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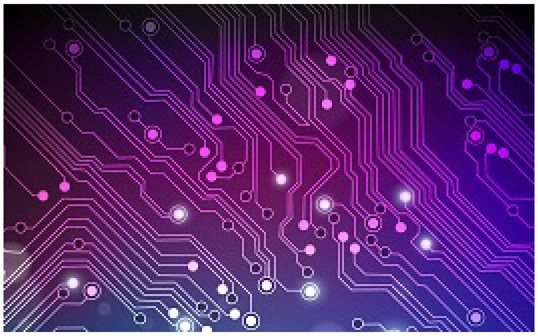

RESEARCH REPORT

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EXECUTIVE SUMMARY

Artificial Intelligence for Automotive Applications

Software, Hardware, and Services for Autonomous Driving, Personalized Services, Predictive Maintenance, Localization and Mapping, Sensor Data Fusion, and Other Use Cases: Market Analysis and Forecasts

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SECTION 1

EXECUTIVE SUMMARY

1.1 ARTIFICIAL INTELLIGENCE ON THE RISE

Artificial intelligence (AI) systems, which use data and algorithms to mimic the cognitive functions of the human mind and have the ability to learn and solve problems independently, are rapidly being deployed across a variety of industries and use cases. The wide-range of use cases from in-home digital assistants like the Amazon Echo to complex AI algorithms used by Facebook to determine what ads to display make it impossible for most people to not encounter AI every single day.

The automotive industry is among the industries at the forefront of using AI to mimic, augment, and support the action of humans, while simultaneously leveraging the advanced reaction times and pinpoint precision of machine-based systems. Today's semi-autonomous vehicles and the fully autonomous vehicles of the future will rely heavily on AI systems. Such vehicles, after being fed tens of millions of miles of training data, and being equipped with powerful onboard and cloud-based processors used to interpret and incorporate data from vehicle sensors, are likely to make their debut on the roads around the world in the next 3 to 8 years. While a world where most vehicles can drive themselves is further in the future, autonomous driving technology, powered by AI systems, could become commonplace within the next 15 to 20 years, and is certainly within the expected lifespan of a teenager getting their first driver's license.

Beyond self-driving vehicles, AI can also be used to make life in the car more convenient and safer, for both the driver and the passengers. In-car assistants, driven by natural language processing (NLP) and machine learning techniques, allow the vehicle's systems to respond to voice commands and infer what actions to take, without human intervention. These can be used to not only control in-vehicle media and entertainment systems, but also manage navigation systems, climate control systems, and some limited vehicle system.

Despite the technological potential of both autonomous vehicles and in-car assistants, an abundance of caution relating to safety concerns, and a desire to ensure that users enjoy a smooth, glitch-free experience, these AI systems likely will be deployed gradually over the next two decades.

1.2 MARKET DRIVERS

The automobile-focused AI system market is driven largely by two factors: enhanced safety and convenience. Ultimately, original equipment manufacturers (OEMs) and transit operators have a vested interest in reducing the number of injuries and fatalities incurred while driving, as accidents can lead to civil and criminal lawsuits. Drivers and passengers, meanwhile, have become accustomed to being able to digitally manage, personalize, and control their environments, and this extends to the in-car experience. Interestingly, the two factors are intertwined, as the way these systems are expected to be deployed will certainly intersect, on both system and functional levels.

1.2.1 ENHANCED SAFETY

Perhaps the most powerful driver for using AI in automobiles is a desire of many parties to make automobile travel safer. World Bank statistics note that 1.3 million people were killed in road accidents annually around the world as of 2015, so there is a clear acceptance that the automobile industry has a responsibility to make their vehicles safer, not only for other drivers and passengers, but for pedestrians who may find themselves in the path of a wayward automobile.

AI is seen as a key enabler of autonomous driving, as it can utilize millions of miles of training data, along with precise sensor data, to develop algorithms that can actually outperform humans, in terms of reaction time and accuracy while driving. Because these systems do not suffer from human emotions, they are not subject to making rash decisions based on anger, fear, or other conditions that can impair decision making.

1.2.2 Desire for Improved Convenience

In 2018, the mere thought of not being digitally connected at all times is often viewed as a major problem; both the young and old in developed countries believe they should be able to instantaneously access information, connect with family, friends, and business associates, and control their environment at the touch of a button or via a simple set of voice commands. However, until recently, the automobile has lagged behind somewhat. This is largely because interaction between people and the vehicle itself, or connecting to the outside world using the vehicle's systems requires specially designed interfaces that take into account the motion of the vehicle, or the fact that the driver cannot (and should not) be hunting around for buttons to press.

As a result, voice control is the most natural way for people inside a vehicle, whether driving or not, to interact with information systems. But voice-activated systems of the past were complex to use, required memorizing specific keywords or phrases, and would not work if the user's syntax or accent happened to fall outside of the acceptable programmed limits.

AI brings the convenience of being able to give the system a command, in plain language, while also using algorithms to truly understand the context of that query. Advanced systems can then feed those results into a machine learning algorithm to help the system learn a user's preferences so that it can automatically predict and choose options for the user on an ongoing basis. As a result, the system is able to respond more like a human being would, thereby making the system much more useful.

1.2.3 New Revenue Streams

Like any industry, the automobile industry is seeking new revenue streams. With the advent of AI, automobile manufacturers are seeking ways to pair AI with commercial services. The idea is to have an AI agent monitor typical behavior, and then suggest various commercial services. For example, if a driver always passes a specific restaurant or gas station, that merchant could then send a coupon or offer to the vehicle, based on the data. While this type of activity usually requires some sort of opt-in agreement, many drivers are likely to accept it, so long as it is paired with some real, non-commercial benefits, such as dynamic, crowdsourced traffic and re-routing services.

Other services, such as roadside assistance, internet access, and ride-sharing and rental car services, can also be optimized using AI to learn users' preferences, driving routes, and entertainment preferences, which can then be monetized via subscription services.

1.3 Market Barriers

Despite the promises of AI, there are significant barriers and challenges that will likely slow the automotive industry's use of AI. While these barriers are real, there is significant momentum in the industry, and all players appear to be willing to commit the time and funding to working through these challenges.

1.3.1 Technology Challenges

The biggest technological challenge lies in aggregating and making sense of the plethora of data required to feed into the AI algorithms and models. Today's vehicles are loaded with sensors; the self-driving cars of the future will require even more sensors capturing extremely granular data.

As a result, there is a large demand placed on processors, both in the vehicle itself, as well as in offline data centers used to "train" self-driving vehicle algorithms, to capture and process this data. While offline centers can simply stack processor arrays, in-vehicle processing is somewhat limited by space, power, and heat dissipation issues.

Furthermore, the challenge to create algorithms that can accurately and consistently address new situations can be daunting. Whereas humans can make a split-second decision using a large number of variables, machine-based intelligence needs to make inferences and connections across a vast, yet somewhat more limited amount of data. Tesla's Autopilot was found to have shortcomings in its algorithms; it could detect a vehicle that was moving, but if it quickly changed lanes and another vehicle was stopped, the Autopilot vehicle crashed because it did not know what to do when quickly confronted with a new object.

1.3.2 Negative Publicity Related to Driverless Vehicle Accidents

Crashes occurring while using Autopilot or the well-publicized autonomous Uber vehicle accident that killed a pedestrian in March 2018 have received significant coverage in both the trade and general press, with many articles questioning the safety of autonomous technology, and cautioning the industry to take steps to clearly explain to drivers what the limitations are with each system.

According to the National Safety Council, there are an estimated 40,000 traffic fatalities on U.S. roads each year, with 90% of them due to human error. However, the very high-profile nature of autonomous and semi-autonomous vehicles means that even one accident will be viewed as evidence that the technology is not safe, and companies testing these vehicles are forced to halt or scale back testing.

Tractica believes that the autonomous vehicle market will face significant resistance to allowing expanded testing of autonomous cars on public roads every time there is a crash, even if these vehicles are statistically safer than regular vehicles. It will be incumbent upon autonomous platform developers and automobile OEMs to take responsibility when the accidents occur, analyze any emerging technological weaknesses or blind spots, and quickly correct these faults so that the public can be confident that progress is being made.

1.3.3 Regulatory Environment

As self-driving cars begin to roll down the street, enhanced regulatory scrutiny is likely to lie just around the corner. The key concern revolves around assigning liability to AI systems that have been designed by humans, but, in fact, make decisions on their own, due to the use of machine learning, machine vision, and reinforcement learning techniques.

Because the systems are designed to essentially learn from past experience during training, there is a question as to whether humans can be held liable for their decisions. Past case law has indicated that in the case of robotic algorithms being used, the manufacturer of the robots could not be held liable when an accident occurred, because it was unable to foresee an issue with the system, and the robot itself met safety standards.

As a result, it appears that new standards and regulations governing AI and self-driving cars will be necessary. This will likely require the cooperation of both government agencies and developers to determine the most appropriate standards to be used to define a "quality" and "safe" algorithm or type of algorithm in self-driving cars.

1.3.4 Costs

Another key challenge, although one that appears to be surmountable, is the cost of developing and bringing AI-based automotive systems to market. While expensive (early Level 5, fully autonomous vehicles are projected to cost in the six-figure range), business models are being devised to support the higher costs of vehicles equipped with high-end sensors and processors.

On the development side, testing (via real-world and simulator) autonomous vehicles and other systems can also be very expensive. But OEMs are clearly dedicated to the cause, as demonstrated by companies like Ford and Toyota, which have each committed billions of dollars over the next few years to bring highly functional autonomous vehicles to market.

The biggest cost, however, could be upgrading the infrastructure around the world to fully enable integrated autonomous driving and services. Many countries and governments struggle with maintaining their current infrastructure of roads, bridges, tunnels, and traffic control devices. Adding enhanced signals and upgrading roads with sensors will be extremely expensive and, in some areas, simply impossible, either due to political opposition or the inability to secure adequate funding to install, manage, and maintain the higher-tech devices.

1.4 Technologies in Use

AI technologies are generally viewed as distinct from strictly programmed routines that simply return static responses based on matching inputs to lists of responses. Instead, various technologies in use today include machine learning algorithms, deep learning, NLP, machine vision, machine reasoning, and strong AI.

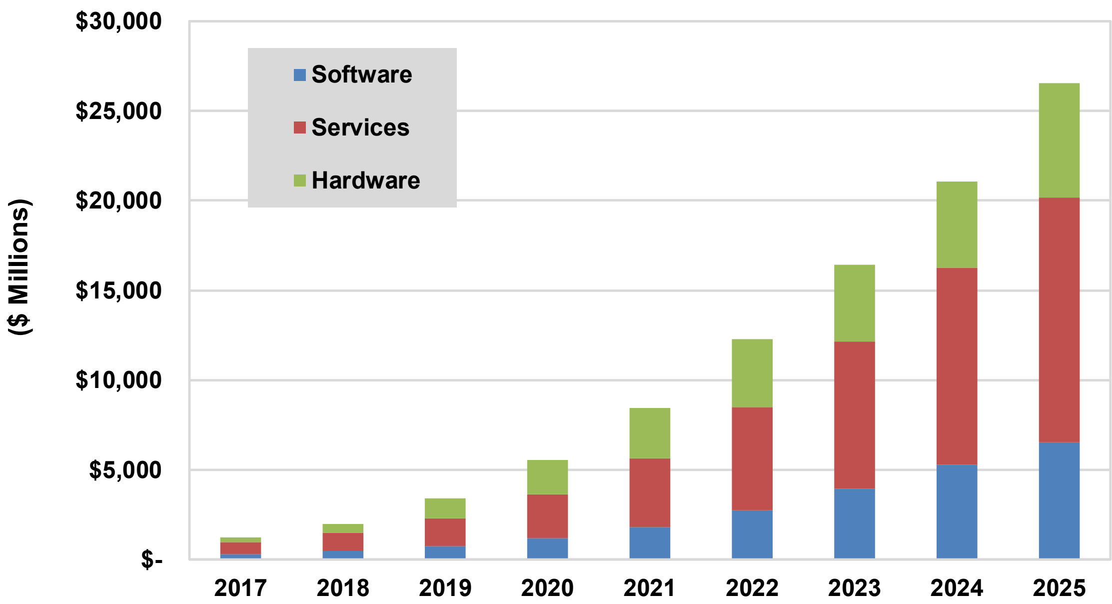
These techniques are generally broken out into the categories of supervised or unsupervised learning, which basically describes whether or not the system is given parameters or limits to guide its responses, or if the system is allowed to draw its own conclusions or solutions based on the input data it receives.

In the automotive space, a variety of supervised and unsupervised learning techniques are deployed, because the tasks involved are highly varied. For example, supervised techniques may be used to help guide and identify objects such as street signs, other automobiles, and pedestrians, while unsupervised learning technology might be used to identify the best way to process and find the quickest route around a traffic jam. Tractica projects that a wide variety of AI technologies will be used for both autonomous driving and in-car infotainment and interaction-based communication tasks.

1.5 Market Forecasts

The market for automotive AI hardware, software, and services is projected to reach $26.5 billion by 2025, reflecting healthy growth of 46.9% on a compound annual growth rate (CAGR) basis, for the 2017 to 2025 timeframe. Revenue in 2017 topped out at just $1.2 billion, split between services ($659 million), software ($316.8 million), and hardware ($249.5 million).

Chart 1.1 Automotive AI Total Revenue by Segment, World Markets: 2017-2025



(Source: Tractica)

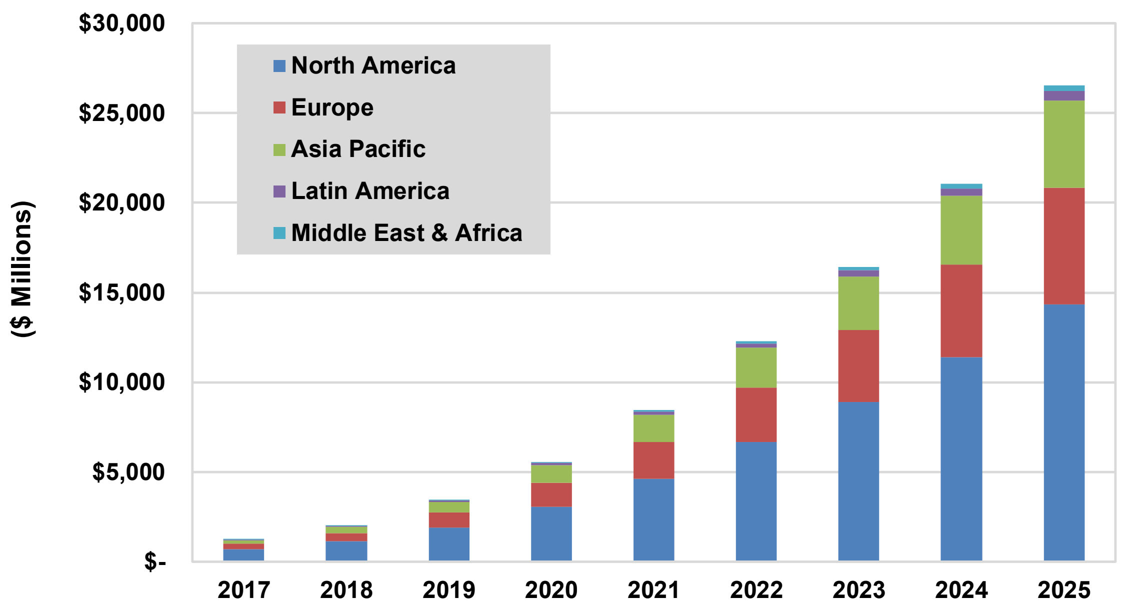
Like many industries, much of the commercial activity is concentrated in three geographic markets: North America, Europe, and Asia Pacific. In the automotive industry, this is due to several factors.

There are simply more vehicles with modern technology produced and purchased in these developed regions of the world. For the AI segment, that is a key point of distinction: AI technology is incredibly expensive to develop and commercialize. Autonomous vehicles have been produced in extremely limited numbers to date, and even by the end of the forecast period, they are likely to be a very small subset of the overall vehicles available. They are expected to be priced well above the average cost of a new vehicle today, which is simply not a sustainable model in developing countries.

Furthermore, many of the services that AI will enable also rely on a robust, fast mobile networking connection. AI-enabled vehicle-to-grid (V2G) or vehicle-to-infrastructure (V2X) services to help enable autonomous or semi-autonomous driving, as well as personalized and localized commercial entertainment, information, or retail services, will require a fast and reliable 4G (or even 5G) connection. Many developing nations simply do not (and will not) be able to deploy such a network within the forecast period.

Tractica projects that North America will generate 54% ($14.4 billion) of all automotive AI revenue by 2025, with a cumulative total revenue of $52.8 billion, over the 2017 to 2025 time period. Europe and Asia Pacific will generate $6.5 billion and $4.9 billion in 2025 revenue, respectively. These two regions will account for total 2017 to 2025 forecast revenue of $23.6 billion and $17.5 billion, respectively, and all three regions will feature strong CAGRs of more than 45%.

Chart 1.2 Automotive AI Total Software, Service, and Hardware Revenue by Region, World Markets: 2017-2025



(Source: Tractica)

Tractica believes that AI, which has made its way into many other fields, is especially pertinent to the continuing development of the automotive market. The ability to attract buyers to new vehicles is dependent upon incorporating new technology that can improve safety, enhance conveniences for the drivers and passengers, and integrate the outside world (via the internet).

Automakers must embrace the development of self-driving cars, which can improve safety and convenience, for both commercial entities, such as fleet, ridesharing, trucking, and taxi services, and for the consumer market of the future.

In all cases, AI is the key to enabling these advances in an efficient manner. Tractica predicts that the market will take off at the turn of the next decade, as these technologies and services begin to become standard equipment in mid- to high-end vehicles, and optional equipment on entry-level vehicles.

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SCOPE OF STUDY

The scope of this study is the global market for AI technology used in automotive applications, for the forecast period from 2017 through 2025. The technologies covered include machine learning, deep learning, NLP, computer vision, machine reasoning, and strong AI. Other AI technologies that seem promising, but have not yet achieved full commercialization, such as algorithms that learn and adapt, and emotional intelligence systems, are also discussed within the report. One of the challenges of creating forecasts in such a highly innovative field is that a technology not yet invented is likely to play a significant role during the forecast period (2017 to 2025) covered by this study.

The forecast covers all geographies, broken into the five major world regions. The forecasts are based on an assessment of both major companies and startup-level activity in the field of AI, because this field is still nascent enough where a previously unknown entity may wind up driving the growth of the market.

SOURCES AND METHODOLOGY

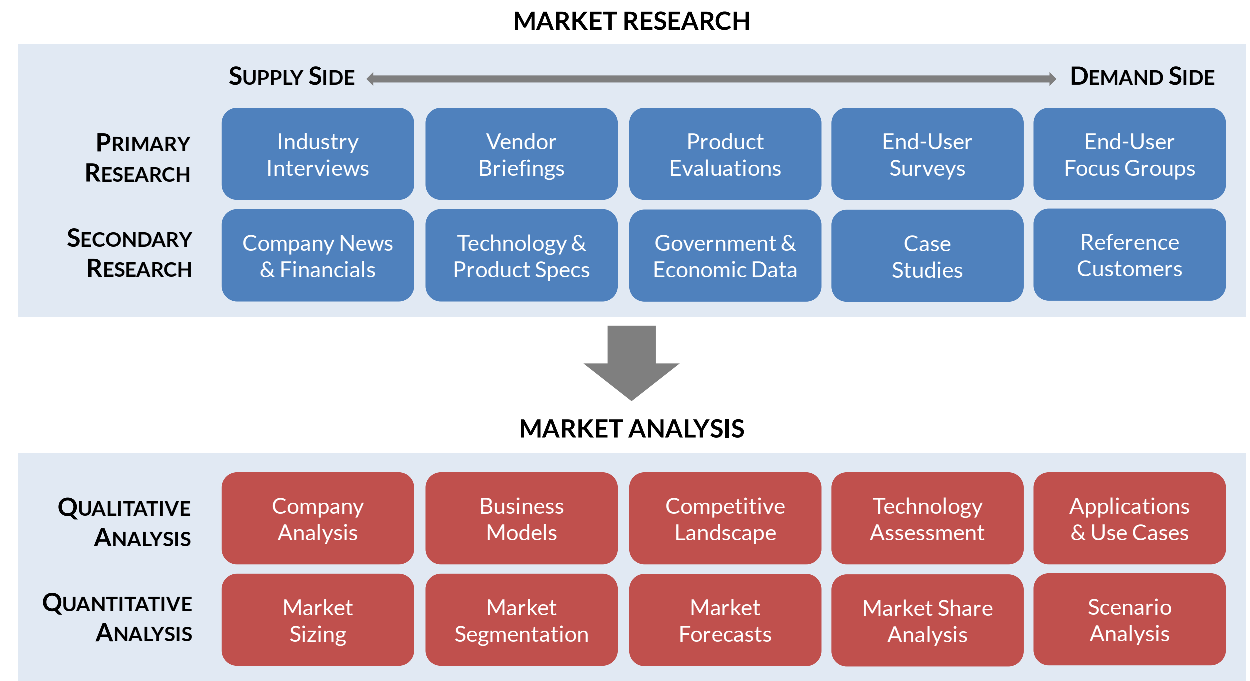
Tractica is an independent market research firm that provides industry participants and stakeholders with an objective, unbiased view of market dynamics and business opportunities within its coverage areas. The firm's industry analysts are dedicated to presenting clear and actionable analysis to support business planning initiatives and go-to-market strategies, utilizing rigorous market research methodologies and without regard for technology hype or special interests including Tractica's own client relationships. Within its market analysis, Tractica strives to offer conclusions and recommendations that reflect the most likely path of industry development, even when those views may be contrarian.

The basis of Tractica's analysis is primary research collected from a variety of sources including industry interviews, vendor briefings, product demonstrations, and quantitative and qualitative market research focused on consumer and business end-users. Industry analysts conduct interviews with representative groups of executives, technology practitioners, sales and marketing professionals, industry association personnel, government representatives, investors, consultants, and other industry stakeholders. Analysts are diligent in pursuing interviews with representatives from every part of the value chain in an effort to gain a comprehensive view of current market activity and future plans. Within the firm's surveys and focus groups, respondent samples are carefully selected to ensure that they provide the most accurate possible view of demand dynamics within consumer and business markets, utilizing balanced and representative samples where appropriate and careful screening and qualification criteria in cases where the research topic requires a more targeted group of respondents.

Tractica's primary research is supplemented by the review and analysis of all secondary information available on the topic being studied, including company news and financial information, technology specifications, product attributes, government and economic data, industry reports and databases from third-party sources, case studies, and reference customers. As applicable, all secondary research sources are appropriately cited within the firm's publications.

All of Tractica's research reports and other publications are carefully reviewed and scrutinized by the firm's senior management team in an effort to ensure that research methodology is sound, all information provided is accurate, analyst assumptions are carefully documented, and conclusions are well-supported by facts. Tractica is highly responsive to feedback from industry participants and, in the event errors in the firm's research are identified and verified, such errors are corrected promptly.

Chart 9.1 Tractica Research Methodology



(Source: Tractica)

Notes

CAGR refers to compound average annual growth rate, using the formula:

CAGR = (End Year Value ÷ Start Year Value)$^{(1/steps)}$ – 1.

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2018 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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