications will be recorded in the general vehicle telemetry.

A number of manufacturers have demonstrated or announced the integration of voice-control agents such as Amazon Alexa[40] and Google Assistant. Closer inspection appears to indicate that these integrations will require network connectivity to work and that they will provide a voice control to existing voice assistant functionality including smart home integrations. A number of vehicle manufacturers offer voice assistance integrations that enable capabilities such as checking the fuel level or enabling the heat or air-conditioning through existing APIs. In both the Alexa and Assistant cases, the waveform of the spoken command is transmitted for processing but this is a relatively small amount of data. And of course, it won't work if there is no network coverage! It is certainly reasonable to suggest that forms of voice control that do not require network connectivity could be integrated within the vehicle, offering the ability to adjust in-vehicle settings by voice such as cabin temperature or seat position. Manufacturers such as Byton[41] have announced their plan to offer gesture control capabilities. Once again, it is likely that the vehicle manufacturers will identify value in understanding how customers use these features so may well want to obtain associated telemetry.

High-definition mapping[42] is often mentioned with respect to next-generation vehicles. It is important to understand that while HD Maps provide fine-grain detail and precision accuracy, they are not intended for use by humans, rather they are intended for consumption by automated systems (machines). A complex mapping process is required in order to generate the various layers that comprise the map. As discussed previously, navigation solutions may be integrated into the vehicle or may be operating on a smartphone, with HD Map information being obtained via a cellular connection, downloaded to the navigation system while the vehicle is in motion. The volume of data for HD Map is higher than that of today's mapping solutions, such as Google Maps, with an estimate of 10MB per mile of roadway at a resolution of 5cm[43]. 'Human readable' or 'Standard Definition' maps can be generated from HD Map information, requiring ~1/4 of the data volume.

36 https://www.nhtsa.gov/
37 https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/readiness-of-v2v-technology-for-application-812014.pdf
38 https://en.wikipedia.org/wiki/Dedicated_short-range_communications
39 https://en.wikipedia.org/wiki/Vehicle-to-everything#3GPP_(C-V2X)
40 https://www.gearbrain.com/which-cars-have-amazon-alexa-2525958778.html
41 https://www.byton.com/m-byte-concept
42 https://www.geospatialworld.net/article/hd-maps-autonomous-vehicles/
43 http://www.roboticsproceedings.org/rss03/p16.pdf

While regular vehicles will be able to contribute updates to particular layers of the map, such as reporting temporal information like traffic congestion, they will not be involved in the creation and maintenance of the base-layer topology since this requires specialist equipment.

Another active area of development is that of Advanced Driver Assistance Services (ADAS). Many manufacturers offer capabilities such as Adaptive Cruise control, using sensor inputs to adjust the vehicles speed based on proximity to the vehicle in front. Others offer functions such as Traffic Jam assistance where below certain speeds, the vehicle will accelerate and brake according to the behaviour of the vehicle in front as well as staying in the traffic lane. TomTom[44] are exploring the intersection of HD Map information and ADAS, looking at how information such as high-definition lane closure information (identify which lane is closed) or obstruction information could be incorporated into driver support solutions. Such solutions will require network connectivity in order to receive the necessary temporal data.

Tesla's Autopilot[45] and Audi's Traffic Jam Pilot[46] both offer a series of driving capabilities under certain circumstances. More advanced capabilities demonstrated by projects such as Toyota's Guardian[47, 48] program show increasing levels of sophistication and ability. None of these solutions requires network connectivity to operate and today, are only able to operate under certain circumstances.

It is worth noting the use of inward-facing cameras as part of the Guardian solution to determine the driver's state of awareness. Such capabilities, known as Driver Monitoring Systems[49] (DMS), will become a significant component of ADAS solutions, especially as more advanced offerings will, rightly or wrongly, offer more opportunities for the driver to focus on things other than what the vehicle is doing. Euro NCAP, the European New Car Assessment Program, has stated in its 2017 report[50] that it will start testing DMS functions in 2020 with a requirement that by 2024, a vehicle must have such a system in order to obtain a '5-star' rating.

[44] https://www.automotiveworld.com/articles/hd-mapping-takes-adas-next-level-says-tomtom/

[45] https://www.tesla.com/en_GB/autopilot?redirect=no

[46] https://www.audi-technology-portal.de/en/electrics-electronics/driver-assistant-systems/audi-a8-audi-ai-traffic-jam-pilot

[47] https://www.digitaltrends.com/cars/toyota-guardian-autonomous-driving-system-ces-2019/

[48] https://www.youtube.com/watch?v=ajreRfot6co

[49] https://en.wikipedia.org/wiki/Driver_Monitoring_System

[50] https://cdn.euroncap.com/media/30700/euroncap-roadmap-2025-v4.pdf

The report produced by the Automotive Edge Compute Consortium[51] (AECC) details the 'Intelligent Driving' scenario (aka ADAS), outlines data collection from the vehicle of the driver, "including biometric sensor data and control data gathered from various sources including movement logs from in-vehicle sensors and on-board biometric sensors/cameras". It notes data processing within a cloud-based data centre, resulting in parameter updates being sent to the vehicle with a generated data volume of 7.5GB per-duty cycle, collected on a periodic basis. Even though it is likely that the range of circumstances under which ADAS capabilities can be used will increase over time, it is also feasible that for many vehicle users, their daily commute may not involve engaging these ADAS solutions. However, it is foreseeable that driver monitoring solutions could become a standard function enabled whenever the vehicle is in motion.

As the Intel slide presented at the beginning of this paper identified, the various sensors that manufacturers install within the vehicle will generate a considerable volume of data. The exact number of each sensor type can lead to a wide variation in the amount of data generated.

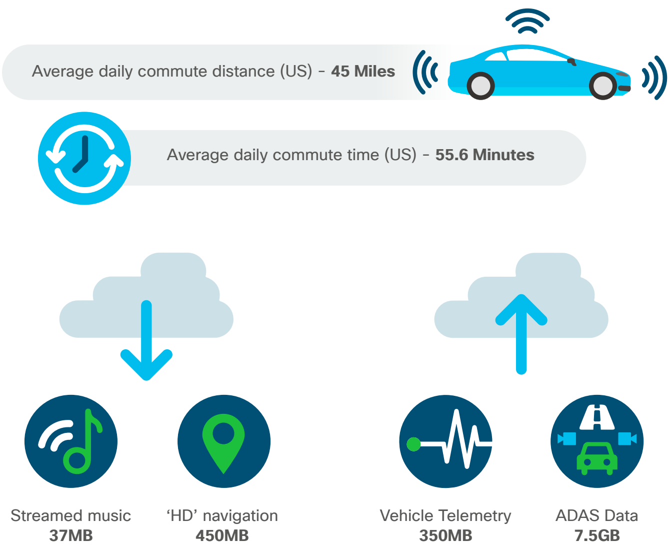
Table 2: Data volume by sensor type[52]

| Car Automation Sensors | | |
|---|---|---|
| **Sensor type** | **Quantity** | **Data generated per sensor** |
| Radar | 4-6 | 0.1-15 Mbit/s |
| LIDAR | 1-5 | 20-100 Mbit/s |
| Camera | 6-12 | 500-3500 Mbit/s |
| Ultrasonic | 8-16 | <0.01 Mbit/s |
| Vehicle motion, GNSS, IMU | - | <0.1 Mbit/s |

One must bear in mind that the raw data volume that is being generated is primarily processed within the vehicle since decision-making functionality needs to be executed within the vehicle. Only a subset will be transmitted back to the vehicle manufacturer.

Applications will be key to determining the data volume to and from the vehicle, vehicle telemetry and sensor data being just one such application. Actual numbers from vehicle manufacturers for future vehicles are hard to obtain, with various papers such as[53] suggesting next-generation vehicles sending 25GB per hour. Information provided by OEM A (a Japanese auto-maker) indicates that they intend to move towards a 'predictive health maintenance' suite of applications and in so doing, expect the data volume to increase from the current 10-15MB per duty-cycle to 50MB in 2020. This will rise towards 300-350MB per duty-cycle in 2022. Their '2nd-generation' Connected Cars are forecast to have a data collection volume in the 35-65GB per duty-cycle range. It is not known at this time as to how much of this data will be collected while the vehicle is in motion versus collected while stationary.

Figure 5: Data volume in 2023




[51] https://aecc.org/wp-content/uploads/2018/02/AECC_White_Paper.pdf
[52] https://www.flashmemorysummit.com/English/Collaterals/Proceedings/2017/20170808_FT12_Heinrich.pdf
[53] https://qz.com/344466/connected-cars-will-send-25-gigabytes-of-data-to-the-cloud-every-hour/

# What's the cost?

It will be tempting to gather more and more data from the vehicle. However, as the volumes increase, the costs associated with its transmission will become increasingly important, requiring vehicle manufacturers to determine who values the data and what the value of the data is. If the value is derived by the owner/user, it is likely that they will be expected to pay[54]. If the value is to the vehicle manufacturer, then the manufacturer will pay.

It is likely that there will be a set of data that manufacturers will want while the vehicle is in motion, such as vehicle telemetry and another set of data that can be recorded to local storage, such as processed sensor data. This can then be gathered at a later point in time – possibly using a WiFi or an Ethernet connection. If the information's value is not time-sensitive, it could be gathered when the vehicle is next serviced, assuming that there is sufficient storage capacity within the vehicle.

One example of 'valuable' data may come from vehicle insurance. In the case of an accident, it would be valuable to combine vehicle telemetry with camera images and Lidar plots from the period in time just before the accident.

The cost point of cellular connectivity may drive manufacturers to make a series of decisions:

- Is the data valuable to the manufacturer? If not, potentially discard.
- Is the data required while the vehicle is in motion? Use cellular.
- Can the data be obtained while the vehicle is stationary? Is the data's value time-sensitive? Choose the most cost-effective path given the available networks, and the amount of data to transmit. This may not be exclusively cellular, it may be WiFi or Ethernet. Additionally, the option may be to store the data locally for collection by a technician.

To illustrate the point, we can use the data projections in conjunction with cost per GB from a range of operators[55]. Such reports highlight the extremes in price that vehicle manufacturers will encounter across the various markets where their vehicles are present and further underscores the importance of determining the value of data being transmitted before deciding to do so.

Alongside the cost of transmission are further cost factors that will need to be considered. Can the data be processed cost-effectively within the vehicle or is it cheaper for the data to be processed remotely? How long must the data be retained for legal and audit purposes? Is it more cost-effective to store the information within the vehicle or stored remotely?

Table 3: Data projections in conjunction with cost per GB

| | Data volume (GB) | Cost per GB (€) - low end (Jio, India) | Cost per GB (€) - high end (Proximus, Belgium) |
|---|---|---|---|
| **2018 cost*** | | 0.2 | 17.7 |
| **2019 data volume per vehicle** | 0.053 | 0.0106 | 0.9381 |
| **2023 forecast cost**** | | 0.009 | 0.83 |
| **2023 data volume per vehicle** | 8.33 | 0.07497 | 6.9139 |

* See footnote 55
** Using Deloitte 3% depreciation

54 https://support.spotify.com/us/article/volvo/
55 https://tefficient.com/wp-content/uploads/2018/09/tefficient-industry-analysis-2-2018-mobile-data-usage-and-revenue-FY-2017-1H-2018-per-operator-8-Sep.pdf

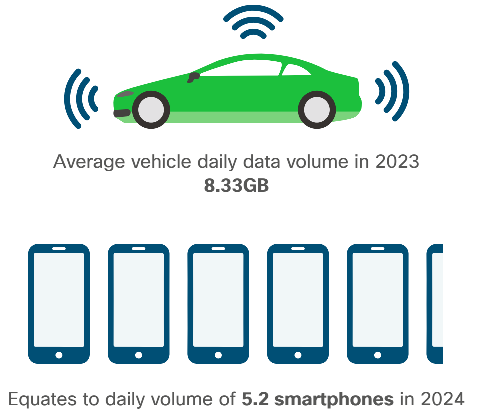
# Conclusion

The volumes of data being transmitted to and from Connected Vehicles will rise rapidly with global production approaching 25 million new vehicles per year[56] and all vehicles forecast to be 'connected' by 2025[57]. With such vehicles being sold world-wide, the impact of communication networks will be seen in all of the major markets.

How will the Connected Vehicle compare to the typical smartphone user? According to a 2018 report[58], monthly mobile data traffic per smartphone in North America will rise to 50GB (1.6GB per day) by the end of 2024. With a 2023 Connected Car transferring ~8GB per day, the data volume from vehicles will rapidly outstrip that of smartphones.

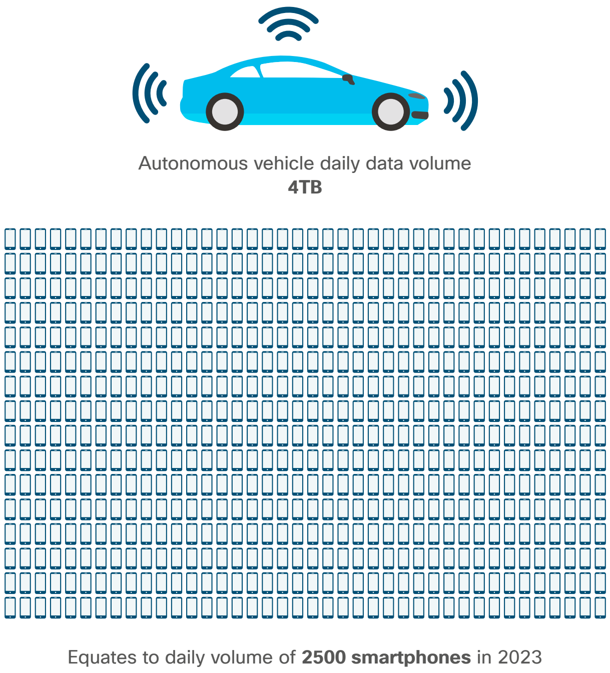
> **"The volumes of data being transmitted to and from Connected Vehicles will rise rapidly with global production approaching 25 million new vehicles per year and all vehicles forecast to be 'connected' by 2025."**

Figure 6: Connected Vehicle vs smartphone in 2023/2024




Looking back at the 4TB figure, to put this in context, if all of the projected data volume were to be transmitted from the vehicle, it would put considerable stress on the communications network infrastructure, since one autonomous vehicle would be generating as much data as 2500 smartphones.

Figure 7: 4TB vehicle vs 1.6GB smartphone




[56] https://www.statista.com/statistics/262747/worldwide-automobile-production-since-2000/
[57] https://www.strategyand.pwc.com/media/file/2017-Strategyand-Digital-Auto-Report.pdf
[58] https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-november-2018.pdf

If the figure were to be closer to 1TB, today's cellular technology would not be able to support the volume. 5G networks are essentially engineered with very similar dimensioning rules and therefore will also be unable to cope, despite the increased bandwidth.

As this paper has illustrated, Connected Vehicles will generate significant volumes of data but:

a) most of the data will be consumed within the vehicle

b) only a 'valuable' subset of the data will be transmitted

c) the commuter vehicle duty-cycle data volume will be ~8GB, not the 4TB figure initially suggested.

Today's cellular networks are able to support the relatively small duty-cycle data volume. As Connected Vehicles become increasingly prevalent and the duty-cycle data volumes increase towards the volumes projected in this paper, the cellular network operators and vehicle manufacturers will have to think how to support cost-effective deployments at a global scale.

This paper has considered the cost of communication but this is only one element of the data transport and processing pipeline between the vehicle and the vehicle manufacturer's data centres. The cost of data needs to be considered in a broader, more holistic context, since the cost of cloud-based computing solutions includes not just the compute but storage and data transmission from the cloud[59], as well.

With vehicle fleets deployed globally and the ecosystem of dealerships, service partners, insurance and finance operating at regional levels, the opportunity exists to exploit in-region data processing capacity to reduce the amount of data that needs to be transported back to the vehicle manufacturer's main data centres. At the same time, the in-region point of presence can serve as a gateway for data exchange with partners in the ecosystem.

5G networks bring increased bandwidth which will be required in order to support such deployments. Data from vehicles will pass over multiple access mechanisms, all of which will need to be managed in a heterogenous way into a 5G network slice. Furthermore, there is the opportunity for collaboration between service providers and vehicle manufacturers with respect to the way network slices and the services within the slice will be contracted, operated and monitored.

[59] https://www.linkedin.com/pulse/cost-internet-from-cloud-william-b-norton/