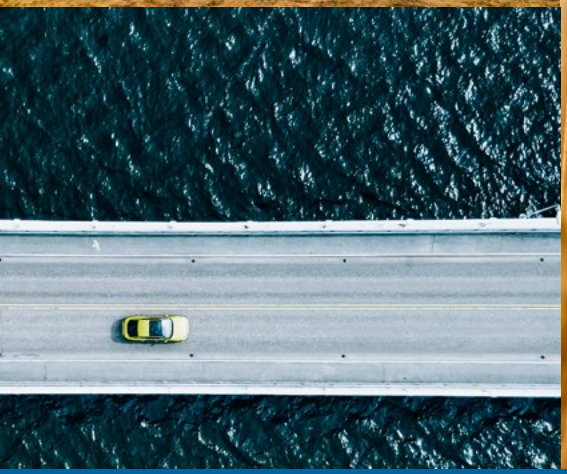





Sensing, thinking and acting – differently

Reevaluating how autonomy works by considering where it works

Autonomy changes by the millisecond. Every data point collected and every millimeter navigated shapes and reshapes the industry's path. So it's critical to evaluate this ever-evolving field with equal dexterity. Click through this guide for a deeper dive into autonomy's value and variance in real-world environments and applications.

What are autonomous vehicles?

In the broadest sense, autonomous vehicles operate with no or limited human intervention. By sensing, thinking and acting in real time, they adapt and function within changing environments and conditions. Autonomy encompasses features in machines and vehicles that we've grown very accustomed to, like emergency braking and lane departure systems. It also includes field applications like 3D blade control and precision farming. But the following concepts and applications are also autonomy:

- Automation
- Command and Control
- Connected Worksite
- Teleoperation
- Variable-Rate Spraying
- Platooning

Autonomy driving the economy

By 2030, companies expect to invest more than $2 trillion in autonomous vehicles worldwide.

Autonomous Vehicle Market Share 2021 Global Trend, Segmentation, Size, Business Growth, Top Key Players Analysis Industry, Opportunities and Forecast to 2030

The 5 levels of autonomy

Level 1: driver assistance, **everything on**
Level 2: partial automation, **hands off**
Level 3: conditional automation, **eyes off**
Level 4: high automation, **mind off**
Level 5: full automation, **everything off**

VIEW INFOGRAPHIC:
A NEXT-LEVEL VIEW OF THE 5 LEVELS

Where the 5 levels fall short

The challenge with the Society of Automotive Engineers (SAE) framework is that it's largely focused on getting passenger vehicles from point A to point B. Its levels describe autonomy as applied to speed and steering control but stop short including the broad range of autonomous tasks that can improve productivity in commercial vehicle applications.

- What about a working machine?
- How about industrial applications?
- Variable-rate spraying differentiates between crops and weeds in real time. Where is that on this scale?

Rapid adoption across applications

In 2021, there were around 39.06 million partially autonomous vehicles worldwide, with 54.20 million projected by 2024.

Statista, April 2021

Artificial intelligence spending in the construction market is expected to reach $4.51 billion by 2026.

Reports and Data, July 2019

Farms worldwide are expected to integrate robotics 7% faster than other industrial markets by 2026. Spending on robots will grow from nearly $5 billion in 2021 to nearly $12 billion in 2026.

MarketsandMarkets, May 2022

Autonomy uncertainty

When we talk about autonomy, perplexity arises in the various definitions, uses and interpretations of the word itself.

- Is automation the same as autonomy?
- Is it driver assistance?
- Is precision blade control on a dozer autonomy?
- What about a connected worksite or command-and-control system?

The short answer is yes to all of the above. We see autonomy as all of these varying points on the journey to more intelligent and more efficient workflows. This is why a more textured definition of autonomy is needed.

Autocorrect: the difference between automation and autonomy

Automated systems operate without human assistance based on a set of predefined parameters. They are restricted in the tasks they can perform based on these specific criteria.

VS.

Autonomous systems are closer in design to the human mind. They sense their environments, adapt to real-time conditions and are able to navigate uncertainties and even system failures without external input. Further, they continuously learn and improve functionality over time.

Big-time buy-in

The global autonomous vehicle market was valued at $76.13 billion in 2020 and is projected to reach $2.16 trillion by 2030, registering a CAGR of 40.1% from 2021 to 2030.

Allied Market Research, Feb. 2022

Autonomy further afield

While the SAE's five levels of autonomy still apply to automotive applications, for other industries, it may be better to organize our thoughts around a more encompassing series of stages. Ones that better suit working machines and account for things like the volume of work done – the amount of earth moved, the number of acres fertilized, etc. We also must account for the number of complicated tasks occurring simultaneously that operators must perform or oversee.

When considering applications in industries like mining, agriculture or construction, Trimble Autonomy looks beyond SAE's five levels to factor in how autonomy is used by businesses in a variety of industries.

4 More levels of autonomy

1 **Operator assistance -** The operator or driver is reliant on a display or visual indicator to provide real-time information indicating where the vehicle or implement should be. This guidance will inform decision making and improve efficiency. Examples include collision warning and steering indication that visually direct the operator onto the nominal path.

2 **Task automation -** A smart system capable of automatically completing part of the job, such as blade control on a dozer, variable-rate spraying on a tractor, and lane keeping across a range of vehicles.

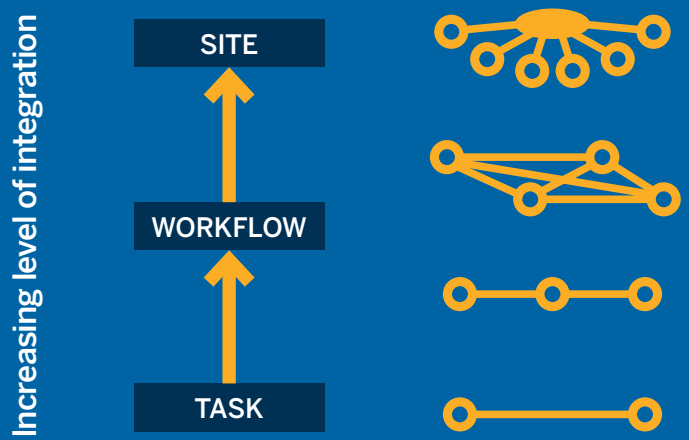
3 **Supervised autonomy -** The operator is in a supervisory role but is still responsible for reacting to unexpected conditions. Both the HORSCH sprayer and Dynapac soil compactor demonstrate this level of autonomy.

4 **Full workflow automation -** Intelligent autonomy, optimizing for a business need and/or operating without direct supervision on-site. Full autonomy can encompass a vehicle or machine that is given a task and is responsible for efficient and safe completion, and can extend to full site autonomy (e.g., a connected worksite or fully connected farm).

Autonomy applied

Unlike in passenger cars, a working machine is really just one cog in a complicated workflow or on a larger job site. So when thinking about autonomy, we must also consider how each machine integrates with other machines and with the project as a whole.

SEE THIS INTEGRATION IN ACTION

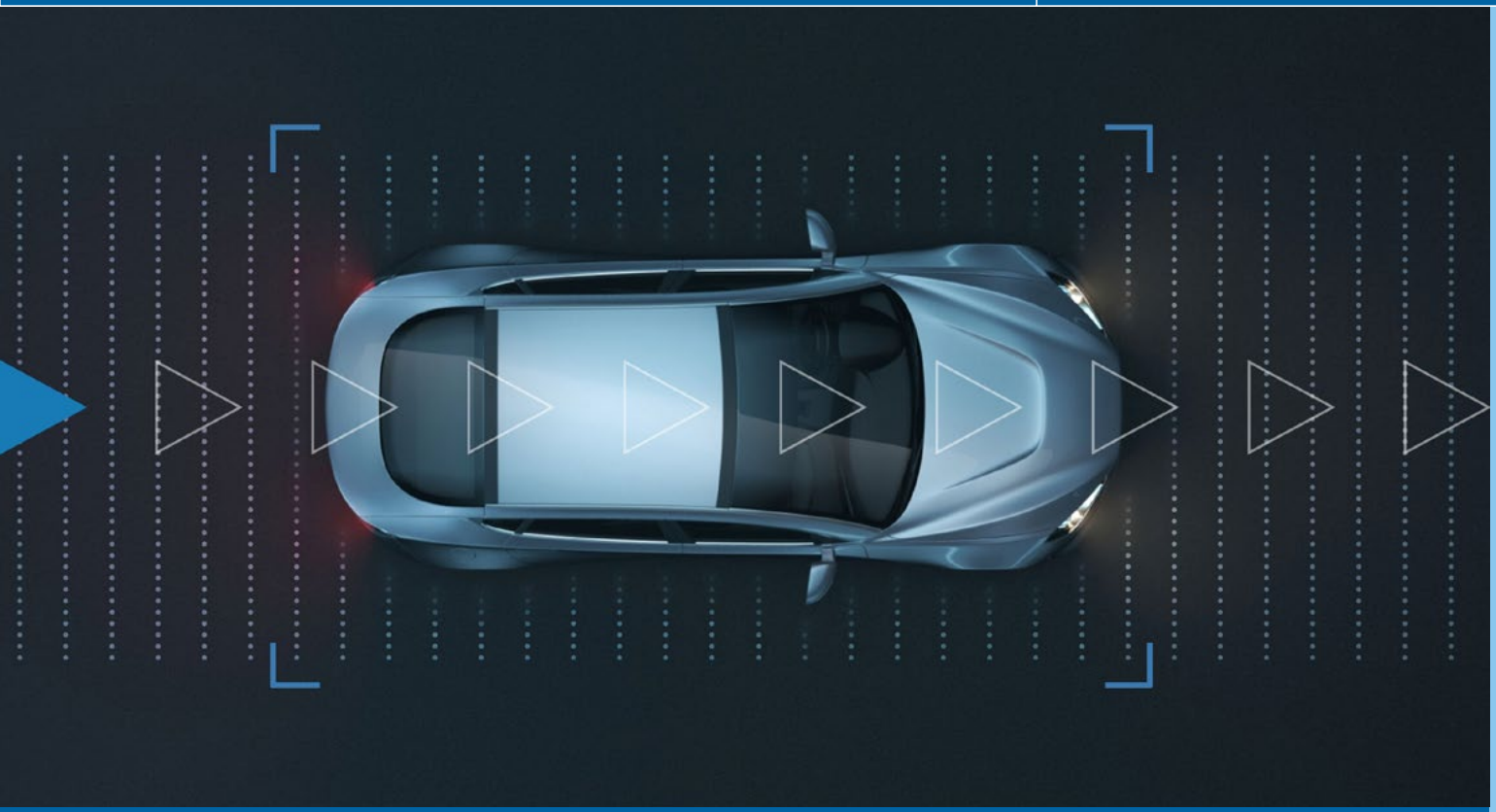


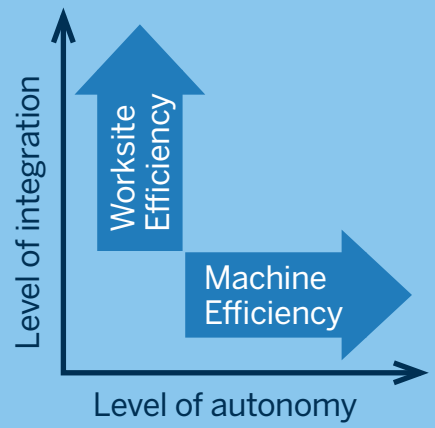
A high-level hub-and-spoke or industry cloud configuration that can coordinate activities across a job site and orchestrate and optimize for business-level goals such as minimizing fuel use or environmental impact.

Coordinating different machine types, machine brands, functions and tasks across an entire job site so everything's integrated and working synchronously.

Moving from a single task (e.g., operating a dozer) to multiple machines working in sync as part of a workflow and sharing data (e.g., paving or the load-haul cycle).

A machine operating independently (manually or autonomously) with the only link being between it and the operator.





Worksite and machine efficiency

Autonomy on its own is an exciting concept. But beyond things that capture the public's imagination like driverless trucks and delivery robots, autonomy promises tangible business value. Increased efficiency, lowered overhead and improved safety (minimizing human error) are just a few of the many advantages already realized. And once fully connected sites come online – wherein autonomy and integration are maximized – the benefits will exponentially build on themselves.

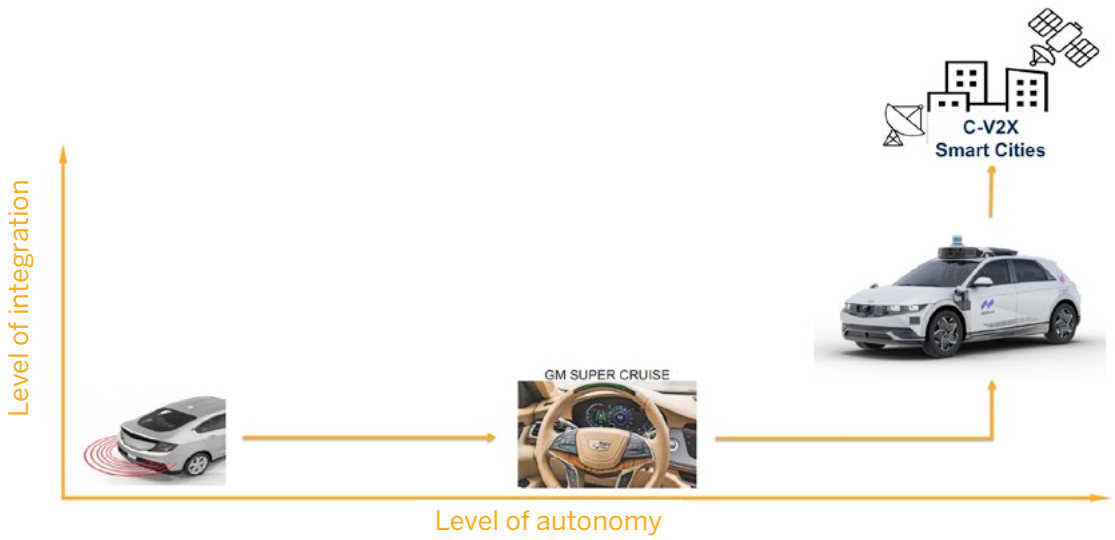
Better. Faster.

48% of business respondents are using machine learning in an effort to increase productivity and speed. And 61% are using it for automation.

Refinitiv, "Artificial Intelligence / Machine Learning Global Study," 2019.

Autonomy in passenger vehicles

Looking down the road from things like lane departure systems and adaptive cruise control, truly connected mobility will transform transportation. Autonomous vehicles and systems will integrate within smart cities wherein entire traffic grids will be optimized for maximum efficiency and safety – not only for passengers but also for pedestrians and the surrounding environment.



Vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) systems could enable the concept of smart cities, wherein whole roads and intersections could help optimize drive times, increase safety, and reduce fuel use and harmful emissions.

At its foundation, systems like lane departure and collision warning systems improve driver and driving safety.

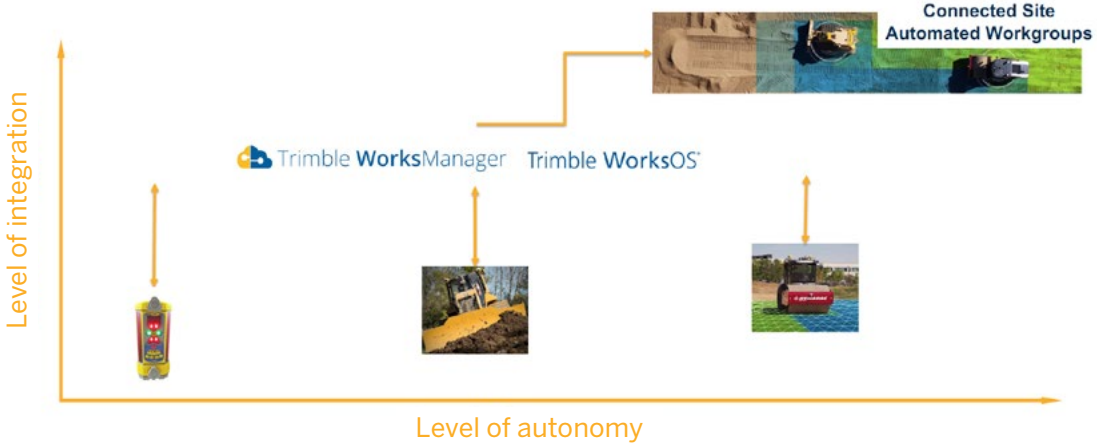
Driving gets safer and more convenient with supervised autonomy and level 2 systems like GM's Super Cruise.

Robotaxis – tied to traffic and routing systems and billing and personal accounts – unlock potentially new ownership models and get more value out of every car with shared mobility.

Take the wheel

The number of driverless cars with at least level 1 autonomy keeps rising every year. In 2021, there were around 39.06 million autonomous vehicles worldwide, with 54.20 million projected by 2024.

Statista, April 2021



With high levels of integration and autonomy, connected sites empower workgroups and fleets to be highly coordinated and efficient across the job site.

From laser-based grade indicators to 3D grade control systems and beyond, we continue to climb the autonomy ladder. These systems require, at a minimum, connection to a plan, making them more integrated than passenger vehicles.

Value is amplified with additional layers of integration. Worksite management systems like WorksManager can coordinate efforts across machines and tasks, distribute updated maps and plans, transmit job status to other machines standing by, and more.

Autonomy in construction

In construction applications, autonomy promises even greater gains than hands-free, stress-free motoring down the highway – even in the face of more rigorous challenges. Rugged terrain, complex environmental factors and serious safety implications mean autonomous applications must work on multiple planes simultaneously and seamlessly. But connected worksites hold incredible promise as autonomy and integration steadily evolve.

Building improvement

In trials, autonomous vehicles mixed with human-operated excavators have delivered a 40% improvement in efficiency compared to conventional means.

The B1M

Autonomy in agriculture

If there's anywhere the SAE's five levels of autonomy are too rigid, it's in agriculture. With so many varied machines and systems at play in such diverse environments, myriad applications must communicate, interoperate and safely work as one. The notion of the connected farm helps farmers realize benefits beyond autonomous tractors and harvesters to create workflows that empower farmers to work more productively and efficiently.

Growing success

The connected farm unites autonomous applications across the agriculture spectrum into one cohesive system that delivers more value than the sum of its parts.

- **Path planning** – Optimizing and automating trajectory, speed and overall path design
- **Land preparation** – Automating the process to reduce labor numbers and costs
- **Planting** – Empowering farmers to oversee – rather than ride in – vehicles
- **Nutrient management** – Ensuring the right amounts to produce the highest yields possible
- **Crop protection** – Spraying herbicide at plant level instead of field level to significantly lower costs and increase environmental protection
- **Harvest** – Enabling single-operator efficiency and collision avoidance
- **Data collection** – Tracking data and generating reports to deliver insight and continual improvement

Cultivating innovation

Farms worldwide are expected to integrate robotics 7% faster than the industrial market by 2026. Spending on robots will go from nearly $5 billion in 2021 to nearly $12 billion in 2026.

MarketsandMarkets, May 2022

Farmers consistently using precision AG technologies saw a:

4% reduction in water use
Full adoption of technologies like soil moisture sensors could result in another 21% drop.

7% increase in fertilizer placement efficiency
Broader adoption could further increase efficiency another 14%, resulting in a 21% decrease in fertilizer used.

9% reduction in herbicide and pesticide use
Full adoption could result in another 15% drop - resulting in a 48 million lbs. reduction in product use.

6% reduction in fossil fuel use
Broader adoption of auto guidance and machine telematics could produce another 16% drop.

Association of Equipment Manufacturers, Study: "The Environmental Benefits of Precision Agriculture," Feb. 2022.

Driving autonomy innovation

Since GNSS technology put Trimble Autonomy on the map in 1984, we've been pioneers on the road to autonomy. With a proven history of bringing first-of-their-kind innovations to market, the company is today one of the major positioning and perception providers with vehicles in market.

Our autonomy platform enables advanced positioning in any environment, meeting customers' needs in real time, ahead of time, when it matters most. And our engineers, researchers and developers are there to guide you along every step of your autonomy journey.

Technologies and capabilities

Along with our ecosystem of industry-leading partners, Trimble Autonomy delivers the building blocks of autonomy's future across numerous industries. Further, we have the expertise to integrate all these functions and the data they produce to provide integrated, purpose-built solutions.

Automotive

Construction

Agriculture

Emerging Industries

Accolades and accomplishments

Measure us by miles, acres, awards, patents or however you'd like. We prefer to gauge our success by the number of successes we deliver for our clients.

Trimble Autonomy

- 1,000 of world-class engineers
- 2 decades of autonomous implementation
- Millions of miles driven
- Billions of acres covered
- 1,000+ unique patents
- 34M+ miles of hands-free operation
- 500K+ machines in install base
- 100K+ subscribers to data services
- 100+ OEMs in autonomy