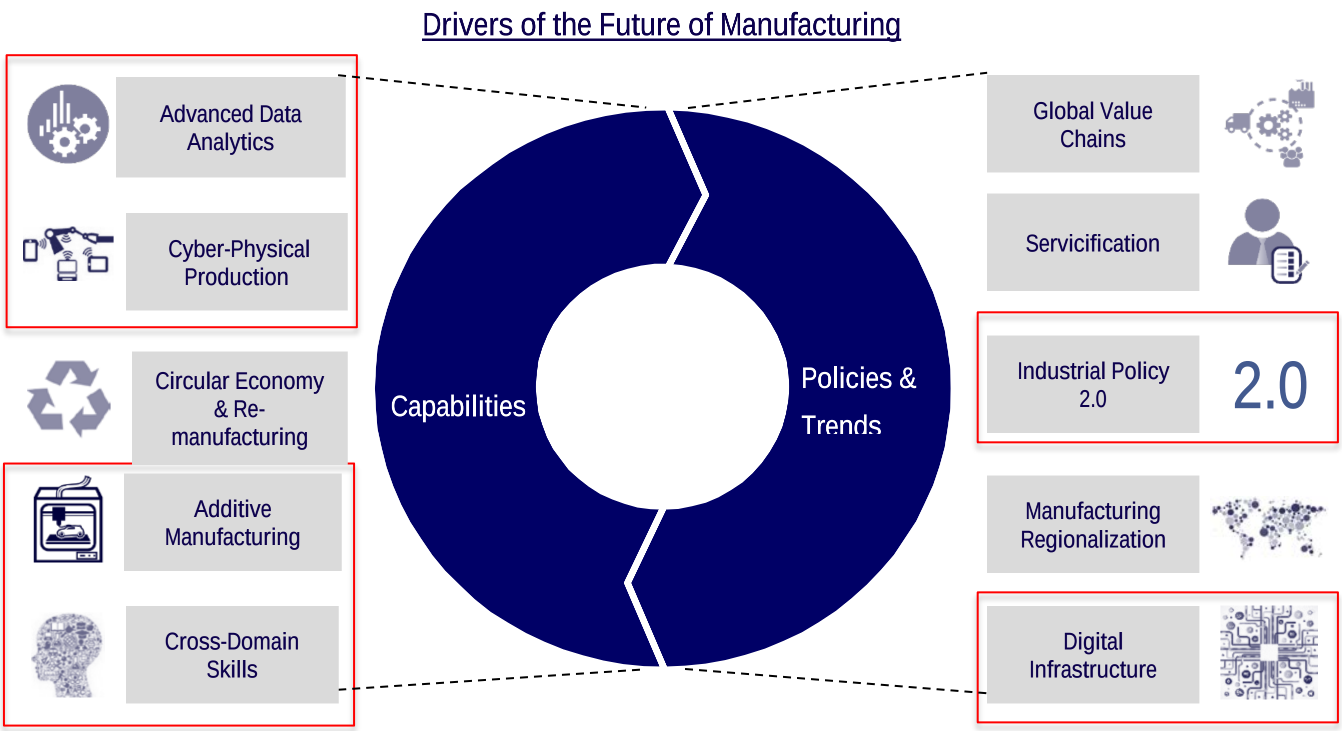
Case 21

Thought Piece on the Future of Manufacturing Know-How in the Automotive Industry



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Executive Summary

Future of Manufacturing Know-How

Dates: 2035 and beyond

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1. Challenge Confronted

Technology is continuously improving customer's lives when it comes to mobility and connectivity, which has already progressed to an advanced status through, for example, the development of smart homes, smart vehicles, or smart phones and the many apps available in the market place. This evolution will continue exponentially into new areas such as manufacturing, logistics, energy transferability, etc.

One of the biggest and most competitive industrial segments is the automotive industry, which requires major changes, cradle to grave: process, product and application. Cars are being designed more efficiently and built faster, despite more variety. As a result, the vehicle industry, including its supply base, has to react proactively to this evolution. Time-to-market will be increasingly important to stay competitive and to meet the needs of the customers. Suppliers will especially be affected by this evolution as they have to be even faster than the OEM itself.

As manufacturing and design will be linked more closely to become more efficient and effective, new production concepts and production technologies will have to be developed. Smart robotics will overtake traditional tasks previously performed by humans to provide improved quality and efficiency. Advanced analytic tools will master the increasing level of complexity due to the use of interconnected production equipment, ensuring flexibility and agility in producing highly customized parts within short turnaround times.

Changes in organizational structure and work regulations will dramatically change the day-to-day routine of the workforce. Advanced manufacturing technologies must be serviced and operated by a workforce that is highly skilled and capable to manage complex digital equipment. Mechatronics and algorithms will be essential tools that people on the shop floor level must be familiar with.

There is potential exposure through the difficulties encountered in filling open positions and/or replacement needs for the skilled workforce of the future. The average age of employees in the West (with very few exceptions) is rising while birth rates are declining. Society perception is pushing young people into higher education as manual labour is often viewed as less desirable or less important. Industry, society and even unions distinguish between blue-collar and white-collar workers in terms of work regulations and compensation. This leads to further erosion of skilled trades as more people try to strive for perceived higher education.

As a result, labour costs will rise all over the world and global mobility becomes an increasing issue as people are accustomed to employment close to their home base. If not managed properly between governments and industry as a part of global free trade, the result will be an unstable socioeconomic environment. Therefore, a great deal of thought needs to be given to future education systems.

2. Solution Used

To ensure a sustainable solution for the future workforce, all accompanying forces have to pull together in the same direction. New workforce regulations will be necessary to ensure socioeconomic standards and competitiveness of nations around the globe. Business models and organizational structures will need to adapt to survive in a volatile manufacturing environment. New jobs have to be created to accommodate the future workforce with respect to future generations, ageing workforce and immigration.

Finally, adequate education must ensure workers capable of an interdisciplinary skill range. Students at an early age need to be exposed to manufacturing career opportunities, while the ageing workforce population needs access to continuous training. Education systems need to be tailored to cater the needs of both industry and individuals. Thus, close cooperation between academia and industry is a key factor.

Description of the Challenge

1. The power of digitalization

It is crucial to understand digitalization is far more than a trend of digital services or connected devices in consumer markets. Smart products, apps and social networks improve customers' lives and thus often cause a societal transformation. The development of these applications is predicted to grow rapidly as a study of Gartner (2014) predicts a typical household by 2022 could contain more than 500 smart devices.[1]

As industry recognizes the power of digital technologies, it is impacting manufacturing technologies and business models dramatically. In 2011, digitalization measurably boosted productivity and employment globally, adding $193 billion to the world economy and providing 6 million jobs worldwide. It will further accelerate as nations move forward to more advanced stages of digitalization.[2] Mid to long term, it is an essential key factor to manufacturing, enabling profitable growth and sustainable competiveness.

The automotive industry in particular will change, adapting to a large number of megatrends, e.g. urbanization, electrification and digitalization. Market requirements change and customer demand will increasingly fluctuate, affecting the entire value chain. To deal with these fluctuations, manufacturers must be agile in their entire production process, including labour and equipment.

Studies show that customers are used to increasing innovation speed from consumer electronics, thus expecting the same pace by automotive industry.[3] Product life cycles will continue to decrease and innovative products have to be developed and produced in decreasing time intervals. Suppliers will especially be impacted by this evolution, as product development times shrink down the supply chain.

As an outcome business models, manufacturing processes and equipment have to adapt to the needs of the digital world to survive in this highly competitive sector. Manufacturing and engineering need merge by physical and cognitive means to implement simultaneous engineering. Job profiles and qualification standards of manufacturing workforce will change, as they have to collaborate with digital manufacturing equipment to create an innovative environment.

2. Implications on manufacturing concepts in 2035

Historically, in the world of manufacturing, the continuous development of disruptive technologies caused what later were referred to as industrial revolutions. Starting with the first water and steam power-driven mechanical production equipment in late 18th century, the world is now moving towards the Fourth Industrial Revolution, which is predicted to be a fusion of physical and virtual world, often named Industry 4.0, Industrial Internet or simply Advanced Manufacturing. Machines will connect with one another, creating intelligent networks of autonomously acting production systems to ensure highly efficient and agile manufacturing processes.[4]

It is not foreseeable if manufacturing will still follow the philosophy of Industry 4.0 in 2035. Other revolutionary steps may have been taken by then. These predictions are first evolutionary steps into a new manufacturing world. A wide range of technologies have been identified as key enablers.[5] They will enhance automatization and perform tasks more efficiently.

Example 1: Advanced Robotics and Artificial Intelligence
Adoption of industrial robots is predicted to grow within 8-12% annually within the next 10 years.[6] They are capable of performing physically exhausting, precise and repetitive tasks with high quality 24/7, backed by decreasing hardware and increasing labour costs. As artificial intelligence and creativity is further developed, non-routine tasks will also become feasible by self-learning robots obtaining any data from the Internet of Everything.[7]

Example 2: Advanced Analytics and Big Data
Due to the use of digital equipment, the level of data produced in manufacturing will explode. Advanced analytic tools will enable decoding complex manufacturing processes by identifying data correlation and interlinkages within a network of machines, tools, material, etc. Previously unsolvable and unforeseen problems will be resolved and real time decision making will be supported.

Example 3: Additive Manufacturing
Currently, additive manufacturing methods are mainly used for rapid prototyping. They get further developed to become powerful instruments using and combining new materials with higher performance, quality and less post-processing. 3D printing in combination with 3D scanning will improve the production of highly customized parts and enable unprecedented shapes.[8]

3. How digitalization will affect the manufacturing workforce

Digitalization often creates the impression that human labour is being completely replaced by machines. This generates fear and creates resistance against new technologies. Repetitive routine tasks in manufacturing have been identified at high risk of being substituted by machines.[9] Technologies will also complement human tasks and additionally create new jobs in other related disciplines (e.g. IT or data science).

Digital technologies will gradually be integrated into existing systems, processes and single tasks implying changes in organizational structure and work regulations. Decentralized decision-making will enable quick reactions on unpredictable changes. Human labour will be centre of various tasks, appropriate to specific human capabilities. The majority of tasks will require interdisciplinary experts, performing abstract and creative tasks with the responsibility to keep production lines running, intervening when necessary. Therefore, the ability to solve unforeseen problems and work with new information is a key strength of humans. Workers performing non-routine, low-skilled tasks will shift to service jobs relying heavily on dexterity and social skills. Routine tasks will be handed over to machines, ensuring quality and productivity which humans are not able to process because of physical limitations. The general picture of manufacturing workforce will necessarily change as they will become highly skilled managers of complex manufacturing equipment.[10]

To ensure successful implementation of new production concepts, new work regulations have to be adopted. Widening regulations to allow more flexible working arrangements seems to be a serious need by industry.[11] Ageing workforce and employees with family will benefit most as they will perform less demanding physical work and have greater flexibility. Future scenarios suggest home office on shop floor level will be possible when digitalized production lines can be easily controlled on remote via secure internet connection.[12]

When less developed countries are industrialized, they catch up in terms of know-how and competitiveness, implying higher wages, benefits and other financial factors (e.g. shipping costs, taxes). Thus, offshoring to these regions is becoming obsolete due to rising financial considerations. Relaunching manufacturing activities in more developed regions is necessary, but only possible if affordable and adequate skilled workforce is available.

4. The needs of the future workforce are relevant for strategy

As a highly skilled workforce is crucial to future manufacturing concepts, heightened investment in people is essential. It is important to understand their specific needs with respect to labour requirements and training.

The rate of natural increase is declining on a global range. More developed countries are at a higher risk of negative total population growth due to declining birth rates and higher social standards. Some countries, such as Japan, are already exhibiting negative growth rates.[13] Immigration as a countermeasure is often challenging due to cultural differences or inadequate skill level, for example. As a consequence, the number of 55+ workers will increase dramatically to maintain or raise GDP.[14] Thus, individual capabilities of the ageing workforce (know-how, physical capabilities, learning capabilities, etc.) have to be considered in future manufacturing concepts. If the trend in decreasing population continues, a lack of potential workforce is predicted.

In 2035, at least three differing generations will have to collaborate, exhibiting differences in terms of digital aptitude, views on private and work life. Older generations are naturally more resistant to innovation. They have difficulties in seeing the benefits based in their past experience. Additionally, they fear of getting substituted, leading to increased frustration and reluctance to adapt. Conversely, the upcoming generation is being very familiar with and accustomed to digital equipment and processes, however they do not want to get into manufacturing. This generation prefers performing tasks which are held in high esteem and not manufacturing jobs often incorrectly labelled as less desirable or less important.

Generation Z's aptitude with digital equipment is already demonstrated by their way of learning. They "Google" solutions and share them with other classmates via social media. If the internet is used to its full potential, educational content can be specialized to individual requirements. In the digital era, students still require face-to-face interaction to build on their social skills to make them capable to successfully work in team environments.

Lessons Learned / Outcomes

1. High skillset is crucial to manufacturing workers in 2035

On a long-term perspective, digital manufacturing will extend the function of human labour into yet hardly regarded disciplines. This requires employees to expand their capabilities by participating high quality training. Interdisciplinary competence will be essential to handle complex manufacturing equipment. However, specific skills, depending mainly on product, process and technologies, are still needed. High affection to manufacturing, stubborn willingness to learn and basic technical knowledge will enable workforce to persist these challenges.

STEM – Science, Technology, Engineering and Mathematics
A solid foundation in STEM skills can be seen as the basement for a successful manufacturing career. High interest and basic understanding in science, technology and engineering fields enables further training in complex manufacturing techniques. High-level mathematic skills are necessary to deal with calculation tasks ranging from machine set-ups to production planning activities. Advanced STEM skills enable employees to invent and operate new manufacturing technologies and products. Low enrolment and less attention in STEM education are often referred as strong barriers for manufacturing companies finding adequate personnel.

MES (Mechanics, Electronics and Software) and Manufacturing Technique
To keep production and assembly lines running, workers need to deal with more cross-functional challenges than ever. Mechatronics will still play an important role to handle and maintain mechanical and electrical components within machines. Additionally, basic knowledge in algorithms and coding will be necessary to collaborate with digital equipment. Thus, employees will need to programme and teach advanced machinery, to uphold connection and communication within the network, and to analyse and solve unpredicted problems. When it comes to operating errors, breakdowns or other unpredictable events, operators have to be aware of their possibilities and react intermediately. Therefore, workers need intensive training in manufacturing techniques, including the machines, tools and material they are working with.

Soft Skills

The biggest differences between human labour and machines are presented by social capabilities, because they are difficult to transfer into bits. These skills are exactly what is needed to manage digital production equipment. They enable humans to solve novel problems and to make fast decisions based on insufficient and new information. Creative and entrepreneurial thinking will foster fast innovation, increasingly important to implement the next big leaps one step faster than competition. Additionally, employees need to be open for change and adapt quickly.

As an example, problem-solving is already referred as the most serious skill deficiency in US manufacturing, followed by basic technical training, employability skills and inadequate math skills.[15] Thus, adequate training has to be one of the top priorities of all entities involved to create a sustainable manufacturing environment.

Description of the Work to be Performed

To counteract a potential lack of adequate skilled personnel, public, private and civil sector have to work in close cooperation. Manufacturing industry has to get revitalized to attract high potential workforce. Education systems and curriculums must ensure adequate training to regional industry needs.

Step 1: Building the environment for the future manufacturing industry

Labour and technology standards must be adapted to the needs of both industry and individuals. Therefore, government, industry and worker representatives on a global range have to collaborate to find suitable solutions.

Wages and benefits usually imply a high investment for industry. They influence regional capabilities to create, or the needs to eliminate jobs in order to stay competitive. International benchmarks are needed to get comparison on a global range, ensuring competitiveness of industrial locations. However, these factors are essential to people when planning their careers or choosing an employment location. Therefore, it is necessary to equalize blue-collar and white-collared workers, avoiding devaluation of manual labour. Regulations need to ensure less demanding tasks, more flexible work time and adequate remuneration to accommodate the aging workforce and attract the upcoming generation.

Step 2: Creating a vision for the manufacturing company of the future

Manufacturing companies need to adapt to the digital world immediately. New business models will be necessary to ensure customer satisfaction and competitiveness. Operational and organizational structures have to be adapted to individual company needs, from shop-floor to office level. Therefore, companies have to develop dynamic capabilities of exploring future challenges while simultaneously exploiting daily business.

Additionally, companies need to invest in people. New jobs must be created with respect to the upcoming generation and the aging workforce. The vision of attractive manufacturing jobs must be actively pursued and communicated to society. Manufacturing industry has to tap into *zeitgeist*, using trendy channels like e.g. social media to attract the generation of digital natives.

Step 3: Preparing the future workforce for a digitalized manufacturing industry

An increasing need of interdisciplinary trained workers with particular knowledge in algorithms and digital equipment is predicted. Filling these positions with adequate skilled personnel will get increasingly challenging for manufacturing companies. Educational concepts have to be adapted to the needs of industry. The right amount of education for apprentices, technicians and academia has to be created in order to balance the skill level of manufacturing workforce.

STEM education is an important factor for getting students interested and well prepared for manufacturing jobs. Focus on this type of education lies mainly within primary and secondary education, often referred as K-12 programmes. Students should not be pushed into a specific industry sector at these stages. They must get access to basic knowledge to success in a broad range of technical disciplines. Recent studies show that an early interest in careers in science is a strong indicator of completing college degrees in STEM fields. However, only 17-19% of US bachelor degrees are awarded in these disciplines.[16]

To teach the future workforce specific manufacturing skills in mechanics, electronics, software and manufacturing techniques, tertiary education is crucial. Universities, technical colleges and apprenticeships are classical representatives therefore. It is obvious that curriculum of these education systems must focus on regional industry demand. Manufacturing companies have to play an active role within this point, supporting theoretical input from education systems via e.g. internships or guest lectures. Dual systems will get increasingly important as practical knowledge can be transferred very effectively by experienced workers and hands-on training.

Additionally, innovative teaching methods that make use of digital technologies seem to be powerful instruments to support classic curriculums. Fab Labs are educational outreaches of the MIT to support gaining deep knowledge about machines, materials, the design and engineering that goes into innovation by providing students access to digital fabrication tools. Massive Open Online Courses, often referred as MOOCs, convey educational context via internet, enabling students to gather information on individual needs regardless from time and space.

Teaching soft skills is often referred as highly challenging to traditional lecturing because they usually develop through experience. Thus, students have to be trained continuously, starting at early ages. It is about getting used to social interaction, independent decision-making and problem-solving based on insufficient information. Team work, roleplay and presentations are often used to get students out of their comfort zone. The HBS Case Method is a classic example of teaching graduate students leadership skills by confronting them with real business issues, placing them in the role of the decision-maker and discussing their findings with other classmates.

To ensure employees are developing in the right direction, awareness of future manufacturing concepts has to be created on all hierarchical levels. They must be capable of learning new disciplines and having fun with it. Therefore, companies need to create training programmes based on their individual job needs, as well as further education for ageing employees. Initial training programmes, lasting between weeks and months, are common methods to make sure employees are capable to fulfil their specific job duties. In-house training concepts range from specific non-routine trainings to a certain amount of work time running into advanced education.

Drivers & Enablers

Governments have high power at all stages due to their influence on national and international regulations and laws. These include generic technology standards, immigration laws and work regulations. International legislation of data usage will become more important than ever in a digital world. Interfaces and protocols need to be standardized on a global range to ensure seamless integration of digital equipment in existing production lines. Politics are also a driving force for educational content closely matching regional industry needs.

Industry has to create business models and manufacturing concepts ready for the Fourth Industrial Revolution. Technological quantum leaps will be necessary to complement human work and create new jobs. Additionally, industry has the responsibility to provide access to specialized training and actively support academia by contextual and financial means.

Academia has a high impact on the interests and knowledge of future workforce. Educational freedom is an important factor to create individuals, but educational context must also be useful for industry, ensuring adequately skilled job starters. STEM-related topics must get tackled mainly by primary and secondary education. Teaching MES and manufacturing technique are tasks of secondary and tertiary education in close collaboration with industry. Soft skills need to be trained from early ages on. Innovative education concepts have to be developed to meet the needs of both students and industry. In the civil sector, new manufacturing technologies and concepts have to be accepted and furthermore lived and breathed. Workers must be open to change, adapt quickly and actively enrol in further training sessions.

Barriers, Threats and Top Challenges Addressed

The level of digitalization will mainly depend on the volatility of markets (and the related flexibility of automation systems) and the costs of digital equipment. These factors strongly depend on the goods produced and the implied production strategy (e.g. single unit production vs mass customization). For example, automotive body manufacturing lines are already almost fully automated, whereas single unit production and assembly lines have not been affected to the same extend yet. Advanced digital technologies are still a high investment and therefore expected to be less desirable on a short-term view. Thus, a lack of adequately skilled workforce is predicted on a long-term view.

To counteract a lack of skilled personnel, all affected parties need to collaborate to find socioeconomic solutions. The entities involved are usually characterized by very divergent views and targets. National and international parties must be involved in defining certain goals and make sure everyone pulls in the same direction. This requires parties to compromising on some points to accomplish one common goal, to ensure a socioeconomic balance on a global range. Naturally, struggle for power and resistance to change hinders efforts to find sustainable solutions among arbitrary parties.

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[1] Gartner, (2014), *Gartner Says a Typical Family Home Could Contain More Than 500 Smart Devices by 2022*. Retrieved October 21, 2015, from Newsroom: http://www.gartner.com/newsroom/id/2839717

[2] Booz & Company. (2013). Digitization for Economic Growth and Job Creation: Regional and Industry Perspectives. *The Global Information Technology Report 2013*, 35-42. World Economic Forum and INSEAD.

[3] Studies of McKinsey & Company (2015) and Strategy& (2015) show customers already demand more sophisticated infotainment systems at low price, and would even change brands for better connectivity. Also autonomous driving cars are highly coveted by customers. About 90% of Chinese and 50% of U.S. and German car buyers are demanding legalization of autonomous cars.

Kaas, H.-W., Kässer, M., Tschiesner, A., & Wee, D. (2015). *What Connected Customers Think about Connected Cars.* (M. &. Inc., Ed.) Retrieved September 29, 2015, from Automotive & Assembly Extranet: http://autoassembly.mckinsey.com

Hirsh, E., Kakkar, A., Singh, A., & Wilk, R. (2015). *2015 Auto Industry Trends*. (Strategy&, Editor) Retrieved September 28, 2015, from Industry Perspectives: http://www.strategyand.pwc.com/perspectives/2015-auto-trends

[4] In Germany and surrounding area the term Industry 4.0 refers to the 4th industrial revolution. It is promoted by an high number of public-private initiatives, e.g. the Platform Industry 4.0. For U.S. we want to highlight the Advanced Manufacturing Partnership 2.0 governmentally driven by President Barack Obama. The global convening organization Industrial Internet Consortium is represented by a high number of large and small industry, entrepreneurs, academics and government organizations.

Promotorengruppe Kommunikation der Forschungsunion Wirtschaft – Wissenschaft. (2013). *Umsetzungsempfehlungen für das ZukunftsprojektIndustrie 4.0 - Abschlussbericht des Arbeitskreises Industrie 4.0.* acatech – Deutsche Akademie der Technikwissenschaften e.V.

The Industrial Internet Consortium. (2015). *The Industrial Internet Manufacturing*. Retrieved October 30, 2015, from http://www.iiconsortium.org/vertical-markets/manufacturing.htm

The White House. (2013). *President Obama Launches Advanced Manufacturing Partnership Steering Committee "2.0"*. Retrieved October 30, 2015, from https://www.whitehouse.gov/the-press-office/2013/09/26/president-obama-launches-advanced-manufacturing-partnership-steering-com

[5] Based on studies of Capgemini Consulting (2014) and the Boston Consulting Group (2015), we have identified eight key technologies to realize production systems of the 4th industrial revolution. Following this, we asked twelve international experts from manufacturing and automotive industry to rate the three technologies showing the highest disruption potential of production processes and therefore impact on future manufacturing workforce (see Figure 1 below).

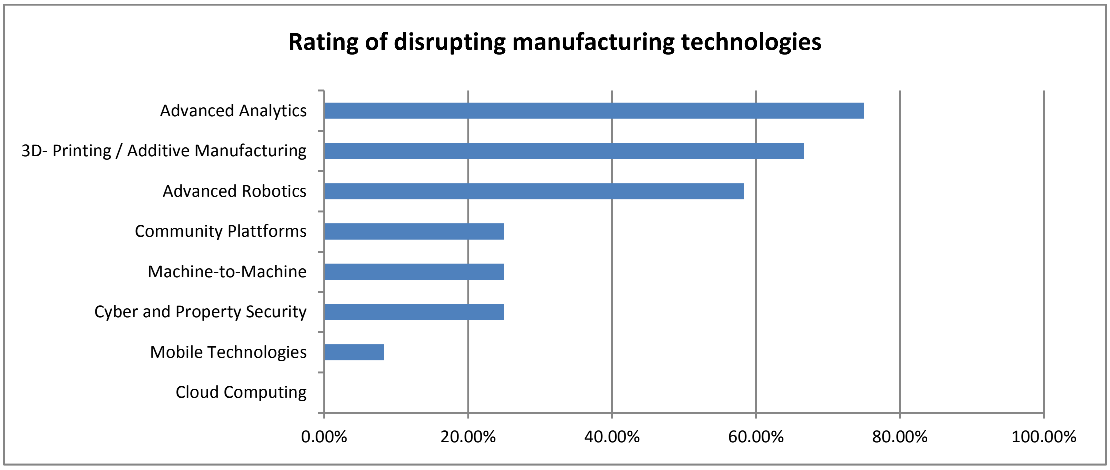

Figure 1: Rating of disrupting manufacturing technologies in n=12 expert interviews

Bechtold, J., Lauenstein, C., Kern, A., & Bernhofer, L. (2014). *Industry 4.0 - The Capgemini Consulting View.* Retrieved September 29, 2015, from https://www.de.capgemini-consulting.com/resources/industry-40-capgemini-consulting

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0 - The future of Productivity and Growth in Manufacturing Industries.* (T. B. Group, Ed.) Retrieved September 29, 2015, from bcg.perspectives: https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/

[6] FR. (2015). *World Robotics Survey 2015*. Retrieved September 23, 2015, from International Federation of Robotics: http://www.worldrobotics.org/uploads/tx_zeifr/Executive_Summary__WR_2015.pdf

Tilley, J. (2015). *The machines march on*. Retrieved September 28, 2015, from McKinsey&Company Operations extranet: https://operations-extranet.mckinsey.com/content/function/Manufacturing/view/20150908_machines_march_on

Sander, A., & Wolfgang, M. (2014). *the rise of robotics.* Retrieved September 28, 2015, from bcg.perspectives: https://www.bcgperspectives.com/content/articles/business_unit_strategy_innovation_rise_of_robotics/

[7] Best Practice in Artificial Intelligence and Artificial Creativity: IBM's computer Deep Blue already the worlds' best chess player Garri Kasparow in 1997. Developed further, IBM's Watson won against the two record holders at the legendary quiz show *Jeopardy!* in 2011. In 2012, the London Symphony Orchestra already played the first computer written composition

Baker, S. L. (2011). *Final Jeopardy: Man vs. Machine and the Quest to Know Everything.* Houghton Mifflin Harcourt .

Ball, P. (2012). *Iamus, classical music's computer composer, live from Malaga*. Retrieved October 20, 2015, from The Guardian: http://www.theguardian.com/music/2012/jul/01/iamus-computer-composes-classical-music?newsfeed=true

[8] Best Practice in 3D Printing: It is already possible to produce highly complex products or very big products with these technologies, as the first printed car is already produced by Local Motors.

Local Motors. (2015). *3D printed car*. Retrieved October 05, 2015, from https://localmotors.com/3d-printed-car/

[9] See a comparison of five studies related to potential job supplementation or creation by digitalization in Table 1.

Author	Core statement	Time horizon
FREY & OSBORNE (2013)	47% of U.S. labor at high risk of being substituted by machine.	2030
BRZESKI & BURK (2015)	59% of German labor at high risk of being substituted by machine.	2030
BONIN, GREGORY & ZIERAHN (2015)	9% of U.S. / 12% of German labor at high risk of being substituted by machine.	2030
WOLTER ET AL. (2015)	Approximately 60.000 jobs in Germany will be reduced – about 420.000 jobs will get reduced mainly in manufacturing, 360.000 will be created in other disciplines.	2030
RÜSSMANN ET AL. (2015)	Approximately 350.000 jobs in Germany will be created– about 610.000 jobs will get reduced mainly in manufacturing, 960.000 will be created in other disciplines.	2025

Table 1: Comparing studies related to employment risks

Frey, C. B., & Osborne, M. A. (2013). *The future of employment: How Suscetible are jobs to computerization*. Retrieved September 23, 2015, from http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

Brzeski, C., & Burk, I. (2015). *Die Roboter kommen.* ING-DiBa AG

Bonin, H., Gregory, T., & Zierahn, U. (2015). *Übertragung der Studie von Frey/Osborne (2013) auf Deutschland.* ZEW - Zentrum für Europäische Wirtschaftsforschung GmbH.

Wolter, M. I., Mönnig, A., Hummel, M., Schneemann, C., Weber, E., Zika, G., . . . Neuber-Pohl, C. (2015). *Industrie 4.0 und die Folgen für Arbeitsmarkt und Wirtschaft.* Retrieved October 23, 2015, from IAB Forschungsbericht 8/15: http://www.iab.de/185/section.aspx/Publikation/k151019301

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0 - The future of Productivity and Growth in Manufacturing Industries.* (T. B. Group, Ed.) Retrieved September 29, 2015, from bcg.perspectives: https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/

[10] The viability into a high versus low skilled society has been extensively researched by economists David Autor, Frank Levy, Richard J. Murnane, David Dorn etc., often referred as a polarization of jobs. German economist Hartmut Hirsch-Kreinsen adds the concepts of a swarm organization, characterized by a high level interdisciplinary skilled workforce.

Autor, D. H., & Dorn, D. (2013). The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market. (A. E. Association, Ed.) *American Economic Review, 103*(5), pp. 1553–1597.

Autor, D. H., Levy, F., & Murnane, R. J. (2003). The skill content of recent technological change: an empirical exploration. *The Quarterly Journal of Economics*, *118*, pp. 1279-1333.

Hirsch-Kreinsen, H. (2015). Entwicklungsperspektiven von Produktionsarbeit. In A. Botthof, & E. A. Hartmann, *Zukunft der Arbeit in Industrie 4.0* (pp. 89-98). Springer Vieweg.

[11] More flexible labor engagement regulations are already claimed by 72.1 percent of German manufacturing companies, according to Spath et al.

Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., & Schlund, S. (2012). Produktionsarbeit der Zukunft – Industrie 4.0. (F. I. IAO, Ed.)

[12] Blanchet, M., Rinn, T., Von Thaden, G., & De Thieulloy, G. (2014). *Industry 4.0 - The new Industrial revolution - How Europe will succeed.* (R. B. GmbH, Ed.) Retrieved September 28, 2015, from http://www.rolandberger.com/media/publications/2014-04-02-rbsc-pub-INDUSTRY_4_0_The_new_industrial_revolution.html

[13] The World Bank Group. (2015). *Indicators*. Retrieved August 18, 2015, from Data: http://data.worldbank.org/indicator

[14] Dobbs, R., Madgavkar, A., Barton, D., Labaye, E., Manyika, J., Roxburgh, C., Madhav, S. (2012). *The world at work: jobs, pay, and skills for 3.5 billion people.* McKinsey Global Institute.

[15] Morrison, T., DeRocco, E. S., Maciejewski, B., McNelly, J., Giffi, C., & Carrick, G. (2011). *Boiling point? The skills gap in U.S. manufacturing.* Retrieved October 29, 2015, from http://www.themanufacturinginstitute.org/~/media/A07730B2A798437D98501E798C2E13AA.ashx

[16] National Science and Technology Council. (2013). *Federal Science, Technology, Engineering, and Mathematics (STEM) education 5-year strategic plan.* (C. o. Education, Ed.) Retrieved October 21, 2015, from https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf