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Aldo Geuna • Marco Guerzoni • Massimiliano Nuccio • Fabio Pammolli • Armando Rungi

Resilience and Digital Disruption

Regional Competition in the Age of Industry 4.0

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Abstract	This chapter explores the main markets for the production and use of robots and 3D printing technologies and presents a comparative analysis of the core robotics and 3D printing competence in the major world digital manufacturing sectors. We focus specifically on Piemonte and its efforts to develop CPS in the automotive sector, a traditional key driver of Italian industrial development. Particular attention is paid to the role of *collaborative robots* compared to the more traditional manufacturing robots already used heavily in automotive production.

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Chapter 4
Digital Manufacturing and the Transformation of the Automotive Industry

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This chapter explores the main markets for the production and use of robots and 3D printing technologies and presents a comparative analysis of the core robotics and 3D printing competence in the major world digital manufacturing sectors. We focus specifically on Piemonte and its efforts to develop CPS in the automotive sector, a traditional key driver of Italian industrial development. Particular attention is paid to the role of *collaborative robots* compared to the more traditional manufacturing robots already used heavily in automotive production.

The analysis is aimed at classifying robot technologies to understand why collaborative robots associated with sensors could revolutionize manufacturing production. The evolution of digital manufacturing and its rapid expansion are evident in many applications in the automotive value chain. This chapter addresses some fundamental questions. For example, how has the automobile market changed in recent years? How are OEMs responding to the challenges posed by Industry 4.0? And what role can Italy (and Piemonte) play in this rapidly changing scenario?

4.1 Challenges to the Uptake of Digital Manufacturing

Despite its far-reaching effects and current advances in the relevant technologies, digital manufacturing is in its infancy. One reason for this is the conservative business strategies and being averse to unproven production processes displayed by industry (Babiceanu & Chen, 2006; Leitão, 2009). For example, a survey of 300 manufacturing leaders, conducted by McKinsey & Company (2015), indicates that only around half (48%) of firms consider themselves prepared for the impact of Industry 4.0. Another reason is related to the persistent and significant challenges involved in operationalizing digital manufacturing. First, more research is needed into autonomous systems to achieve self-organization among production cells, which would allow learning capabilities and dynamic and evolvable reconfigurations (Leitão, 2009; Brettel et al., 2014). These advances would mean that systems could

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react faster, contribute more to the decision process, be more able to undertake small-lot production, and be more effective in helping enterprises identify constraints and opportunities (Brettel et al. 2014).

In the case of multi-agent systems (MAS), in particular, further research is needed on their distributive and autonomous capabilities (Shen et al., 2006; Pěchouček & Mařík, 2008). Current technologies only allow for communication through cloud-assisted industry wireless networks (IWN) (Wang et al., 2016). However, holonic manufacturing systems (HMS) require proven design methodologies that can deliver consistency and reliability in a given system, and adaptability to available computing systems (Babiceanu & Chen, 2006). It should be noted that beyond the identified agent technologies, there is some emerging research and several projects on bio-inspired robot designs, which provide the possibility to build robots that mimic natural morphologies and self-organization (e.g. animal-like movements, self-organization, and self-assembly behaviour in nature) (Pfeifer et al., 2007).

Furthermore, research on systems autonomy must account for user adoption and firm integration. System behaviour should be predictable and stable for human workers; there is also a need to develop methodologies that support easy, fast, transparent, and reusable integration of physical automation devices (Leitão, 2009). At the firm level, local enterprise integration for small and medium-sized enterprises (SMEs) is impossible due to their isolated, heterogeneous, and obsolete legacy systems (Shen et al., 2006; Brettel et al., 2014).

In relation to firms, there are issues related to firm capabilities and cyber-security. Reconfigurable manufacturing systems (RMS) are impeded by a lack of powerful IT systems and their integration with other systems, and inadequate employee knowledge of production processes (Brettel et al., 2014). Leitão (2009) raises similar issues with regard to user acceptance among enterprise managers and directors of emergent terminologies and distributed approaches to problem-solving. Realizing horizontal integration across heterogeneous institutions may also be difficult for reasons of trust, data protection, and security related to firm know-how and customer information (Jazdi, 2014; Wang et al., 2015; Brettel et al., 2014). Existing system configurations continue to have vulnerabilities: an entire PLC network is easily accessible by a single search engine, such as SHODAN (Wang et al., 2015). In recent years, the US Department for Homeland Security (DHS) has issued warnings about hacking at industrial sites; vulnerabilities and actual hostile hackings have threatened both private and public sector facilities systems (Wang et al., 2015).

At the shop-floor level, there are challenges related to components and agent configurations. For instance, RFID-sensor tags are impaired in the presence of water and large amounts of metal (Brettel et al., 2014). There are problems, also, related to conflict resolution, production deadlocks, and production disturbances involving intelligent agents (Wang et al., 2016; Monostori, 2014). When human agents are introduced into the production dynamics, problems related to the optimal configuration between machine self-organization and appropriate control methods emerge (Monostori, 2014; Wang et al., 2015). Nevertheless, the continued improvements in the preconditions for the smart factory seem to be addressing the issue of production deadlocks and improvements to agents' decision-making are already being explored

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(Wang et al., 2016). Regarding the components themselves, some important research is being carried out on digital twins which provide predictive capabilities through simulations (Rosen et al., 2015) and prognostics and health management techniques (e.g. a 'time machine' snapshot stored in the cloud) that can be used to increase self-awareness and self-prediction (Lee et al., 2014, 2015).

Finally, there are difficulties related to interoperability, and design and data standardization. Ontologies in existing industrial applications are often proprietary, simplistic, and hierarchical structures of concepts (Leitão, 2009). Human biases (exacerbated by the presence of agents from different backgrounds) significantly influence the development of a common ontology (Leitão, 2009). While much research has been conducted on ontological methods, protocols, and semantic interoperability (Pěchouček & Mařík, 2008; Wang et al., 2016), considerable work needs to be done to integrate entire systems with related technologies, e.g. RFID technologies and wireless networks (Leitão, 2009). Table 4.1 summarizes the problems and opportunities discussed above, ranked by proximity to robotics research advancements. The research described below identifies the current state of robotics with a particular focus on robots for industrial applications. It combines publicly available information from company press releases, news articles, peer-reviewed journals, and trade and industry reports.

4.1.1 Robot Technologies

The International Organization for Standardization (ISO) and the United Nations Economic Commission for Europe (UNECE), through the 2012 ISO-Standard 8373, loosely define a robot as a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response. The International Federation of Robotics (IFR), the sector's main special-interest organization, and other national industry associations, such as the US Robotics Industries Association (RIA) and the UK's British Automation & Robot Association (BARA), have adopted similar definitions (BARA, 2017b; IFR, 2017; RIA, 2017).

Various but related developments in hardware and software technologies, academic research, and the industry have enabled sustained expansion of nascent sub-sectors such as advanced industrial and practical applications. For instance, refinements to software systems are allowing robots to interact physically with the environment and also to modify it. In another installation, wide functional scope is enabling robots to become viable solutions in populated areas and almost any environment (air, land, and sea) and for any purpose (e.g. surgery, laboratory research, defence, and mass production of consumer and industrial goods) (Boston Consulting Group, 2015; Deloitte, 2015). AU1

These continued advances can be regarded as positive for the future workplace: as better robots are developed, the possibilities increase for them to perform dangerous

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t1.1 **Table 4.1** Select Industry 4.0 challenges and research opportunities, ranked by proximity to robotics research

t1.2	Challenges	Specific issues	Research opportunities
t1.3	Emergent self-organization among autonomous systems		Alternative agent systems, e.g. bio-inspired robot designs (Pfeifer et al., 2007)
t1.4			Adaptability and prediction mechanisms in agent-based systems, particularly regarding production disturbances (Leitão, 2009; Monostori, 2014)
t1.5		Multi-agent systems (MAS)	Distributive and autonomous capabilities (Shen et al., 2006; Pěchouček & Mařík, 2008)
t1.6			Continued investigation on ontology methods and contract net protocols (CNP) (Wang et al., 2015)
t1.7		Holonic manufacturing systems (HMS)	Consistency, reliability, and interoperability with available computing systems (Babiceanu & Chen, 2006)
t1.8	Components and agent configurations	Sensor technologies	Continued development of related technologies, RFID technologies (Pěchouček & Mařík, 2008; Brettel et al., 2014)
t1.9		Production deadlocks and agent negotiation	Introduction of digital twins that provide predictive capabilities through simulation (Rosen et al., 2015)
t1.10		Human–machine symbiosis	Development of prognostics and health management techniques, e.g. remote diagnostics, time machine snapshots (Jazdi, 2014; Lee et al., 2014, 2015)
t1.11			Inclusion of human agents in system architecture design
t1.12			Development of user interfaces that allow for human interference, e.g. context-sensitive and context-broker systems (Gorecky et al., 2014)
t1.13			Development of user assistance systems (Gorecky et al., 2014)
t1.14	Interoperability, design, and data standardization		Harmonization of ontology methods, protocols, and semantic interoperability (Pěchouček & Mařík, 2008; Wang et al., 2016)
t1.15			Identification and understanding of the relevant information in manufacturing big data (Wang et al., 2015)
t1.16			Continued integration of autonomous systems with related technologies, e.g. RFID technologies and wireless networks (Leitão, 2009)
t1.17			Integration and accessibility of virtual systems, e.g. virtual reality (VR), simulation (Brettel et al., 2014; Monostori, 2014)

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Table 4.1 (continued)

Challenges	Specific issues	Research opportunities
User acceptance	Unit predictability	Autonomous system behaviour must remain predictable and stable for human workers (Leitão, 2009)
	Accessible integration	Methodologies development that supports easy, fast, transparent, and reusable integration of physical automation devices (Leitão, 2009)
		Enterprise integration for SMEs that have isolated, heterogeneous, and obsolete legacy systems (Shen et al., 2006; Brettel et al., 2014)
Data protection and cyber-security		Continued development of cyber-security-related technologies

Source: author's analysis

Table 4.2 Robotics capabilities and definitions

Ability	Definition
Sensing	Robots employ sensing technology to acquire information about their environment
Intelligence	Robots process information captured through sensor technology and produce outputs for decision-making, coordination, and control
Motion	Robots automatically follow instructions that are pre-programmed or generated in real time based on sensor input to perform a deliberate, controlled, and often repeated, mechatronic action, including point-to-point mobility

Source: ABI Research, 2016

tasks (i.e. nuclear power plant decontamination), repetitive, stressful, labour-intensive (i.e. welding), or menial. Furthermore, robots promise cost-efficiencies and greater accuracy and reliability relative to human agents (ABB Group, 2016; PwC, 2017).

Robots vary greatly in their users and suppliers and the technologies and mechanisms used. However, it is generally agreed that robots must exhibit the sensing, intelligence, and motion capabilities. The interaction among these capabilities (the 'sense-think-act' formula) allows robots to perform tasks without external stimuli, thereby giving them autonomy—the technology's distinguishing feature (Table 4.2).

While there are innumerable possible hardware and software combinations that can be regarded as robots, all machine systems share a number of core components in their construction—these include sensors, end effectors, and control systems (Consortium on Cognitive Science Instruction, 2017).

Sensors allow robots to 'perceive' their environment, thereby allowing an entire machine system to respond appropriately. Sensors enable monitoring of parts locations and machine orientations during production, which allows the robot to compensate for any variation in processes (Society of Manufacturing Engineers, 2017). Some important sensor types include visual, force and torque, speed and acceleration, tactile, and distance sensors (although the majority of industrial robots utilize

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only binary sensing) (USLegal, 2017). More complex sensor types include light detection and ranging (LIDAR) abilities that use lasers to construct three-dimensional maps of the robot's environment, high-frequency sounds-based super-sonic sensors, and accelerometers and magnetometers that allow the robot to sense its movement relative to the Earth's gravitational and magnetic fields (Consortium on Cognitive Science Instruction, 2017).

Robots (particularly in industrial applications) require an end-effector or an end of arm tooling (EOAT) attachment to hold and manipulate either the tool performing the process or the piece upon which the process is being performed (MHI, 2017). The most common end effectors are general-purpose grippers, the most common of these being finger grippers with two opposing fingers or three fingers in a lathe-chuck position; the grippers' strength is augmented by pneumatics and hydraulics and through the inclusion of additional sensors may be equipped with sensory capabilities (BARA, 2017a; Consortium on Cognitive Science Instruction, 2017; USLegal, 2017).While these components are coordinated by the robot's controller, end effectors require to be operated and powered independently and need changing should the system have to be refitted for another task (US Patent and Trademark Office, 2017).

The robot's actions are directed by a combination of programming software and controls, which give the system automated functionality allowing for continuous operation (MHI, 2017). Available robot control systems range from simple pre-programmed robots, which perform the simplest operations, to more complex robots that are able to respond appropriately in increasingly complicated environments (Consortium on Cognitive Science Instruction, 2017). Industry observers predict that innovation in software and AI will be fundamental to the development of next-generation robots (Keisner et al., 2015). Industry stakeholders believe that the continuing reductions in sensor prices and the increasing availability of open-source robot software will drive the technological possibilities of robots (Anandan, 2015).

4.1.1.1 Robotics Classifications

Robots can be classified in various ways—according to their mechanical structures and mechanisms. Some of the most common approaches involve using the robot's' mobility, work envelope shape (robot's area of operations, determined by its coordinate system, joints arrangements, and manipulator length), and kinematic mechanisms (the movement allowed by the joints between robot parts) (Zhang et al., 2006; Asada, 2005; Lau, 2005; Ross et al., 2010) as the bases for differentiation.

The IFR and industry more generally favour two industry classifications of robots according to their purpose: industrial robots (IR) and service robots (SR).

An IR is an automatically controlled, reprogrammable, multipurpose manipulator, programmable along three or more axes, which can be fixed or mobile for use in industrial automation applications (ISO 8373, 2012). Table 4.3 provides a list of the

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Table 4.3 Industrial robots (IRs) classification by mechanical structure and application

Category	Description	Industrial application
Linear robots (Cartesian and gantry robots)	Cartesian robot whose arm has three prismatic joints and whose axes are coincident with a Cartesian coordinate system	Handling for plastic moulding Sealing Laser welding Pressing
SCARA robots	A robot, which has two parallel rotary joints to provide compliance in a plane	Assembly Packaging
Articulated robots	A robot whose arm has at least three rotary joints, great payload capacity, and flexible mounting possibilities for optimizing working range; might be combined with SCARA elements	Handling for metal casting Welding Painting Packaging Palletizing Handling for forging
Parallel robots (delta)	A robot whose arms have concurrent prismatic or rotary joints	Picking and placing Assembly Handling
Cylindrical robots	A robot whose axes form a cylindrical coordinate system	Medical robots (DNA screening, forensic science, drug development, and toxicology)
Others		Robots in hazardous environments Operations under water Operations in atmospheres containing combustible gases Operations in space
Not classified		Automated guided vehicles (AGVs)

Source: Strujik, 2011, International Federation of Robotics, 2015

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available IRs ranked according to their mechanical structure and industrial application.

Interactive robots (often called *social robots*) are an emerging sub-set of robotics that envisage the next-generation robotic systems. These robots are expected to be viable in human environments involving various forms of interactions with human agents, and are intuitive, easy-to-use, and responsive to user needs (Christensen et al., 2016). Because their commercialization is in its infancy, the IFR classifies interactive robots as either IRs or SRs, the latter of which include the sub-set of social robots that exhibit social characteristics (KPMG, 2016).

While the realization of such systems is extremely complex and restricted (ABB Group, 2016; Christensen et al., 2016), a cooperative environment involving human agents and automated systems is an attractive proposition because of their distinct advantages relative to other configurations: they would combine the flexibility and adaptability of the former in complex tasks, with the consistency and high productivity in simple tasks of the latter (Michalos et al., 2010).

Contemporary human–machine configurations in the workplace vary based on the form of support that the robot can provide to the agent—often depending on the degree of assistance that the combination of sensors, actuators, and data processing

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within the system can provide. Generally, robot systems and human agents perform their tasks either jointly or separately. The level of interaction is strongly influenced and limited by the ability of the entire environment to avoid collisions with human agents. Interactive robots promise to deliver cooperation that goes beyond collision avoidance (Krüger et al., 2009).

Current IRs fall into several different categories: (1) robot assistant, (2) collaborative robots (co-bots), and (3) humanoid or anthropomorphic robots. Robot assistants are interactive and flexible robotic systems that provide sensor-based, actuator-based, and data processing assistance (Helms et al., 2002). First designed by the German non-profit Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer Institute IPA), current-generation robot assistants are complex mechatronics systems that consist of mobile platforms with differential gear drives and energy supply for autonomous workflow (Krüger et al., 2009). These are often multifunctional, are adaptable to varying requirements of automation, and provide interactive guidance to the user (Pew Research Centre, 2014).

Collaborative robots or co-bots are human-scale, articulated robots that directly work with human agents. Invented by Northwestern University McCormick School of Engineering professor Edward Colgate (alongside Michael Peshkin), these are mechanical devices that provide guidance through the use of servomotors while a human operator provides motive power (Krüger et al., 2009; Morris, 2016). In practice, the co-bots' distinct feature is their ability to directly provide power support to the human agent in strenuous tasks while maintaining a high degree of mobility AU6
(Lau, 2005). While co-bots tend to be employed in manufacturing tasks,[1] they are also used in non-traditional applications such as surgery (Delnondedieu & Troccaz, 1995) (see Table 4.4 for a list of popular collaborative robot types).

Humanoid or anthropomorphic robots act autonomously and safely, without human control or supervision. They are not designed as solutions to specific robotic needs (unlike robots on assembly lines), but built to work in real-world environments, interact with people, and adapt to their needs (Coradeschi et al., 2006; PwC, 2017). The human-inspired design of humanoid robots is combined with a safe, lightweight structure (Krüger et al., 2009). Generally, these robots are designed for applications that IRs do not cover (World Technology Evaluation Centre, 2012): assembly processes where position estimation and accuracy of the robot are significantly below assembly tolerance, tasks where the robot works closely with (and may interact directly with) human agents, and processes where the robot target's dimensions are relatively uncertain (Albu-Schaffer et al., 2007).

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[1] The employment of co-bots in industrial applications, particularly in the automotive sector, will be explored in the later sections.

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Table 4.4 Prominent types of collaborative robots

Type	Summary	Applications
Power and force limiting	Incidental contact initiated by the robot is limited in energy to not cause operator harm	Small and highly variable applications
		Conditions requiring frequent operator presence
		Machine tending
		Loading and unloading
Hand guiding	The operator leads the robot movement through direct interface	Robotic lift assist
		Highly variable applications
		Limited or small-batch productions
Speed and separation monitoring	Robot speed reduces when an obstruction is detected	Simultaneous tasks
		Direct operator interface
Safety-rated monitored stop	Co-bot responds promptly (stopping or moving) in the presence of its operator	Direct part loading or unloading
		Work-in-process inspections
		Speed and separation monitoring (stand-still function)

Source: Robotic Industries Association, 2014

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4.1.2 Global Competition and Markets in the Robotic Industry

The robotics industry has experienced rapid growth in recent years. A comparison based on robotics expert Frank Tobe's industry-dedicated database, the Robot Report's snapshots of firms and research institutions in 2012 and 2015, is indicative of the sector's rapid growth. The institutions' geographical data suggest geographical agglomeration: start-ups and service robotics companies are located near prominent universities and research institutions (e.g. Carnegie Mellon, MIT, Harvard, UC Berkeley, Stanford) or areas of innovation (e.g. New York city), while industrial robot companies are prevalent in traditional industrial regions (e.g. Germany and the UK) (Tobe, 2012). The sector's activity is further highlighted by the increasing sources of funding for robotics-related ventures and consolidation among existing robotics firms. Tobe's 2016 data in the Robot Report on mergers and acquisitions (M&A) (Tobe, 2017b) and funding-related activities (Tobe, 2017c) reinforce the industry's activeness. Funding of robotics-related start-ups reached USD 1.95 billion (50% more than in 2015), while M&A activity accounted for at least USD 18.867 billion. Overall, the data suggest some interesting developments: (1) Chinese companies are positioning themselves aggressively in the industry (e.g. the USD 5.1 billion acquisition of German robotics KUKA AG by Chinese consumer products manufacturer, Midea Group); (2) large blue-chip US firms are acquiring robotics start-ups (e.g. Honeywell International Inc.'s acquisition of materials handling

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solutions firm, Intelligrated, for USD 1.5 billion, USD 0.6 billion acquisition of start-up Cruise Automation, which is developing autopilot systems for existing cars of General Motors); and (3) the sustained success of Silicon Valley start-ups in raising funds (5 of the top 10 companies by amount funded in 2016 are in Silicon Valley or in the greater California area).

IFR 2015 unit sales data indicate that China has become the largest robotics market, with an installed count of 68,000 industrial robots (a 20% increase on 2014 figures). Both the USA and Germany remain key robotics markets with peaks of 27,504 units (up 5% in 2014) and 20,105 units (up from 20,051 units in 2014), respectively. The USA is the fourth-largest robots market and Germany the fifth-largest. During the same period, UK sales decreased to 1645 units.

The sustained growth of the industrial robotics market is attributable mostly to the automotive sector: robotics sales CAGR from 2010 to 2015 was approximately 20% and the 2015 sector installed count approximated 97,500 units (or 38% of the total robotics supply at the time) (International Federation of Robotics, 2016). Other AU7 valuable sectors that the IFR analysis (2016) identifies are the electrical and electronics (installed count of 64,600 units in 2015) and metal and machinery (29,450 units); sales to all industries sales (except for automotive and electrical and electronics) in 2015 increased by 27% on average.

Relative to the industrial robots' market, the service robots market remains a nascent sub-sector. IFR (2015) unit sales data show that sold units in 2015 reached 41,060 units. Sales of service robots for professional use were largest in logistics (19,000 units or 46.27% of the total unit supply), defence (11,207 units or 27.29%), field (64,440 units or 15.68%), and medical (1324 units or 3.22%) (IFR, 2015). The AU8 IFR (2015) forecasts that these applications will remain key growth segments for service robotics from 2016 to 2019.

Collaborative Robots

While still in its infancy, the collaborative robots (or co-bots) sub-sector is expected to drive growth in the industry significantly. Despite achieving market acceptance and recognition only quite recently (Lawton, 2016; Universal Robots, 2016), it is AU9 already a multi-million dollar market (approximately USD95 million in 2014) (Tobe, 2015) and (alongside the digitization of mechanical systems) is a hot topic among industry stakeholders (e.g. collaborative robots as one of the main themes in AUTOMATA 2016, one of the sector's most prominent trade conventions) (Tobe, 2016). Some of the major players in the category include Rethink Robotics, a producer of the popular robots Baxter and Sawyer, and Universal Robotics, makers of the world's first co-bot and the current market leader by installed base (Universal Robots, 2016a, 2016b) (Table 4.4 provides a list of selected robotics companies producing co-bots).

Analysts and stakeholders alike are optimistic that it will become a billion-dollar trade by 2020, with some more bullish than others (such as Barclays Capital which forecasts a market valuation of USD3 billion by 2020) (ABI Research *in* Lawton, 2016; Zaleski, 2016; Universal Robots *in* Thor, 2017). Europe is expected to AU10 maintain a significant role in the market's development for several reasons including

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(1) the strong presence of European robotics manufacturers in the global landscape; (2) the activeness of European companies in maintaining their advantage in the emerging co-bot market (e.g. Universal Robotics, ABB Group, KUKA); and (3) the strong robotics research base in the region (e.g. Fraunhofer Institute) (Bogue, 2016).

There are various aspects feeding the appetite for co-bots. First, the greater human–robot collaboration enabled by co-bots has resulted in greater productivity on the shop floor (Shah, 2011). Early adopters, particularly established carmakers such as Ford, Mercedes-Benz, and Toyota, have achieved productivity gains from using co-bots alongside additional human workers (Nisen, 2014; WEF, 2016; Zaleski, 2016). AU11 AU12

Furthermore, unlike traditional industrial robots that are large in size and require significant investments (making them ideal for mass production), co-bots are compact and easy to use, making them viable solutions for the untapped SME market and low-volume and high-mix production (Lawton, 2016; Zhang, 2017). In addition, co-bots are affordable: Rethink Robotics' Baxter and Sawyer cost around USD25,000–30,000 (22,880.50 EUR to 27,456.60 EUR),[2] Universal Robotics' products range in price from USD23,000 to USD45,000 (21,050.06 EUR to 41,184.90) (Tobe, 2015), and co-bot variants are often available for 20,000 EUR to 40,000 EUR (Bogue, 2016). Bogue (2016) adds that these robots often have short payback periods, generally 1 year or less.

Finally, the co-bots' design features address safety concerns often associated with traditional industrial robots (Table 4.5). Co-bots are designed with rounded surfaces (to reduce the risk of impact, pinching, and crushing) and are equipped with integrated sensors to detect human presence (and to stop in such conditions) and force-limited joints (to sense forces due to impact) (Tobe, 2015; Zaleski, 2016; Zhang, 2017). Thus, manufacturers (and even service providers) are able to employ co-bots in a variety of ways that are beyond the capabilities of industrial robots (Tobe, 2015; Lawton, 2016; Universal Robotics, 2016).

Warehouse Automation and Logistics Robots

The continued growth of e-commerce is expected to sustain the appetite for warehouse and logistic robotics. Amazon's USD775 million purchase in 2012 of market-leading Kiva Systems (now, rebranded Amazon Robotics) (Rusli, 2012) has served as proof of concept for the logistics industry regarding the benefits of warehouse automation. Shifting consumer expectations have increased pressure on service providers to automate. Industry estimates suggest that the robotic market's valuation could be around USD20 billion by 2020 (Tractica, 2017).

While Amazon's acquisition left the sector with no established leader in 2012, a combination of start-ups and acquisitions has filled the gap. Some of the more notable start-ups include (1) Locus Robotics, a spin-off founded by Massachusetts-based Quiet Logistics to provide warehouse automation solutions to third-party logistics providers (with DHL Supply Chain, as its most notable client);

[2]FX rate on December 31, 2015 (date of report publication) was 1 USD = 0.91522 EUR (via exchange-rates.org)

Uncorrected Proof

Author's Proof

Table 4.5 Collaborative robots of select companies

Company	Base of operation	Co-bot	Feature summary	Product status	Base price (in USD)
Rethink Robotics	North America	Baxter	2-armed co-bot	On sale	25,000.00
		Sawyer	1-armed co-bot	On sale	29,000.00
Universal Robotics	Europe (Denmark)	UR3 robot	3-kg payload capable co-bot	On sale	23,000.00
		UR5 robot	5-kg payload capable co-bot	On sale	35,000.00
		UR10 robot	10-kg payload capable co-bot	On sale	45,000.00
MRK-Systeme	Europe (Germany)	KR5 SI robot	Co-bot software for robot systems	NA	NA
F&P Personal Robotics	Europe (Switzerland)	P-Rob 2	1-armed co-bot	On sale	NA
Robert Bosch GmbH	Europe (Germany)	APAS System	1-armed co-bot	In-house use	NA
ABB Group	Europe (Germany)	YuMi	2-armed co-bot	On sale	40,000.00
MABI Robotic	Europe (Switzerland)	Speedy 6 robot	6-kg payload capable, 1-armed co-bot	On sale	NA
		Speedy 12 robot	12-kg payload capable, 1-armed co-bot	On sale	NA
FANUC Corporation	Japan	CR-35iA	35-kg payload capable 1-armed co-bot	On sale	NA
KUKA	Europe (Germany)	LBR iiwa	13.64-kg payload capable, 1-armed co-bot	On sale	100,000.00
Kawada Industries	Japan	HRP humanoid robot	2-armed co-bot	On sale	60,000.00

Source: Adapted from Tobe (2015); Co-bots guide (https://cobotsguide.com); various company websites

Uncorrected Proof

(2) Fetch Robotics, a San Jose, California-based producer of the mobile cargo system 'Freight' and the mobile manipulator 'Fetch' (both of which work collaboratively with human agents in the facility); and (3) Aethon, Inc., a producer of automated guided vehicles (AGVs) that are also used in hospitals (Banker, 2016; Romeo, 2016; Clark & Bhasin, 2017). Apart from these enterprises, established firms are developing (or acquiring) their own logistics automation solutions: e.g. (1) KUKA's acquisition of materials handling and logistics automation provider Swisslog; (2) Toyota Industries' purchase of Netherlands-based Vanderlande Industries, another materials handling and logistics automation provider; and (3) Hitachi's Racrew, its mobile warehouse robotics system that is in development (Banker, 2016; Capron, 2017). AU13

Author's Proof

Various developments have made warehouse and logistics automation an attractive proposition. First, Amazon's deployment of robotic systems in 2012 demonstrated substantial cost reductions and productivity gains in warehouse management—recent research suggests that the firm is saving around USD 22 million in each fulfilment centre equipped with Amazon robots (Kim, 2016). Moreover, current-generation automation solutions are more adaptable, flexible, and intelligent, thereby allowing service providers to maintain zero-defect logistics processes and to rapidly expand services and facilities (D'Andrea *in* ROBO Capron, 2017; Parsons, 2017).

Third, shifting consumer expectations (due to the rise of e-commerce) have put pressure on service providers to adopt automation technologies. In particular, the introduction of same-day deliveries (and the preference for fast delivery among consumers) has resulted in various challenges in logistics and warehouse management (Table 4.6) including (1) maintenance of multiple distribution facilities which are often located in rural areas and face labour-related challenges and (2) exacerbation of the 'last-mile' problem, as goods are no longer delivered to retail stores, but directly to households. Robotics seemingly offer viable solutions to these problems (Clark & Bhasin, 2016; Romeo, 2016; Harnett & Kim, 2017; Bray, 2017).

4.1.2.1 USA

Overview. The USA is an important robotics player, being the fourth-largest robots market by sales in 2015 and home to the most robotics start-ups (IFR, 2016b; IFR 2016c). Much of robotics' growth in the country comes from American industries' efforts to maintain competitive advantage through production automation (IFR, 2016a). Moreover, US robotics is a mature sector: it comprises a number of leading robotics research institutions (Carnegie Mellon University, MIT), subsidiaries of foreign companies (ABB Group, KUKA AG, FANUC), notable robotics start-ups (Boston Dynamics), and the largest technology companies (Google, Amazon) that are delving into robotics.

Industry and Technical Support

Across the USA, there are three prominent robotics clusters: (1) Boston, Massachusetts; (2) Pittsburgh, Pennsylvania; and (3) Silicon Valley, California. Boston seems the most mature among the three: it is already a thriving robotics hub, with 100 companies and 3000 robotics employees and attracting multi-million investments annually (Subbaraman, 2015). It is also home to a number of robotics companies with diverse specializations (e.g. Amazon's Kiva Systems, the largest US household robot provider iRobot Corporation, and prominent start-up Boston Dynamics), a number of universities with robotics programmes (MIT, University of Massachusetts Lowell, and Olin College of Engineering), and various industry partnerships (e.g. Google's Project Wing with MIT, Toyota's commitment with MIT's Computer Science and Artificial Intelligence Laboratory) (Subbaraman, 2015).

Uncorrected Proof

Author's Proof

t6.1 **Table 4.6** Warehouse automation and logistics robots of select companies

	Company	Base of operations	Robotic solutions features	Product status
t6.2	Company	Base of operations	Robotic solutions features	Product status
t6.3	Kiva Systems (Amazon Robotics)	North America	Autonomous mobile robot systems for orders fulfilment	In-house use
t6.4	Locus Robotics	North America	Autonomous mobile robot systems for orders fulfilment	On sale
t6.5	Fetch Robotics	North America	Autonomous mobile robot systems for orders fulfilment	On sale
t6.6	Vecna Technologies	North America	Autonomous mobile robot systems for orders fulfilment	On sale
t6.7	InVia Robotics	North America	Autonomous mobile robot systems for orders fulfilment	On sale
t6.8	IAM Robotics	North America	Autonomous mobile robot systems for orders fulfilment	On sale
t6.9	6 River Systems	North America	Autonomous mobile robot systems for orders fulfilment	In development
t6.10	Magazino GmbH	Europe (Germany)	Autonomous mobile robot systems for orders fulfilment	On sale
t6.11	Hitachi Solutions	Japan	Autonomous mobile robot systems for orders fulfilment	In development
t6.12	Clearpath Robotics	North America	Autonomous guided vehicles	On sale
t6.13	Aethon	North America	Autonomous guided vehicles	On sale
t6.14	Grezenbach Maschinenbau GmbH	Europe (Germany)	Autonomous guided vehicles	On sale
t6.15	Knapp AG	Europe (Austria)	Autonomous guided vehicles	On sale
t6.16	KUKA Swisslog	Europe (Switzerland)	Autonomous guided vehicles	On sale
t6.17	MiR Mobile Industrial Robots	Europe (Denmark)	Autonomous guided vehicles	On sale
t6.18	Starship Technologies	Europe (Estonia)	Autonomous guided vehicles	In development
t6.19	Dispatch	North America	Autonomous guided vehicles	In development
t6.20	Grey Orange India Private Ltd.	India	Autonomous goods-to-person system	On sale
t6.21	Scallog	Europe (France)	Autonomous goods-to-person system	In development
t6.22	RightHand Robotics	North America	Grasping technology	In development
t6.23	Google, Inc.	North America	Unmanned aerial vehicles	In development
t6.24	Balyo	Europe (France)	Vision systems for logistics automation	In development
t6.25	Seegrid Corporation	North America	Vision systems for logistics automation	In development

t6.26 Source: Adopted from Banker (2016); Romeo (2016); Tobe (2016); Bray (2017); various company websites

Uncorrected Proof

Author's Proof

Pittsburgh hosts the CMU (a major actor in the ARM institute),[3] one of the leading US universities for robotics, and a healthy ecosystem of venture capitalists with robotics expertise (e.g. General Electric Ventures, The Robotics Hub) and various university spin-offs and start-ups (e.g. high-tech baby gear producer, 4moms, and bipedal robots' developer, Agility Robotics) (Anandan, 2016).

While known more as an ICT innovation cluster, Silicon Valley is also home to various robotics enterprises and start-ups, particularly those involved in SRs and AI. Most of the Valley's robotics projects are international in scope and attract interest from both established and emerging institutions (e.g. Bosch, Fetch Robotics, SRI International) (Anandan, 2016).

The Robotic Industries Association, founded in 1974, is the sector-dedicated trade group in North America. Member organizations include leading robot manufacturers, users, systems integrators, component suppliers, research groups, and consulting firms (Robotics Industries Association, 2017).

Institutional Support

In 2011, the US Government launched the Advanced Manufacturing Partnership (AMP) to drive investments and collaboration between industry, academia, and government in emerging technologies related to manufacturing (National Institute of Standards and Technology, 2011). Through AMP, in the same year, multiple federal agencies, including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Institute of Health (NIH), and the US Department of Agriculture (USDA), launched the National Robotics Initiative. With annual funding of around USD 40 million to USD 50 million, the programme sought to accelerate the development and adoption of next-generation robotics in the USA through the development of fundamental research (National Science Foundation, 2011). In 2016, the NSF released the National Robotics Initiative 2.0: Ubiquitous Collaborative Robots (NRI-2.0) to not only serve as a continuation of the original programme but also to promote research on the scalability and variety of next-generation robotics (Computing Community Consortium, 2017).

More recently, the US Department of Defense (DoD) announced the new Advanced Robotics Manufacturing (ARM) Innovation Hub award to American Robotics, Inc. in Pittsburgh, Pennsylvania (US DoD, 2017). The US DoD (2017) stated that the American Robotics, Inc., a consortium of stakeholders from both the public and private spheres, had contributed USD 173 million (around 162.56 million EUR[4]); federal government is matching it with a budget of USD 80 million (approximately 75.17 million EUR). The ARM institute will include 123 industry partners, 40 academic and academically affiliated partners, and 64 government and non-profit partners (US DoD, 2017). The ARM programme joins the larger Manufacturing USA programme, a federal-sponsored network of industry, academic, and federal

[3] To be discussed in the succeeding sections.

[4] FX rate on 13 January, 2017 (date of report publication) was 1 USD = 0.93964 EUR (via exchange-rates.org)

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Author's Proof

stakeholders that is investigating identified high-potential technologies in future manufacturing (among others, biopharmaceuticals, regenerative manufacturing, AI) to sustain the country's competitiveness (Manufacturing USA, 2014). AU14

The ARM Institute is spearheaded by Carnegie Mellon University (CMU) and is focused on critical growth manufacturing sub-sectors which forecasts high levels of robotics adoption (e.g. aerospace, automotive, electronics, textiles, logistics, and composites) (ARM Institute, 2017b). To expand its reach, the institute is launching eight Regional Robotics Innovation Collaborative (RRICs), which are semi-autonomous institutes that will facilitate the networking of manufacturing and robotics companies and accelerate the adoption of robotics within their regions (ARM Institute, 2017a).

Demand-Side Trends

Besides the continued demand from American manufacturers for production automation, another notable demand-side development is related to the aggressiveness of US technology companies in acquiring robotics companies or researching related technologies. A prominent case is the online retailer Amazon's acquisition of warehouse automation provider, Kiva Systems, to improve productivity in its facilities (Guizzo, 2012). Another is automatic test equipment provider Teradyne's acquisition of Universal Robots (UR) in 2015 in order to (1) maintain its competitive advantage in its core offerings, as its customer base clamoured for the automation of the manual processes around its testing offerings, and (2) participate in the emerging co-bot market in which UR holds a near 60% market share (Robotics Business Review, 2015). Other examples include investments by technology companies, such as Google, of USD20 to 30 billion in AI R&D (Columbus, 2017).

While the USA remains an innovation hub and an important robotics market, there are concerns that none of the established market sector leaders are US companies (Cuban 2016; Statt, 2017). Many important US players are subsidiaries of foreign companies and the notable US robotics companies often serve niche or nascent demand.

4.1.2.2 China

Overview

China was the largest robotics market by sales in 2015, with an installed count of 68,000 industrial robots (a 20% increase on 2014 figures) across its provinces (IFR, 2016). IFR (2016) statistics suggest that China will continue to be a net importer, with foreign robot suppliers maintaining an approximately 70.12% market share. Increasing labour costs in China, brought about by the mass movement of multinational enterprises (MNCs) to China during the 1980s and the country's ageing workforce, have driven manufacturers to adopt robotics in their production processes (Bland, 2016). MNC-owned Chinese factories are prominent in the robot drive: Ford's Hangzhou facility features over 650 IRs while similar machines are found in General Motors' Shanghai and Wuhan factories (Bradsher, 2017).

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Apart from its market size, China, through its domestic firms, has remained in the headlines because of its continued aggressiveness in acquiring several foreign robotics companies. Since 2015, the Chinese have been involved in numerous landmark acquisition deals including AGIC Capital's purchase of Italian end-of-arms tool supplier GIMATIC Srl, AGIC, and state-funded Guoxin International Investment Corp.'s purchase of German IR integrator KraussMaffei Group, and the USD5.2 billion takeover of German KUKA AG by the Chinese Midea Group (Tobe, 2015).

Industry and Technical Support

Industry support is mainly from the China Robot Industry Alliance (CRIA), an association of Chinese manufacturers, robot end users, research institutes, colleges, and universities which is supported by various Chinese government agencies and the China Machinery Industry Federation (CMIF) (CRIA, 2015a). Founded in April 2013, it has 152 member organizations (DGI, 2016).

CRIA aims to become a platform for various stakeholders to promote the use and development of robotics in China while also ensuring that the overall direction follows both national industrial policies and market trends (CRIA, 2015b). CRIA was instrumental in developing China's national standards for industrial robots; it is currently working on standards for service robotics (The State Council of the People's Republic of China, 2016).

Institutional Support

Industry observers believe that the Chinese effort in robotics is indicative of China's drive to become the market leader in manufacturing and manufacturing innovation, as embodied in the 'Made in China 2025' (MiC 2025) plan. MiC 2025 is the first of three comprehensive plans to upgrade Chinese industry and transform China into a manufacturing power by 2049 through the adoption of advanced manufacturing technologies from abroad and the promotion of domestic brands and R&D capabilities (Xinhua News Agency, 2015). Some of the specific targets identified by MiC 2025 for the Chinese robotics industry are related to promotion of various robotics-related research for industrial applications and investigations in high-potential sub--fields such as SRs and social works robotics (MIIT, 2016) (details of MiC 2025's sector-specific Robot Industry Development Plan are provided in Table 4.7). AU15

While details of exact sums and policy strategies expected from the Chinese are scarce (Lee, 2015), there is significant activity at the provincial level. For instance, the province of Guangdong promised to invest USD 8 billion for automation-related projects in 2015 to 2017 (Bland, 2016). Knight (2016) has a higher estimate: USD 150 billion to equip Guangdong factories with IRs and to establish two new centres for advanced automation (Knight, 2016). Lianoning's provincial capital, Shenyang, has launched a USD7 million fund to support high-technology industries (Schuman, 2017).

Firm-Level Information

At the firm level, local Chinese companies are launching robotics-focused enterprises and subsidiaries to challenge established robotics firms in product pricing

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Table 4.7 Details of China's Robot Industry Development Plan

Objective	Specific targets
Larger production scale	Domestic robot supply >100 k units
	6-axis robots >50 k units
	SRs revenue >30 billion RMB
Elevated production capabilities	Reach of international standards on mean time between failures (MTBF)
	Advancement in key robot technologies
Breakthrough in core components	CN firms' share in domestic market >50%
	Capabilities to produce their own robot components
Significant achievement in integrated solutions	Robot density > 150 robot units per 10,000 workers
	Integrated robot solutions >30 solutions in traditional industries

Source: Macquarie Research (2016)

(Bland, 2016). Bland offers an example: Shanghai-listed machine producer for the plastics sector, Ningbo Techmation, has launched a subsidiary, E-Deodar, which produces IRs for the plastics industry that are 20–30% cheaper than that produced by ABB and KUKA. Another case is Chinese technology giant Baidu's various investments and partnerships in AI and machine learning (Bajpai, 2017).

Contemporary Issues

Despite the broad-based efforts in Chinese private and public sectors, observers have raised several concerns about the nation's manufacturing aspirations. First, China's manufacturing sector, relative to global competition, draws most of its competitive advantage from labour-intensive production. Statistics suggest that it remains low-technology-based (2016 value-added share was only 19% while more developed countries, e.g. the USA and Germany, achieved around 30%) and its R&D capabilities remain weak (most are in developed regions) (Euromonitor International, 2017). Despite being the largest robotics market, analysts believe that China remains a laggard in industrial automation: only 60% of Chinese companies use industrial automation software (e.g. Enterprise Resource Planning) and robot density is only at 49 units per 10,000 employees (Lee, 2015; IFR, 2016). Moreover, correspondence with Chinese companies reveals that they are focused mainly on production automation rather than holistic integration of value chains through data analytics (espoused by programmes such as Industry 4.0) (Meyer, 2016). Realizing MiC 2025's vision requires a broader effort from the Chinese government since firm capabilities remain uneven (Wang, 2017).

Particular to the Chinese robotics landscape is continued over-investment and population instability: observers note the rapid establishment of different small robotics companies and lack of established Chinese robotics components (e.g. speed reducers, servo-motors, and control panels) manufacturers, which may prevent the sector from achieving scale (Tobe, 2017a). Analysts predict that it could take China between five and 10 years to produce firms and products on a par with

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their German and Japanese counterparts (Macquarie Research, 2016; Manjoo, 2017).

Related to debt financing at the local level, observers worry that there is overcapacity in local governments' debt instruments as Chinese municipalities race to participate in the robotics sector (Taplin, 2016). Taplin (2016) describes the case of Wuhu city, west of Shanghai and situated in Anhui province: to establish its robotics park, it has already incurred a debt of USD332 million and is planning to raise an additional USD181 million to sustain developments.

Last, a confluence of factors (such as cost pressures and an emphasis on automation) have led to some factories across China indiscriminately adopting advanced automation processes and robotics—Knight (2016) describes a Shanghai-based Cambridge Industries Group (CIG) factory that is already adopting machines to replace Chinese workers and is planning entirely automated factories or 'dark factories'. In another example, Taiwanese consumer electronics manufacturer, Foxconn Technology Group, has plans to fully automate its Chinese factories; the firm has stated that already it can produce 10,000 units of its Foxbots, IRs that can replace human labour (Statt, 2017). Industry observers are worried that such actions could jeopardize the country's still-enormous manufacturing workforce (Knight, 2016). Some believe that as complex manufacturing tasks are automated, most Chinese workers will be forced to move into the services sector (Williams-Grut, 2016).

4.1.2.3 Japan

Overview

Japan is a powerhouse in the robotics landscape: it was the third-largest robot market by sales in 2015 (IFR, 2016). IFR (2016) data indicate that Japan has seen a growing trend of 10% on average since 2010 following decreases between 2005 and 2009.

Japan's sustained performance in the robotics sector stems from how the Japanese view robots as more than machines, and social agents that embody Japanese culture. How the Japanese regard robots is based mostly on their view of technological progress as a cultural phenomenon (Samani et al., 2013). Often, Japanese scientists and engineers incorporate traditional cultural and social narratives and values into their robotics developments (Šabanović, 2014). Robotics has become pervasive in Japan beyond traditional applications, and enjoys high levels of social acceptance on the island.

Thus, it is unsurprising that Japan produces most of the world's robots (EU-Japan Centre for Industrial Cooperation, 2015). Japanese firms are increasingly export-oriented: already 65% of production is for exports with the remaining third for the domestic market (primarily because of shrinking domestic prices and an already saturated market) (EU-Japan Centre for Industrial Cooperation, 2015). It is no surprise that Japan is home to three of the world's top robotics companies by installed base in 2015: FANUC Corporation (with the largest robot installed base of 400,000 units), Yaskawa Corporation (with the second-largest installed base of

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around 300,000 units), and Kawasaki Heavy Industries, Ltd. (with the fourth-largest installed base of around 110,000 units) (Montagim, 2015).

Japanese companies produce a wide variety of robotics: in manufacturing, there are IRs for automotive, E&E, chemicals, machinery and metal processing, and logistics applications (EU-Japan Centre for Industrial Cooperation, 2015). The EU-Japan Centre for Industrial Cooperation report (2015) explains that while Japan is engaged in both IR and SR production (and adheres to the IFR industrial classification), it has a particular strength in the production of high-precision servo-motors, cables, and many different sensor types and components essential for robot construction and maintenance—industry stakeholders have assigned them the separate classification 'RoboTech'.

The Japanese New Energy and Industrial Technology Development Organization (NEDO) and the Ministry of Economy, Trade and Industry (METI) forecast that the Japanese robotics sector will double in value by 2020 and that growth from 2020 to 2035 will be around 10% to 15%. NEDO projects are increasing also in areas where Japan enjoys a competitive advantage (e.g. RoboTech production).[5]

Industry and Technical Support

Japanese robotics enjoy strong institutional support; robotics-related research is funded by the Japanese government through various government agencies including METI, NEDO, Advanced Telecommunications Research Institute International (ATR), Agency for Advanced Industrial Science and Technology, National Institute of Environment and Disaster Prevention, Japan Science and Technology Agency, Ministry of Education, Culture, Sports, Science and Technology, Bio-Mimetic Control Research Centre, and Ministry of Land Infrastructure and Transport to name a few. A notable example is the Japan National Research and Development Institute of Science and Technology's (JST) maintenance of an industry–university cooperation development platform to accelerate the promotion of robotics technologies and ventures (Nirmala, 2016).[6] AU16

Institutional Support

Coinciding with the renewed growth of robotics in Japan is the nation's current bid to reclaim sector leadership. Having been overtaken by China in IR supply in recent years, Japan intends to become the world's largest society supported by robots through the promotion of both SRs and IRs (Yamasaki, 2016). In 2015, Japan launched its Robot Revolution Initiative, a public–private programme to expand the country's robotics capabilities and global footprint, and increase social acceptance of robots in the domestic market (METI, 2015). AU17 The private sector is expected to invest the required JPY100 billion (around USD 838.08 million or 740.71 million EUR[7]) funding while the public sector will be responsible for policy and regulatory

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[5] NEDO expects the RoboTech sector to grow 20% annually in the next 5 years.

[6] Selected current Japanese robot projects are listed in Table 4.3.

[7] FX rate on 10 February 2015 (publication date) was 1 USD = 119.32 JPY; 1 USD = 0.88382 EUR (via exchange-rates.org)

Author's Proof

Table 4.8 Select existing Japanese robot projects

Project name	Project summary	Cost	Start	End
Project to Promote the Development and Introduction of Robotic Devices for Nursing Care	Development of assistive robotics for nursing care to reduce caregivers' burden in providing elderly care	NA	JFY 2013	JFY 2017
Innovative Cybernetic System for a ZERO intensive nursing care society	Development of cybernetic systems that combines the brain-nerve-muscular system, robots, and other devices to improve/assist humans who would otherwise require intensive nursing care	NA	NA	NA
Tough Robotics Challenge	Development of the fundamental technologies for outdoor robots, thereby leading to the development of autonomous robots for disaster response	NA	NA	NA

Source: JARA, 2017

reforms (METI, 2015a). In addition, the Japanese government is committing around JPY 26 trillion (around USD 229.44 billion or EUR 203.38 billion[8]) to develop related technologies such as AI and big data analysis and cyber-security systems (JETRO, 2016).

Demand-Side Trends

Apart from the needs of its factories, demand for robots and increased automation in Japan originates from various demographic challenges, including among other things, falling birth rates, ageing population, and declining workforce productivity. However, Japan's problems are more severe relative to its peers: its population is expected to shrink by 30 million in the next 35 years and its over-65 population is expected to rise to a 40% share by 2025 (Kemburi, 2016). Thus, particular emphasis is laid on SR developments for medical and nursing care (2015, EU-Japan Centre for Industrial Cooperation). Ongoing projects listed in the Japan Robot Association (JARA) confirm these observations as several projects are focused on medical care (e.g. Project to Promote the Development and Introduction of Robotic Devices for Nursing Care, Innovative Cybernetic System for a ZERO intensive nursing care society, and Tough Robotics Challenge) (JARA, 2016) (Table 4.8).

Apart from medical care, Japan, through the Robot Revolution Initiative, has also identified four (out of a total of (5) other high-growth robotics sub-sectors: these include (1) manufacturing; (2) services; (3) infrastructure and disaster response; and (4) agriculture (METI, 2015a). By 2020, Japan aims to achieve the following: a 25% increase in the rate of utilization of robots in large manufacturing (10% for SMEs), a 30% increase in use of robots in services (particularly, in picking, screening, and

[8] FX rate on 18 February 2016 (publication date) was 1 USD = 113.32 JPY; 1 USD = 0.88643 EUR (via exchange-rates.org)

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Author's Proof

checking purposes), increased societal awareness regarding robots for medical care, a 30% increase in adoption of infrastructure robots, and the introduction of around 20 robot variants for agriculture (METI, 2015b).

To stimulate interest in robotics, the Japanese government is planning a Robot Olympics alongside the 2020 summer Olympic Games, which will feature competitions and exhibits that involve a variety of machines such as humanoid robots and IRs (Phys.org, 2016).

Japanese Firms

The private sector includes a wide variety of firms that are market leaders or specialists in industrial applications. These include FANUC, Kawasaki Heavy Industries, Toyota Motor Corporation, Panasonic Corporation, Honda Motor Co. Ltd., Fuji Heavy Industries Ltd., ZMP Inc., and Yamaha Motor Co. Ltd. Among others (EU-Japan Centre for Industrial Cooperation, 2015). The successful cases are also the top-three Japanese robotics firms by installed base.[9]

4.1.2.4 Korea

Overview

South Korea is an important robotics market and the second-largest by sales in 2015 (IFR, 2016b). IFR (2016b) states that 2015 performance is equivalent to around a 30% to 35% increase on 2014 values. South Korea has the highest robot density in general industry, at around 411 robots per 10,000 employees (for IRs alone, the number is higher at 531 robots per 10,000 employees). However, analysts have noted that South Korea does not have any sector-leading firms and it is lagging behind the USA, Europe, and Japan in technological innovation (Jae-Kyoung, 2016; Prakash, 2016; Kyung, 2017).

Industry and Technical Support

South Korea has several industry groups and associations that provide technical and market support including the Korea Robotics Society, the Korea Institute for Robot Industry Advancement, the Korea Association of Robot Industry, and the Institute of Control, Robotics, and Systems (Edwards, 2016). Numerous Korean research institutes have had successes in robotics throughout the years: Centre of Intelligent Robotics at the Korean Institute of Science and Technology's development of the household service robot CIROS, the Korean Institute of Ocean Science and Technology's half-ton maritime robot Crabster (CR200), and the Korea Advanced Institute of Science and Technology's maritime robotics project on coastal preservation (Edwards, 2014).

Moreover, the sector enjoys an active academic and research base that is engaged in expanding robotics applications. Some examples include the long-standing efforts of Korea University's Intelligent Robotics Laboratory (IRL), Chonnam National

[9] A more comprehensive list of Japanese robotics suppliers is available in Appendix C.

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University's investigation into robotics technologies for cancer and intravascular treatments, and the collaborative work of various Korean universities (e.g. Korea University, Pohang University of Science and Technology, Seoul National University, Sogang University, and Sungkyunkwan University) on AI (Edwards, 2014; Hyun-chae, 2016).

Institutional Support

South Korea has been active in its the robotics sector since 2012 when national government pledged around USD 316 million investment. In 2014, the Korean government, through the Ministry of Trade, Industry and Energy (MOTIE), made an additional 2.7 billion USD commitment for the development of advanced robotics (MOTIE, 2014).

The latest institutional assistance to the sector has come from an additional public commitment of around USD450 million (or approximately EUR 400 million) (Yonhap News Agency, 2016). The Yonhap News Agency (2016) stated that both the public and private sectors would will spend around 350 billion KRW to localize key fundamental robotics technologies, with more than 100 billion KRW to be poured into corporate research centres. In addition, the Korean MOTIE is allocating USD13.5 million (approx. EUR 12 million) for humanoid robotics R&D and necessary workforce development until 2020, and around EUR 18 million to 24 million (USD 20.25 million to 27 million) for the development of grassroots research up to 2022 (Hong, 2017).

The latest investment stems from the Korean government's belief that most widely used SRs in country's market are vacuum robots for the household, medical, and agricultural sectors (Van Boom, 2016; Yonhap News Agency, 2016). The Korean MOTIE aims that through the programme, Joint Robot Industry Development Initiative, it will help expand the country's demand robotics base through market creation and system maintenance (Hong, 2017). Hong (2017) states that the agency has identified four high-growth sub-sectors in which government intends to launch 90 projects by 2020: medical and rehabilitation use, unmanned robotics, social works, and security. In the near term, MOTIE will sponsor the introduction of 5–10 robots in National Rehabilitation Centres and 10–15 robots for assistive roles in general hospitals. By 2018, the agency will introduce 10 social robots in local post offices and 5 surgical robots in national hospitals (Hong, 2017).

Firm-Level Information

The Korean private sector is similarly active. Korean conglomerates are involved in various sponsorships related to robotics research. In 2015, Samsung Electronics made a USD100 million investment in an R&D laboratory focused on drones, robotics, 3D printing, and virtual reality (Robotics Business Review, 2015). Another case is Korean conglomerate Hyundai Heavy Industries' investments in medical SRs, with several robot deployments in various medical centres across Korea (Chougule, 2016). Korean SMEs, through government sponsorships, are producing several robot products for various applications including education, agriculture, medical rehabilitation, national defence, culture, manufacturing, environment,

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home services and parts, and security (Korean Institute for Robot Industry Advancement, 2017).

4.1.2.5 Europe

Europe has always been interested in pushing the technological frontier and its experience with robotics is another case in point. European experience with automated machines dates back to the 1970s; since then, the region has developed considerable technical and commercial competence across the growing science of robotics (Forge & Blackman, 2010). Recent IFR statistics (2016) confirm the continued relevance of Europe in robotics: the second-largest regional market posted a 10% increase in sales to 50,100 units in 2015, and it continues to have the highest robot density among all macro-regions at 92 units.

However, a number of factors are threatening European competitiveness: automation adoption remains uneven at the country level including the emergence of East Asian countries (China, Japan, and South Korea) in the global robotics landscape, and the rapid expansion and development of the overall sector (IFR, 2016).

In 2014, the EU included robotics as a key research focus in its Horizon 2020 programme, a 7-year 80-billion EUR initiative that is Europe's primary mechanism for reinvigorating research and innovation in emerging technologies and contemporary societal challenges (The EU Framework Program for Research and Innovation, 2014). This programme is expected to attract participation and financial contribution from universities, research institutions, and the private sector (The EU Framework Program for Research and Innovation, 2016).

Provision for robotics research is included in the Leadership in Enabling and Industrial Technologies (LEIT) priority, which is expected to receive 22% of the total funding (Juretzki, 2014). Apart from the funding amount, Juretzki (2014) describes other innovations introduced in Horizon 2020 (which will directly affect the dynamics of robotics R&D activities within the programme) that include the promotion of pre-commercial procurement (PCP) and public procurement of innovation (PPI).

A prominent Horizon 2020 project is EU SPARC—The Partnership for Robotics in Europe, a contractual partnership between the Commission and the euRobotics AISBL (Association Internationale Sans But Lucratif), a non-profit association for private and academic stakeholders in European robotics (euRobotics, 2017). With EUR 700 million funding until 2020, SPARC is the largest civilian robotics programme in the world; it includes over 180 member organizations from Europe to strategically position the region in the global robotics space (EU SPARC, 2017).

Another notable robotics-related project is the 'Factories of the Future' initiative, another public–private partnership between the European Commission and the European Factories of the Future Research Association (EFFRA), a non-profit, industry-driven association that seeks to promote the development of advanced and sustainable production technologies (EFFRA, 2017). The 'Factories of the Future' programme is a EUR 1.15 billion partnership that intends to realize the AU22

Uncorrected Proof

Author's Proof

EU's objective of digitizing and advancing the manufacturing production process (EFFRA, 2017).

Germany

Overview

Germany is a manufacturing powerhouse and a prominent player in the robotics industry. The sector is characterized by stable networks between OEMs,[10] lead suppliers, and notable SMEs (GTAI, 2017). Germany has globally recognized strengths in the development of industrial robots, particularly in machine vision technologies and human–robot collaboration development (GTAI, 2017).

Industry and Technical Support

Germany has several robotics and industrial automation clusters including (1) the Automation Valley Northern Bavaria cluster, (2) its OWL—Intelligente Technische Systeme OstWestfalenLippe, and (3) Silicon Saxony e.V (GTAI, 2017). The Automation Valley Northern Bavaria cluster is a vast network of companies and research institutions from a broad range of industries that include the mechanical engineering company Shaeffler-Gruppe, the IT service provider Datev, the sporting goods manufacturer Adidas, and public research institutions such as the Fraunhofer Institute and the University of Bayreuth (Invest in Bavaria, 2015). OWL cluster is a technology network of 180 businesses, universities, research institutes, and organization whose purpose is advancement of mechatronics to intelligent technical systems; it is working currently on 46 applied research projects with funding of 100 million EUR (it's OWL, 2017). Silicon Saxony is a 300-strong network of semiconductor, electronics, microsystems, and software stakeholders (Silicon Saxony, 2017). The cluster's current activities involve investigations in advanced sensor applications (e.g. CPS, RFID technologies) and the latest microsystems technologies developments (Silicon Saxony, 2017; Silicon Saxony, 2017). AU23

Germany has a strong base of academic researchers investigating varied robotics sub-fields. Examples include (1) the Institute of Robotics and Mechatronics, which investigates developments across the entire robot development process, (2) the DFKI Robotics Innovation Centre, which focuses on robot technologies for various dangerous environments (e.g. space and underwater), and (3) the Technical University of Munich and its work on CPS and other SRs (e.g. medical robots and humanoid robots) (Edwards, 2015).

Institutional Support

Industrie 4.0 is Germany's main innovation programme in advancing manufacturing through the development and convergence of key ICT and robotics technologies. Part of Germany's Action Plan High-tech strategy 2020, Industrie 4.0 started in 2013 as a collaborative effort among the nation's leading business associations BITKOM,

[10] OEMs are often the original producers of vehicle components.

Uncorrected Proof

Author's Proof

VDMA, and ZVEI (Platform Industrie 4.0, 2017). In 2015, the German government committed approximately 500 million EUR to the programme (Temperton, 2015). Today, it is an institutional commitment (led by the German Ministries of the Economy and Research) and involves over 300 stakeholders from over 150 public and private organizations (Smit et al., 2016; Banthien, 2017).

AU24

Demand-Side Trends

The country is the fifth-largest market by sales and in spite of already possessing a high robot density of 301 units per 10,000 employees, annual sales remain high (IFR, 2016b). The automotive sector is the leading client sector for German robotics while the electrical and electronics industry is the second largest (GTAI, 2017). GTAI (2017) details that the metal processing and machinery, plastics and chemicals, and food industries in Germany are other major client sectors.

The year 2016 was another record year for sales for German robotics companies, with sales reaching a new high of EUR 12.8 billion (VDMA, 2017). VDMA statistics (2017) show that 57% of German robotics are exported, with China being the biggest market (accounting for 10%) and North America the second biggest (9%). The industry association expects that 2017 robot sales will accelerate by 7% because of increased foreign demand (Reuters, 2017).

The German robotics industry falls into three main sectors: robotics sub-sector, integrated assembly solutions (IAS) sub-sector, and machine vision technologies sub-sector (GTAI, 2017). 2016 robot sales suggest that while all sub-sectors posted increasing sales, IAS remains the largest (VDMA, 2017).

France

Overview

France is considered an important robotics market in Europe, and has embraced increased automation in its production process (even though its installed base and sector performance remain low relative to other developed regions). 2016 IFR statistics indicate that France posted an increase in robot sales, with 3045 units in 2015.

Industry and Technical Support

Sector support is available through industry associations, such as the SYROBO Group, and industry research organizations and platforms, such as the Technical Centre for Mechanical Industry, the French Robotics Research Group, and the French National Robotics platform. The SYROBO Group is a robotics industry association that represents the interests of private stakeholders in service robotics (SYMOP, 2017). The Technical Centre for the Mechanical Industry is a private-led institution that facilitates interaction between academia and various industries regarding the adoption and development of advanced manufacturing technologies (CETIM, 2017). The French Robotics Research Group and the French National Robotics platform are networks that foster cooperation and collaboration among academics, researchers, and engineers (Business France, 2017; FEMTO-ST, 2017).

Uncorrected Proof

Author's Proof

Institutional Support

Since 2013, France has shown strong commitment to developing emerging technologies (including robotics) through various levels of institutional support, the most prominent being the 'New Face of Industry in France' programme (Ministère de l'economie, 2015b). The reported support for the robotics and related technologies was around 1.2 billion EUR (Ministère de l'economie, 2015a). In 2015, the French reindustrialization plan entered its second phase—the 'Industry of the Future' programme. The current programme is expected to build on the 'Factory of the Future' plan through further investments in key advanced manufacturing technologies (among others, additive manufacturing and production digitization). Particular to robotics, the programme provides an additional 2.1 billion EUR financial support until 2017 (Ministère de l'economie, 2015). Around the same time, a collaborative platform, Alliance Industrie du Futur, for firms and academic and technological partners was formed to help realize the programme's goals (Alliance Industrie du Futur, 2015).

AU25

Firm-Level Information

France is home to a number of notable robotics companies: humanoid robot developer Aldebaran Robotics (Softbank Robotics), French UAV copter provider Infotron, and surgical robots firm Medtech (Tobe, 2014; Medtech, 2017; Softbank Robotics, 2017). Apart from these, despite perceptions regarding the rigidity of its labour regulations, France already has an emerging start-ups scene that enjoys the healthy optimism of its stakeholders (Cellan-Jones, 2017).

Contemporary Issues

Despite the positive developments in the French robotics landscape, there are concerns that there is underrepresentation of these systems because of social perception and risk aversion (Pape, 2017). Moreover, there were doubts regarding proposals from the French socialist government to tax robots. Observers believe that if this persists it could disadvantage France because it is likely to be ineffective for arresting the consequent technological unemployment among low-skilled labourers through automation and would discourage firms from innovating (Bershidsky, 2017).

Uncorrected Proof

United Kingdom

Overview

The UK is a promising robotics market, although there is notable underinvestment in the sector relative to the other industrialized nations. 2016 IFR statistics suggest that there is a sustained decrease in sector performance in the UK: 2015 robot sales decreased to 1645 units.

Industry and Technical Support

Institutional support is available mostly through the industry associations, such as the British Automation & Robot Association (BARA), and special interest networks,

Author's Proof

such as the UK Robotics & Autonomous Systems (UK-RAS) Network. BARA is one of the most prominent robotics association in England and draws membership from both robotics and related industries (e.g. system integrators, components, and ancillary parts) (BARA, 2017). The UK-RAS Network is an academe-led network of universities, companies, and public research institutions that aims to promote the development of UK robotics' capabilities (UK-RAS Network, 2017a). The UK-RAS Network is responsible for the annual UK Robotics Week and for several competitions related to various robot applications (e.g. surgery robotics, social care robotics, robots for educational purposes) (UK-RAS Network, 2017b).

Furthermore, there are robotics-dedicated research institutions in British universities. Examples include the Centre for Robotics Research (CORE) in King's College, the Bristol Robotics Laboratory (BRL) of the University of Bristol and the University of West England, the Robot Vision Group at the Imperial College London, the Robotics Research Group in the University of Oxford, the Centre for Automation and Robotics Research at Sheffield Hallam University, and the Robotics and Intelligent Systems Lab at Plymouth University (Robotics Business Review, 2014). Some facilities investigate various robotics sub-fields, such as in CORE and BRL, while others are more specialized, such as in the Robot Vision Group (The Robot Vision Group, 2014; BRL, 2017; CORE, 2017).

Institutional Support

Since 2015, the British government has recognized the technology's potential for improving British manufacturing productivity and has committed to building the country's research and industry capabilities (Department for Business, Innovation & Skills, 2015). Institutional support is mostly channelled through the Engineering and Physical Sciences Research Council (EPSRC), the 500 million GBP-funded UK innovation agency Technology Strategy Board, and the recently formed Leadership Council in Robotics and Autonomous Systems (DBIS, 2015; Westlake, 2015). 2016 EPSRC-sponsored investigations in robotics applications in manufacturing amounted to approximately GBP 350 million (around 410.66 million EUR[11]) and involved various universities across Britain (among others, the University of Cambridge, Imperial College London, University of Leeds, University of Manchester) (UK-RAS Network, 2016). Furthermore, the UK-RAS Network (2016) identifies seven research centres ('Catapult Centres') that enable companies to access equipment, expertise, and information needed to develop and commercialize ideas and innovations. More recently, PM Theresa May's government announced a GBP 4.7-billion Industrial Strategy 2020, in which robotics and related technologies are a key focus (HM Government, 2017).

Nevertheless, observers are cautious about Britain's renewed enthusiasm towards robotics; the country traditionally has been slow to commercialize its research and sustaining sector growth requires converting the potential demand base into innovation partners (Williams, 2015; Westlake, 2015).

[11]FX rate on 13 January 2017 (date of report publication) was 1 GBP = 1.1733 EUR (via exchangerates.org.uk)

Uncorrected Proof

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Demand-Side Trends

Despite remaining a key global manufacturing nation and despite various investments in production automation, the UK does not participate in the design, development, and manufacturing of key robotics technologies (Cheeseman, 2017). Industry observers note that outside of the country's automotive sector, there is notable risk aversion to robot adoption in manufacturing processes (Tovey, 2016). Some attribute this conservatism to certain aspects of British manufacturing experience, such as British financial institutions' preference for short-term returns on loans and a technical skills gap related to robotics technologies (Hadall & Wilson, 2017). Moreover, contemporary conversations surrounding the subject remain centred on robots' perceived negative consequences for employment (Williams, 2016; Flaig, 2017).

Recent reports suggest that the UK is making significant progress towards increased automation. Around 58% of general British manufacturing have made automation-related investments and reaped clear benefits (Barclays PLC, 2015). Among Scottish manufacturers, the figure is higher: 72% have reported investments in production automation (Wilcock, 2015).

Firm-Level Information

Despite the situation in British robotics, there are a number of notable UK-based emerging robotics companies (particularly, in medical care applications) and start-ups. Renishaw PLC is a Gloucestershire-based firm with expertise in robotics surgery—its neuro-robotic device, called Neuromate, is used for various surgical procedures in several countries (e.g. the UK, France, and Germany) (Demaitre, 2016). Another example is Cambridge Medical Robotics, whose work is focused on developing next-generation universal robotic systems for minimally invasive surgery (Cambridge Medical Robotics, 2017). Meanwhile, UK-based robotics start-ups have varied focuses, but most trace their beginnings to a university: examples include bio-mechanics developer Animal Dynamics (Oxford University), educational bipedal robot producer Robotical (University of Edinburgh), and companion and assistive robotic systems developer Consequential Robotics (University of Sheffield) (Macaulay, 2017).

Uncorrected Proof

Italy

Italy is a key robotics market, the second largest in Europe after Germany and the seventh largest in the world (IFR, 2016b). In the context of European production of robots applied to automotive manufacturing, and due to the specific contribution of Piemonte, Italy is the top ranked manufacturer. The latest IFR (2016) statistics show that Italy continued its increasing robot intake, with a 7% increase in 2015 sales and + 1.1% increase in revenues. Moreover, IFR statistics from the Italian Trade Agency (2016) suggest that the country has the second-highest robot density in Europe. After a period of crisis between 2011 and 2013, the sector started to grow again reaching a dominant position in the global supply of robots. In 2015, in

Author's Proof

Table 4.9 Italian robotics sector (EUR million)

	2015	2016	% of increase
Revenue	528	534	1.1
Export	188	190	1.1
Local market	340	344	1.2
Import	325	332	2.2
Trade balance	137	142	/

Source: Ucimu (2017)

Table 4.10 Italian firms in robotics by class of revenue

Revenue (bln of Euro)	2013	2014	2015	2016
<2.5	16.0%	13.4%	6.7%	8.3%
2.5–5.0	11.1%	13.3%	20.0%	16.7%
>5.0	72.2%	73.3%	73.3%	75.0%
Tot.	100.0%	100.0%	100.0%	100.0%

Source: Ucimu (2017)

Europe, there was a 10% growth in total production with 20,000 robots produced in Germany, 6700 in Italy, and 3800 in Spain. This represents significant growth, but small compared to China which produces 70,000 robots annually (IFR, 2016b).

The results for the Italian robotics sector are confirmed if we break down the supply chain. According to data on Italian robotics for 2016 provided by UCIMU—the research and corporate culture centre, there have been stable increases in both exports and internal sales. Consumption of robots in Italy registered a 1.7% increase, accounting for EUR 676 million (UCIMU, 2017) (Table 4.9).

Italy's heavy adoption of and strong interest in robotics comes as no surprise when set against its manufacturing capabilities and history of technological competence. Italy has a strong industrial machinery and related products sector—2016 statistics demonstrate the country's continued relevance in the global industrial landscape and its industry's export-based orientation (UCIMU, 2017). However, there are only a few large industrial and ICT firms in the sector; Italian manufacturing is founded deeply on small and medium-sized enterprises (Italian Ministry of Economic Development, 2017).

Industry support and representation are available through industry trade associations, such as the UCIMU-Sistemi per Produrre. UCIMU is the official interest group for the domestic machine tool, robots, automation systems, and ancillary products manufacturers (UCIMU, 2017). Current membership statistics suggest that the association represents over 200 companies accounting for over 70% of the selected industries (UCIMU, 2017).

UCIMU splits Italian firms working in robotics into three macro-categories according to revenue: large firms with revenues higher than EUR 5 million; medium-sized firms with revenues of between EUR 2.5 million and 5 million; and small firms with less than EUR 2.5 million revenue. In general terms, large firms are prominent and account for 75% of Italian robotics production (Table 4.10).

Uncorrected Proof

Author's Proof

Table 4.11 Type, units, and % of robots in Italian supply chain, 2016

Type	Unit	%
Handling	75.078	65.4
Welding	33.503	19.6
Assembly	7.466	6.5
Cute	3.481	3.0
Other	6.345	5.5
Tot.	114.873	100.0

Source: Ucimu (2017)

Analysing the whole Italian production in robotics, in 2016 there were 114,873 robots operating, with an annual increment on 2015 of 6823 units (UCIMU). 75,078 units (65% of total robots production) are engaged in the manipulation activities, followed by welding with 33,503 units (19.6%), followed by assembly robots with 7466 units (6.5%), cute robots with 3481 units (3.0%), and other robots (5.5%) (Tables 4.11 and 4.12).

Technical and research support is available within the high-skilled workforce located across Italy's main cities of Milan, Turin, Rome, Pisa, and Genoa, among others (Italian Trade Agency, 2016). For instance, the IIT (Italian Institute of Technology) in Genoa is working with the precision-motion company, Moog, Inc., towards the development of next-generation actuation and control technologies for autonomous robots (Heney, 2016).

Italy's institutional support for robotics is in the form of its National Plan, 'Industria 4.0'. Industria 4.0 is an 18 billion EUR comprehensive public–private partnership that offers the domestic industry a wide array of complementary measures (e.g. tax credits, favourable loan terms for adopters, and preferential services to SMEs) to spur investment in advanced manufacturing technologies and provide streams of financing to domestic enterprises (Italian Ministry of Economic Development, 2016a; 2016b). Among Industria 4.0's instruments, the most important are 'hyper-depreciation' and 'super-depreciation'—where the Italian government allows a 250% tax benefit on purchases of Industry Industria 4.0-related tangible assets, and a 140% tax benefit on the cost of Industria 4.0-related investments (PwC, 2017).

In addition, there is a notable public-led programme which is the Italian Trade Agency's 'Machines Italia' Campaign. This project, which provides an innovation platform for Italy's machinery manufacturers, aims to demonstrate the country's strengths in manufacturing, machinery, robotics, and related areas (MIT Technology Review, 2016; Machines Italia, 2017).

Uncorrected Proof

Piemonte—Turin

Italian robotics companies are concentrated in the North of Italy. Lombardia and Piemonte account for, respectively, 33.4% and 25% of firms operating in robotics. Piemonte shows a higher concentration of revenues (62.8%) and employees (60%).

Author's Proof

Table 4.12 Main firms competing in robotics in Italy, their location, and the kind of robots they produce (excluding Piemonte)

Name	Region	Robot production
ABB	Lombardia	Assembly robot, welding robot, robot for didactic, others
AMADA ITALIA s.r.l	Emilia-Romagna	Welding robots, others
AUOTOMATOR INTERNATIONAL s.r.l	Lombardia	Press automation
BUCCI AUTOMATION s.p.a	Emilia-Romagna	Cartesian coordinate robot
CB FERRARI A SOCIO UNICO s.r.l	Lombardia	Cartesian coordinate robot
CESMA INTERNATIONAL s.r.l	Lombardia	Welding robot
COSBERG s.p.a	Lombardia	Assembly robot
FARINA PRESSE s.r.l CON SOCIO	Lombardia	Cartesian coordinate robot
FICEP s.p.a	Lombardia	Cartesian coordinate robot
HIWIN s.r.l	Lombardia	Measurement robot
INTER.CAR s.n.c DI GAITO	Campania	Cartesian coordinate robot
NUOVA C.M.M s.r.l	Veneto	Welding robot, others
OPPENT	Lombardia	Others
ROLLON s.p.a	Lombardia	Cartesian coordinate robot
SIR. s.p.a	Emilia-Romagna	Cartesian, cylindrical, and polar coordinate robot, welding robot, mounting robot, robot for didactic
SPERONI s.p.a	Lombardia	Measurement robot
STAR s.r.l	Lazio	Welding robot, assembly robot, Cartesian coordinate robot
TIESSE ROBOT s.p.a	Lombardia	Assembly robot, welding robot, robot for didactic, Cartesian coordinate robot, others
ZUCCHETTI CENTRO SISTEMI	Emilia-Romagna	Others

Source: UCIMU

Uncorrected Proof

The industry area related to robotics present in Piemonte and, mostly, Torino is innovative and typically is characterized by large firms. Firms such as COMAU, Olivetti, DEA, Prima, and others entered the market in the 1970s and have reached a predominant role. In 2011, Istat registered 3900 firms in mechatronics/robotics in Piemonte (1900 in Torino), with 62,000 employees (27,000 in Torino). In the robotics sector alone (excluding mechatronics), there are 250 firms with 12,000 employees, who represent 44% of the national share. According to Istat, in 2013, Piemonte's share was around 11% of national exports in the industry, worth EUR 2.5 billion in value, including EUR 1.3 billion generated in Torino (Tables 4.13 and 4.14).

Author's Proof

Table 4.13 Robotic/mechatronic industry in Piemonte. 2011

Robotic/mechatronic	Firms	Employees	Export (bn Euro)
Piemonte	3900	62,000	2.500 (11% of Italian export)
Turin	1900	27,800	1.308 (5.8% of Italian export)

Source: ISTAT 2011

Table 4.14 Main robotic firms in Piemonte region

Name	Robot production
COPROGET s.r.l	Cartesian coordinate robot
HEXAGON METROLOGY s.p.a	Measurement robot
KUKA ROBOTER ITALY s.p.a	Assembly robot, welding robot, robot for didactic, measurement robot
PRIMA INDUSTRIE s.p.a	Robot for cutting, welding, and microboring
COMAU	Welding robot, assembly robot, others
EIKAS	Welding robot

Source: UCIMU

Uncorrected Proof

Piemonte regional firms have been able to create a district specialized in technologies that are related to automotive. Piemonte has developed an ecosystem, including regional institutions, manufacturing industry, craft and agriculture, research centres, and universities.

Since 2009, Piemonte has supported an active industrial policy to foster technological innovation. With POR FESR plans 2007–2013, the Regional Operative Programmes financed by the European Fund for Regional Development, Piemonte gave birth to innovation poles (Poli di Innovazione), which are clusters of independent firms (large, medium-sized, and small) together with research centres working on specific sectors and coordinated by a managing authority.

These poles group together the actors involved in the innovative process stimulating interactions, sharing of installations, knowledge, and experience, and contributing to the wide spread of information and technologies across firms. Moreover, poles need to interpret the technological needs of firms in order to guide the region in its decisions related to research and innovation. For 5 years the regional programme has financed research and innovation projects, feasibility studies, and services.

The MESAP pole was conceived specifically for robotics and mechatronics for advanced production systems. Its implementation was cross-sectoral involving shaping/plant and design/robotics, automotive, aerospace, electrical appliance, railroad, textile, print, energetic/environmental, agro-industrial, and construction industry/housing sector. Three fields of research and innovation have been financed:

- Smart products: mechatronic applications to consumer and industrial products.
- Flex processes: mechatronics and advanced production system applications for flexibility of productive processes.
- Green processes: mechatronics and advanced production system applications for energy efficiency and eco-compatibility of productive processes.

Author's Proof

Projects cover a variety of production: sensors to enlarge mechatronics applications; reduction of energetic and environmental impact of manufacturing; automated microprocessor systems; mechatronic systems for vibration control; mechatronic systems for accumulation and power management; open-source integrated environments for mechatronic applications product process; flexible automation systems; flexible mechatronic systems for distributed printing; monitoring and control of industrial processes; MEMS (microelectromechanical systems) adaptive testing; automotive and mechatronic systems; and components product development and manufacturing.

In the pole, 36 projects have been financed, totalling EUR 41.53 million in investments and a contribution of EUR 21.45 million. MESAP has 170 members, 2 universities, 9 research centres, 129 PMI, 30 large firms, and 14 industrial sectors; the management is entrusted to Centro Servizi Industrie Srl, a service company of the industrial union of Turin.

POR FESR 2014/2020 has further boosted Piemonte's investments in mechatronics and robotics, giving innovation poles continuity. In the new funding programme, the Piemonte region shows a unity of purpose with local private actors offering support to enforce the smart specialization of manufacturing and, particularly, of robotics and advanced production systems. Measures published for those sectors refer to fundamental actions to achieve the following objectives:

- Building a technologic platform on advanced production systems which can compete at global level.
- Strengthening the role of innovation poles making them regional agencies for innovation.
- Facilitating the update of productive machines and plants.
- Increasing the presence on markets of firms belonging to the most relevant supply chains of Piemonte.

4.1.3 Additive Manufacturing (AM)

Uncorrected Proof

AM is the official industry standard term (ASTM F2792) concerning the process of joining materials to make objects from 3D model data (Wohlers Associates, 2010). AU32
3D printing is the most popular term.

According to EY (2016), a growing number of global industrial firms have AU33
acquired experience on AM and consider it strategic for their growth, but most companies still have no experience with 3DP. The major obstacle to adoption is the high degree of uncertainty on how this technology can be applied.

Depending on the degree of confidence in the possibilities of 3DP for the productive process, manufacturing companies consider 3DP simply as i) an additional approach to fabrication; ii) a hybrid technology integrating the existing processes; and iii) a technology that will replace actual manufacturing systems in most of the industries.

Author's Proof

AM includes seven main subtechnologies (Conner et al., 2014): material extrusion, vat photopolymerization, binder jetting, powder bed fusion, directed energy deposition, material jetting, and sheet lamination. The materials adopted are mainly metals and polymers, but ceramic is expanding. Among companies already using **metal 3DP**, **aerospace, and automotive** companies are at the top of the list.

AM is based on the concept of **rapid prototyping** in areas of production characterized by low volume, low complexity, and low levels of product customization. Printed prototypes are more cost-effective and can be produced more quickly and used for design and marketing purposes, in particular.

Beyond prototyping, operational efficiency can also be achieved through direct manufacturing of particular types of items. In particular, as suggested by Conner et al. (2014), AM can be effective for **complex products** production and **customized manufacturing** in both mass and artisanal production. For example, serial 3DP is applied to lightweight parts and functionally integrated components, bringing value to aerospace companies and automotives (sports cars).

Typical limitations to adoption are cost, technology, and business organization. AM is still expensive because of the price of systems, materials, and related services; thus, some companies are not unwilling to invest without a clear strategic vision of the actual applications. Technological limitations are related to building envelope and product sizes, constraints in the use of materials and multi-materials, and careful control over product quality. AM sets demanding business challenges related to lack of in-house expertise, management of IP issues, and integration with the status quo in the productive chain.

According to Wohlers (2017), 97 manufacturers produced and sold industrial AM systems in 2016. This is up from 62 companies in 2015 and 49 in 2014. Growth in 3D printer sales slowed in 2016, due to a slowdown at **3D Systems** and **Stratasys**, the two industry leaders by revenue. Together, they represent $1.31 billion (21.7%) of the **$6.063 billion** AM industry. The 3DP market is expected to grow by about 25% annually until 2020 (EY, 2016)—resulting in a total market value in that year of US$12.1 billion. Market volumes have increased from $1.5 billion in 2011 to $4.2 billion in 2015. In worldwide **revenues in 2016,** the AM industry grew by only 17.4%, down from 25.9% the previous year.

Companies interested in entering 3DP production have two main options. They can purchase from systems manufacturers and build an in-house system, or rely on service providers for the supply of 3D-printed items.

System manufacturers are the masters in the 3DP value chain (Fig. 4.1) since they can supply final clients directly or establish business-to-business relationships with manufacturing companies and service providers. They account for about 55% of the total 3DP market, while service providers represent around 25%. The most important systems manufacturers are Stratasys, 3D Systems, EOS, Concept Laser, SLM Solutions, ExOne, and Ultimaker.

Material Suppliers provide the different materials used in the production of items. The most complex and expensive segment is metals related.

Software Developers typically belong to traditional software houses or international technological groups which use this channel to explore the 3DP market.

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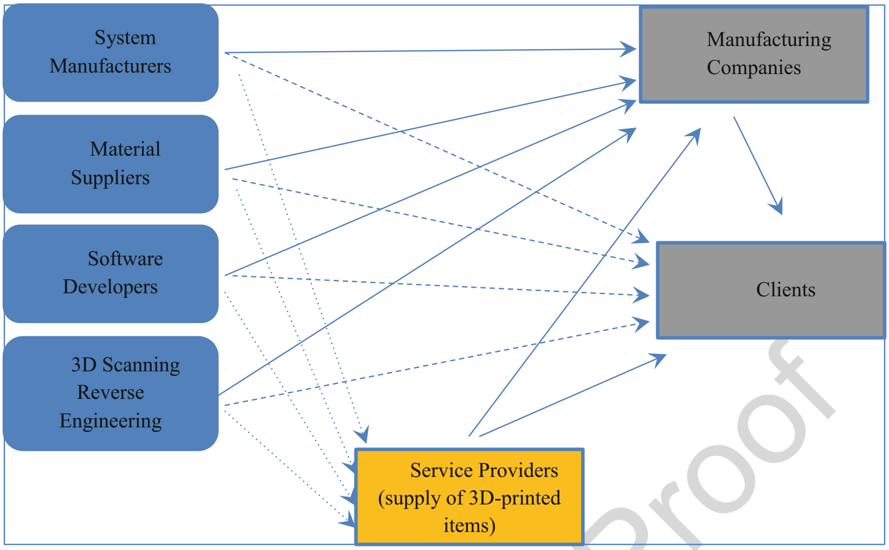

Fig. 4.1 Value chain in the 3dp market. Source: EY (2015)

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t15.1 **Table 4.15** Top 5 vendor 3D printer market share by unit volumes and printer revenues, global personal/desktop printers 2016 https://www.contextworld.com/3d-printing-research-update-12-apr-2017

2016 Rank by Units	Company	2016 Units	2016 Share by Units
1	XYZprinting	80,902	25%
2	Monoprice	27,944	9%
3	Ultimaker	24,058	8%
4	M3D	21,656	7%
5	FlashForge	17,321	5%

2016 Rank by Unit Revenue	Company	2016 Revenue	2016 Share by Unit Revenue
1	Ultimaker	$44.0M	13%
2	XYZPrinting	$39.7M	12%
3	Stratasys/MakerBot	$38.9M	12%
4	Formlabs	$30.3M	9%
5	Aleph Objects	$17.7M	6%

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3D Scanning companies are a small group of players who design existing products for testing or performance purposes.

As already mentioned, the second relevant segment of players is *service providers*, which print objects professionally with endless customization. Both are clients of the previously mentioned suppliers and also supply industrial companies and other clients (Fig. 4.1).

3DP systems are divided into two major segments: personal/desktop printers and professional/industrial printers. The former is a quite competitive and relatively contestable market (Table 4.15). In the latter, Stratasys, 3D Systems, and EOS accounted for about 70% of market share in 2015. In 2016, this side of the market was marked by decreased sales from the industry leaders, Stratasys and 3D Systems

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Table 4.16 Top 5 vendor 3D printer market by revenue from industrial/professional machines shipped 2016

2016 Rank	Company	Revenues from Machines Sold	2016 Global Revenue Share	Y/Y Change
1	Stratasys	$ 427M	34%	-5%
2	EOS	$ 210M	17%	15%
3	3D Systems	$ 144M	11%	-19%
4	SLM Solutions	$ 76M	6%	21%
5	Concept Laser	$ 66M	5%	41%

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(USA), which reached a peak in 2014, while EOS (Germany) increased its share thanks to its growing metals business (Table 4.16). Both American companies were weakened by the market entry of two major multinational businesses. GE has embarked on a strategy of acquisition and established the GE Additive. HP entered into the market in 2016 with the shipment of their first Multi Jet Fusion printers. In 2015, more than 76% of industrial investors were already in the 3DP business, reflecting the strong consolidation pressure in the market. This consolidation trend will continue as large systems manufacturers adopt new technologies by acquiring smaller, specialized players.

The market for service providers is led by two players: Materialise96 and ProtoLabs (for which 3DP accounts for around 10% of their revenue). Nevertheless, the service provider market is characterized by a large number of small service providers and start-ups.

It not possible to say whether companies prefer in-house systems or service providers. Given the high cost of investment, on-demand production seems to be a growing trend. Extreme customization pushes companies to select locations near end-use markets, and to open new opportunities to return manufacturing to Western countries (reshoring).

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4.1.3.1 Italy and Piemonte

AM is one of the sectors set to grow the most in the near future in Italy. Excluding public administration, healthcare, and research centres, the market value of 3D printing in the industry sector stands at EUR 245 million (about 3.5% of the world market). Of this, EUR 140 million are from hardware and materials and EUR 105 million are from software and services. Forecasts between 2016 and 2018 saw an increase to EUR 390 million in 2018 (NetConsulting cube & Cherry Consulting; 2017) (Fig. 4.2).

The technologies linked to 3D printing offer a multitude of solutions in various fields and, particularly, in areas of Italian excellence such as automotive, spacecraft,

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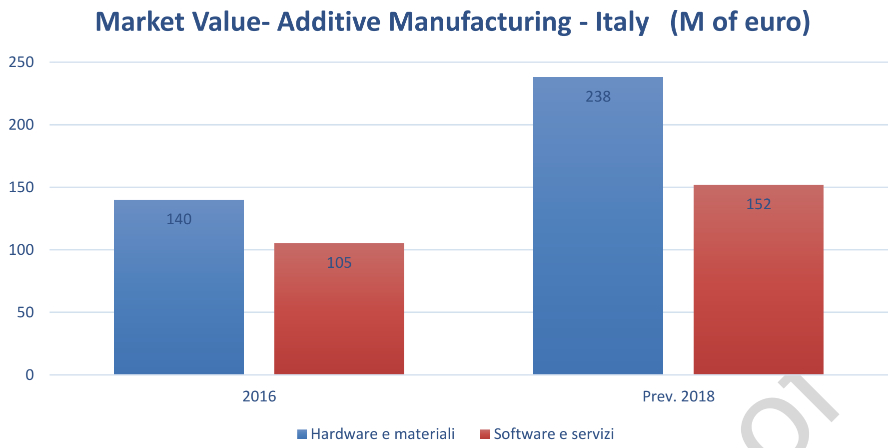

Fig. 4.2 AM value in Italy. Excluding PA, healthcare, and research centre. Source: NetConsulting cube and Cherry Consulting, 2017

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biomedical, and packaging. 3D printers have the ability to create highly complex projects and structures, greatly reducing costs and time out in different business segments.

For example, AM technologies can reduce the time needed to enter the market because of their ability to implement R&D projects faster than traditional technologies.

Nonetheless, 3D printing is able to produce significant benefits in the various production steps, such as greater agility in design, reduced production times, increased production efficiency, and, especially, a major reduction in production chain errors.

The advantages of add-in manufacturing technologies can be summarized as:

- Possibility of a wider range of alloys than traditional technologies.
- Possibility of using materials that are difficult to use in traditional casting processes.
- Production of components and objects of any shape.
- Reduction in production costs.
- Reduction in time spent on production processes.
- Weight reduction through topological optimization (simulation of software production), which also means less material consumption.
- Reduction in the number of moulds expected.
- Integration of multiple components into one part.
- Mechanical properties superior to fusion.
- Significant reduction in percentage of waste compared to traditional merger.

One of the significant aspects related to Italian excellence is the possibility to create highly complex structures in one mould thanks to additive technologies. So far these structures have been produced as separate parts and assembled at a later

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Table 4.17 Estimates of main application area of AM in Italy

Industry	2014 (%)	2014 (Revenue in mln of Euro)
Aerospace	17.7	23.1
Industrial	17.7	23.1
Healthcare	15.5	20.1
Automotive	11.1	14.4
Jewellery	11.1	14.4
Energy	4.4.	5.7
Others	22.5	29.2
Total		130

Source: Cherry consulting

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stage. This feature is particularly valued by the automotive and aerospace sectors, where complex components can be realized by reducing the weight of the structures. Also, in the field of design, it is possible to obtain more sophisticated bends otherwise unattainable using traditional technologies.

The entire Made in Italy sector of excellence is able to renew and innovate in different fields to face the challenges posed by new technologies, in a country where adoption of AM focuses mainly on the prototyping and production of components with important handicraft and customization features. Table 4.17 presents estimates of the main areas of application of additive manufacturing in the Italian sector in 2014.

In addition to the production phase, the benefits of AM can be found in the design, prototyping, logistics, and post-sales assistance phases. In other words, additive technology is able to generate both product and process innovations, redefining the entire industry supply chain. Due to the relevant role of 3D printing technologies in automotives and in the field of space technology, production time is reduced dramatically. For example, in automotive production, traditional technology requires some 36–40 months while AM times can be as little as 18 months (Confindustria Centre).

Piemonte is a leading region for the number of companies using 3D printing technology. AM in Piemonte represents a technological excellence, thanks mostly to Avio Aero (GE Aviation Group), a leader firm with plants in Rivalta di Torino and in Cameri (Novara). Avio Aero is linked to an important chain of companies specialized in the production of hi-tech components for aerospace, energy, and racing. Its headquarters was established in Cameri in 2013, representing, with its 60 3D printing machines, one of the world's most highly accredited manufacturing plants. The goal of the pole is to become a leader firm in aeronautical industrial production for specific segments such as lighter structures to reduce fuel consumption, emissions, and production times.

However, 3D printing features confirm Piemonte as the leading actor also in design, which is one of the areas where, historically, it has played an important role; now 3D printing is enabling direct transfer of CAD graphics to prototypes and original productions, cutting out numerous assembly phases.

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Table 4.18 Main competitors in AM in Piemonte region

Firms	Location	Activities/sector
Plyform composites srl.	Novara	Aeronautic
3D System Italia Srl	Torino	Prototyping
Aerosoft Spa	Torino	Aeronautic
Altair Engineering Srl	Torino	Filtration and air purification
Apr Srl	Torino	Precision mechanics
Axist Srl	Torino	Dimensional testing, oordinate measuring machines (CMM)
Ec International France Sas	Torino	Prototyping
Esi Italia	Torino	Design and construction
Itacae Srl	Torino	CAD design
Microla Optoelectronics Srl	Torino	Laser marking machines
Reinshaw Spa	Torino	Metal additive manufacturing
Ridix Spa	Torino	Prototyping
Spring Srl	Torino	Prototyping
Avio Aero	Novara/ Torino	Additive manufacturing for aeronautic
Prima Industrie	Torino	Laser system for industrial application, sheet metal machinery
Ellena	Torino	Precision mechanics
Comau	Torino	Industrial automation
Prima Electro	Torino	Machine industry

Table 4.18 lists the major companies in Piemonte involved either in manufacturing or in segments which are close or complementary to AM technology.

4.1.4 Automotive Industry

The automotive in 2013 is still one of the major manufacturing industries although its pivotal role in the world economy is heterogeneous across countries. Its contribution to value added and employment in the OECD countries is relatively small, but strongly correlated to the business cycles and private consumption of most advanced economies.

Worldwide sales reached a record 88 million autos in 2016 (PwC, 2017) with record sales in the USA (17.5 m vehicles in 2015), while in the EU 12.6 million new cars were registered well below the 18 million in 2007 (PwC, 2016). On the demand side, the Middle East and African markets are growing and emerging markets are stagnating. AU38

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Table 4.19 2016 Country rankings by production

#	Country	Cars and trucks production	%	Peak Year
1	China	28,118,794	30%	2016
2	USA	12,198,137	13%	1999
3	Japan	9,204,590	10%	1990
4	Germany	6,062,562	6%	2007
5	India	4,488,965	5%	2016
6	South Korea	4,228,509	4%	2011
7	Mexico	3,597,462	4%	2016
8	Spain	2,885,922	3%	2000
9	Canada	2,370,271	2%	1999
10	Brazil	2,156,356	2%	2013
11	France	2,082,000	2%	1989
12	Thailand	1,944,417	2%	2013
13	UK	1,816,622	2%	1963
14	Turkey	1,485,927	2%	2016
15	Czech	1,349,896	1%	2016
16	Russia	1,303,989	1%	2012
17	Indonesia	1,177,389	1%	2014
18	Iran	1,164,710	1%	2011
19	Italy	1,103,516	1%	1989
20	Slovakia	1,040,000	1%	2016
–	**World Total**	**94,976,569**	100%	2016

Source: OICA

Performance indicators are not encouraging: total shareholder return is 5.5% on average vs. 14.8% S&P500 and 10.1% DJI; ROI is around 4% vs. about 8% of the industry cost of capital (PwC, 2017).

Therefore, automotives are showing high levels of innovation related to connected, intelligent, and driverless cars. In the meantime, the industry is exhibiting two major trends: increasing concentration and power of large established companies, and a long upstream and downstream value chain (Smitka & Warrian, 2017). In addition to consolidation, the rising costs of software and digital technology, safety, and environmental regulation, are calling for solutions such as shared platforms, exploration of distribution channels, and outsourcing of technological development (PwC, 2017).

In 2016, more than 94 million cars have been produced in 20 countries around the world, around 30% in China, followed by the USA (13%), Japan (10%), and Germany (6%) (see Tables 4.19 and 4.20). While China and the USA are the biggest markets for sales, Japan and Germany are the production leaders. Their respective major carmakers, Toyota and Volkswagen, have been competing for rank leader and delivering around 10 million vehicles each. Below, we focus on carmakers and the development of robotics technologies.

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Table 4.20 Manufacturers' ranking by production (2015)

#	Manufacturer	Cars and trucks production	
1	Toyota Group	10,083,831	JPN
2	Volkswagen Group	9,872,424	GER
3	Hyundai-Kia	7,988,479	KOREA
4	General Motors	7,485,587	USA
5	Ford	6,396,369	USA
6	Nissan	5,170,074	JPN
7	Fiat Chrysler	4,865,233	ITA-USA
8	Honda	4,543,838	JPN
9	Suzuki	3,034,081	JPN
10	Renault	3,032,652	FRA
11	PSA Peugeot Citroen	2,982,035	FRA
12	BMW	2,279,503	GER
13	SAIC	2,260,579	CHI
14	Daimler (Mercedes-Benz)	2,134,645	GER
15	Mazda	15,405,76	JPN
16	ChangAn	1540,133	CHI
17	Mitsubishi	1,218,853	JPN
18	Dongfeng	1,209,296	CHI
19	BAIC	1,169,894	CHI
20	Tata	1,009,369	IND

Source: OICA

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Production in Italy amounts to just over 1 million cars per year and sales of 2 million. We examine the traditional Italian car capital Piemonte. France and especially Italy and UK are large markets, but have lost most of their productive capacity (Figs. 4.3 and 4.4).

Global automotive manufacturing is a very concentrated industry with large OEMs and high entry barriers. On the other hand, manufacturing of parts and accessories is very fragmented and competitive. According to Zion Market Research (2017), the global car accessories market was valued at USD 360.80 billion in 2016 and is expected to reach approximately USD 519.01 billion by 2022, growing at a CAGR of around 6.4% between 2017 and 2022. AU40

AM could be a huge opportunity for the whole industry from two perspectives: first, it is a major source of innovation thanks to its flexibility; second, it can transform business models and renovate the actual supply chain. According to Deloitte (2014), AM allows for a reduction in capital to achieve both economies of scope in the design of products and scale in the possible variety of customized items. The trade-off in performance between capital vs. scope and capital vs. scale is visualized in four paths of value in the adoption of AM in the automotive industry (Fig. 4.5).

Most OEMs and suppliers are still on path I, exploring technologies to improve current production, but without substantial changes to products and supply chains.

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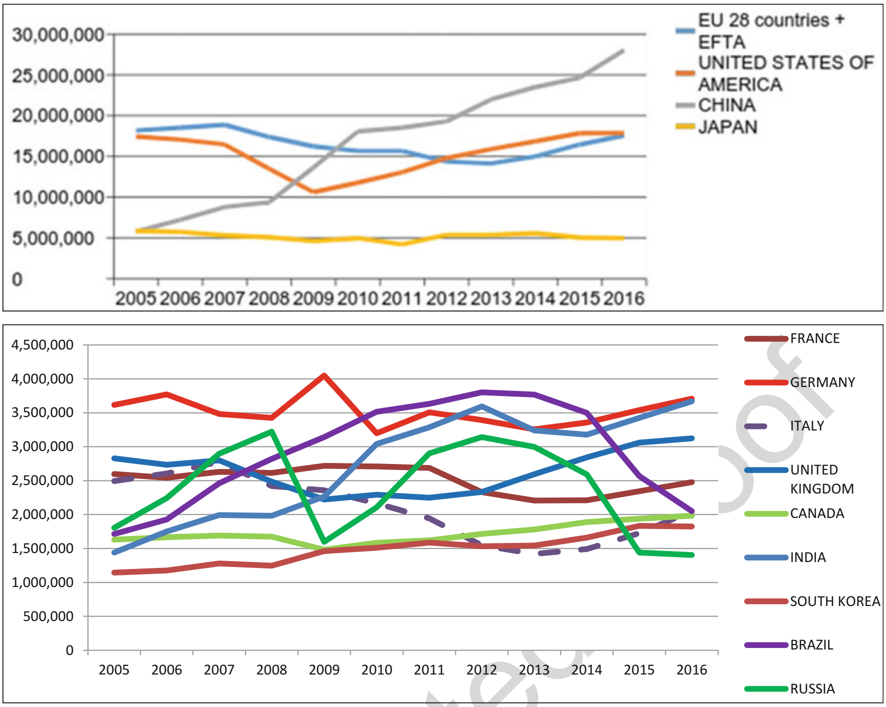

Fig. 4.3 Registration or sales of new vehicles (OICA, 2017)

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AM allows i) improved flexibility, speed, and quality in the prototyping phase and ii) reduced dependence and costs related to tooling and casting in the design phase and enhanced customization. According to BMW, customized tools helped to save 58% in overall costs and have reduced project times by 92%.[12] For a single component, such as an engine manifold, developing and creating the prototype usually costs about USD 500,000 and takes around 4 months. Using AM, Ford can develop multiple iterations of a component in just 4 days at a cost of USD 3000.[13]

Tier 1 and tier 2 suppliers should investigate exploiting AM capabilities along path II producing components on demand and at locations closer to end users. Competition in the after-sales market will be based on servicification: shorter delivery times and full availability of components but a reduced inventory. For OEMs, the achievement enabled by new business models associated with path IV goes through product evolution (path III). In the near term, it will be possible to develop lighter weight components aimed at fuel savings, which would satisfy both environmental regulation and consumers. Another form of cost savings is

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[12] Troy Jensen, 3D printing: A model of the future, PiperJaffray, March 2013.

[13] Ford Media Centre, 'Ford's 3D-printed auto parts save millions, boost quality', in Deloitte (2014).

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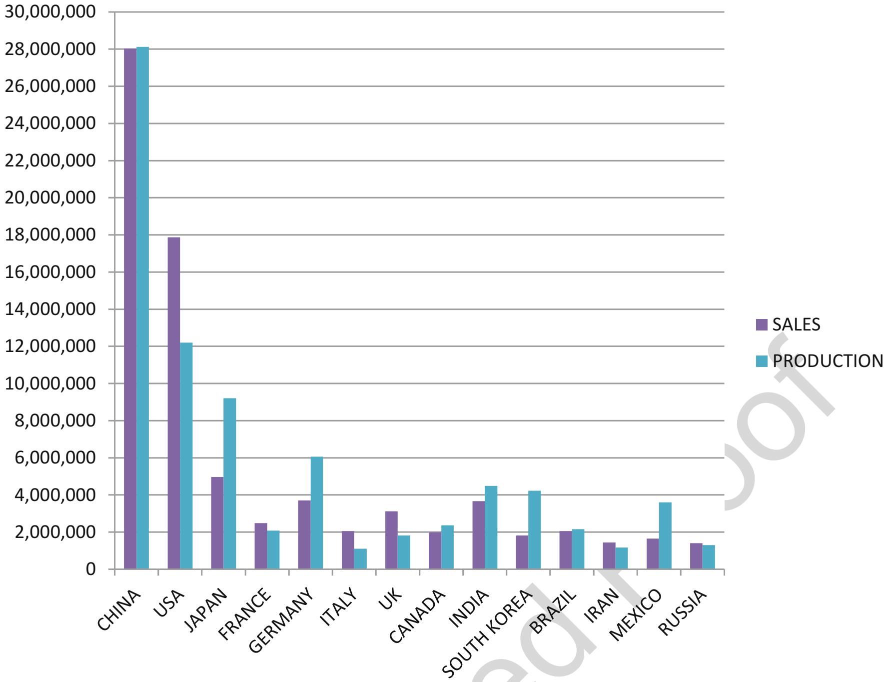

Fig. 4.4 Production and sales of vehicles by country (2016). Source: OICA 2017

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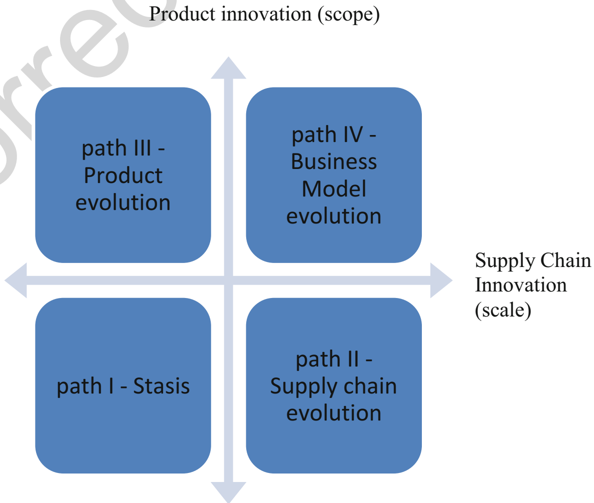
Fig. 4.5 Framework for understanding AM paths and value. Source: Adapted from Mark Cotteleer and Jim Joyce, '3D opportunity: Additive manufacturing paths to performance, innovation, and growth', Deloitte Review 14 January 2014



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represented by reductions in the number of components required, simplifying the assembly process and eventually improving quality. Full customization is already possible in the extreme luxury segment: path IV will be characterized by smaller supply chains and mass customization.

4.1.4.1 Robotics and Japanese Automotives

Japan is home to some of the world's largest automotive OEMs. The Japanese automotive sector currently is characterized by a strong base of OEMs combined with lead suppliers, whose interlocking business relationships emphasize efficiency, prices, and quality (Putra et al., 2016). Production is global; Japanese OEMs are maintaining a presence in cost-competitive and growing locations abroad (Putra et al., 2016). Japanese carmakers are retaining a global share of approximately 30% (Putra et al., 2016).

Japanese carmakers' competitive advantages derive from production efficiency, strategic partnerships, and mass production. The sector first emerged when, during the Second World War, Japan selected industry champions (in Nissan and Toyota) to meet the country's transport needs. With sector liberalization in the post-ward period, car companies raced for market leadership—most formed strategic alliances with suppliers for critical parts, which led to production modularization and an emphasis on cost-efficiency (Schaede, 2010). Automotive OEMs and lead suppliers maintain close relationships that allow the sharing of information on technologies and product design, and critical responsibilities (Kobayashi, 2006; Schaede, 2010). Certain Japanese approaches, such as *kaizen* (the culture of continuous improvement), *keiretsu* (enterprises with interlocking business interests), and just-in-time (JIT) production (demand-driven supply chains), make the Japanese carmaking experience distinctive (Putra et al., 2016).[14]

As a result, Japanese car manufacturers are able to enjoy greater quality, cost, and product reliability advantages relative to other firms. However, this has some drawbacks: such factors indicate that these carmakers are limited in terms of the innovations they can introduce on the shop floor because any miscalculation could erode the already small profit margins (Putra et al., 2016).

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Japanese Automotive: OEMs and Lead Suppliers

The degree to which auto manufacturers rely on outsourcing is difficult to pinpoint since it can differ across product categories, product complexity, firm size, and the prevailing subcontracting system used within a sub-industry. For instance, Toyota outsources a wide range of its component needs to Denso, from electronic fuel

[14] These sensibilities were incorporated into a production system called the Toyota Production System, which was adopted by most Japanese carmakers.

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injection systems to air conditioning (Ahmadjian & Lincoln, 2001; Schaede, 2010). Generally, Japanese car manufacturers tend to keep only the production of main parts in-house while they outsource other modular pieces to a small set of closely affiliated firms (Schaede, 2010).

Toyota

Toyota obtains many of its automobile parts from local suppliers, mostly through long-term contract agreements which ensure steady supply and efficient delivery of components. The company is more likely to work with suppliers whose facilities are located within a 56-mile radius of its plants. Toyota currently maintains a large number of suppliers, varying according to the region of production. Some examples include Fuel Total Systems Corp., TAIHO Manufacturing, OTICS USA, Tesla Motors, Samsung Electronics, Bridgestone Americas Cypress Semiconductor, Magnuson Products, IPT Performance Transmission, Nippon Denso Co., Aisin Seiki Co., etc. (North America), and Aisin.

Honda

Honda also maintains business relationships through long-term contracting across its assembly plants in Europe, North and South America, and Asia. For instance, in North America, from which almost half of 2015 total sales come, some of the main suppliers include American Mitsuba, AGC Automotive, Takata, Nippon Seiki, Nasco, ThyssenKrupp, and Automatic Spring Products (Table 4.21).

4.1.4.2 Robotics and German Automotive

Germany boasts one of the most prominent and valuable automotive manufacturing sectors in the world. Across Europe, 2015 data indicate that Germany is both the largest total vehicle producer and the biggest market by total vehicles registered (see Fig. 4.6) (European Automobile Manufacturers Association, 2016). At the national level, the sector is the largest industry by sales (404 billion EUR in 2016) and accounts for a substantial share (around 35%) of the entire German R&D expenditure (21.7 billion EUR in 2016) (Germany Trade & Invest, 2017).

Germany hosts several automotive OEMs and key tier 1 automotive components suppliers,[15] such as the BMW Group (BMW), Daimler AG (Mercedes-Benz), the Ford Motor Company (Ford), Adam Opel GmbH (Opel), Volkswagen AG (Audi, MAN Group, Porsche, Volkswagen), Robert Bosch GmbH (Bosch), and Continental AG (Continental) (see Table 4.22).

Considering the sector's breadth and scope of activities, it is unsurprising that German carmakers were one of the earliest adopters of advanced technologies and investigators of the Industry 4.0 environment.

[15] Tier 1 companies are often regarded as the largest or the most technically capable companies in the OEM's supply chain. They often develop close working and business relationships with OEMs (via Investopedia.com and chron.com)

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Table 4.21 R&D facilities of select Japanese automotive companies in Europe t21.1

Manufacturer	Company	Headquarters/ Division office	Current functions	
UK				t21.3
Honda	Honda R&D Europe (U.K) Ltd.	Swindon, UK	Technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design, vehicle design, prototype production	t21.4
	Honda Racing Development Ltd.	Bracknell, UK	Development of F1 racing cars	t21.5
	Honda GP Ltd.	Brackley, UK	Development of F1 racing cars	t21.6
Nissan	Nissan Design Europe Ltd.	London, UK	Styling and general design, parts design, vehicle design, prototype production	t21.7
Germany				t21.8
Honda	Honda R&D Europe (Deutschland) GmbH	Offenbach, Germany	Evaluation of vehicles, styling and general design, vehicle design, prototype production, marketing research	t21.9
Isuzu	Isuzu Motor Germany GmbH	Gustavsburg, Germany	Technical support for procurement of parts for local production, evaluation of parts, parts design	t21.10
Mazda	Mazda Motor Europe GmbH	Leverkusen, Germany	Evaluation of vehicles, styling and general design, vehicle design, prototype production, marketing research	t21.11
Mitsubishi	Mitsubishi Motors R&D Europe GmbH	Trebur, Germany	Technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, styling and general design, parts design, vehicle design	t21.12
Toyota	Toyota Motor Sports Germany GmbH	Cologne, Germany	Development of F1 racing cars	t21.13
Subaru	Subaru Test & Development Centre (STCE)	Ingelheim am Rhein, Germany	Evaluation of parts, evaluation of vehicles	t21.14
France				t21.15
Toyota	Toyota Europe Design Development S.A.R.L.	Nice, France	Styling and general design, parts design, vehicle design, prototype production, marketing research	t21.16
UK / Belgium				t21.17
Toyota	Toyota Motor Europe N.V./S. A..	Zaventem, Belgium Burnaston, UK	Technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design	t21.18

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Table 4.21 (continued)

Manufacturer	Company	Headquarters/ Division office	Current functions
UK / Spain/ Belgium/ Germany			
Nissan	Nissan Technical Centre Europe Ltd.	Cranfield, UKBarcelona/ Madrid, SpainBrussels, Belgium, Bruhl, Germany	Technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design, vehicle design, prototype production

Source: Japan Automobile Manufacturers' Association (JAMA, 2017)

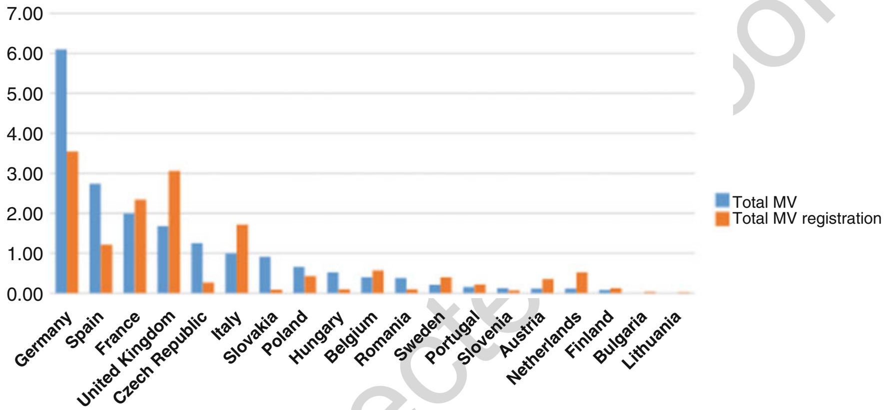

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Fig. 4.6 EU total motor vehicles production and registration 2015, in millions. Source: European Automobile Manufacturers' Association (ACEA, 2016)

The next section examines the advanced technologies and robotics that the major German OEMs (and related brands when applicable) have adopted in their production processes. Similar case studies are presented for the two largest automotive components suppliers in Germany: Robert Bosch GmbH and Continental AG. A brief but comparable discussion is constructed for the automotive supplier SME SEW-Eurodrive to demonstrate that the current technological transformation across the German automotive industry is sector-wide.

German Automotive: OEMs

BMW Group

Within the automotive space, the BMW Group (BMW) has been one of the pioneers in adopting the most recent technologies in its manufacturing process. Currently, several of the manufacturer's plants in Germany and in the USA have been retrofitted with various autonomous robots that enable greater human–robot

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Table 4.22 List of automotive OEMs (and their marketed brands) and select automotive components suppliers located in Germany

OEM parent company	Brands[a]	Automotive components suppliers	
Adam Opel GmbH	Opel	Bosch	Draexlmaier
BMW Group	BMW	Continental	Eberspaecher Holding
Daimler AG	Mercedes-Benz	ZF Friedrichshafen	Getrag
The Ford Motor Company	Ford	Thyssen Krupp	Leoni
Volkswagen AG	Audi	BASF SE	KSPG
	MAN Group	Mahle	Freudenberg
	Porsche	Schaeffler	Webasto SE
	Volkswagen	Bentheler Automobiltechnik	Infineon
		Hella KGaA	Leopold Kostal
		Broze Fahrzeugtechnik	Trelleborg Vibracoustic
			Kautex Textron

[a]Listed brands are those that have significant operations in Germany
Automotive components suppliers with German headquarters
Source: Author's classification, adapted from GTAI (2017)

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collaboration (hereafter referred to as collaborative robots or co-bots when applicable) than allowed by traditional machines. BMW's first lightweight robot came online in its Spartanburg, SC, plant (BMW Group, 2017a) and allowed the carmaker, together with MIT, to identify that collaborative human–robot environments result in an 85% drop in workers' idle time and that this combination is more effective than teams of either humans or robots alone (Knight, 2014).

Since then, BMW has capitalized on its knowledge by commissioning more of these robots in its other plants. Today, BMW uses co-bots to undertake tasks such as the lifting of bevel gears during axle transmission assembly (BMW Group Dingolfing plant) and the application of viscous adhesive to front window installations (BMW Group Leipzig plant) (BMW Group, 2017a). Similar collaborative and autonomous robots have been introduced in the company's transport and logistics management: Smart Transport Robots (STR) and laser-guided autonomous tugger trains are employed in the Wackersdorf and Dingolfing plants, respectively (BMW Group, 2016c).

The BMW Group also uses other proximate technologies that benefit both humans and robots alike: 3D printing technology in rapid prototyping, manufacturing validation (MIT Technology Review, 2014), and additive manufacturing (BMW Group, 2016b), laser-based guidance systems (BMW Group Regensburg plant), augmented reality applications and intelligent devices, and robotic exoskeletons for strenuous tasks (BMW Group, 2017a).

Daimler AG

Daimler AG was another early adopter of advanced manufacturing technologies exploring the many possibilities of Industry 4.0. Even before the sector-wide shift, the then Daimler Chrysler was experimenting with agent-based HMS in its

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Mercedes-Benz V6 and V8 engines assembly plant (NVM) in Stuttgart (Bussmann & Sieverding, 2001). Currently, within the Mercedes-Benz brand, Daimler AG has defined and achieved two stages: (1) global component standards, a standardized systems architecture and standardized automation, regulation, and control technologies, and (2) globally standardized technology modules for its robotics and production processes. Furthermore, Mercedes-Benz is able to simulate the production process from press plant to final assembly, allowing the car manufacturer to examine 4000 individual processes prior to actual production (Daimler AG, 2015b).

Various other related technological shifts have been exploited in selected Mercedes-Benz variants: for instance, Mercedes-Benz S Class production recently shifted from its large traditional robotic machines to the smaller and lighter co-bots in the Sindelfingen plant in what the carmaker refers to as ‘robot farming’; the human workers are expected to provide the required adaptability and the flexibility to achieve mass customization (Gibbs, 2016). For its latest E Class (213 series), the carmaker is implementing a networked and digital-based production approach: 87 body-in-white production systems are equipped with 252 programmable logic controllers, 2400 robots, and 42 technologies and are linked to approximately 50,000 intelligent network participants (IP addresses), thereby allowing continuous monitoring without human intervention (Daimler AG, 2015a). Unmanned production tracking is enabled by combinations of antennae and Wi-Fi networks. Again, workers become valuable because of the flexibility that they provide in the shop floor (Daimler AG, 2015a).

Beyond its premium vehicle segment, Daimler AG maintains key facilities in its Sindelfingen location that enable it to advance its production processes. An example is the TecFactory, which is a test factory where the company tests new production concepts and ideas, particularly in man–robot cooperation and innovative logistical solutions (i.e. driverless transport systems or DTS) (Daimler AG, 2015b). Another facility is the Virtual Reality Centre which is used for prototype design and virtual prototype simulation, such as the case of the Mercedes-Benz Class E (213 series) (Daimler AG, 2015a).

Daimler is also actively involved in inter-firm collaborative research to advance the current technologies. The carmaker, together with the University of Stuttgart, Fraunhofer IPA, and Bosch, founded the project Active Research Environment for the Next Generation of Automobiles (ARENA2036). ARENA2036 is a public–private platform that investigates agile and flexible production systems and human–robot cooperation (International Federation of Robotics, 2016).

The Ford Motor Company

As part of its efforts to participate in Industry 4.0, the American car manufacturer Ford Motor Company (Ford) has installed co-bots in its Cologne factory. In Ford’s approach, the co-bots are relied on to assist the workers in fitting shock absorbers into the wheel arches of its Ford Fiestas: the machines are used to handle the lifting and positioning tasks, while the human workers supervise the installation (Zaleski, 2016). Regarding worker safety, Ford relies on intelligent machines that stop

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immediately when they detect a human presence (even just a finger) in their path (Ford Motor Company, 2016).

Adam Opel GmbH

Adam Opel GmbH (Opel) is still in the early phases of advanced technologies adoption and Industry 4.0 investigations. Rüsselsheim am Main-based Opel's ITEZ—Advanced Manufacturing Technologies (AMT) team, together with its supply chain and manufacturing IT personnel, is actively researching intelligent systems and self-organizing production (Scherer, 2017). Another ITEZ division, called the Structural Development Laboratory (SDL), applies laser-based and simulation technologies to prototyping and testing of brake systems (Scherer, 2016). These internal efforts are supplemented by work done by graduate interns, such as investigations into intelligent self-organizing production (Opel Post, 2016). However, Opel is beginning to adopt smart technologies and intelligent robotics on its shop floor. For instance, it relies on Fanuc R-2000iB, a heavy-duty robot, to work with its human counterparts in door installations for the company's Insignia models in its Rüsselsheim plant (Wollny, 2016). Smart technologies, such as augmented reality devices and wearables, are used for supply chain management in Opel's ADAM vehicles (Opel Eisenach plant) and components assembly (Opel Kaiserlautern plant) (Scherer, 2017).

Volkswagen AG

Production processes in Volkswagen AG (Volkswagen) facilities have been highlighted in the literature because of their innovativeness, such as the employment of RFID technologies during post-production logistics management (Huang et al., 2009). In the Industry 4.0 landscape, Volkswagen is involved in several initiatives that drive and investigate company-wide implementation of advanced and smart technologies: (1) Data:Lab in Munich, which handles ideas related to big data, advanced analytics, machine learning, and AI; (2) Berlin-based Digital:Lab, which handles ideas related to end-customer engagement (e.g. mobility services); and (3) Smart.Production:Lab in Wolfsburg, which develops both software and hardware pilots and prototypes that are implemented in Volkswagen's smart factories (Volkswagen AG, 2015). The group-wide level of IT standardization for production management was 88% in 2016 (Volkswagen AG, 2016).

In particular, through its Smart.Production:Lab, the carmaker, together with the German Research Centre for AI (DFKI), is carrying out research for the development of greater cooperative human–robot capabilities within the same production space (Simpson, 2016). Propriety systems will be able to process human waves, gestures, and motion, which will allow for greater responsiveness and interaction capabilities in robots (Volkswagen Group Italia S.P.A., 2016).

Simultaneous with the general measures being undertaken at the parent-company level, Volkswagen brands have also adopted market-available solutions. For instance, Audi's Neckarsulm facility was one of the early adopters of co-bots for handling coolant expansion tanks (Euromonitor International, 2016). Another instance is Audi's Ingolstadt facility which combines a high level of automation with a multitude of other advanced technologies, such as optics-driven, low-power

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laser systems and regenerative braking in lift and conveyor systems. In its Audi A3 body shop, Audi employs robots that roughly equal the number of its employees (800); these machines do most of the more strenuous tasks (Juskalian, 2014).

There are several intelligent systems employed in the Audi Ingolstadt facility: body assembly is jointly produced by an autonomous group framer and several robotic arms that spot-weld the components in place (Juskalian, 2014). Juskalian (2014) refers to the Ingolstadt *automatisierter* Anbau (INTA)—a fully automated door assembly process that uses an array of sensors, robotic arms, and lifts in which the unique combination of technologies allows for efficient handling of A3 body variants and installation of corresponding doors. Audi, together with research institutions, is also using the Ingolstadt facility as a site to investigate the viability of nascent intelligent technologies, such as smart mobile assistants, in industrial applications (Angerer et al., 2012) (Table 4.23).

German Automotive: Automotive Components Lead Suppliers

Continental AG

Continental AG (Continental) has implemented several Industry 4.0 technologies in its Regensburg facility: networking co-workers, co-bots, and driverless transportation systems (ROI Management Consultants, 2015).

In its other lines of businesses, particularly tyre manufacture, Continental has established its High Performance Technology Centre (HPTC) in Continental Corporation’s Korbach location. HPTC machine and equipment are equipped with sensors and software, allowing for the emergence of a complete network. The system allows for continuous display and complete documentation of all the processes and materials involved (Continental Corporation, 2016b) using data to run simulations and investigations of tyre variants, thereby reducing development time (Continental Corporation, 2016a).

Robert Bosch GmbH

Bosch’s automotive plant near Immenstadt im Allgäu, Germany, is a testbed for intelligent manufacturing processes that the company might implement across its facilities. The plant is equipped with various advanced technologies: sensor (RFID) technologies and digital twins are made available in all machinery and tools, allowing plant managers to obtain real-time information on plant efficiency and health (Juskalian, 2016). Moreover, Juskalian (2016) explains that the facility is connected to a main data centre in Stuttgart, where granular data from 11 Bosch facilities are consolidated and analysed.

Bosch is also one of the founding members of ARENA2036 (see *Daimler AG*).

SEW-Eurodrive

SEW-Eurodrive’s factory in Baden-Württemberg features several robotic technologies that aid its human workers: (1) a robotic workbench that assembles near-complete drive systems and (2) robotic arms that assist workers in load handling (Hollinger, 2016) (Table 4.24).

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t23.1 **Table 4.23** Advanced technologies of German OEMs in Germany

	Parent firm	Facility name	Plant city	Plant state	Adopted technology	Targeted production process
t23.3	BMW Group				3-D printing technology	Rapid prototyping; manufacturing validation; additive manufacturing
t23.4					Augmented reality technology	Early-phase concept validations, initial sampling inspections
t23.5					Intelligent devices	Supply chain management
t23.6					Robotic exoskeletons	Supply chain management
t23.7		BMW Group Dingolfing plant	Dingolfing	Bavaria	Collaborative robots	Assembly—axle transmission
t23.8					Autonomous transport systems	Transport and logistics management
t23.9		BMW Group Leipzig plant	Leipzig	Saxony	Collaborative robots	Installation—windows
t23.10		BMW Group Regensburg plant	Regensburg	Bavaria	Laser-based guidance systems	Transport and logistics management
t23.11		BMW Group Wackersdorf plant	Wackersdorf	Bavaria	Smart transport robots (STR)	Transport and logistics management
t23.12	Daimler AG				Standardized systems architecture and automation	
t23.13					Standardized technology modules for robotics and production	
t23.14					Simulation technology	
t23.15		TecFactory	Sindelfingen	Baden-Württemberg		Investigations in man—robot cooperation and logistic solutions
t23.16		Virtual Reality Centre	Sindelfingen	Baden-Württemberg		Prototype design and virtual simulation
t23.17		Mercedes-Benz			Autonomous production systems	
t23.18					Sensor technology	

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t23.19 **Table 4.23** (continued)

	Parent firm	Facility name	Plant city	Plant state	Adopted technology	Targeted production process
t23.21		Mercedes-Benz Sindelfingen plant	Sindelfingen	Baden-Württemberg	Collaborative robots	Production—Mercedes-Benz S Class
t23.22		Mercedes-Benz Sindelfingen plant	Sindelfingen	Baden-Württemberg	Collaborative robots	Production—Mercedes-Benz E Class (213 series)
t23.23	The Ford Motor Company	Ford Cologne plant	Cologne		Collaborative robots	Installation—shock absorbers
t23.24	Adam Opel GmbH	ITEZ—AMT	Rüsselsheim am Main	Hesse		Investigations on intelligent systems and self-organizing production
t23.25		ITEZ—SDL	Rüsselsheim am Main	Hesse	Laser-based sensor technology	Prototype design and virtual simulation
t23.26					simulation technology	
t23.27		Opel Rüsselsheim plant	Rüsselsheim am Main	Hesse	Collaborative robots	Installation—doors
t23.28		Opel Eisenach plant	Eisenach	Thuringia	Intelligent devices	Supply chain management
t23.29		Opel Kaiserslautern plant	Kaiserslautern	Rhineland-Palatinate	Intelligent devices	assembly—Automotive components
t23.30	Volkswagen AG				Standardized systems architecture and automation	
t23.31					Sensor technology	
t23.32		Data:Lab	Munich	Bavaria		Investigations on big data, advanced analytics, ML, and AI
t23.33		Digital:Lab	Berlin	Berlin		Investigations on CRM
t23.34		Smart.Production: Lab	Wolfsburg	Lower Saxony		Investigations on smart production
t23.35		Audi Ingolstadt plant	Ingolstadt	Bavaria	Laser-based sensor technology	Transport and logistics management

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t23.36		Audi Neckarsulm	Neckarsulm	Baden-Württemberg	Collaborative robots	Supply chain management
t23.37					Collaborative robots	Supply chain management
t23.38						Assembly—body
t23.39						Installation—doors

t23.40 Source: author’s analysis

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t24.1 **Table 4.24** Advanced technologies of German automotive suppliers in Germany

	Parent firm	Facility name	Plant city	Plant state	Adopted technology	Targeted production process
t24.2						
t24.3	Continental AG	HPTC	Korbach	Hesse	Sensor technology	Machine health and prognostics management
t24.4						Processes and materials behaviour documentation
t24.5						Prototype simulation
t24.6			Regensburg	Bavaria	Collaborative robots	
t24.7					Autonomous transport systems	
t24.8	Robert Bosch GmbH		Stuttgart	Baden-Württemberg	Big data analytics	Machine health and prognostics management
t24.9			Immenstadt im Allgäu	Bavaria	Sensor technology	Machine health and prognostics management
t24.10	SEW Eurodrive			Baden-Württemberg	Collaborative robots	

t24.11 Source: author's analysis

German Automotive: German Cars

Current-Generation Driver Assistance Systems

German OEMs have at least kept pace with other leading carmakers across the world in use of the latest technologies in driver assistance systems such as autonomous self-parking, lane-keeping and cruise-control, and traffic jam assistants.

For instance, the BMW i3 model is the first car to offer a fully automatic parking option (BMW Blog, 2014). Other BMW variants, Mercedes-Benz, offer hands-off and feet-on technologies while Audi and Volkswagen offer experimental vehicle-to-infrastructure (V21) communication alongside other features (IEEE Spectrum, 2014d).

The Volkswagen Touareg has one of the more advanced lane-keeping systems on the market and can track lanes at night-time (IEEE Spectrum, 2014c). Volkswagen has advanced the technology in its other models by allowing the system to continuously counter-steer to maintain the vehicle in its lane (Passat CC) (Volkswagen, 2017). BMW currently offers lane departure warning systems, while Mercedes-Benz have lane-keeping technologies. All German OEMs have cruise-control technologies, although BMW variants are notable in providing low-speed steering capabilities (IEEE Spectrum, 2014a).

Among the most recent German vehicles available in the market, the Mercedes-Benz E Class (213 series) is among the most advanced: the car is equipped with

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ultrasonic sensors and a 360° camera for traffic analysis and accident prevention (Daimler AG, 2015a). Daimler AG (2015a) also states that the E Class (213 series) has the firm's latest car-to-X communication technology, remote parking pilot via smartphone applications, and a digital vehicle key through near-field communication (NFC) technology.

Next-Generation Automotive Systems

Several initiatives among German OEMs and German tier 1 automotive suppliers are being carried out to investigate next-generation vehicles systems. While some firms conduct their investigations internally, most are carried out in collaborative inter-firm (and sometimes including a research institution) environments.

Bosch currently is working on an advanced braking system which allows the car to take over control from the driver in situations where it identifies potential accidents (IEEE Spectrum, 2014b). IEEE Spectrum (2014b) explains how the car processes information through sensory data acquired by means of a chip installed in the windscreen; it returns control to the driver when it concludes that the danger has passed.

Continental is working with the University of Oxford and the Technical Universities in Darmstadt and Munich on investigating the application of neural networks in the cameras of its advanced driver assistance systems (Continental Corporation, 2017). In 2015, Continental, Deutsche Telekom, Fraunhofer ESK, and Nokia Networks have demonstrated the viability of real-time communication between vehicles via the LTE network; the research has the potential for latency reduction of car-to-car communication and viability of existing networks for connected motorways (Continental Corporation, 2015).

Among German OEMs, BMW, together with the Israeli firm vehicle safety systems provider, Mobileye, and chip maker Intel, will begin testing vehicles that rely on a reinforcement learning approach in the second half of 2017 (Knight, 2017; Etherington, 2017; BMW Group, 2017b). The carmaker is concentrating its development resources in Unterschleissheim, near Munich, and intends to release self-driving, electric, and fully connected vehicles by 2021 (BMW Group, 2016a).

Another BMW endeavour is the generation of real-time data through camera-based Advanced Driver Assist System (ADAS): the car manufacturer is working with Mobileye to equip its 2018 vehicles with Mobileye's Road Experience Management (REM™) data generation technology. The collaboration will allow BMW vehicles to access and contribute to Mobileye's Global RoadBook (GLRB™), a crowd-sourced collection of HD maps with highly accurate localization capabilities. The agreement allows both parties to further promote automated driving (BMW Group, 2017c).

Daimler AG and the UK-based Delphi are currently experimenting with the installation in their vehicles of up to four light detection and ranging sensors (LiDARs), devices that map the environment in 3-D with lasers (Simonite, 2016). Simonite (2016) notes that Daimler has invested in the technology company, Quanergy, for the development of next-generation LiDARs.

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Recently, Volkswagen AG presented a concept for an autonomous self-driving car called Sedric. It is a level-5 autonomous driving concept car which was designed and constructed by the Potsdam-based Future Centre Europe and the Wolfsburg-based Volkswagen Group Research (Volkswagen AG, 2017). The car is envisaged as a battery-powered electric vehicle with no conventional controls and operated through remote control (Noakes, 2017). Volkswagen AG is also actively investing in ride-sharing technologies, such as Israeli-based ride-hailing service Gett (Kokalitcheva, 2016).

Like its parent firm, Audi has been active in researching future technologies. Recently, the car brand created a new subsidiary, Autonomous Intelligent Driving, which will work for the entire Volkswagen Group to research self-driving technology (Korosec, 2017). Across its vehicles, Audi is working with the technology firm, NVIDIA, to develop the Audi Q7. NVIDIA's DRIVE PX 2 in-car computer is the foundation for the local neural net in the Audi Q7; primarily, it studies driver behaviour and uses the data to infer behaviour (Etherington, 2017). A consortium of Audi, Ericsson, Qualcomm Technologies, SWARCO, and the University of Kaiserslautern is to carry out demonstration trials for vehicle-to-everything communications through 4G/5G LTE-based vehicle-to-network (V2N) technology (IEEE Connected Vehicles, 2017).

Environment for Next-Generation Automotive Systems

Regarding the overall environment for the development of networked driving, the German Federal Ministry of Transport and Digital Infrastructure advises on the following areas of action: infrastructure law, innovation, networking, and IT security and data protection (VDA, 2016).

Existing German regulations, particularly the Road Transport Law and the Road Traffic Act, allow the use of automated systems, but make no exact provisions in the case of accidents that involve self-driving cars (VDA, 2016). However, in October 2015, Germany adopted the Vienna Convention on road transport, which permits automated driving in traffic, provided that these technologies can be overridden by the driver any time (UNECE, 2016).

Various initiatives are investigating the proper standards for the vehicle-to-X communications network infrastructure (see *Next-generation automotive systems*). The German automotive association, the German Association of the Automotive Industry (VDA), has worked with the federal and state government data protection authorities to develop a standard on data protection aspects of use of networked and non-networked vehicles (VDA, 2016).

4.1.4.3 Piemonte and Torino

Piemonte represents the most developed region within the Italian automotive sector. The past and recent history was characterized by the important presence of the FCA group (FIAT SPA until 2014). FIAT allowed massive development of companies linked to the local automotive ecosystem, which, over the decades, have been

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Table 4.25 Data on the Piemonte automotive industry

Automotive Industry	Italy	Piemonte
Firms	1.956	712
Revenue	38.8 billions	15.2 billions
Employers	136.000	55.400
Export	75%	81%
Export revenue	+ 4,2%	+ 3,3%
% of export revenue	40%	45%
Dependence on FCA	79%	87%
R&D	72%	74%

Source: Moretti A., Zirpoli F., (2016), 'Osservatorio sulla componentistica automotive 2016', Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari

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specializing throughout the automotive supply chain (product development, components, design, output, after-sales).

According to the latest data provided by the Italian automotive components Observatory 2016, Piemonte significantly increased its automotive productivity and revenue in 2015. Within the region there are 712 companies, which represent more than 36% of total Italian suppliers. There are more than 77,000 employees in the supply chain and 55,500 in the automotive industry.

In 2016, FCA production in Italy was 721,126 cars (+8.2% on 2015 and + 84% on 2013). Most of the production is concentrated in the South (Melfi, Pomigliano, and Cassino), but Mirafiori-Torino and Grugliasco are still relevant for bodywork production of Alfa Romeo and Maserati. Italian factories employ almost 34,000 workers (Table 4.25).

The FCA group is not only the main group in the automotive sector in Piemonte but is also a starting point for satellite activities in the region. Over 85% of the companies interviewed for the Observatory report said that part of their revenue came directly or indirectly from FCA, while the national figure stands at 79.9%.

Considering the entire automotive industry, Piemonte is able to generate a total revenue of EUR 19.9 billion, a 6.5% increase with respect to 2014. That accounts for 39% of Italian sales in automotive.

What appears to be an interesting update about the increased production in Italy and Piemonte is the change in the production mix. In fact, the production of higher unit volume segments, such as Monovolume and Suv, has increased considerably, while lower band production (A, B, C) was reduced.

Table 4.26 shows the most developed and productive sectors in the Piemonte automotive supply chain, where the specialist segment plays a crucial role.

Piemonte is the main actor in Italy for development of research and innovation. The Piemonte region invests EUR 2.4 billion of in-house resources in innovation, equal to 17% of total spending on R&D by Italian companies.

The entrepreneurial sector invests 78% of its regional expenditure on innovation (the average for Italy is 54%). Innovation is realized mainly in the specialized ICT segment and advanced specialist services. Those firms that are more innovative are

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Table 4.26 Firms, employees, and revenue of the automotive supply chain—Piemonte region

2015	Firms	Revenue automotive supply chain (Bn of Euro)	Revenue automotive industry (Bn of Euro)	Employees automotive supply chain	Employees automotive industry
Sub-providers	351	2.499	1.442	13.369	7.366
Specialist	242	10.568	7.630	39.716	24.942
Engineering and design	86	749	652	4.905	4.287
Systems engineers	33	6.090	5.487	19.455	18.832
Total	712	19.906	15.211	77.445	55.428

Source: Moretti A., Zirpoli F., (2016), 'Osservatorio sulla componentistica automotive 2016', Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari

characterized by smaller employment (less than 50 employees), less than 5 years of activity, and average investment of 4% of their turnover in R&D activities.

This strong inclination for product innovations in the field of advanced ICT and advanced services is generating positive effects in many segments of the regional automotive supply chain, as well as influencing the component sector. Data show that in 2015, 74% of component companies were involved in innovation activities (8% more than in 2014).

Two crucial segments in the field of R&D investment are subcontractors and engineering and development. While the first appears to be the less innovative within the supply chain due to the production of essentially standard components, engineering and development activities are highly innovative.

In Piemonte, the engineering and development segment accounts for 16% of the entire chain (against an Italian average of 12%). This is evidence of significant regional performance in the field of innovation and development of state-of-the-art engineering solutions. Combined with a great propensity to innovate in the field of specialized services and ICT, this allows Piemonte region to act as the national innovation leader in the automotive sector. As already mentioned, the Piemonte automotive sector is characterized by the presence of the FCA Group which, together with CNH Industrial, represents the two main manufacturers in the automotive sector in the region.

Around these big groups, one can find both important firms along the supply chain, as shown by the industry overview, and important companies that represent the region's excellence in research, components, and, most importantly, design (Table 4.27).

As already mentioned, FCA has a significant impact on local suppliers. The reopening of many of the group's manufacturing facilities and the recovery of the automotive industry globally and locally have contributed to the multinational's re-emergence as a customer for many component suppliers in the region.

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Table 4.27 Main competitors—Piemonte region

Group	Firm	Employees	Location	Activities
FCA				
	Fiat	5.001–10.000	Torino, TO	Manufacturing
	Maserati	501–1000	Grugliasco, TO	Luxury production
	Magneti Marelli	2.001–5.000	Venaria, TO	Manufacturing
CNH Industrial		Over 10.000		
	Iveco	1.001–1.500	Torino, TO	Manufacturing
	New Holland	251–500	San Mauro Torinese, TO	Manufacturing
General Motors				
	Global Propulsion System	501–1.000	Torino, TO	Engineering research centre
Valeo		1.001–1.500	Pianezza, TO	Components
Pininfarina		501–1.000	Cambiano, TO	Design
ItalDesign—Giugiaro SPA		501–1.000	Moncalieri, TO	Design
Jac Italy Design Centre		51–200	Pianezza, TO	Design

Source: Moretti A., Zirpoli F., (2016), 'Osservatorio sulla componentistica automotive 2016', Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari

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Despite progressive diversification in local suppliers' customers in the last few years, since 2014 the trend has changed. Analysis of the distribution of Piemonte's turnover generated by supplying FCA shows the impact of the group has grown compared to the recent past. This is true more especially for the regional cluster than for the rest of Italy. More than 86% of companies stated that part of their revenue for 2015 came from direct or indirect relationships with FCA. That value decreases to 79% when we consider the Italian level. The detailed percentages show that almost 34% of Piemonte companies earn more than 75% of their revenue from the Italian-American group, against 29% earned by other Italian companies.

In 2014, the average percentage of (direct or indirect) supply to FCA decreased (32%), but in 2015 the share rose again to 49%. This growth was experienced not only by the domestic market (33% vs 26% in 2014), but also by the average percentage of sales for foreign production (16% vs 6%).

There are some interesting aspects to the degree of openness to the foreign market based on prospect data. Sub-alpine businesses historically have been characterized by a high degree of openness to foreign markets. This propensity allowed the chain in Piemonte to overcome the recent global economic crisis, which severely affected the car market, and to maintain high levels of competitiveness and entrepreneurial specialization.

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After 2014, when components sales abroad had halted, Piemonte exports continued to grow and reached nearly EUR 4.5 billions (about 37% of Italian car exports) in 2015. This represents an increase of 3.1% compared to the previous year.

In 2015, for the first time in 10 years, the value of sub-alpine car sales exceeded those of parts and components, increasing by 33% compared to 2014 (EUR5.8 billions). This was due to the expertise and experience in the Piemontese entrepreneurial system, acquired over the years, particularly in the Turin area where FCA produces some Maserati and Alfa Romeo brands. Today, Piemonte automotive exports account for almost 30% of domestic car sales abroad, a share that has increased progressively in recent years (21% in 2008). This confirms the importance of the sub-alpine territory in an international context.

The opening of Piemonte companies to foreign markets is confirmed by the responses to the Observatory survey: in the last edition of the Observatory, 81% of Piemonte suppliers (79% in 2014) declared being exporters, against 75% of suppliers nationwide. The greater propensity to export is supported by the degree of intensity with which companies rely on it: for one-quarter of the sample surveyed, export accounts for more than 75% of the turnover.

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