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5G AND INDUSTRY 4.0 FOR AUTOMOTIVE MANUFACTURING

EXECUTIVE SUMMARY

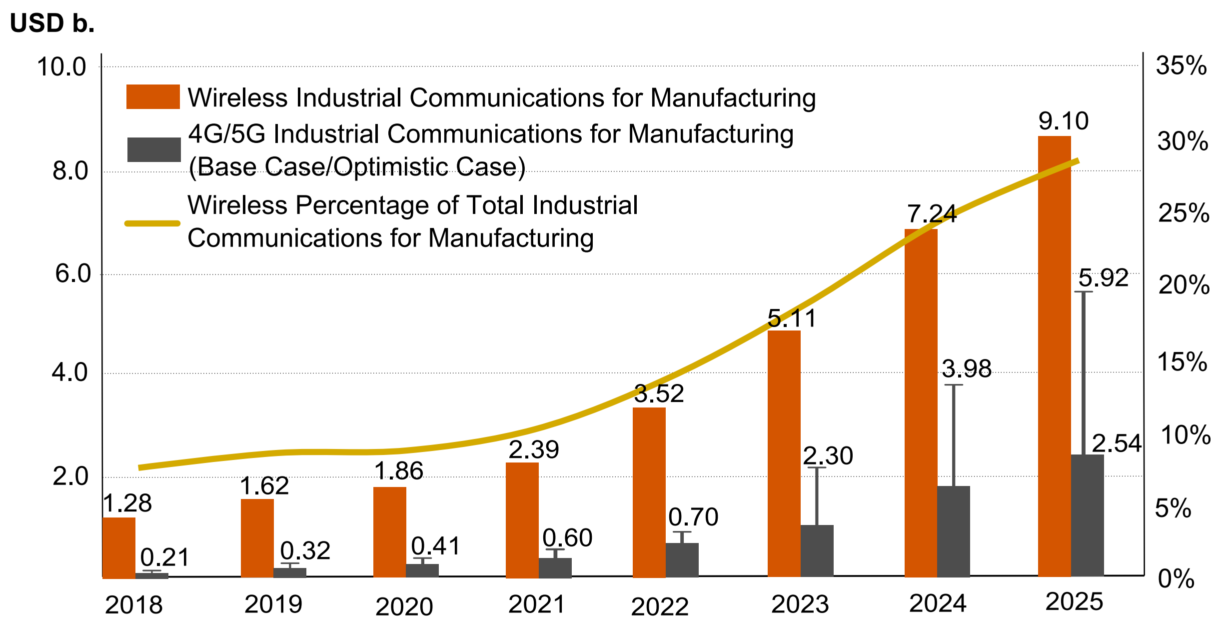
Manufacturing industries face tremendous disruption with increased market competition and unprecedented end-user demands for personalized and customized products. This has culminated in initiatives like Industry 4.0, which emphasizes operational agility with technologies that bring convergence between cyber and physical systems. Wireless technology is key to most Industry 4.0 initiatives and capital expenditures for wireless industrial communications equipment for manufacturing is forecast to increase from 1.28 to 9.10 billion US dollars, between 2018 and 2025, (see Exhibit 1).

Wireless technologies used in manufacturing plants today are predominantly unlicensed, and there is growing interest in 4G and 5G licensed spectrum technologies because of their improved reliability, robustness and latency performance. However, the prospects for 4G and 5G are uncertain and depend on a variety of success factors, including radio spectrum and network availability, ecosystem maturity and dependability, and 4G/5G compatibility with the industrial technologies used in manufacturing environments. Base-case and optimistic forecasts for 4G/5G are illustrated in Exhibit 1 and reach between 2.54 and 5.92 billion US Dollars in 2025. Some of the factors that will impact the prospects for 4G/5G, such as ecosystem maturity, business case justification and radio spectrum availability, are relevant across all industry verticals, while other factors are specific to the industry involved. In particular, the 5G prospects for automotive manufacturing are impacted by:

- *Vehicle product and market disruptions, which include vehicle electrification, and autonomous and self-driving and other connected vehicle capabilities. These disruptions coupled with tremendous market competition and customer expectations are fueling efforts to transform automotive manufacturing.*
- *Conservative technology innovation strategies because of the tremendous financial impact of production outages and product recalls.*
- *Complex and high precision manufacturing processes, which cannot be easily automated and will depend on vehicle assembly personnel for the foreseeable future. This contrasts Industry 4.0 emphasis towards automation and has caused technology over-reach by disruptive companies like Tesla. Efforts to augment the capabilities of assembly personnel (e.g. virtual and augmented reality and collaborative robots etc.), rather than focusing primarily on automation, will create opportunities for 5G in human-machine-interface (HMI) and operational IT technologies.*
- *Industrial connectivity technologies like Fieldbus and Industrial Ethernet and standards like Time Sensitive Networks, and OPC-UA, which impact 5G integration requirements. This is exacerbated by equipment infrastructure lifecycles, which are typically in excess of 25 years.*

Carmakers like Audi and VW in Germany and FAW in China are trialing 5G in automotive manufacturing plants with technology partners including Ericsson and Nokia. As suitable 5G use-cases are identified, we expect other carmakers to follow suit. Although 5G can theoretically deliver real-time and low latency connectivity needed for manufacturing plant and process automation, we believe that it is best applied for this purpose in new installations and for new operational processes that benefit from 5G agility. In established operations, 5G runs the risk of creating unintended and costly operational disruptions. In these cases, 5G is better suited to human-machine-interfaces (HMI) and operational IT applications that capitalize on advancements in technologies like augmented and virtual reality, collaborative and mobile robots and autonomous guided vehicles.

Exhibit 1: Wireless Industrial Communications Equipment Forecast
Source: *Tolaga Research, 2019*



A Disrupted Industry

The automotive industry has faced decades of disruptions. These disruptions are still in full swing and are driving fundamental changes to automobiles and their manufacturing processes. There is a lot at stake. Six of the top ten global manufacturing companies are carmakers.

In 2009 Google kicked off its 'self-driving car project' to pioneer the subsequent proliferation of assisted and autonomous driving solutions. Telsa launched its Model S in 2012 to revolutionized electric vehicle technology and proved that the tremendous barriers for entering the automotive industry could be overcome. Telsa also 'broke the mold' by aggressively pursuing smart manufacturing techniques. While Tesla's approach towards manufacturing was bold, it resulted in production difficulties, particularly for its low-cost Model 3 vehicle. Telsa underestimated the complex and high precision assembly processes associated with automotive manufacturing, and the challenges these processes create for operational automation.

A Complicated Landscape for Innovation

Automotive industry disruptions coincide with broader market trends, such as industrial digitization, and more specifically Industry 4.0 in the case of smart manufacturing. It also coincides with the proliferation of cloud computing, and tremendous advancements in artificial intelligence and machine learning and consumer, enterprise and industrial technology standards.

There is no shortage of innovative technologies to drive industry disruption. However, the automotive industry has a strong inertia towards status quo manufacturing, where infrastructure equipment typically remains the field for more than 25 years. Carmakers are necessarily conservative because of the complex and high precision processes that automotive manufacturing involves. This is punctuated by growing demand for vehicle customization, electrification and new features, such as assisted and autonomous driving technologies.

While robotics and process automation play important roles in automotive manufacturing and have done so since the 1980's, product-line personnel are still needed for the vehicle assembly processes. This is unlikely to change in the foreseeable future, even with advancements in artificial intelligence (AI) and computer vision; and creates unique challenges as carmakers apply the principles of Industry 4.0. Most notably, carmakers must balance the promises of new technology innovations against the risk of technology over-reach as they face new and disruptive production demands (e.g. electrification and autonomous and assisted driving). This is further exacerbated by changes in product lifecycles, product service mix and increased demand for product customization, all in the face of tremendous market competition.

In 2016, Mercedes-Benz stated that it was “de-automating” to rely more on product-line personnel to install the endless options that their luxury customers required. In the same year, Tesla's CEO Elon Musk promoted his company's aggressive approach towards automation, saying that "You really can't have people in the production line itself. Otherwise you'll automatically drop to people-speed,". However, in 2018 Musk relented when he tweeted, "Yes, excessive automation at Tesla was a mistake. To be precise, my mistake.

What is this Report About?

Automotive manufacturers have been trialing 5G technologies since 2018. For example, in August 2018 Audi announced 5G technology trials with Ericsson, in May 2019 Nokia and FAW Group announced a collaborative 5G initiative to accelerate digital transformation in the Chinese automotive sector. Nokia also announced in March 2019, its plans to build out private LTE and 5G coverage for an automotive research factory in Stuttgart, in collaboration with Daimler, Bosch and TRUMPF (a multinational industrial technology company). In addition, at the Hannover Messe conference in April 2019, Qualcomm demonstrated a 5G based process quality control system for automotive manufacturing.

There is no shortage of interest in potential 5G use cases for automotive manufacturing. However, not all the proposed use cases are viable and 5G will only succeed in automotive manufacturing if it is shown to deliver sufficient business value.

This report investigates the drivers and inhibitors for 5G adoption in automotive manufacturing plants. These include:

- Changes in end-user demand, such as electrification and assisted and autonomous vehicle functions. These changes disrupt market status quo, with new product requirements that require operational transformation.
- Efforts to drive efficiencies and operational agility and Industry 4.0 principles, by horizontally integrating operations technologies (OT) and with vertical integration between OT and enterprise IT systems.
- Legacy operational functions and technologies, particularly those associated with critical product line functions.
- Technology standards and adjacent market dynamics where economies of scale and technical know-how can be achieved, or not and;
- Regulations and regulatory frameworks (such as for radio spectrum) that impact the adoption and availability of new technologies, including 5G.

This report is the first in a series of reports to investigate the vertical market opportunities for 5G. A systems based approach and causal framework model is used to assess the key factors that impact 5G adoption. These key factors are then evaluated by combining primary and secondary research with Tolaga's natural language processing (NLP) algorithms for both qualitative and quantitative assessments.

Tolaga's Natural Language Programming (NLP) Methodology

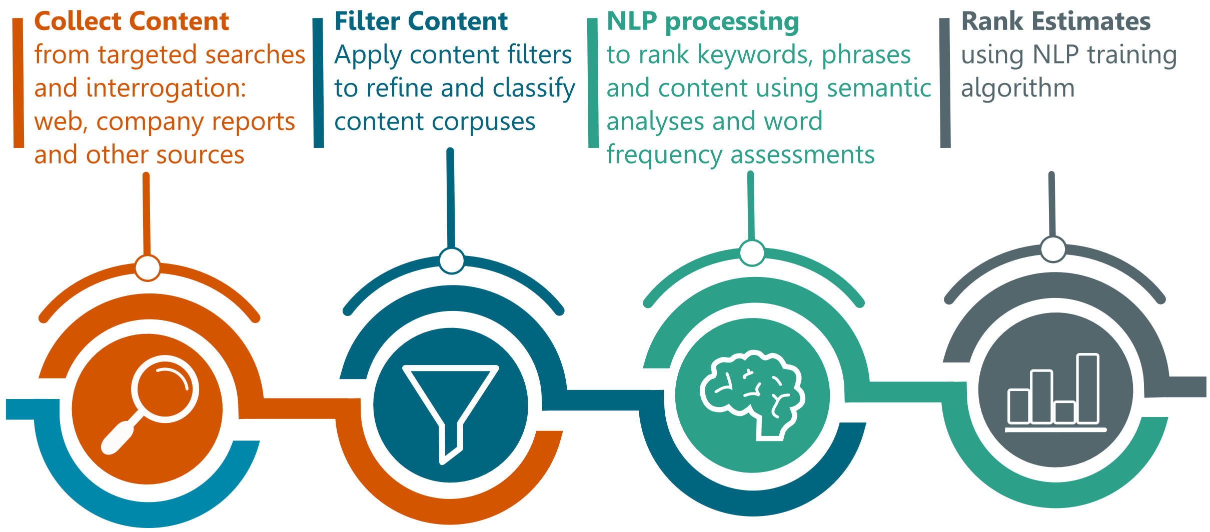
Web content, company reports, and other publicly available content provides a rich source of intelligence that can be analyzed using NLP techniques to extract and quantify unique industry insights.

Tolaga's cognitive computing platform incorporates state-of-the-art unstructured big data harvesting, analytics and NLP algorithms. A schematic of the platform functionality used in this report is shown in Exhibit 2.

In this report, the factors that impact 5G in automotive manufacturing are represented as keywords and phrases, which are applied to targeted content searches. The search results are parsed and filtered to provide a consistent corpus of relevant content on a year-by-year basis for each keyword and phrase reviewed. This corpus is then applied to a proprietary ranking algorithms. The algorithms combine several modeling and AI techniques including the following:

- **Graph-theory** to estimate the strength and relevance of keywords in the content. Graph-theory is widely used to rank content for Internet search algorithms. Keywords are represented as graph-vertices, and the graph-edges connect related words. The keyword dominance is estimated from the quantity and magnitude of connecting edges and connected words.
- **Web content ranking** using the Alexa Rank of the website where the content was sourced.
- **Cosine-Difference** to estimate the similarity between relevant keywords, and;
- **Relevant keyword frequency** across the documents in the corpus relative to the total word count to assess the density of the keyword usage.

Exhibit 2: NLP functionality for '5G-Rank' assessment
Source: *Tolaga Research, 2019*



A Systems Approach for Modeling 5G Adoption

Automotive manufacturing is complex and encompasses precision processes that have been refined over decades. These processes are currently under pressure with growing market competition and demands for new vehicle functionality, such as electrification, enhanced infotainment systems, assisted driving and other customized features.

5G can theoretically enable agile and flexible connectivity capabilities to support the advancements needed in automotive manufacturing. However, although there are many potential 5G use-cases for automotive manufacturing, not all are suitable. Furthermore, individual use-cases are not well represented when treated in isolation, or without broader consideration of the automotive market, and manufacturing environments and technologies involved.

A systems-based framework model is used in this report for assessing key drivers and inhibitors for 5G adoption for automotive manufacturing, see Exhibit 1. The framework model has four domains, which include:

1. the automotive market,
2. transformation in vehicle manufacturing,
3. connectivity technology and,
4. 5G and its ecosystem development.

While each of these domains have their own unique characteristics, their interdependence is represented by causal relationships. In Exhibit 3, three types of causal relationships are shown, namely:

- **Reinforcing (marked green)** - where an increase/decrease in one factor causes an increase/decrease in the other factor.
- **Opposing (marked red)** - where an increase/decrease in one factor decreases/increases the other factor.
- **Uncertain (marked grey)** - where the relationship between factors is not known and depends on other external considerations. For example, standards based OT connectivity will only impact 5G if there is adequate coordination between relevant standards organizations.

Exhibit 3: System model for 5G Adoption in Automotive Manufacturing
Source: *Tolaga Research, 2019*

Market Demand Disruptions Drive Industry Transformation

Recent headlines are a poignant reminder of uncertainties and disruptions that the automotive industry must navigate:

Automakers' Job Cuts Are at 38,000 and Counting – Bloomberg, May 23, 2019

Ford CEO Hackett reassures investors of EV plans as it pours money into electric F-150, 'Mustang-inspired' crossover – CNBC, May 9, 2019

Automakers have a choice: Become data companies or become irrelevant TechCrunch, May 24, 2019

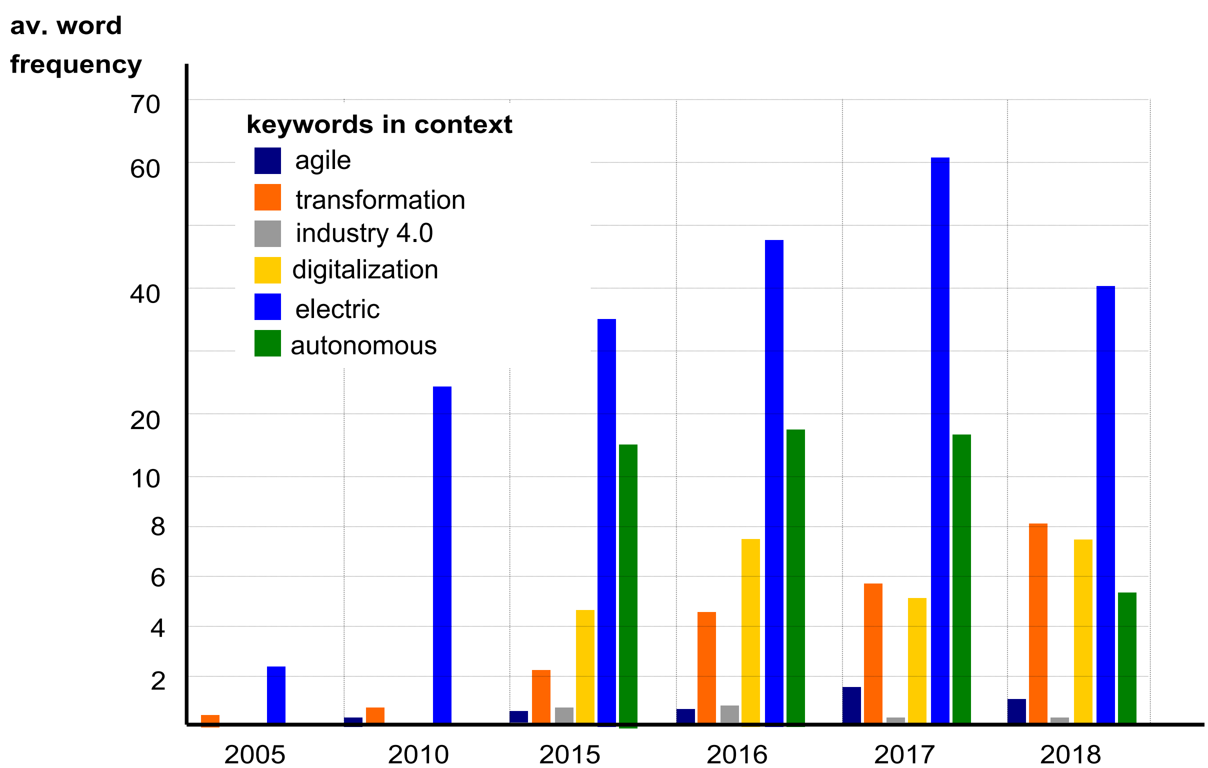
Bosch fined $100 million over emissions-cheat software – Auto News Europe, May 23, 2019

Tesla dominates other premium automakers in California, pushes EV market share over 5% - Electrek, May 23, 2019

Market disruptions have plagued the automotive industry for many years. Exhibit 3, shows that automotive market disruptions reinforce manufacturing transformation and vice versa. Amongst its peers, Tesla has been the most aggressive in its efforts to transform traditional automotive manufacturing. This has contributed to operational challenges particularly with Telsa's efforts to scale its Model 3 business. To reflect the potential pitfalls with overly aggressive transformation in manufacturing, the causal model in Exhibit 3 accounts for the potential impact of **Vehicle Manufacturing Transformation** on **Vehicle Recall Volume** and **Production Outages** and the dampening effect this has on the rate of manufacturing transformation.

Industry disruptions are reflected the annual report disclosures of car makers. For example, average word frequency of 'electric' and 'autonomous' in the context of vehicle functionality in the annual reports of a basket of twelve carmakers is shown in Exhibit 4. Disclosures relating to electric vehicles increased dramatically between 2005 and 2010 and for autonomous vehicles between 2010 and 2015. The frequency of other keywords in the context of automotive manufacturing, including those relating to 'agility', 'transformation', 'industry 4.0' and 'digitization' were also shown in Exhibit 4. Except for 'industry 4.0', the frequency of the keywords relating to manufacturing transformation in annual report disclosures has increased dramatically between 2010 and 2015 and have continued to increase in subsequent years.

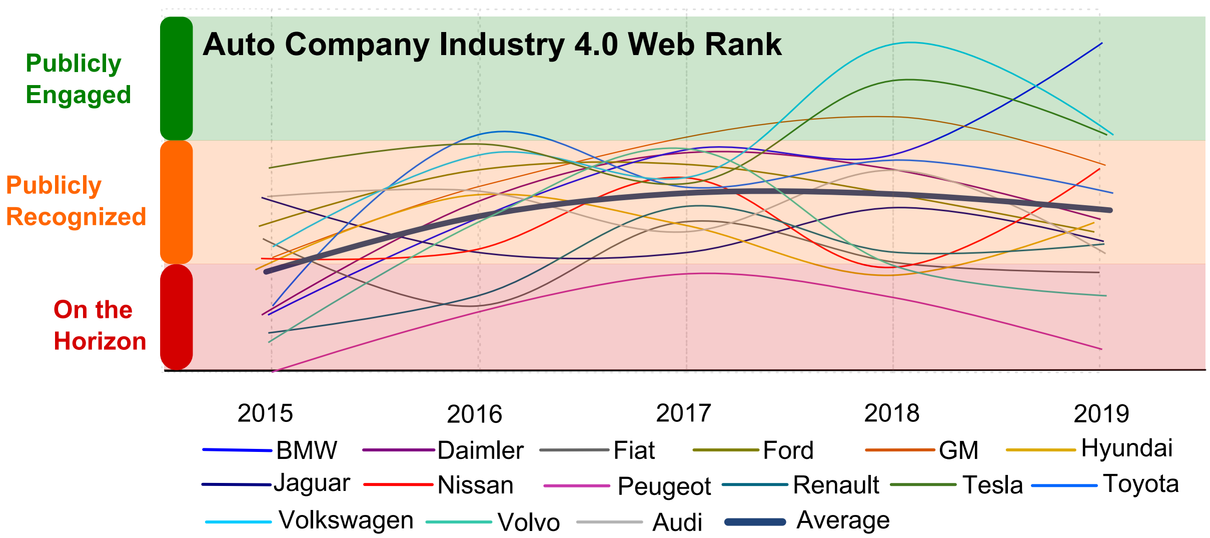
Exhibit 4: Keyword frequency in company annual reports
Source: *Company Reports and Tolaga Research, 2019*



Industry 4.0 only features prominently in annual report disclosures from Daimler and Volkswagen (VW). Exhibit 4 assesses that rank of the phrase 'Industry 4.0' for major automotive manufacturers from targeted web content searches. While there are some outliers, such as General Motors, Tesla and Volvo, most automotive manufacturers are not vocal champions Industry 4.0.

It is clear that the general principles of Industry 4.0 are applicable to automotive manufacturing, however the focus on automation and operational agility must be refined. For example, rather than focusing primarily on replacing product-line personnel with automation technologies, Industry 4.0 must also emphasize the role of digital technologies in automotive manufacturing to enhance the capabilities the personnel that remain, with collaborative robots (cobots), and other technologies like augmented reality. The prospects for cobots are assessed in a subsequent section of this report.

Exhibit 5: Most carmakers are not vocal champions of Industry 4.0
Source: *Tolaga Research, 2019*



TRANSFORMING AUTOMOTIVE MANUFACTURING

As carmakers contend with disruption and market competition, they are eager to transform their manufacturing processes to reduce costs, improve operational efficiencies and agility, as shown in the system model in Exhibit 3. However, before new transformations are operationalized, they are subjected to rigorous testing to minimize the risk for operational outages and ensure adequate business value is created. Car makers are pursuing two broad transformation efforts which include the:

- Horizontal integration amongst operational technologies (OT) to enable efficient, flexible and agile manufacturing processes, and;
- Vertical integration between OT and enterprise IT systems to improve end-to-end operational flexibility and efficiencies.

These efforts broadly align with the smart manufacturing principles of Industry 4.0, but are greatly impacted by incumbent technologies, the adoption of proprietary and standards-based solutions and the extent of wireless connectivity.

Friction between Proprietary and Standards-Based Solutions

The age-old debate between standards based and proprietary solutions is alive and well in industrial operations. Proprietary solutions are widely adopted and bring the benefit of vendor specific innovations with reliability, speed to market and vertical integration. In contrast, standards ease multi-vendor integration challenges, aid third party developments and generally drive economies of scale. For automotive manufacturing, the debate between standards based and proprietary solutions is punctuated by heightened technology reliability demands. Carmakers are necessarily conservative with technology innovation and standardization for fear that it might cause costly operational downtime, and vehicle recalls in cases where innovations cause unforeseen quality issues.

Carmakers need 'one-throat-to-choke' when operational problems occur and generally require systems integration services from their vendors, rather than in-house. Vendors normally have strong incentives to strategically combine standards-based solutions for economies of scale, with proprietary solutions to differentiate and create vendor lock-in. This has a tremendous impact on the pace and diversity of innovation for automotive manufacturing. With so much at stake, status quo is difficult to disrupt. Most OT technologies remain operational for 25 years or more and any replacements are scrutinized carefully and only implemented when equipment either wears out or can be reliably upgraded with solutions that deliver sufficient incremental value.

The dynamics between proprietary and standards based solutions have a direct impact on automotive manufacturing transformation and the appropriate positioning of 5G.

Reliability Reigns Supreme for OT Connectivity

Reliability is at the heart of OT technology decisions and the standards used. This can vary dramatically depending on the application. For example, programmable logic controllers (PLC) and micro-controllers require highly reliable connections with latencies less than one millisecond, for applications such as real-time motion control. Other adjacent non-real-time operational functions have much less stringent connectivity requirements. The various connectivity demands in a typical manufacturing environment are supported by range of standards based and proprietary connectivity technologies These technologies will have a direct impact on 5G and its adoption in manufacturing environments.

Fieldbus solutions are widely used for industrial connectivity. Originally developed in the 1980s, Fieldbus has many variants, with Profibus, Modbus-RTU and CC-Link being the most dominant. In recent years, Fieldbus has been superseded by Industrial Ethernet based technologies.

Industrial Ethernet comes in many flavors and capitalizes on Ethernet economies of scale for Data-Link-Layer (OSI Layer 2) functionality. Protocols like EtherNet/IP, Profinet, EtherCAT, and Modbus-TCP have different upper layers (OSI Layers 3-7) and in some cases modify Ethernet Layer 2 for real-time and mission critical connectivity.

The different flavors of Industrial Ethernet commonly create systems integration challenges, particularly in multi-vendor environments and when operational convergence and agility is a priority. Several standardization efforts which aim to ease operational integration challenges include Ethernet TSN, OPC-UA and OpenPLC.

The total Industrial communications market was USD89 billion in 2018 and expected to reach USD159 billion by 2025. In 2018, shipments of Ethernet surpassed Fieldbus based solutions.

Only 8 percent of industrial connections were wireless in 2018, but this is forecasted to increase to 30 percent by 2025, see Exhibit 1. This growth will be primarily driven by advancements in agile manufacturing and the proliferation of industrial IoT. A proportion of wireless connections will use 5G. This proportion will vary depending on the ease of integration of 5G with key technologies such as the Industrial Ethernet variants.

Ethernet TSN Standardizes Real-Time Capabilities

Ethernet Time sensitive networking (TSN), is a feature of the Ethernet standards (IEEE 802.1). TSN enables Ethernet resources to be partitioned into separate virtual channels, with distinct service classes that account for key performance factors such as latency and bandwidth. TSN can be implemented in native Ethernet environments, but requires controller functionality to coordinate resources according to policies and system demands.

Industrial Ethernet standards like EtherNet/IP, Profinet, EtherCAT and Modbus-TCP can function transparently with native Ethernet-TSN. When used, TSN would substitute the real-time and mission critical functions in current Industrial Ethernet protocols.

In its favor, Ethernet-TSN is applicable to all Ethernet installations and is likely to be widely used for enterprise IT and high performance Ethernet applications, such as in-vehicle networking.

The web ranks in Exhibit 6 show that interest and the public profile of Ethernet-TSN increased in recent years, particularly in the 2015-2016 timeframe. This interest has been driven by vendor support and collaboration with standards organizations including the OPC Foundation and Industrial Internet Consortium. TSN also has its share of skeptics, who believe that TSN upgrades are not justified and lack sufficient incremental business value relative to the solutions used today. However, we believe that TSN will be adopted for industrial applications including automotive manufacturing.

5G-TSN inter-working is being developed and will have broad market applicability beyond industrial manufacturing (e.g. in vehicle networking). However, 5G-TSN inter-working does not eliminate 5G inter-working requirements for the various Industrial Ethernet standards. (e.g. EtherNet/IP, Profinet, EtherCAT and Modbus-TCP).

OPC- UA is a Bellwether for OT and IT Integration

OPC-UA (Unified Architecture) is an architectural framework for industrial connectivity that is maintained by the OPC Foundation. OPC-UA specifies information exchange for industrial systems, within and between OT devices, and between OT and IT systems. OPC-UA has interoperability for all major Industrial Ethernet protocols and recently incorporated TSN capabilities for real-time communications. In addition, OPC-UA is collaborating with the VDMA organization for computer vision technology.

In its favor, OPC-UA implementations can be agnostic to the communication protocols used and promises to reliably and securely enable horizontal OT and vertical OT-IT integration needed for agile and efficient manufacturing.

The web ranks in Exhibit 6 show growing interest in OPC-UA, with a significant rise in the 2015-2016 timeframe. This reflects the growing support for OPC-UA from technology vendors and other standards organizations. OPC-UA skeptics complain that it is complicated, and its charter is overly ambitious and difficult to achieve. **On balance, we believe that 5G interoperability with OPC-UA should be a high priority** for its penetration into vertical markets such as automotive manufacturing.

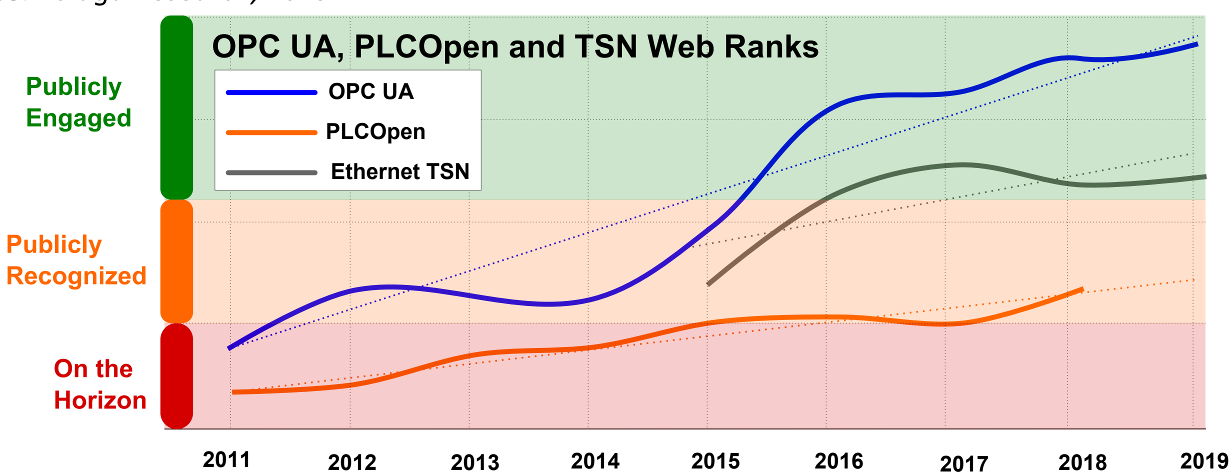
PLCOpen Contends with a Bias Towards Platform Integration

PLCOpen was originally established in 1992 to promote standardized and open industrial automation software to enable platform independence and to ease systems integration challenges. While PLCOpen has admirable endeavors, and a large membership base, its progress has been modest as it contends with strong inertia towards proprietary solutions.

In essence, PLCOpen is hindered by the business models for major automation equipment providers.

PLCOpen has gained market traction with targeted solutions, but is unlikely to be widely adopted until equipment vendor business models change. This reflects a general bias towards proprietary and vertically integrated platform architectures and accounts for the modest interest in PLCopen that is implied by the web ranks shown in Exhibit 6.

Exhibit 6: Ethernet-TSN, OPC-UA and OpenPLC Web Ranks
Source: *Tolaga Research, 2019*



5G Trialed for Automotive Manufacturing

Industry pundits have high expectations for 5G market opportunities with vertical industry applications, including automotive manufacturing. From the outset of its creation, 5G has incorporated specific functionality such as network slicing, support for ultra-low latency and ultra-reliable connectivity and access agnostic core network functionality, to address the demands of industrial applications.

Automotive manufacturer, including Audi and its parent VW have been trialing 5G for its manufacturing operations. These trials typify broad industry interest in 5G. However, the success of 5G in automotive manufacturing will be determined by many interdependent factors, illustrated by the causal framework model in Exhibit 3.

Radio Spectrum is a Linchpin for 5G Availability

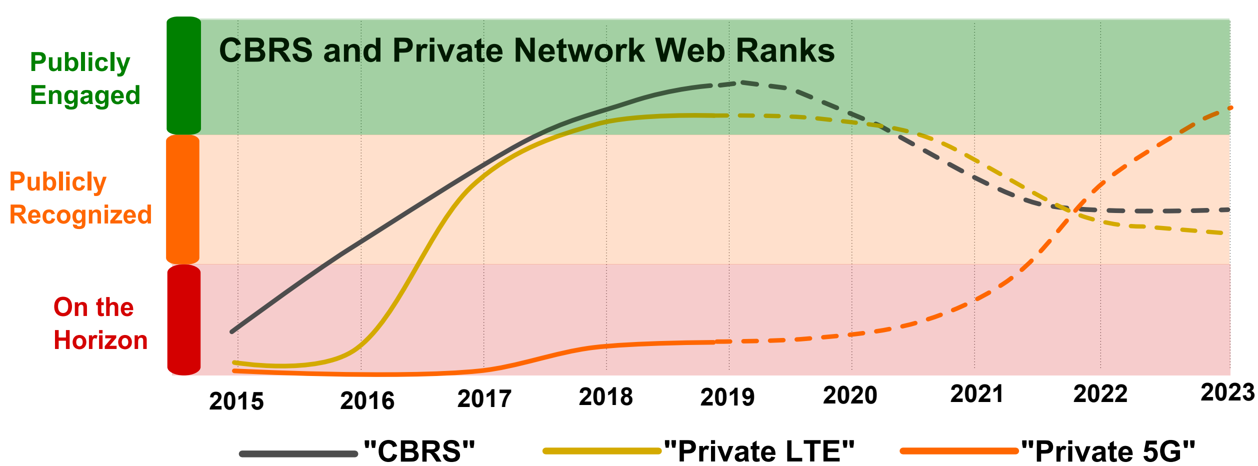
5G requires regulators to allocate suitable radio spectrum resources. In many markets, regulators are allocating spectrum in 2.6 and 3.5 GHz and in millimeter wave bands above 20GHz. To benefit from advanced technologies such as massive MIMO, wideband time division duplex (TDD) band plans are being adopted. The frequency division duplex (FDD) allocations used in existing cellular spectrum bands are less suitable for 5G because of the reduced MIMO gains they enable.

The rate of spectrum licensing is a primary factor for 5G network availability. Although most 5G spectrum will be allocated for public networks, there is growing interest in private networks to support vertical industries, like automotive manufacturing. 5G incorporates network slicing capabilities so that the unique requirements of specific vertical industry applications can be supported on public networks. However, most vertical industry companies prefer dedicated private networks rather than sliced resources on public networks. This is particularly the case when 5G is used for live operations.

In some markets such as Germany and the United States, spectrum is being licensed for industrial and private 5G services. In particular, in Germany the local regulator BNetzA has earmarked 3.7-3.8GHz spectrum for industrial use. VW has stated that it plans to deploy 5G in its manufacturing facilities in Germany in the 2020 timeframe. Citizens Band Radio Service (CBRS) spectrum has been allocated in the United States for public and private mobile services. The CBRS band is used by the US Navy for radar systems, but is available for commercial and private use in areas where the 'CBRS radars' are not operated. CBRS was initially earmarked for 4G-LTE, but has subsequently been made available for 5G.

Exhibit 7 shows that the web ranks for CBRS, Private LTE and Private 5G. The rank for CBRS has increased consistently since 2015 and Private LTE experienced a major rank increase between 2016 and 2017 and has continued to increase since then. The web rank for Private 5G started to gain some momentum in 2017 and although Private 5G remains 'On the Horizon', its related web content demonstrates building momentum, which we believe will be reflected in a significant rank increase in the 2020-2021 timeframe. It will take another 2-3 years after this timeframe (2022-2024) before Private 5G can be expected to gain meaningful market momentum.

Exhibit 7: CBRS Private LTE and Private 5G Web Ranks
Source: *Company Reports and Tolaga Research, 2019*



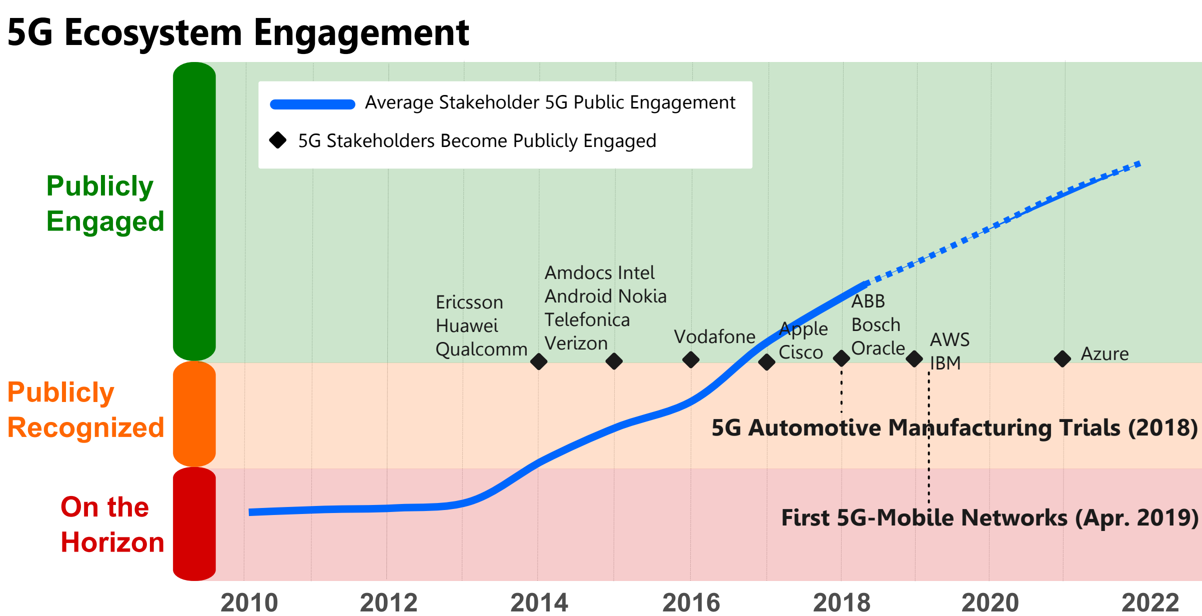
Crucially, Private LTE and 5G networks are not limited to markets where dedicated spectrum is allocated by regulators. In some cases network operators have partitioned spectrum resources for private operations within geographically limited areas (i.e. campus systems). We believe that campus systems that use public radio spectrum will be crucial for 5G adoption for vertical industry applications, such as automotive manufacturing. In addition, since campus networks will the same spectrum as public networks it would alleviate potential device compatibility challenges

Since 5G is a complicated network technology, it will drive demand for network automation and managed services, particularly to support private network deployments. Network operators, technology vendors and other third parties, such as systems integrators that combine vertical industry and 5G expertise are well positioned to provide managed network services to support private 5G operations.

5G Ecosystem Will Take Years to Mature

Although 5G has exceeded expectations for its standardization and subsequent deployment for consumer markets, it is still a nascent technology and depends on the support amongst many stakeholders for vertical industry adoption. The stakeholders involved have different priorities, incentives and vested interests that impact the rate at which they engage with 5G. The public engagement estimates for twelve 5G stakeholders were derived using NLP techniques and are shown in Exhibit 8. Technology and service providers became engaged in 5G in the 2014 timeframe. It took another five years for the first commercial mobile 5G network deployments in 2019. Initial 5G automotive manufacturing trials occurred in 2018 and we believe it will take another four to five years (i.e. in the 2023-2024 timeframe) before meaningful 5G commercial deployments for automotive manufacturing. This timeframe will be compressed with 5G adoption in adjacent markets, such as for in-vehicle and connected vehicle functionality. This is reflected in the forecast shown in Exhibit 1 and the causal framework model shown in Exhibit 3.

Exhibit 8: Ecosystem Engagement Rates for 5G Stakeholders
Source: *Tolaga Research, 2019*



5G Use Cases for Automotive Manufacturing

As 5G technology matures, its potential role in automotive manufacturing will become better understood. Even though Major carmakers including Audi, Daimler, and equipment providers like Bosch and TRUMPF are heavily invested in 5G trials, the value proposition for 5G is yet to be refined. For example, in a May 2019 interview with the head of Audi's production lab with Henning Löser said that 'the technology is really cool, but we first need to know the problems it can solve - which we couldn't solve before'. Others question whether 5G delivers necessary and differentiated functionality relative to existing wired and wireless LAN and 4G-LTE technologies. With wireless occupying such as small percentage of automotive factory connectivity, 5G must offer significant value across a range of use-cases to justify its adoption. In addition, 5G must integrate seamlessly with legacy systems and emerging standards such as those associated with OPC-UA and Ethernet-TSN.

The potential automotive manufacturing use-cases for 5G can be divided into several categories, which include, plant and process automation, logistics and warehousing, and human-machine-interfaces (HMI) and operational IT. Each category has unique requirements which present distinct opportunities and challenges for 5G.

Plant and Process Automation

Ordinarily industrial manufacturing processes and workflows are automated to drive the cost-effective industrial mass production of quality products. It was this viewpoint that we believe unpinned Elon Musk's 2016 comments where he stated that 'people' had to be taken out of the automotive process to make it more efficient. However, this approach was clearly wrong and illustrates the unique characteristics of plant and process automation associated with automotive manufacturing. While many functions in automotive manufacturing plants have been automated using robots and closed loop control applications with PLCs, motion controllers, etc., skilled persons are needed for to fulfill more complex tasks, such as vehicle assembly.

Control systems associated with plant automation, such as PLCs, generally have stringent real-time connectivity demands. Since connection failures can lead to costly outages, plant designs are necessarily conservative. **We believe that the automotive industry will be slow in adopting 5G for plant automation** because of performance concerns and possibly systems integration challenges.

Logistics and Warehousing

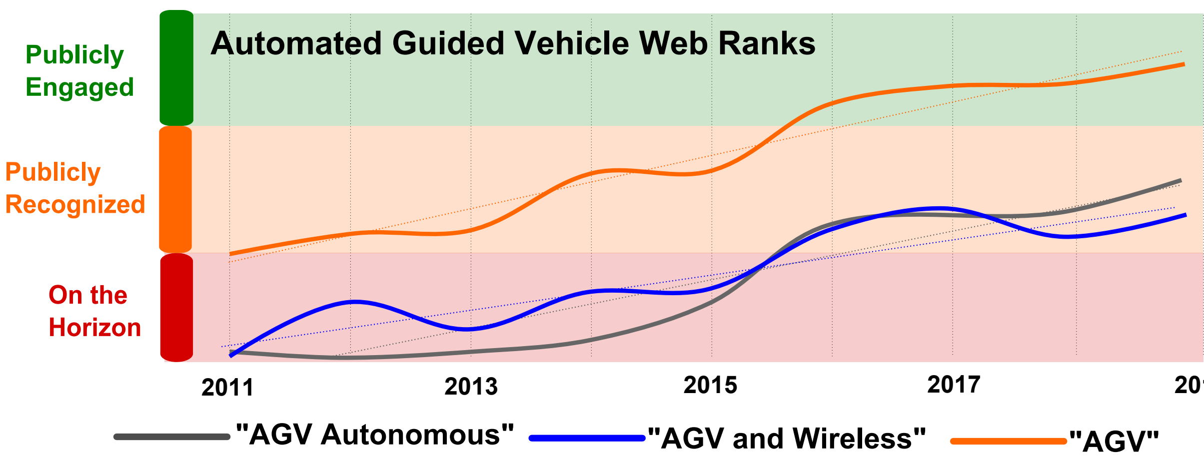
Effective logistics and warehousing are crucial for automotive manufacturing production lines to function efficiently. Monorail systems are used to shuttle vehicle assembles through the production process. Other shuttle systems, mobile robots and automated guided vehicles (AGV) deliver materials and subassemblies to specific locations along the production lines. These delivery systems typically have predefined guidance and navigation capabilities. In particular shuttle systems run on monorails. AGVs and mobile robots typically follow paths that are mapped out with physical indicators, such as paint, magnetic tape or inductive wire. Some delivery systems are free ranging with laser/LIDAR based navigation systems.

Production line delivery systems are controlled by fleet software to integrate warehouse, logistics and enterprise resource planning and inventory management systems to ensure that the plant operations meet the overall business objectives.

Conventional logistics and warehousing processes are relatively deterministic for each model of vehicle being produced. However, the increasing demands for customized features challenges conventional processes. Some carmakers like Mercedes Benz have responded to production challenges by 'de-robotizing' some of their production processes to 'accommodate custom features'. Wireless technologies potentially ease the challenges with custom vehicle features by enabling plant operations to adapt to the changing production requirements.

Currently a small but growing percentage of mobile platforms for logistics and warehousing use wireless connectivity. Even though wireless is not widely used, it is an optional connectivity feature of most mobile robot and AGV solutions. Today these solutions generally use proprietary implementations of industrial Wi-Fi technology. In addition, there is growing interest in using wireless technologies to support autonomous AGV and mobile robot capabilities to increase the agility and flexibility of non-critical operational functions. Growing interest in wireless and autonomous AGV solutions is reflected in the web ranks shown in Exhibit 9.

Exhibit 9: Web Ranks for Automated Guided Vehicles
Source: *Tolaga Research, 2019*



Logistics and Warehousing functions vary in their criticality for automotive manufacturing. For example, reliability is critical for shuttle systems, mobile robots and AGVs that are synchronized in real-time to deliver vehicle sub-assembles along a production line. In contrast warehousing and inventory management functions that are not directly linked to production processes are less critical. **Although 5G is being trialed for operationally critical functions, we believe it is the less critical functions or adjacent capabilities to operationally critical functions that are more appropriate initial target applications for 5G.** These target applications include autonomous AGVs and robots in warehouse environments, and computer vision applications with artificial intelligence to complement existing real-time logistical functions.

Human Machine Interfaces (HMI) and Operational IT

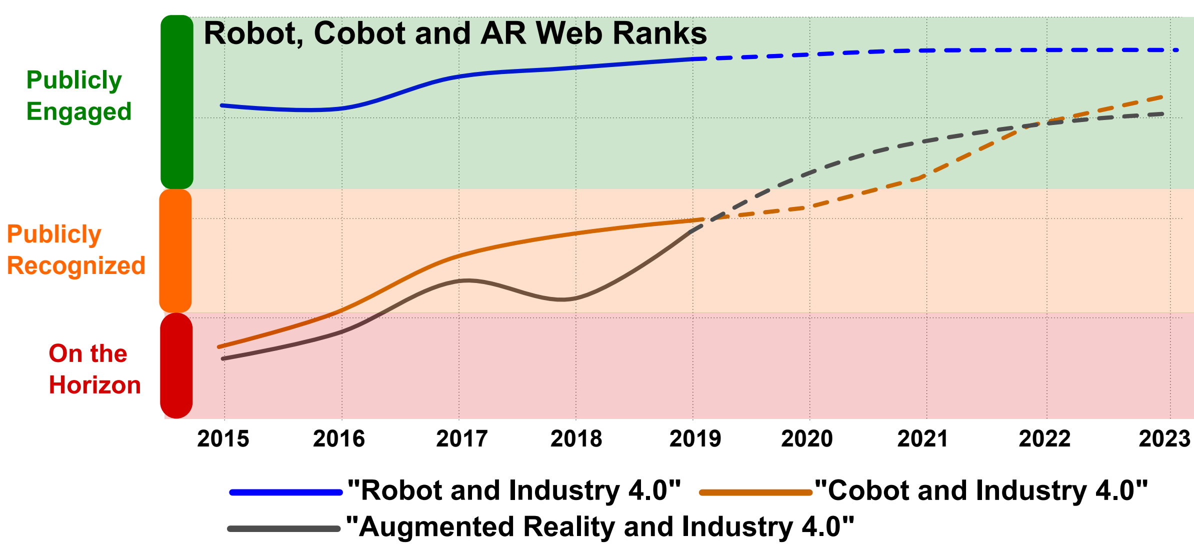
Although robots have been used for decades in automotive manufacturing, particularly for vehicle subassembly welding and painting, automotive manufacturing processes are complex and precise and cannot be supported entirely by robots.

Even with recent advancements in computer vision and autonomous technologies, automotive manufacturing will continue to require assembly personnel for the foreseeable future. Carmakers must carefully manage their investments in automation. These investments must be balanced relative to technology innovations that enhance the capabilities of assembly personnel, rather than to replace them. Notable technologies include mixed reality solutions that capitalize on massive sensor networks to augment and enhance human-machine-interfaces (HMI), and cooperative robots (aka cobots) such as exoskeletons to enhance the physical capabilities of assembly line workers.

Exhibit 10 shows the web rankings for the phrases: "Robot and Industry 4.0", "Augmented Reality and Industry 4.0" and "Cobot and Industry 4.0". The ranking for augmented, virtual and mixed reality (AR/VR/MX) accelerated in 2018 and we expect this acceleration to continue because of the broad range of applicable applications. The web rank for cobots has increased since 2015 and will continue to increase as cobots become more commonly adopted in industrial, enterprise and consumer markets.

Since assembly personnel are mobile, HMI and other operational IT, such as production monitors, remote controls and other handheld devices are ideally suited to wireless connectivity. Today most wireless connectivity is supported adequately using industrial WLAN technology. However **emerging solutions such as AR/VR/MX and cobots have high bandwidth low-latency requirements that are likely to require 5G capabilities.** We believe that this creates promising 5G opportunities, particularly for automotive manufacturing, where assembly personnel will be required for the foreseeable future.

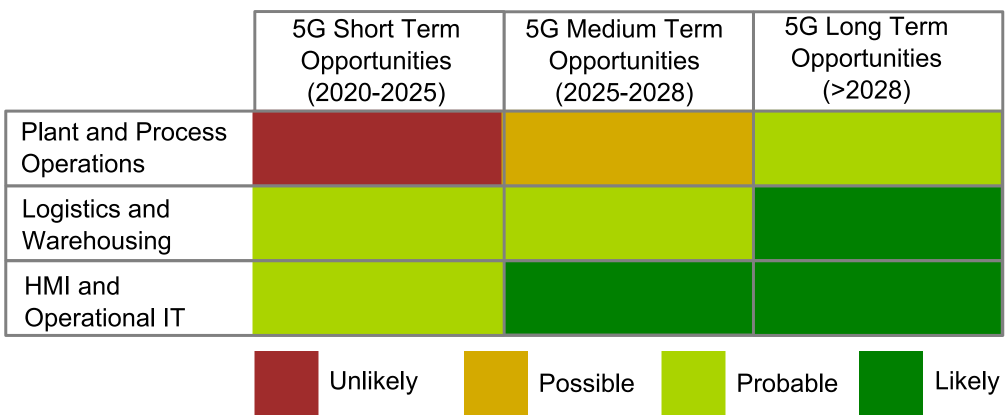
Exhibit 10: Web Ranks for Robots, Cobots and Augmented Reality with Industry 4.0
Source: *Tolaga Research, 2019*



5G Value Proposition Must Justify Costs

While the general value proposition for 5G is to untether operational infrastructure for agile and cost-effective operations, automotive manufacturers are necessarily conservative with new technologies like 5G. Live plant and process operations have the most stringent performance requirements in terms of connection latency and reliability. Although 5G can theoretically address the demands for live plant and process operations, we believe that most automotive manufacturers will favor conventional technologies instead, for the next five to ten years. In contrast, logistics and warehousing and HMI and operational IT provide tangible opportunities for 5G in medium and long-term time frames (see Exhibit 11). However, before these solutions are viable, 5G must bring aggregate business value to justify its deployment in the manufacturing plants where it is to be used.

Exhibit 11: 5G Opportunity Assessment for Automotive Manufacturing
Source: *Tolaga Research, 2019*



Conclusion

Automotive manufacturing is confronted with disruptive market demands and tremendous market competition, which is driving the need for operational transformation. The tenets of Industry 4.0 that focus on cyber-physical convergence, and operational agility and efficiency are relevant to automotive manufacturing. However, in contrast to traditional manufacturing where automation is of primary importance, automotive manufacturing encompasses complex and high precision operations which will continue to depend on assembly personnel for the foreseeable future.

Automotive manufacturing was amongst the earliest industries to embrace robots, and while robots continues to be widely used, product customization has seen manufacturers like Mercedes Benz 'de-robotize' parts of the assembly process. Manufacturing complexities have challenged companies like Telsa, whose aggressive approach towards automation has challenged its ability to maintain product quality for low cost, high volume production.

Carmakers are necessarily conservative with their technology innovation. However, operational automation, agility and transformation has featured with increased regularity in their public filings since 2015. This coincides with increased interest in vehicle electrification and autonomous vehicle control and driver assistance and heightened market competition.

As carmakers transform their manufacturing operations, they are trialing and adopting standards-based technologies like OPC-UA and Ethernet-TSN to ease integration challenges amongst OT and between OT and IT systems. However, since legacy systems will remain operational for the foreseeable future, systems integration demands will remain a key inhibitor for operational transformation.

Carmakers including Audi and VW in Germany and FAW in China have been conducting extensive 5G trials and are conservatively optimistic towards opportunities for 5G to transform their manufacturing operations. However, 5G must prove itself in delivering sufficient business value with solutions that are compatible with industrial technologies, such as OPC-UA, the various Industrial Ethernet protocols and standards like Ethernet-TSN. In addition, 5G solutions must be initially targeted towards applications that deliver tangible value without overly disrupting existing operational systems.

To succeed in automotive manufacturing, 5G must offer sufficient value to offset its implementation costs, without technology over-reach. We believe that 5G solutions targeted towards HMI and Operational IT and Logistics and Warehousing offer short- and medium-term opportunities. Although 5G has the capabilities to support real-time plant and process automation functions, we believe that these capabilities might only come to fruition in the long term. Furthermore, if too much emphasis is paid towards promoting 5G for plant and process automation, 5G runs the risk of over-reaching its capabilities and being deemed a failure before it has had the opportunity to mature into its role in delivering vertical market solutions.

About Tolaga Research

Tolaga Research is a leading consulting and advisory firm with a focus towards communication networks and the Fourth Industrial Revolution. Tolaga was founded in 2009 and is the world's first firm to apply artificial intelligence with natural language processing and system dynamics modeling to industry research. By combining these sophisticated capabilities with its extensive primary research, Tolaga delivers unique and actionable insights that are fortified with robust data science and system modeling solutions.

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