DEVELOPMENT OF A HIGHLY AUTONOMOUS DRIVING INFRASTRUCTURE

A technology blueprint overview
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1. INTRODUCTION

Autonomous vehicle technology is set to disrupt the transportation industry with profound long-term implications on our society affecting the way we live, work, and do business. Autonomous driving technology promises to reduce the amount of traffic fatalities as well as reduce congestion and free up time. It also introduces new transportation paradigms—including self-driving taxis and transportation-as-a-service shared vehicle ownership models. Autonomous driving products and service packages further include self-parking and self-maintenance. Land use and urban design stands to benefit as well—due to fewer cars on the road. This comes with significant cost savings from more efficient fuel usage and lower operating costs.

However, autonomous vehicles also present substantial challenges:

- Driving might be challenging in conventional cars—even more so, for an automated failsafe system that must operate with very low error tolerance under all driving conditions.
- Data generated and consumed by autonomous cars is large—The global market for connected cars is expected to grow by 270 percent by 2022, according to a new report. More than 125 million passenger cars with embedded connectivity are forecast to ship worldwide between 2018 and 2022, it says.1
- Developing autonomous driving in the aggregate will cost billions of dollars while the price tag for fully autonomous driving in an individual car could be as much as $100,000.2
- Infrastructure will require upgrades. Roads may need to become smarter to ensure safety and consistency for the new types of vehicles. Achieving this level of consistency internationally or even just within cities will be challenging.
- Regulatory and liability issues will also demand consideration (for example, if an autonomous car causes an accident, who is at fault: the driver, the carmaker, or the company that developed the autonomous software?).
- Consumer education and awareness is also needed to ensure consumers are making informed choices, and not reacting to rumors, myths, or misperceptions about the industry and technology.

As long as there have been automobiles, technology has defined the cutting edge of automobile safety. Beginning in the 1970s, automakers introduced airbags and annually saved thousands of lives. Antilock brakes, common since the 1990s, reduce nonfatal crash involvements by 6% to 8%.3 However, car accidents still kill nearly 1.3 million people every year.4

The culmination of high-performance computing, machine learning, new sensing technologies (for example, LIDAR), and powerful edge computing offer the prospect of drastically cutting down these senseless deaths by implementing autonomous driving.

Traffic congestion is also worsening as economies grow and urbanization accelerates. The average urban commuter spends 40 minutes every day in traffic. Over a year, that worker has wasted 167 hours—more than four full-time workweeks—sitting behind the steering wheel, unable to pay attention to anything other than, of course, the task of driving.

Driverless cars will play a key role in the future of smart cities—and will impact how cities’ infrastructure are designed and built. Today, the U.S. alone has more than 700 million dedicated parking spaces, a square mileage equivalent to the footprint of the entire state of Connecticut. The average car uses just 4% of the time, whereas some estimates of self-driving fleets show that utilization will be closer to 75%.5 For these reasons, autonomous fleets are expected to be the backbone of future smart cities.

Autonomous driving and shared mobility solutions together are expected to result in the convergence of e-hailing and car sharing business models.

According to the report published by Allied Market Research, the global autonomous vehicle market was estimated at $54.23 billion in 2019, and is expected to hit $556.67 billion by 2026, registering a CAGR of 39.47% from 2019 to 2026.6 Highly Autonomous Driving (HAD) and the semi-autonomous features in advanced driver assistance systems (ADAS) demand a compute and sensing platform at both the core and the network edge. HPE high-performance storage and archiving solutions further augment a robust deployment, which protects data and makes it ready for analysis. Many HAD solutions may require as-a-service and other pay-as-you-go consumption models, which HPE GreenLake flexible solutions specialize in—simplifying IT infrastructure while maintaining privacy and control.

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1 “Connected cars report: 125 million vehicles by 2022, 5G coming,” Internet of Business, 2018
2 “The true cost of autonomous cars,” Axios, 2018
3 “Government study confirms ABS effectiveness, but mysteries linger,” Consumer Reports News, 2009
4 “Road traffic injuries,” World Health Organization, 2018
5 “How self-driving cars will help solve America’s parking problem,” Axios, 2018
6 “Global Autonomous Vehicle Market is Expected to Reach $556.67 Billion by 2026,” Allied Market Research, 2019
This white paper will outline the scope of the HAD problem, including the key building blocks and components of a highly automated or autonomous vehicle solution:

- Section 2 will outline the traditional levels of vehicle autonomy (Levels 0 to 5).
- Section 3 will discuss the nature, size, and scope of the data involved in an HAD vehicle.
- Section 4 touches on the end-to-end journey for a typical HAD Level 3 and Level 4 solution.
- Section 5 describes HPE Pointnext Services and partnerships relevant to an HAD deployment.

### 1.1. Scope of the problem

![Diagram of key building blocks in the development of an autonomous car](image)

1. **Sensing**—HAD relies on vehicles’ built-in sensor technology. The primary sensors are GPS/Inertial Measurement Unit (IMU), cameras, LIDAR, radar, ultrasound, and various sensors from the interior and powertrain. Some technologies are already well established (for example, GPS, cameras), whereas others like LIDAR are expensive today but are expected to drop in price and size as the HAD market matures. This first building block then involves integrating the car's entire suite of sensor input to establish a data-rich description of the surrounding environment.

2. **Understanding**—Machine learning models in the car (the edge) and at connected data centers (the core) run simulations to match the sensor data with known and preprocessed scenarios (for example, those of a congested road on a rainy day, or a parking lot at nighttime). A vehicle will base its decision-making, in part, on the models it relies upon to understand its surroundings and ensure safety. As new data comes in, the vehicle also needs to be able to cross correlate it and trust the data streams where it originated.

3. **Object detection**—The detection step differentiates between other vehicles, road lanes, traffic signs, pedestrians, drive routes, and so on. The goal is to detect objects in the environment and infer context—whether on as-yet undetermined surroundings or on high-definition maps. Detecting road signs is of course essential, as is communication between the vehicle and the infrastructure as well as other vehicles (V2X).

4. **Perception**—Perception involves running models against the new data to discover the objects and their relationship with the larger environment. The components of this block are localization (Where is the car?), contextualization (What is the environment, perhaps using high-definition maps?), object recognition (integrating LIDAR and other sensor data), and object tracking (via intelligent models).

5. **Decision**—Decision is about preparing for action. What does the car do next? Should it turn? Should it brake? Should it proceed forward? A vehicle's primary processing unit makes its decisions based on sensor data situated in a vehicle's environmental context. Models are trained using machine learning and fed the large amounts of data captured by the suite of sensors. This creates algorithms that can be used to infer potential outcomes based on live feeds of contextual information. From this, logic can be applied to determine the preferred course of action. The main goal is driving strategy—involving obstacle avoidance, behavior planning, GPS control, route planning, and prediction of unseen events.

6. **Action**—Once a decision has been made about what to do next, the vehicle needs to implement the decision as rapidly as possible. Software intelligence is needed here, as understanding the proper scope of the action in context is essential. If it's a sunny summers day with dry roads, the conditions to turn the car to the left, is of course very different from if it's a winter day with slippery road conditions. Car manufacturers have already begun to tackle this problem using the cars' lane-change assist or adaptive cruise-control features. However, it is still a challenge to ask a control system to properly tune itself depending on the world around the vehicle.
Keeping the above building blocks in mind, consider a HAD system’s key components. Sensor data is typically collected in measurement boxes in the trunk of the cars (see “Data Acquisition, transformation, analytics,” section). The first challenge with HAD testing is to unload the data and store it in an ingest station (also called an upload station or buffer). The main datastore typically is a hybrid cloud solution with the majority of components in the data center with the ability to make use of the cloud if there is a peak.

Based on the complexity of the car and how much software simulation is used, development testing of HAD solutions typically involves three steps:

- **Model-in-the-loop (MIL)** trials test the system’s model and operating environment without also testing the HAD system’s hardware (It normally runs on generic workstations.). MIL testing typically happens at the early stages of a development cycle.

- **Software-in-the-loop (SIL)** trials test and validate the auto-generated code used in the system’s controller. SIL testing is often tested in a simulated environment, also without HAD system hardware.

- **Hardware-in-the-loop (HIL)** trials test and validate HAD system hardware—to reveal any faults caused by target compiler or hardware architecture.

There are multiple ways to handle the data collected from different sensors. Video data can be stored together with drivetrain data or LiDAR information. The data files are stored in the back-end platform and used for AI processing as well as for hardware and software-in-the-loop (HIL/SIL) testing. External sensor developers use this data to test and enhance vehicle sensors.

![FIGURE 2. A high-level view of the end-to-end HAD development components](image)

![FIGURE 3. The classification of HAD autonomy levels, established by the Society of Automotive Engineers (SAE)](image)

7 “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles,” J3016_201806, SAE International, 2018
2. LEVELS OF AUTONOMY

According to the SAE—endorsed by the National Highway Traffic Safety Administration (NHTSA)—vehicle autonomy is measured on a six-tiered hierarchy, from Level 0 to Level 5:

- **Level 0: No automation**—Full-time driving is done by the human driver. The car might be equipped with some warning systems, but the dynamic driving task is fully performed by the human.

- **Level 1: Driver assistance**—The vehicle is able to execute specific tasks like deceleration and acceleration using information obtained from the environment. However, the human driver is expected to be in control and perform the dynamic driving task.

- **Level 2: Partial automation**—The vehicle is able to steer (lane changing) and accelerate/decelerate. However, the human driver is still in control all the time performing all the remaining aspects from the dynamic driving task.

- **Level 3: Conditional automation**—The vehicle is responsible for all aspects of the dynamic driving task—although the human driver should be able to intervene whenever requested.

- **Level 4: High automation**—The vehicle is responsible for all dynamic driving and can make decisions even if a human does not respond at a request to intervene. However, this is true only under certain driving scenarios like urban ride sharing or regions where a good level of mapping has been performed.

- **Level 5: Full automation**—The vehicle can perform the entire dynamic driving task under all roadway and environmental conditions that can be performed today by a human driver.

Recent investments and acquisitions underscore the industry’s interest in pursuing HAD development—and the race to Level 5 autonomy. Ford has invested $1 billion in Argo AI, GM has invested in Lyft and acquired Cruise Automation; Volvo has developed a joint venture with Uber; Uber has purchased Otto; Intel® invested $15.3 billion to buy Mobileye; Hyundai and Toyota each have announced their own investments in HAD R&D. This is only a small but representative sample of the activity in this very dynamic industry.

Some OEMs are investigating self-driving cars as a service and expect it to be a major revenue generator. Level 3 vehicles will be a turning point for technology testing, opening the gateway to mass-market adoption of HAD technology.

While the race to achieve Level 5 is heating up, most major car manufacturers today are either developing or partnering with another entity that’s developing an autonomous vehicle program. Each OEM’s approach is different. Waymo (an Alphabet/Google™ company) announced that they are interested only in Level 5. Other companies like Uber and Ford are preparing for Level 4. Daimler together with Bosch announced that it would pursue both Level 4 and 5 trying to make them a reality by the beginning of the next decade. Other companies have chosen the incremental route, by passing through each respective level of autonomy as their HAD technology matures.

3. DATA ACQUISITION, TRANSFORMATION, ANALYTICS

Bringing HAD infrastructure building blocks together leads to complex data pipelines from the vehicle to the back end and vice versa. While building the next HAD vehicle, at-the-edge (the car) cameras, LiDAR, and other sensors generate large amounts of data, as the data center trains AI models and tunes them for live decision-making while driving.

An average sensor data stream is about 33 Gbps, which means ~120 TB per 8-hour test drive. While the technology is still under development, this data must be stored in its entirety due to legal regulations. Collecting data from one day’s test drive of 80 vehicles leads to 10 PB of raw data. Therefore, a small fleet of cars might be expected to generate anywhere between 100 PB and 500 PB per day.

3.1 Key principles

In addition to providing a flexible, scalable, and high-performance file system, an HAD R&D environment needs to support concurrent development, simulation, and test efforts for multiple developers and development teams. In order to support the diverse requirements of developers, HPE can provide cloud-like development environments as close to the data as possible both at the core and at the edge.

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8 "Ford invests $1 billion in Pittsburgh-based Argo AI to build self-driving cars by 2021," TechCrunch, 2017
9 “GM Invests $500 Million in Lyft, Sets Out Self-driving Car Partnership,” Reuters, 2016
11 “Volvo Cars and Uber present production vehicle ready for self-driving,” Volvo Cars press releases, 2019
12 “Uber buys self-driving truck startup Otto; teams with Volvo,” Reuters 2016
13 “Intel buys Mobileye in $15.3B deal, moves its automotive unit to Israel,” TechCrunch, 2017
14 “Ford aims for self-driving car with no gas pedal, no steering wheel in 5 years, CEO says,” CNBC LLC, 2017
15 Future mobility: Bosch and Daimler join forces to work on fully automated, driverless system
In these environments, it is imperative to minimize data movement and bring the compute power to the data, as well as allow rapid scheduling of shared compute and acceleration resources in order to maximize utilization. Solutions such as platform and software as a service can be useful in this setting, as well as containers that can be quickly brought up to run a particular job.

Tools are available to build Continuous Integration/Continuous Development (CI/CD) pipelines to enable agile and efficient testing and the development of algorithms.

4. THE END-TO-END JOURNEY OF HAD

Level 3 and 4 HAD systems require innovative IT technologies. As one of the world’s leading HPC providers, HPE powers the highest performing solutions for customers with the most complex computational challenges today.

The ultimate goal (Level 5) expected to be delivered by autonomous driving technologies is ubiquitous car sharing where riders are no longer drivers, and indeed there may be no riders at all for some portion of the route. Meanwhile, the vehicles will be communicating with each other providing continuous awareness of their intentions and progress while leveraging wireless technologies such as Wi-Fi and 5G.

Until we reach that level of autonomy, Level 3 and 4 driving and testing still requires a robust framework for collection, ingestion, transformation, retention, and consumption of data. In this infrastructure, data flows via sensors into the car’s datalogger. Then, via on-board storage, it travels into the ingestion station. From here, it is ingested into the data lake where it is transformed and prepared for analysis and consumption.

Central to the data flow is the data lake, which stores all the data collected by the vehicles as well as the outputs generated by the system’s activities. See Figures 4 and 5 for the different stages of the data workflow supplied by a data lake.
4.1 Data logging

Test vehicles’ onboard equipment collects and stores data coming from its sensors, with data rates exceeding 30 Gbps. For example, an operational fleet of 80 vehicles collecting 18 TB of data per 8-hour shift at 5 Gbps in-vehicle data rate generates 1.44 PB raw data per shift. For the same fleet collecting at an in-vehicle rate of 30 Gbps, the data generated per shift increases to 8.64 PB.

For such high data rates, HPE Edgeline EL8000 Converged Edge System platform is recommended. The system provides a modular, converged platform with sensors connectivity, compute, and storage in one. The HPE EL8000 is ruggedized and can be managed remotely. HPE EL8000 is a datalogger, which represents an integrated extension of the data center.

The HPE EL8000 can ingest tens of gigabits per second for the LiDAR, radar, and video data streams, making this a practical converged in-vehicle compute platform for test and development. The HPE EL8000 PCIe links its I/O directly to the processor, achieving direct access to the crossbar inside the CPU. Thus, data routing to/from memory as well as processor cache and other PCIe devices is direct.

HPE EL8000 is not just a storage unit either. It supports 64-bit x86 CPUs as well as specialized compute accelerators such as GPUs and FPGAs. In this sense, HPE EL8000 represents the first step of the data transformation pipeline. In fact, HPE EL8000 can significantly reduce one of the dataflow bottlenecks by providing automatic, on-the-fly content tagging, reducing the amount of preprocessing needed.

4.2 Data ingestion

There are two different options for offloading the data:

- **Physical media replacement:** The HPE EL8000 has hot swappable drives that can be loaded and removed from the in-vehicle system. The media is based on SSDs to minimize risk of data loss due to handling and transportation. Media received from the remote center are loaded and then transferred to the data center using high-speed LAN infrastructure.

- **High-speed LAN offloads to ingestion stations or data centers:** This approach uses LAN offload from the in-vehicle device to ingestion station. Ingestion stations are located in the data centers where high-speed LAN networking is used to connect vehicles to data center infrastructure. Once connected, vehicles offload their data using 100 Gb uplinks to the specified target.

- With the projected arrival of 5G, the HPE EL8000 will have the ability to upload data—or representative portions of it—while driving if the logger is equipped with a 5G card.

An additional ingest station may also be used to buffer data coming directly from the development car, enabling it to return to the road as quickly as possible.
In addition to buffering uploads, the ingest station is also the first point of the data triage. In any given test drive, the vast majority of data is likely uneventful and will have a lower immediate value to the development process. Some events, however, will hold greater value to developers. For those cases, prioritized uploads are handled at the ingest station, freeing the car sooner and bringing developers the most important data first. Developers might choose to implement different types of prioritization, which would require larger compute capacity that the HPE EL8000 can provide.

![Image of file systems performance and scalability]

**FIGURE 6.** Various file systems according to their performance and scalability

### 4.3 Data lake

The main challenge for the storage technology to be adopted for this workflow is its capability to scale. In Figure 6, one can find the various possibilities of file systems—each with a different level of scalability or performance.

Parallel file systems like Lustre allow the linear scaling of a solution. Lustre has been engineered to configure building blocks of a given size and performance, with the flexibility to add more building blocks as required. There are very few solutions on the market that have proven performance, capacity, and scalability at these rates.

Parallel file systems also provide connectors and support for traditional POSIX file systems, as well as Hadoop connectors for traditional Big Data environments.

Some customers use other distributed scale-out environments like the Hadoop Distributed File System (HDFS), Ceph, or even S3-compliant storage products. For example, HDFS is geared to run on standard hardware and easily scale out. HDFS also defines storage tiers according to temperatures of data. Hot data that needs to be accessed quickly is placed on the fastest drives, with lower temperature data handled by lower speed drives. This approach allows a cost-effective data lake to be built based upon the criticality and needs of the data.

### 4.4 Software-in-the-loop and hardware-in-the-loop techniques (HIL/SIL)

In a report published in 2016, the RAND corporation calculated that in order for autonomous vehicles to reduce the fatalities on the roads by 20%, they need to be driven about 11 billion miles. With a fleet of about 100 cars, which are driven 24 hours per day, 365 days per year at an average of 25 miles per hour, it would take 518 years to complete the needed task. Clearly, another alternative is needed.

To overcome this challenge, autonomous driving companies today use SIL and/or HIL techniques and models to accelerate the testing.

HPE has provided simulation systems for automotive companies worldwide. These HPE solutions typically use the HPE Apollo 2000 Gen10 chassis configured with the HPE XL170r for the CPU compute portion and the HPE XL190r for GPU.

Custom SIL workflows are built upon a control and management system (CMS). The CMS supports time-based scheduled events as well as processing queues that will be executed in parallel based on resource availability.

Having the SIL systems located with storage provides greater flexibility to meet bandwidth requirements needed for optimal SIL operations. Access to the SIL systems can be on a worldwide basis to support engineers from different regions.

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Hardware-in-the-loop (HIL), too, can be integrated in the main data center fabric in order to provide fast access to the data lake. Due to the high levels of performance required, high-speed interconnect fabrics like InfiniBand or Intel Omni-Path are preferable for an HAD configuration, with secondary 10GbE available for global connectivity as well as for custom HIL solutions.

### 4.5 Archive/backup

Building a HAD system can take a large number of test vehicles, each vehicle generating terabytes of data per day. It is easy to see how such a fleet can rapidly generate hundreds of petabytes. At the same time, once the data is acquired, it needs to be cleaned, split, and transformed generating different versions (in different formats) of the same information.

Dependent upon legislation and a company’s individual compliance policies, archive and backup may be needed as well. For long-term data retention, HPE provides the Data Management Framework (DMF) product, a hierarchical storage manager with more than 20 years of successful deployment.

HPE DMF automatically tracks the free space on a managed file system ensuring that sufficient amount of space is always available—liberating the system administrators from the time-consuming task of repeated monitoring and provisioning of storage.

HPE DMF maintains both metadata information and file data from prior versions of files so that administrators have a complete history of the evolution and contents of file systems and can go back and restore any or all of them. During restaging, administrators can restage file systems—or portions of file systems—using a point-in-time designation.

One tape HPE DMF solution is based on the HPE TFinity® ExaScale tape library built on Spectra technology. The TFinity ExaScale is the world’s largest single-footprint storage system. A single TFinity EE is capable of storing up to 53,450 tape cartridges across 44 frames. If using TS1150 compressed media technology, system capacity will exceed 1 exabyte. Thanks to its Dual Robotics and its 72 LTO-8 drives, it can achieve writing speeds of ~21 GB/s, with a capacity of 100.2 PB via 8350 LTO-8 carts (four rims).

### 5. SERVICES AND PARTNERSHIPS

HPE, with its leading market share in HPC worldwide is well positioned to support the demanding compute, storage, and networking needs of a HAD solution. Less well known are the services HPE offers to build high-performance computing environments, and ultimately, to support its worldwide customer and user base.

#### 5.1 Build

HPE Pointnext Services organization, HPE Pointnext Services, builds out the platform for customers from the data center to the edge (in this case ingest stations and car dataloggers) to the applications on the platform ready for developers to consume. Depending on a customer’s needs and goals, experienced AI and data experts from HPE Pointnext Services can enable users to:

- Explore use case objectives and priorities for business, data, and IT stakeholders
- Identify AI and analytics functionalities to reach their defined objectives
- Reveal dependencies and data sources to develop an intelligent data strategy

#### 5.2 Run

Once the platform has been built, the platform can be moved into production. To run in production means having the correct level of operational support for all components, ensuring optimal availability to support the business. Through Operational Support services from HPE Pointnext Services, HPE can take over the operational aspects of a HAD system.

HPE Adaptive Management Services are an integrated component of HPE GreenLake solutions, delivering IT outcomes in a pay-per-use model. This framework addresses the operational challenges through the service operations stage of a company’s infrastructure covering servers, storage, networking, infrastructure software, hypervisor, backup/restore, and security, as well as middleware and applications for both HPE and select third-party assets.

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16 spectralogic.com/products/TFinity-exascale/overview/
5.3 Consume
Gain the flexibility of the public cloud on-premises and under your control with HPE GreenLake—a set of consumption-based IT solutions. Choose from a catalog of complete, curated solutions that deliver IT outcomes with hardware, software, and expertise on-premises in a pay-per-use model.

5.4 Partner
There may be times in this HAD journey that it makes sense for HPE to partner not only with our end customer but also with other organizations to deliver the best HAD platform and service. An example of such partnership would be the shipping of data for test cases on remote test drives. Available bandwidth at a test drive location may dictate that data upload may well not be possible. By partnering with a courier service, we can ensure that data is delivered to the nearest viable ingest point as soon as possible.

Partnerships can also take other forms. Perhaps a customer already has an IT service provider and wants the HAD platform to be run under the same umbrella. Maybe our customers want HPE to work with those service providers to ensure that the transition from build to run happens as seamlessly and painlessly as possible. Through collaboration with service providers HPE can ensure that, to the end customer, the build and run services are a blend between HPE and others. Each partner brings their own services to the ecosystem and delivers an end-to-end service for the customer.

6. CONCLUSION
Approximately 1.35 million people die each year as a result of road traffic crashes. Road traffic crashes cost most countries 3% of their gross domestic product. Between 20 and 50 million, more people suffer non-fatal injuries, with many incurring a disability as a result of their injury.18

Highly Autonomous Driving is a rapidly growing market with a mission to improve public health and safety. It has been estimated that, for AV penetration rates of 10%, 50% and 90%, a corresponding 1.100, 9.600, and 21.700 lives saved per year in the U.S. can be expected.19

However, HAD is not an easy problem. Indeed, it requires some of the most advanced and sophisticated technologies in the market today—among them are machine learning and deep learning neural networks, cutting edge accelerated compute, high-bandwidth networks, and interconnect fabrics.

HPE addresses the automotive industry’s need for a comprehensive portfolio of HPC and AI solutions that can provide an edge to cloud HAD deployment that a customer can purchase and operate themselves or can contract with HPE (via HPE Pointnext Services, HPE GreenLake, and other service offerings) to operate some or all of the HAD compute environments for them. HPE’s full performance portfolio of compute, storage, networking, and worldwide support and services ensures developers today can build the optimum HAD solutions for the robust and safe transportation grids of tomorrow.

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18 “Road traffic injuries,” World Health Organization, 2018