The following is a redacted version of the original report. See inside for details.

Goldman Sachs

Manufacturing is undergoing its greatest transformation since the Industrial Revolution. A wave of intelligent technologies is shaping a more connected, flexible and efficient factory floor—and redefining the ecosystem of equipment providers in the process. In the latest in our **Profiles in Innovation** series, we examine the six technologies driving this transition and explore how it could yield more than US$500 bn of cost savings.

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PROFILES IN INNOVATION

Factory of the Future

Beyond the Assembly Line

The Goldman Sachs Group, Inc.

Table of Contents

Prices in this report are as of the close of April 12, 2016.

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Note: The following is a redacted version of "Profiles in Innovation: Factory of the future—Beyond the assembly line" originally published April 13, 2016 [83pgs]. All company references in this note are for illustrative purposes only and should not be interpreted as investment recommendations.

FACTORY OF THE FUTURE in numbers

UNREALISED POTENTIAL

>US$500 billion

The **cost-savings opportunity** from bringing manufacturing up-to-date with the latest technology. This equates to c.10% of current fixed investment.

10%-15%

The average **potential cost-savings per factory** from introducing the latest automation technologies.

COST-EFFECTIVE & COLLABORATIVE

1 vs. 3 years

The approximate amount of time it will take to **recoup an investment** in a collaborative robot (or "**cobot**") in 2020 vs. the amount of time for an **industrial robot**.

PRIVATE INTEREST

188%
139%

The increase in **venture capital** investment in **industrial software** and **robotics**, respectively, over the past four years.

INNOVATIVE SOLUTIONS

6

The number of cost-saving **automation technologies** we think will make the largest impact on manufacturing.

>US$250 billion

The estimated **size of the market** for these **technologies** by 2020, vs. the US$100+ bn automation industry today.

TECHNOLOGY IN PRACTICE

20%

The **increase** in **output per employee** at Scott Fetzer Electrical Group after introducing cobots and automated guided vehicles.

41 vs. 2

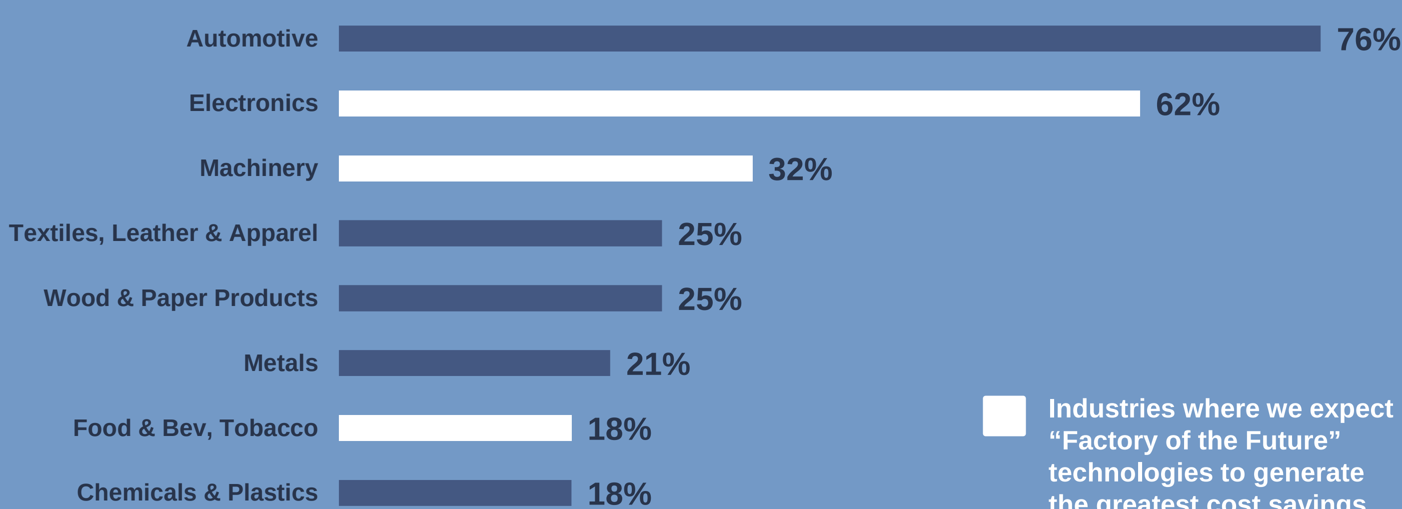
The number of **buildings** on Harley-Davidson's York campus before and after adopting automated guided vehicles and robots to **streamline production**.

50%

The **reduction in time-to-market** Maserati achieved using product lifecycle management software.

MAN VS. MACHINE

Current level of automation by industry (maximum of 100%)



Portfolio manager's summary

We focus on the key emerging manufacturing technologies that should allow significant cost savings, including much faster time to market

Manufacturing is entering a decade of significant transformation comparable to the industrial revolution. While the years of abundant EM infrastructure investment are gone, a growing middle class continues to demand higher wages, the skilled manufacturing talent pool is shrinking, and new global competitors have emerged. Across most manufacturing industries, companies are faced with the challenges of less demand and greater supply, putting strains on margins already challenged by growing labour and transportation costs.

This report leverages on our extensive interactions with companies and experts in the field globally (some of those profiled throughout the report). We identify the latest developments in manufacturing technologies that can materially improve cost structures, either through capacity utilisation or time to market. These should allow companies to maintain or improve their profitability and returns in an increasingly competitive environment. We also consider how these technologies might develop, reshaping the equipment makers' competitive and regional landscapes.

What technologies lead the Factory of the Future (FoF)?

We estimate the TAM of the six technologies we analyse at >US$250 bn by 2020, around half the US$500+ bn overall potential cost savings we see as available to manufacturers (c.10% of global fixed investment)

The concept of 'Factory of the Future' is a broad one. We narrow the scope of our analysis to three areas: (1) **manufacturing design and production simulation** – this includes technologies such as product lifecycle management software (PLM) for both factory and product design and Internet of Things software (cloud computing, data analytics); (2) **physical manufacturing** – industrial robots, collaborative robots allowing for human interaction (cobots), additive manufacturing (3D printing); and (3) **in-factory logistics** – automated guided vehicles (AGVs), radio frequency identification (RFID). We also take a brief look at adjacent technologies that might allow optimisation of manufacturing processes or enable these six technologies (including virtual and augmented reality, machine vision, machine learning, nanotechnology and demand response).

Opportunity for >US$500+ bn of cost savings

Electronics, food & beverage and machinery makers are the largest verticals for deployment

We estimate the total addressable market (TAM) opportunity for the 'Factory of the Future' capped by the **potential cost savings in the key adoption verticals at US$500-650 bn (equating to c.10% of global fixed investment). We see the largest vertical opportunities as electronics, food & beverage and machine making** (e.g. tool makers, electrical, resource and construction equipment). The TAM will likely be split between payments to firms making enabling equipment, and benefits passed on to customers to remain competitive. Margin increases for first-mover adopters are possible near term, but likely will erode as adoption spreads to the rest of the industry. We use two approaches to estimate TAM:

(1) **Bottom-up** (what is the revenue potential for equipment providers?): we assess the six key innovative technologies we think are most relevant in taking out stranded manufacturing costs, considering current penetration and potential pace of adoption to forecast the size of their markets. These six technologies add up to >US$250 bn by 2020E.

(2) **Top-down** (what is the cost savings potential for industries?): we break down fixed investment by industry and look at its level of automation (i.e. robot penetration) and digitisation (i.e. software penetration). We pro-rata the opportunity in each case, looking at the gap vs. the currently most-advanced manufacturing environment (automotive in robots; electronics in software), and at the average cost savings indicated for each industry by manufacturers of the key technologies. We estimate the TAM is capped at US$500-650 bn.

Cross-technology synergies, other technologies not profiled, deflating prices of technology as adoption broadens and, most importantly, benefits sharing between makers and users explain why our top-down forecast exceeds our bottom-up forecast.

Where will these technologies be built?

Cost structures likely to converge regionally over time

We believe these technologies will allow manufacturers to be more agnostic over where they locate their capacity, as cost structures become more similar across regions, with the main determinant increasingly location of demand. While EMs should be able to leapfrog stages of manufacturing infrastructure development (given less legacy physical capacity), adoption of the technologies detailed here will likely decrease the dependence of DMs on labour costs (still the main roadblock to reshoring of capacity in DMs).

Winners and losers in a changing competitive landscape

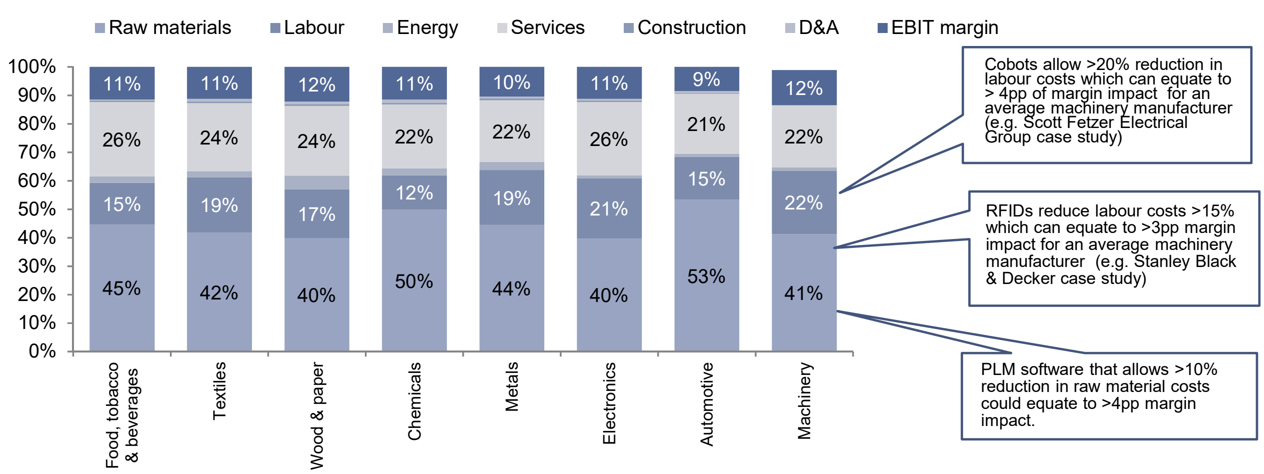
We expect to see tectonic shifts in the competitive landscape of equipment providers. The number of players is rising, as software firms start to break into the industrial field, traditionally led by hardware players (e.g. Cisco recently acquired IoT platform provider Jasper). This will likely lead to new business models appearing (e.g. performance-based contracts, equipment as a service). In addition, key breakthroughs in technology are increasingly being driven by private, small firms. As a result, we expect more M&A within product categories, as well as regionally. We believe traditional capital goods incumbents with solid balance sheets will engage in material consolidation of smaller players. Regionally, we see government support and the pressure from rising labour costs as driving Chinese companies to look to acquire international winners (albeit hurdles for deal completion remain high).

What could derail increasing adoption?

Standards, IP and legacy assets are key barriers to adoption

Excess manufacturing capacity (fixed investment-to-GDP has been high for several years), legacy asset bases, IP questions and a lack of standards for data transfer and compatibility are the key roadblocks to wider adoption of these technologies, despite healthy corporate balance sheets to fund deployment. In addition, while technology cost has been falling, in several cases it is either still prohibitive, or the productivity gains achieved remain insufficient to materially change the user's cost structure.

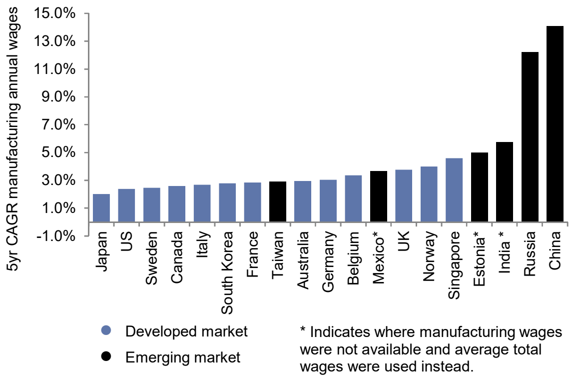
Exhibit 1: The cost breakdown of each manufacturing industry is different and therefore so is the technology impact
Average cost structure by end market (EU-27) and machinery cost savings examples



Source: Eurostat, Goldman Sachs Global Investment Research.

Factory of the Future in six charts

Exhibit 2: Labour costs continue to increase the pressure to automate
5-year CAGR of annual manufacturing wages; local currency



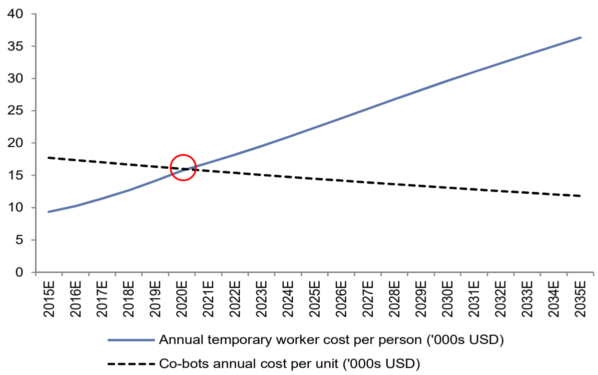
Source: International Labor Organization, Haver, Trading Economics, Eurostat.

Exhibit 3: Customers are demanding unprecedented levels of customisation and flexibility
Combinations available when buying a Ford F150 pick-up

Equipment options	Variants	Theoretical combinations
Trim	6	6
Passenger compartment	3	18
Power train	2	36
Cargo space	4	144
Engine	3	432
Transmission	3	1,296
Rear axle ratio	7	9,072
Wheels	9	81,648
Tires	8	653,184
Seats	18	11,757,312
Power seats	2	23,514,624
Radio	5	117,573,120
Running boards	4	470,292,480
Rear windows	3	1,410,877,440
Colors	12	16,930,529,280
Interior trim colors	3	50,791,587,840
16 individual options	12,870	**653,687,735,500,800**

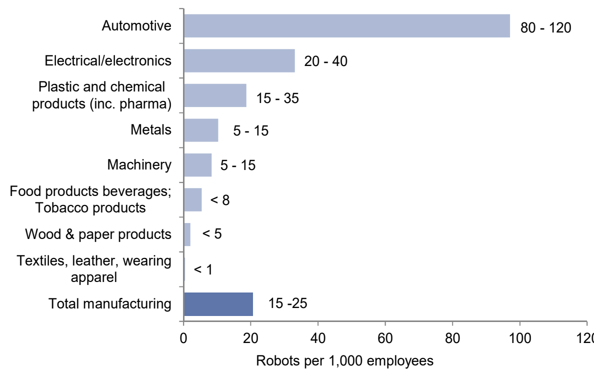
Source: Siemens.

Exhibit 4: New, more affordable and flexible technologies are emerging as solutions
Labour costs and cobot installation costs, China



Source: Goldman Sachs Global Investment Research.

Exhibit 5: Automation adoption rates vary dramatically across industries
Robot density per 1,000 employees



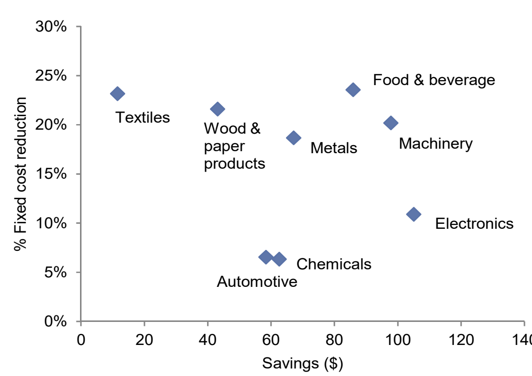
Source: Goldman Sachs Global Investment Research.

Exhibit 6: Six technologies are most relevant
Summary of current level of automation, technology penetration and relevance

Industries	Current level of automation	Current technology penetration						Relevance
Manufacturing sub-sectors	Automation index	IoT PaaS software	PLM software	Cobots	3D printing	AGVs	RFIDs	Relevant technologies
Automotive	76%	◕	◕	◔	◑	◔	◑	All
Chemicals	18%	◔	◕	○	○	○	○	IoT PaaS & PLM
Electronics	62%	◑	◑	◔	◔	◔	◔	All
Machinery	32%	◔	◑	◔	◑	◔	◑	All
Food & Beverages	18%	◔	◔	○	○	◔	◑	All (ex. 3D printing)
Metals	21%	◔	○	◔	○	◔	○	IoT PaaS, PLM & AGVs
Wood & paper products	25%	◕	○	○	○	◔	○	IoT PaaS, PLM & AGVs
Textiles & apparel	25%	○	◔	○	◔	◔	◔	All (ex. 3D printing)

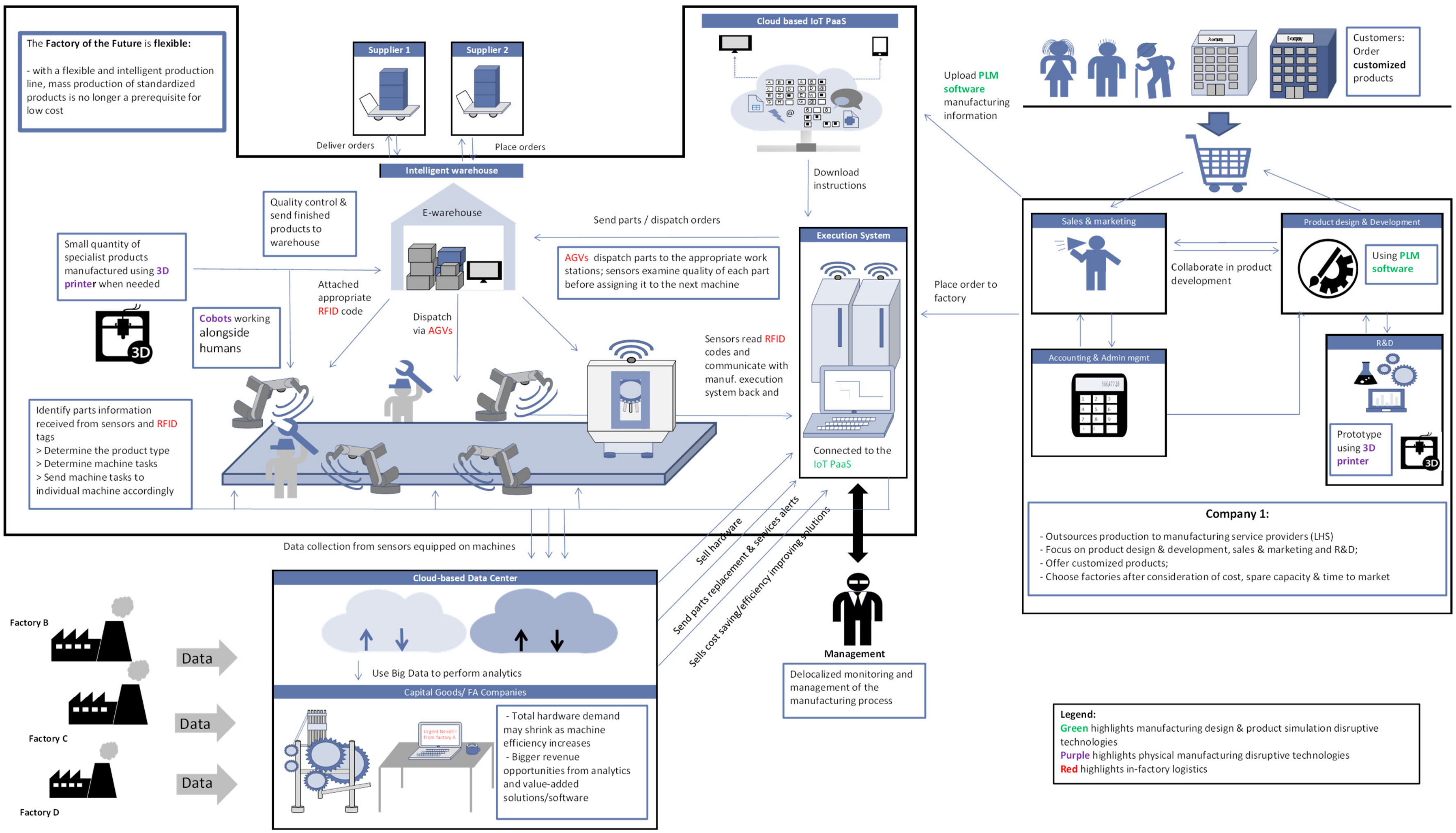
Source: Goldman Sachs Global Investment Research.

Exhibit 7: Top-down analysis suggests a >US$500 bn opportunity for those that become best in class
% fixed cost reduction vs. savings (mid-point)



Source: Goldman Sachs Global Investment Research.

Exhibit 9: From design to servicing, the entire manufacturing ecosystem is becoming more connected and more intelligent
Factory of the Future ecosystem



Source: Goldman Sachs Global Investment Research.

Why are we talking about the Factory of the Future?

The current state of manufacturing

Today, manufacturing accounts for 16% of global GDP. It is an important driver of an economy's productivity growth, quite often the largest component of an economy's foreign trade, and accounts for the largest share of private R&D spending in most major economies. Over the past two decades, companies have often relocated to EMs to take advantage of better growth and labour/environmental cost arbitrage. However, in the past three years, growth has faded, putting pressure on returns. This is driving companies to rectify key cost lines. Many factories are operating in a "disconnected" environment where the root causes of inefficiencies are rarely fully understood – automation and connectivity offer a solution to this.

Current manufacturing mostly lacks cost efficiency in three dimensions that drive sub-optimal capacity use:

- **Machine-to-machine communication;**
- **Two-way data transfer (from factory to enterprise resource planning system (ERP), but also from ERP to factory); and**
- **Inter-factory integration.**

While automation is already a US$100+ bn global industry, and robots are no longer science fiction, the penetration of semi-intelligent or intelligent production systems is still limited to a couple of industrial areas (autos and electronics). Automation is easier to achieve when a small number of products are made in large quantities. Major automakers and some other companies have already created production systems that are able to respond readily to these challenges, in terms of volume and product mix (e.g. Toyota has perfected Kanban manufacturing over many years and continues to refine it to this day; see Appendix 1). However, smaller companies and industries with end products that are not as large have yet to put such systems in place, and ample room exists for capacity and cost optimisation through broader technology adoption.

The emergence of new technologies heralds an era of significant change in manufacturing. This is illustrated by the increased investment by venture capitalists (page 57) as well as large corporates. The opportunity allows some equipment providers to still benefit despite the trend of declining customer budgets (capex-to-sales), a characteristic of mature industries.

Ten reasons why we're talking about the Factory of the Future

Until the beginning of the last decade, factory automation was mostly triggered by the need for traditional manufacturers to cut costs while increasing productivity, in order to remain competitive with aggressive, lower-cost manufacturers entering their industries (e.g. US automakers such as GM in the 1980s fighting for survival in the face of intense Japanese competition).

Slowing growth recently, post 15 years of super-cycle, has seen a refocusing on manufacturing margins and returns. Since the financial crisis, returns have stagnated, as operating leverage has faded and fixed costs have continued to rise (mainly labour costs). We highlight ten reasons why we believe manufacturing will see a significant focus on implementing newer technologies over the coming years:

1. **DMs need to reduce costs to remain competitive vs. EMs.** The average DM manufacturing hourly labour cost is still more than four times higher than the average manufacturing wage in China.

2. **But, rising EM wages are lowering the 'low-cost location' edge.** For example, in China, wages are growing at mid-teens percentages vs. less than 3% growth in most developed markets.

3. **Specialised manufacturing labour is increasingly scarce.** The scarcity of specialised labour is exacerbated in the largest manufacturing nations by ageing populations (e.g. retiring baby boomers) and in EMs by younger generations that no longer aspire to work in the factories.

4. **Productivity is increasingly a way to differentiate when legacy capacity is abundant.** The last 15 years have seen an unprecedented level of capex globally. This drove a new set of competitors to emerge, and in turn led to unproductive capacity in many global industries, making time and cost to produce more significant differentiators between manufacturers than availability of capacity.

5. **There is an increased push to shorten time to market**, particularly by eliminating stranded inventories. Today's market environment means information comes faster and is more accessible than ever, with customers now expecting products sooner. This is a key source of being able to generate a better return on capital for a manufacturer.

6. **Customers demand unprecedented customisation.** Personalisation today is used as a competitive tool to capture sales and is something customers look for to distinguish their purchases. In addition, the growth of consumers from emerging markets, which are made up of a diverse range of cultural and ethnic groups, increases the complexity of manufacturing in consumer segments when attempting to appeal to these new, large markets.

7. **Focus on safety and security has increased dramatically.** A more automated, controlled and less labour-intensive environment should reduce the likelihood of accidents and costly litigation. In addition, factories need to be safe from cyber-attacks, owing to the increasingly important role data has in the manufacturing process.

8. **Several governments are actively pushing to stay ahead in manufacturing.** In a globalised world, with lower trade barriers, scarcer demand and greater supply, countries have to fight hard to maintain competitiveness and to position themselves as locations of choice for manufacturing. We have seen numerous initiatives over recent years that stress this (e.g. China Manufacturing 2025, Germany's Industrie 4.0).

9. **Short-term demands from shareholders for dividends and buybacks put further strain on cash available for organic investments.** Short-term macro uncertainty and a lack of visibility over growth has led to increasing demand from investors for cash returns from corporates (dividends and buybacks). While this might not be a sustainable form of long-term capital allocation, it has weighed on the short-term considerations of corporates and puts further pressure on optimising FCF generation through more productive capex.

10. **Finally, key technologies now exist for fully optimised and connected manufacturing.** There have been rapid improvements in the capabilities of a number of technologies which can drive substantial change in factories across the world (e.g. sensors, computing power and robots).

See the section on *Drivers and Barriers* for more detail.

The Ecosystem

Factory of the Future - Sizing the Market

Total Addressable Market for Enabling Technologies (2020E)

US$230-285 bn MANUFACTURING DESIGN AND PRODUCTION SIMULATION

US$30-35 bn Product Lifecycle Management Software
Development stage: *Commercialised*
Used to simulate the lifecycle of a product from inception to servicing to end of useful life

US$200-250 bn Internet of Things Platform as a Service
Development stage: *Early commercialisation*
Used for machine-to-machine communication and remote control of factories

US$28-34 bn PHYSICAL MANUFACTURING

US$25-30 bn Additive Manufacturing (3D Printing)
Development stage: *Early commercialisation*
Used to create 3D objects from a digital model

US$3-4 bn Collaborative Robots (Cobots)
Development stage: *Early commercialisation*
Used to perform unstructured, often repetitive tasks alongside humans

US$4 bn IN-FACTORY LOGISTICS

US$2 bn Automated Guided Vehicles
Development stage: *Early development*
Used to move materials throughout production and storage

US$2 bn Radio Frequency Identification
Development stage: *Mature with new applications*
Used to identify and track objects via radio signals

Cost-Savings Potential by Industry

			Technologies with greatest potential					
Manufacturing vertical	Max cost-savings potential (USD)	(as a % of fixed investment)	IoT	PLM Software	Cobot	3D Printing	AGV	RFID
Electronics	$120 bn	13%			⦿	⦿	⦿	⦿
Machinery	$110 bn	23%	⦿		⦿		⦿	
Food & Bev, Tobacco	$100 bn	27%	⦿	⦿			⦿	
Automotive	$70 bn	8%			⦿		⦿	
Chemicals & Plastics	$70 bn	7%	⦿					
Metals	$70 bn	21%	⦿	⦿			⦿	
Wood & Paper Products	$50 bn	25%	⦿				⦿	
Textiles, Leather & Apparel	c.$10 bn	27%	⦿		⦿		⦿	⦿

Goldman Sachs

Exhibit 10: Our top-down analysis suggests a US$500-650 bn opportunity to bring manufacturing to best-in-class
Industry-by-industry potential addressable market

Industries	Current size of industry[1]		Current degree of automation [2]					Potential savings [6]	Maximum opportunity size
Manufacturing sub-sectors	% of global manuf. fixed asset investment	Amount ($bn)	Robot intensity per 1,000 employees [3]	Robot penetration index	Software % of fixed asset investment[4]	Software penetration index [5]	**Automation index**	Savings from FoF technologies	**($bn)**
Automotive	19%	895	97	90%	9%	63%	**76%**	6 - 8%	**50 - 70**
Chemicals and plastics	21%	990	19	19%	3%	17%	**18%**	5 - 7%	**50 - 70**
Electronics	20%	965	33	34%	17%	90%	**62%**	9 - 13%	**90 - 120**
Machinery	10%	485	8	9%	9%	54%	**32%**	17 - 23%	**90 - 110**
Food products, beverages & tobacco	8%	365	5	6%	5%	30%	**18%**	20 - 27%	**70 -100**
Metals	8%	360	10	11%	5%	30%	**21%**	16 - 21%	**60 - 70**
Wood and paper products	4%	200	2	2%	8%	47%	**25%**	18 - 25%	**40 - 50**
Textiles, leather & wearing apparel	1%	50	0	0%	8%	49%	**25%**	20 - 27%	**c.10**
Others / Not classified	9%	440	13	14%	7%	42%	**28%**	8 - 10%	**40 - 50**
Total Manufacturing	**100%**	**4750**	21	21%	8%	47%	**34%**	10 - 15%	**500 - 650**

Industries	Pressure to automate							Current technology penetration [7]						Relevance factor					
Manufacturing sub-sectors	Net margins (2010-14) [6]	Net margins (2015-18E)	Δ net margins	30yr average age [7]	Current age (2015)	% difference	**(100 = very likely)**	IoT PaaS software	PLM software	Cobots	3D printing	AGVs	RFIDs	IoT PaaS software	PLM software	Cobots	3D printing	AGVs	RFIDs
Automotive	4.9%	5.4%	0.5%	6.1	6.5	6.3%	85	◕	◕	◔	◑	◔	◑	1.00	1.00	1.00	1.00	1.00	1.00
Chemicals and plastics	7.0%	7.5%	0.5%	8.0	7.9	-1.4%	72	◔	◕	○	○	○	○	0.25	1.00	0.00	0.00	0.00	0.00
Electronics	10.2%	10.0%	-0.3%	7.5	9.5	27.2%	80	◑	◑	◔	◔	◔	◔	1.00	1.00	1.00	1.00	1.00	1.00
Machinery	7.9%	6.3%	-1.6%	9.3	10.5	13.1%	86	◔	◑	◔	◑	◔	◑	1.00	1.00	1.00	1.00	1.00	1.00
Food products, beverages & tobacco	9.3%	9.9%	0.6%	8.5	8.6	1.4%	68	◔	◔	○	○	◔	◑	1.00	1.00	0.75	0.50	1.00	1.00
Metals	2.0%	2.7%	0.7%	11.8	11.4	-3.7%	72	◔	◔	○	○	◔	○	0.75	1.00	0.00	0.50	0.75	0.50
Wood and paper products	4.8%	7.0%	2.2%	8.0	9.2	13.9%	74	◕	○	○	○	◔	○	1.00	0.75	0.50	0.25	1.00	0.75
Textiles, leather & wearing apparel	n.a.	n.a.	n.a.	9.2	12.2	33.0%	n.a.	○	◔	○	◔	◔	◔	1.00	0.75	1.00	0.50	1.00	1.00

Notes:
[1] GFCF data from the World Bank, broken up using data from the OECD and China Statistical Yearbook
[2] Robot penetration indexed against automotive; software penetration indexed against electronics
[3] Weighted average of density in Germany, Japan, France, Italy and UK
[4] Software as a % of investments in private non-residential fixed assets in the US; automotive includes other transport equipment
[5] Automotive software penetration adjusted up according to analyst discretion
[6] Net margins of global GS coverage in each industry, note not entire industry and some companies in the sample have exposures to other industries
[7] Average age data is for the US only
[8] Qualitative assessment of penetration at analyst's descretion (actual penetration may be less or greater)

Source: Goldman Sachs Global Investment Research.

Technologies

Bottom-up: >US$250 bn addressable market

- Technological advancement is enabling greater flexibility, productivity and connectivity within and among factories
- We see six technologies as most disruptive, falling into three groups:

Manufacturing design and production simulation

1. Product lifecycle management software (PLM)

2. Internet of Things: Platform as a Service (IoT PaaS)

Physical manufacturing

3. Collaborative robots (cobots)

4. Additive manufacturing (3D printing)

In-factory logistics

5. Automated guided vehicles (AGVs)

6. Radio frequency identification (RFID)

Six innovative technologies for the Factory of the Future

The factory is evolving and is entering an era of new technological innovation. We see six technologies as key to this evolution: PLM software, Internet of Things (IoT) platform as a service, collaborative robots, additive manufacturing, automated guided vehicles (AGVs) and RFID. In the factory of the future, manufacturing should become increasingly flexible with seamless integration of a range of physical and digital systems, and devices communicating with each other to optimise production. We believe these technologies will allow the shift from mass-production to mass-customisation that is required in the next era of manufacturing.

We expect the entire production process to become more intelligent, from design to services:

1. **Intelligent design:** From inception, factories and products will be designed more intelligently using the latest modelling and simulation software, optimised to reduce downtime and with the construction process less likely to be subject to delays and complications. This is particularly crucial since we estimate that choices made during the design phase can affect up to 70% of the costs of a new product.
2. **Intelligent administration:** A remotely managed factory, allowing supervision of factories located in low-cost areas, while working from the corporate HQ. Supply chain management, allowing manufacturers to monitor and manage inventory in real-time, across different factories/geographies, reducing transportation and inventory costs.
3. **Intelligent production:** Smart factories improving operational performance through greater productivity and reduced costs. This is continuously being optimised using automation equipment and the data it collects. Cloud factories might emerge, enabling manufacturers, particularly new entrants, to focus on design and sales, rather than heavy factory investment. Smaller-scale production closer to customers is also a possibility.

"Industrie 4.0 will impact the whole product lifecycle end to end – from design to production, the actual usage phase until end-of-life – and cannot be attributed to one single department of the firm. The digital transformation is a cross-functional effort that needs to be addressed by the whole company."

Dr. Reinhold Achatz, Head of Corporate Function Technology, Innovation & Sustainability at ThyssenKrupp Corporation

4. **Intelligent product:** Big data of users' experiences helps make product design adjustment/upgrades easier, as well as increasing customisation of products. Data emitted also helps generate after-sales.
5. **Intelligent sales:** Increased customer-to-manufacturer direct sales. Optimised sales/ advertising channels based on buyers' prior purchases.
6. **Intelligent after-sales:** Predictive maintenance, resulting in more stable cash flow generation and avoiding unnecessary downtime for the customer, as well as unnecessary, costly after-sales personnel (see Kaeser Kompressoren vignette page 46).

The technologies we focus on in this report address each of these steps above. When taking a deep-dive into the practical equipment/software that allows these benefits to be realised, we cluster these technologies into the three areas discussed previously: **manufacturing design and production simulation** (1, 2, 4 and 6 above); **physical manufacturing** (2 and 3 above); and **in-factory logistics,** a part (although not all) of that encompassed in 2, 3 and 5.

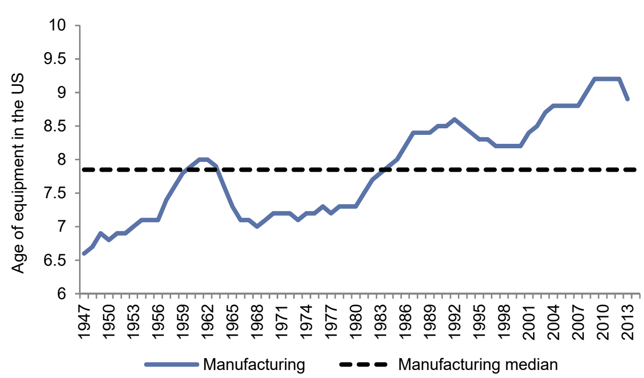
A bottom-up approach to forecasting TAM for six core technologies

We make a detailed assessment of the six technologies that we believe will be most disruptive to current manufacturing, grouped into three key areas: (1) manufacturing design and production simulation; (2) physical manufacturing; and (3) in-factory logistics. We forecast the TAM for each technology independently. For some, we rely on third-party research. For others, we estimate and take into account the following factors:

- The current status of the installed base where these technologies will be applicable (e.g. cobots replacing labour that is in short supply);
- The level of existing penetration of the disruptive technology (e.g. PLM software penetration is currently around 20%-30% according to Siemens, and currently only 1%-2% of in-factory vehicles are automated);
- We estimate the evolution of the penetration rates of these technologies over the next five years (e.g. we estimate AGV penetration to rise to over 15% in manufacturing). While many technologies in unconstrained conditions should follow the path of Moore's Law, in reality, technology adoption will likely be driven by the following elements:
    - The average age of equipment in each industry, as an indicator of the level of cumbersome legacy equipment (potentially incompatible with new technologies) that remains as a barrier to adoption;
    - The regional pressures to automate/digitise, such as labour cost growth, constraints on skilled labour, government incentives, etc.; and
    - The development of key technology enablers' cost curves and value-add potential, in order to command a greater proportion of customer spend.

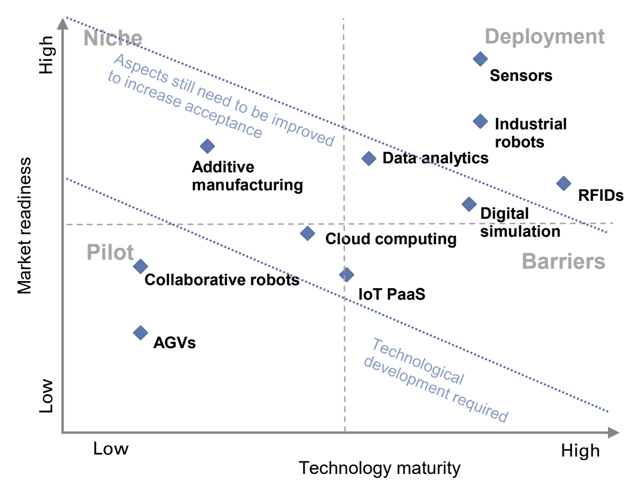
Clearly, technologies are adopted at unpredictable rates, and entirely unexpected applications can arise to dominate their uses. Furthermore, while we look at each technology in isolation here, many of these emerging technologies will be used in conjunction with each other, potentially multiplying their impact.

Exhibit 11: Age of legacy equipment should be a key determinant of adoption of new technologies
Average age of manufacturing assets in the US; 1947-2014



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 12: Market readiness and maturity of key technologies
Key technologies market readiness vs. technology maturity



Source: Goldman Sachs Global Investment Research.

FoF technologies as enablers of the Internet of Things

The Internet of Things (IoT) concept is starting to revolutionise the manufacturing landscape. Equipment is becoming more digital and connected, forming networks of machines and new ecosystems. While we are still in the nascent stages of adoption, we believe that the timing of the transformation will resemble that seen in the consumer sector (e.g. penetration of mobile phones rose from 5% to 100% in 20 years), but that the economic implications will be much bigger (we have seen estimates of 2.5-5.0x the size of the consumer internet). The technologies highlighted in this report both help enable the IoT and are critical to harnessing its full potential.

Less is more at Daimler

We interviewed Markus Schaefer, Member of the Divisional Board of Mercedes-Benz Cars, Production & Supply Chain Management, discussing what the company is doing to stay ahead of the competition in automotive manufacturing.

The challenge: Daimler realised at an early stage that rapid growth of car production, a greater number of products (ten years ago, it had 15 models; now it has 40), increased customisation and complexity of those products, and a rapidly changing business environment require a very flexible and efficient production network.

The solution: To increase its flexibility and ability to handle complexity, Daimler is investing in its global production network to standardise the plants and adopt the latest production technologies. The company is moving away from fixed conveyance production lines into smaller individual production cells. This more fragmented system will reduce the number of robots by increasing the utilisation of each, and also prevent the possibility of an entire production line having to be halted in order to reprogramme an industrial robot. The use of IoT networks and AGVs will allow for just-in-time transport between cells, quicker than a sequential production line. The process is also made more flexible through the use of technologies such as collaborative robots that can work alongside human operators; Daimler believes such technology will play an important role in the future of manufacturing. At the moment, it is working alongside robot supplier Kuka in particular, and currently employs 20 cobots in production. The company notes, however, that this technology first needs to overcome a number challenges, for example, to become more affordable and lighter, and that it requires regulatory and other approvals.

Some things don't change: When asked how Daimler chooses a factory location, Mr. Schaefer reiterated that the most important factors are closeness to end markets, logistics cost, low labour costs and tariff incentives (beyond location of demand). Its arsenal of technologies will be deployed when appropriate, regardless of location.

Exhibit 13: The use of individual production cells and AGVs makes assembly more flexible

Source: Daimler.

Exhibit 14: A Kuka cobot working inside a Daimler car while humans work from the outside

Source: Daimler.

MANUFACTURING DESIGN & PRODUCTION SIMULATION

Product Lifecycle Management software

US$30-35 bn (2020E base case)

- Advanced computational methods to create a 3D simulation of entire product life cycles
- Commercialised
- Savings example: MWV reduced time-to-market from 18 to 6 months using Dassault Systemes' PLM software

The increasingly complex nature of products and the manufacturing process of these, suggest that the future manufacturing process itself will be designed and perfected in a virtual design and simulation. Manufacturers can use advanced computational methods to create a 3D simulation of the entire manufacturing process, avoiding costly errors, optimising the efficiency of the factory, and dramatically increasing time-to-market. Sensors and detection hardware help to "synchronise" simulation and reality at every point in the production process. Using similar technology, manufacturers can create a simulation of the entire life-cycle of a product, from inception, through design and development, to servicing and disposal. Better designs are a pre-condition for applying new manufacturing technologies, realising full productivity potential and dealing with the indirect costs associated with increased technological complexity. Payback times typically range between one and five years, depending on the current status of the process implemented, the addressed problems and the maturity of the business.

The challenges

Engineering software needs to be developed differently for each industry, and requires a learning ramp-up to use the software and to adjust engineering techniques. Another challenge is the constraint imposed by computational capabilities; the greater the computational power, the more simulations are possible and the more effective the software.

The markets disrupted

This technology disrupts conventional 2-dimensional design and architecture. It dramatically reduces production errors and increases time-to-market. Therefore, engineers have to adapt and incorporate it or risk being left behind.

Applications and industries exposed

PLM software has historically been high-usage in complex manufacturing industries and is now penetrating all industries. For example, Dassault Systemes focuses on four core industries: aerospace & defence, transportation & mobility, marine & offshore, and industrial equipment. However, it also now highlights new industries: consumer retail & packaged goods, energy, process & utilities, high tech, financial services, natural resources, construction and even life sciences.

Sizing the revenue opportunity

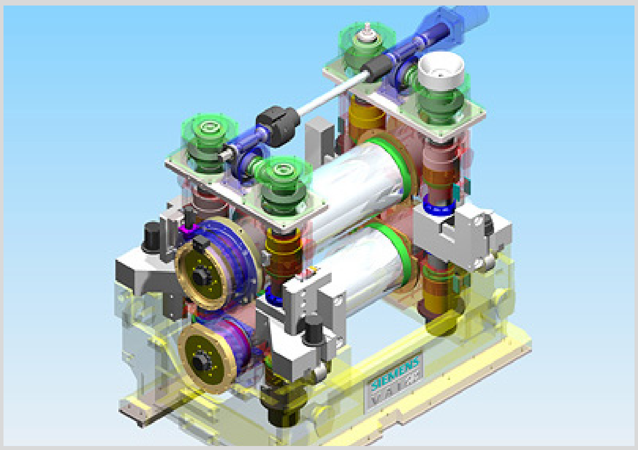
PLM software has a potential TAM of US$30-35 bn by 2020E.

Siemens' PLM software achieves a three-fold increase in process planning capacity

The challenge: Perkins, a manufacturer of diesel engines and power solutions, wanted to eliminate late-stage changes to expensive tooling and production processes. It also wanted to reduce the risk of escalating costs and disruption to production schedules.

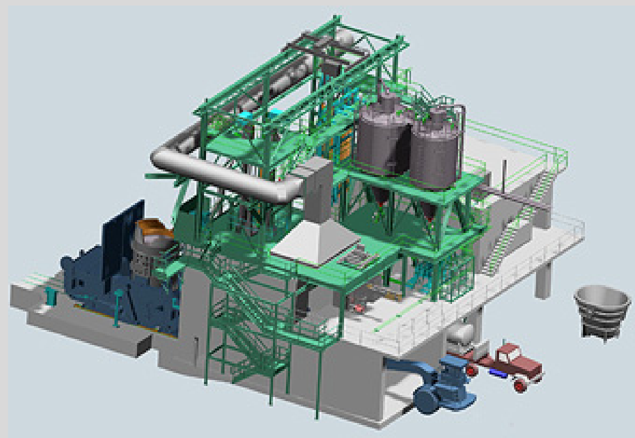
The solution: The company introduced Siemens' PLM software: Teamcenter and Tecnomatix for successful new engine launches; this achieved a three-fold increase in process planning capacity compared with its previous approach. It was able to significantly reduce its time-to-market and continually increase its unique customer sales configurations (the 1200 series had 100 configurations in comparison to less than 40 previously). Other benefits included tighter collaboration among colleagues, vendors and customers throughout the product lifecycle.

Exhibit 15: Siemens PLM software designs products…



Source: Siemens.

Exhibit 16: ...plants, processes and more



Source: Siemens.

MANUFACTURING DESIGN & PRODUCT SIMULATION

Internet of Things Platform as a Service

US$200-250 bn (2020E base case)

- Smarter manufacturing, increased productivity, reduced downtime/costs
- Early commercialisation
- Savings example: GoPro cut its freight costs by 75% & inventory costs by 9% by introducing SAP's platform to manage the supply chain

Internet of Things platform as a service (PaaS) encompasses software applications, cloud-based storage, big data analytics and an industrial internet operating system that serves as the platform. In our view, this will be a differentiated growth avenue for select industrial/technology companies that gain first-mover advantage. Already, a significant number of companies are spending more than 20% of their tech budgets on big data, and we believe this is about to accelerate. In our view, the next step is an integrated platform with horizontal applications (e.g. asset monitoring, predictive maintenance, dynamic manufacturing), like GE's Predix, that allow for exponential data capture/analysis and real-time decision making.

The challenges

Cyber security, legacy infrastructure and protocol standardisation: (1) as IoT software becomes more sophisticated, and more operations fall under the supervision of a holistic system, privacy, data security and network reliability become increasingly important concerns; (2) legacy infrastructure has been a bottleneck, but the exponential increase in connected devices has been an enabler; (3) there is a lack of defined standards for machine connectivity, which a platform like GE's Predix aims to resolve.

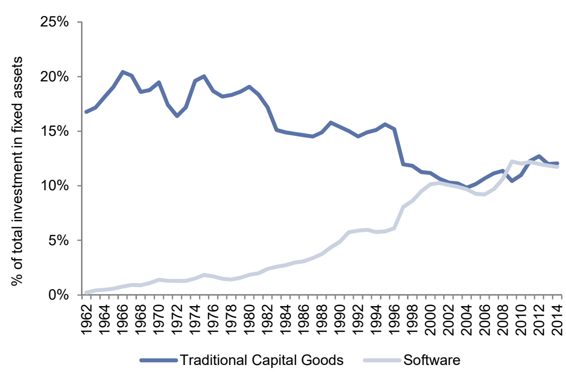
Applications and industries exposed

Asset monitoring and safety/reliability checks have been around for over two decades, but these were largely limited to either regular servicing visits by engineers (which help preempt downtime) or circuit breaker type checks built in to shut down a system in the event of a safety hazard. With IoT PaaS, companies can now: (1) predict when a malfunction is imminent; (2) perform real-time assessments to help improve performance; and (3) remotely adjust operations. In our view, this application is relevant to all industries.

Sizing the revenue opportunity

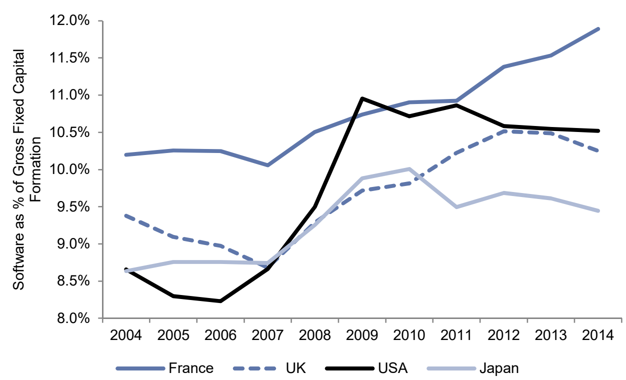
IoT PaaS has the potential to be worth US$200-250 bn by 2020, we believe. Both GE and Cisco believe the market for cloud computing and IoT-based software/analytics will exceed US$220 bn by 2020.

Exhibit 17: Software penetration in fixed investment has been increasing for a while in the US…
Traditional capital goods equipment vs. software as a percentage of total investment in fixed assets; US



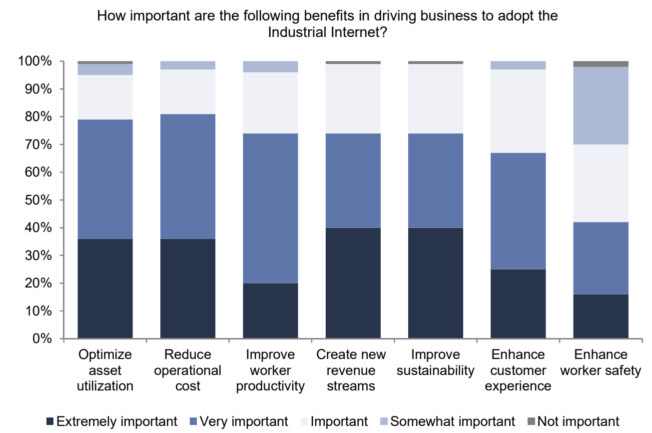
Source: US Bureau of Economic Analysis, Goldman Sachs Global Investment Research.

Exhibit 18: …and in other countries
Software as a percentage of gross fixed capital formation



Source: OECD, Goldman Sachs Global Investment Research.

Exhibit 19: Improving efficiency is one of the key benefits of the industrial internet…
Survey of 250 industry executives



Source: World Economic Forum (2015).

Exhibit 20: …and big data has an impact across the entire manufacturing value chain
Use of big data in the manufacturing value chain matrix

	R&D and design	Supply-chain management	Production	Marketing and sales	Aftersales services
Build interoperable, cross functional R&D and product design databases to enable concurrent engineering	✓		✓		
Aggregate and share customer data to improve service, increase sales, and enable design-to-value	✓	✓		✓	
Source and share data through virtual collaboration sites (idea marketplaces to enable crowdsourcing)	✓		✓	✓	✓
Implement advanced demand forecasting and supply planning across suppliers and use external variables		✓	✓	✓	
Implement lean manufacturing; model and optimize production; develop dashboards			✓		
Implement sensor data-driven analytics to improve throughput and enable mass customisation			✓		
Collect real-time after-sales data from sensors and customer feedback to trigger services and detect flaws.		✓	✓	✓	✓
Improve supply-chain visibility through control towers and organisation-wide collaboration		✓	✓	✓	✓

Source: McKinsey Global Institute.

Predix – GE's Internet of Things platform as a service

What is Predix? GE's Predix, a cloud-based, open-sourced platform, is designed specifically for the industrial user. Think of it as the industrials version of Windows/Android with horizontal applications (e.g. asset performance, brilliant manufacturing, etc.) that can be customised by industry. Predix is meant to be the world's first and only cloud-based software platform built by and for the industry. Domain expertise and industrial internet capability are key areas that GE believes will differentiate its offering from more mainstream tech companies like Amazon (AWS), Microsoft (Azure) and Salesforce.

As an example:

The challenge: GE Aviation analysed 340TB of data from 3.4 mn flights on 25 airlines to help improve asset performance and minimise disruptions.

The solution: The result of implementing Predix: performance was boosted 287x and cost lowered 7x.

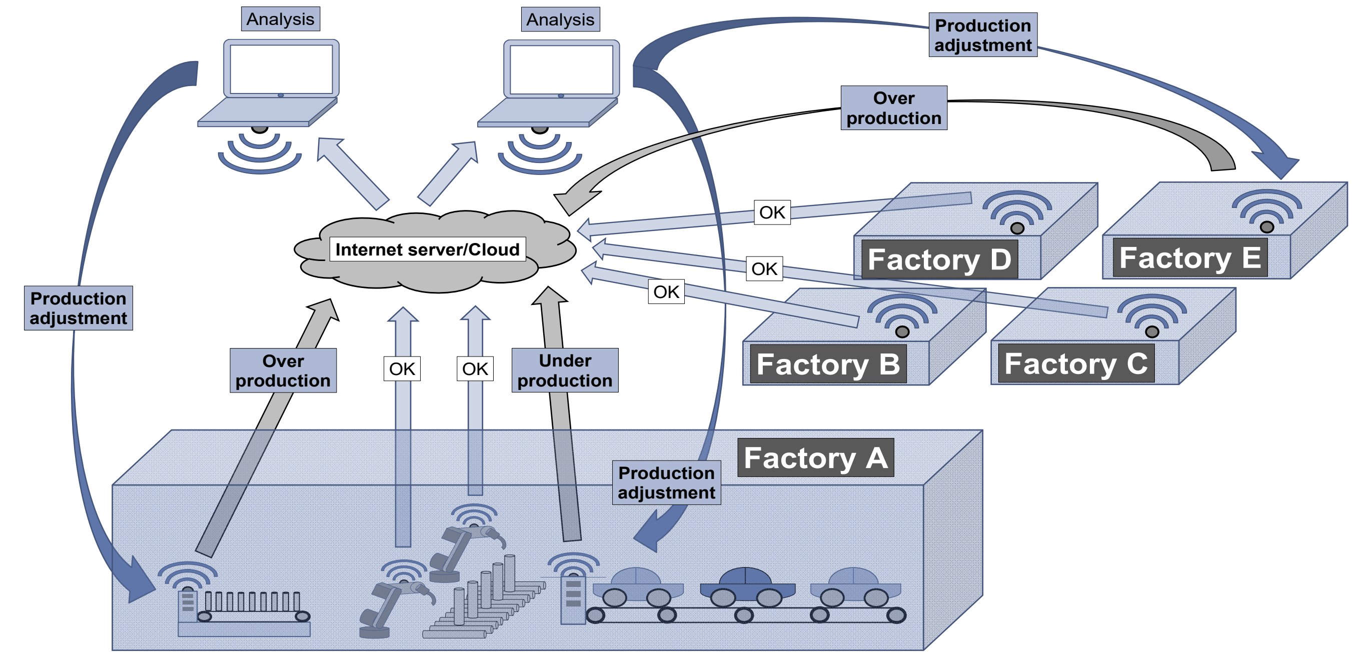
Enabler: Cloud computing

The cloud decentralises storage, managing and processing of data. This, in turn, results in a more productive and flexible way for companies to manage their IT, with the bulk of computational work and storage done remotely, allowing them to streamline their businesses and focus on their core competencies.

Enabler: Big data analytics

Previously, factory managers and workers gathered on location to discuss and resolve issues in the production process. In the future, big data analytical software should allow for automatic identification and adjustment of the manufacturing process to monitor and improve efficiency.

Exhibit 21: Cloud-based software helps manage production within a single factory and across a network of factories



Source: Goldman Sachs Global Investment Research.

PHYSICAL MANUFACTURING

Collaborative robots

US$3-4bn (2020E base case)

- Lower-cost, smaller and more flexible robots capable of working alongside humans
- Early commercialisation stage
- Savings example: PLC Industries boosted its output per worker 40% using cobots supplied by Universal Robots

We see collaborative robots or "cobots" (robots that work alongside humans), as one of the fastest-growing areas in manufacturing machinery. The technology is typically smaller, lighter, cheaper and more flexible than traditional robots. Until recently, the robotics industry was dominated by the "big four": Fanuc, Yaskawa, Kuka and ABB; but cobots open up the market to smaller players and start-ups, as well as increasing the economic viability of robotics in general industry. We estimate the payback time of a cobot to be less than one year in comparison to nearly three years for industrial robots. As the technology develops, we expect it to displace low-skilled, repetitive labour tasks and in the future, expect these robots to incorporate increasing degrees of self-learning and rational independent decision making. Key enablers, machine vision and machine learning, are discussed in this chapter.

The challenges

Standardisation, improving performance, safety, weight and cost. The potential for cobot use is huge, but first it must overcome a number of challenges: (1) there needs to be a standardised programmable platform to increase adoption rates; (2) performance (such as speed) must continue to improve; (3) they need to be safe and meet regulations as they will often be used in hazardous environments; and (4) the cost and capability of the robot must be sufficient for investments to be economically viable (currently US$40-90k).

Applications and industries exposed

Cobots still work more slowly than conventional industrial robots, and can only perform simple operations. Therefore, we do not foresee them being used on highly automated lines requiring little human input. However, we believe cobot penetration could advance relatively quickly in areas where human involvement in production is needed, including distribution/conveyor lines and assortment lines that use AGVs, as well as flexible production cells. As the performance of cobots improves, we forecast a gradual increase in their use on food/medicine packaging lines and semiconductor assembly lines.

Sizing the revenue opportunity

We estimate total sales of cobots of US$3+ bn by 2020 and >US$6 bn by 2025. Using data from the US, Japan, Western Europe, South Korea and China, we forecast cobot demand to have greater potential in countries with the following features: (1) a likely large decline in the manufacturing workforce; (2) labour costs exceeding/catching up to robot installation costs; and (3) a certain level of conventional industrial robot penetration and productivity. Subject to these and supply assumptions, we forecast the cobot TAM to 2025.

Exhibit 22: Cobot cost recovery period should be dramatically shortened over 10 years

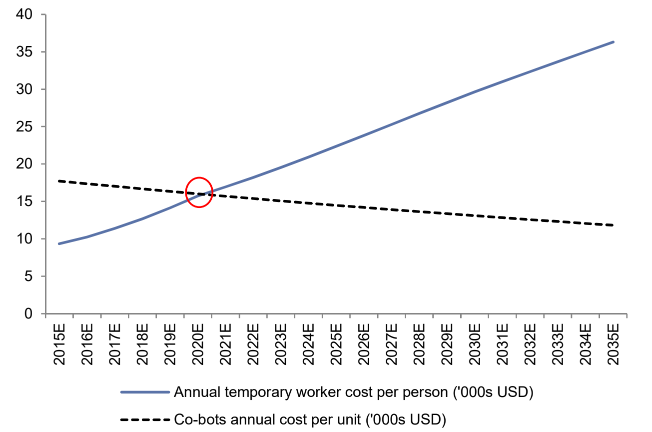
Cost recovery model for cobots ('000s US$)

Co-bots	2015E	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Average robot price	30.0	29.1	28.2	27.4	26.6	25.8	25.0	24.2	23.5	22.8	22.1
System Integration cost	60.0	58.2	56.5	54.8	53.1	51.5	50.0	48.5	47.0	45.6	44.2
Total cost	**90.0**	**87.3**	**84.7**	**82.1**	**79.7**	**77.3**	**75.0**	**72.7**	**70.5**	**68.4**	**66.4**
YoY, %		*-3%*	*-3%*	*-3%*	*-3%*	*-3%*	*-3%*	*-3%*	*-3%*	*-3%*	*-3%*
Working hour per unit (hours)	24	24	24	24	24	24	24	24	24	24	24
Average labor cost	25.5	26.4	27.8	29.5	31.2	33.2	34.7	36.2	37.8	39.5	41.2
YoY, %		*3%*	*6%*	*6%*	*6%*	*6%*	*4%*	*4%*	*4%*	*4%*	*4%*
Working hour per man (hours)	8	8	8	8	8	8	8	8	8	8	8
Net staff replaced	2	2	2	2	2	2	2	2	2	2	2
Depreciation saved	3.0	2.9	2.8	2.7	2.7	2.6	2.5	2.4	2.4	2.3	2.2
Maintenance costs	9.0	8.7	8.5	8.2	8.0	7.7	7.5	7.3	7.1	6.8	6.6
Payback period (years)	**2.0**	**1.9**	**1.7**	**1.5**	**1.4**	**1.3**	**1.2**	**1.1**	**1.0**	**0.9**	**0.9**

Source: Goldman Sachs Global Investment Research.

Exhibit 23: Labour costs likely to exceed robot installation costs by around 2020 in China

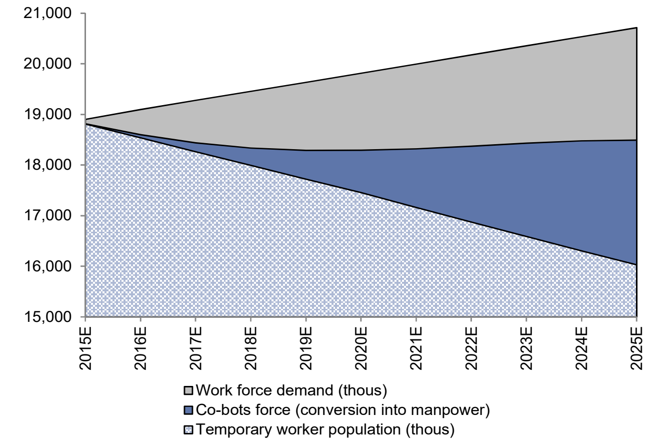
China: Comparison of labour costs and installation costs



Source: Goldman Sachs Global Investment Research.

Exhibit 24: Cobot demand to emerge early in advanced economies

Major advanced economies: Workforce and latent cobot demand forecasts



Source: United Nations, Goldman Sachs Global Investment Research.

Exhibit 25: Estimating the potential of the collaborative robotics market

US$ mn

Collaborative robots	2015E	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Total worker population (thous)	1,471,313	1,470,389	1,468,401	1,465,884	1,463,566	1,461,897	1,460,635	1,459,805	1,459,161	1,458,189	1,456,496
Population ratio for manufacturing	23.5%	23.5%	23.5%	23.4%	23.4%	23.3%	23.3%	23.3%	23.3%	23.3%	23.2%
Population ratio (temporary worker)	38.3%	38.2%	38.2%	38.1%	38.1%	38.1%	38.0%	38.0%	38.0%	37.9%	37.9%
Manufacture regular worker population (thous)	**213,622**	**213,340**	**212,883**	**212,342**	**211,838**	**211,446**	**211,170**	**210,970**	**210,807**	**210,594**	**210,266**
Temporary worker population (thous)	**132,433**	**132,013**	**131,485**	**130,908**	**130,361**	**129,894**	**129,529**	**129,221**	**128,943**	**128,639**	**128,266**
Annual regular worker cost per person ($thous)	26.2	27.1	28.6	30.3	32.1	34.1	35.6	37.2	38.8	40.5	42.3
Annual temporary worker cost per person ($thous)	13.1	13.5	14.3	15.1	16.0	17.0	17.8	18.6	19.4	20.3	21.1
Total worker cost ($bn)	**7,329**	**7,567**	**7,967**	**8,409**	**8,888**	**9,419**	**9,824**	**10,240**	**10,683**	**11,138**	**11,597**
Work force demand (thous)	**133,095**	**133,620**	**134,047**	**134,439**	**134,836**	**135,262**	**135,731**	**136,250**	**136,823**	**137,457**	**138,157**
Worker's productivity growth, %		5.3%	5.0%	4.7%	4.4%	4.1%	3.9%	3.7%	3.5%	3.3%	3.1%
Total Population	2,294,289	2,303,647	2,312,542	2,320,895	2,328,621	2,335,659	2,341,973	2,347,567	2,352,484	2,356,791	2,360,544
GDP per capita	14,719	15,145	15,570	16,000	16,436	16,879	17,328	17,783	18,242	18,704	19,171
GDP growth, %		3.3%	3.2%	3.1%	3.1%	3.0%	2.9%	2.9%	2.8%	2.7%	2.7%
Needed additional temporary worker (thous)	**662**	**1,607**	**2,562**	**3,531**	**4,475**	**5,368**	**6,202**	**7,029**	**7,880**	**8,817**	**9,891**
Co-bots effectivity (conversion into manpower)	1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.4
Co-bots install base demand unit (thous)	**16**	**115**	**251**	**421**	**615**	**827**	**1,046**	**1,267**	**1,479**	**1,712**	**1,977**
Substitutable ratio by Co-bots	4%	12%	17%	22%	26%	30%	35%	39%	42%	45%	48%
Substitutable ratio by Industrial robots	96%	88%	83%	78%	74%	70%	65%	61%	58%	55%	52%
Co-bots real install base unit (thous)	**5**	**39**	**102**	**193**	**307**	**440**	**590**	**746**	**899**	**1,060**	**1,245**
Penetration rate	29%	34%	41%	46%	50%	53%	56%	59%	61%	62%	63%
Co-bots density (unit/10,000 workers)	0	2	5	9	14	21	28	35	43	50	59
YoY growth, %		763%	161%	89%	60%	44%	34%	27%	21%	18%	18%
Co-bots annual cost per unit ($thous)	17.9	17.5	17.2	16.8	16.5	16.1	15.8	15.5	15.2	14.9	14.6
YoY growth, %		-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
Co-bots work force	**7**	**66**	**178**	**349**	**580**	**867**	**1,211**	**1,596**	**2,004**	**2,463**	**3,016**
Initial Co-bots cost ($mn)	81	606	1,065	1,484	1,819	2,050	2,228	2,231	2,087	2,129	2,381
Additional Industrial robots cost ($mn)	67	376	450	494	489	448	380	313	250	230	222
Temporary worker + Co-bots work force	**132,590**	**133,090**	**133,745**	**134,557**	**135,497**	**136,521**	**137,579**	**138,602**	**139,549**	**140,499**	**141,479**
YoY growth, %		0.4%	0.5%	0.6%	0.7%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%
Total cost ($bn)	**7,329**	**7,568**	**7,969**	**8,411**	**8,890**	**9,422**	**9,826**	**10,242**	**10,686**	**11,140**	**11,600**
YoY growth, %		3.3%	5.3%	5.5%	5.7%	6.0%	4.3%	4.2%	4.3%	4.3%	4.1%
New Co-bots sales ($mn)	81	606	1,065	1,484	1,819	2,050	2,228	2,231	2,087	2,129	2,381
Co-bots replacement sales ($mn)	0	20	168	429	793	1,239	1,741	2,287	2,834	3,345	3,867
Co-bots replacement unit (thous)	0	1	10	26	48	77	110	148	187	225	265
Replacement rate	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
Total Co-bots sales ($mn)	**81**	**626**	**1,234**	**1,914**	**2,612**	**3,289**	**3,969**	**4,518**	**4,921**	**5,474**	**6,247**

Source: Goldman Sachs Global Investment Research.

Scott Fetzer Electrical Group has optimised production costs by 20% by using Universal Robot's cobots

The challenge: Tennessee-based Scott Fetzer Electrical Group (SFEG) manufactures a wide range of products in low volumes, meaning that manufacturing tasks are constantly changing depending on demand. SFEG was under pressure to remain competitive globally as the Asian electronics market expanded and wanted to avoid having to upgrade its entire existing asset base. Given the high-mix, low-volume nature of order intake, traditional industrial robots were not an economically viable option as lines would be unused for long periods of time.

The solution: Universal Robots' model UR5 was adapted to work on a variety of tasks along with human operators, when more capacity is needed. According to IFR, for example, one day the robot could be bedding metal sheets, the next it could be performing pick and place tasks. The robot does not require a safety guarding like traditional industrial robots; the robot arm will automatically stop operating if it encounters obstacles. To build on the collaborative potential of the new robots, SFEG has put them on top of AGVs and now has a fleet of mobile UR robots deployed throughout the sheet metal department, integrating them into the entire production cycle, from cutting the initial blank on the blanking press to forming, folding and final assembly of the electrical components. Multiple robots are also being connected to work together on complementary tasks, such as moving parts between workstations. Live testing of final products was also automated. The cobots can turn the product on/off, run it for a couple of seconds and repeat that task for a full cycle of testing (up to 400 hours). Furthermore, the robot collects live data from all tests across several important variables. Preparing the robots for their tasks is also a much simpler process than for traditional industrial robots: this can be done through a simple user-friendly screen or by simply grabbing the robot arm and performing the desired task. SFEG says it took 30%-50% less time than with traditional robot implementations.

The result: According to the company, before it had the cobots on the transformer line, an operator could make on average 10 parts per hour; collaboration with the robots increased this productivity by 20%. SFEG says it has won back market share against Chinese competitors and brought back to the US some of its Chinese-sourced manufacturing as a consequence. The company says the payback for UR robots was 12-14 months.

Glory (Japanese machinery maker) deploys cobots on cash register assembly lines

The challenge: Obtaining production line workers for factories to manufacture cash registers became a problem for Glory in various countries because of declining/ageing populations.

The solution: The company introduced Kawada Technologies' humanoid robot, Nextage, on assembly lines in 2012. Cobots were given nicknames that matched local currencies (Yen-chan, Dollar-kun, Euro-kun) to help workers feel comfortable with their new colleagues. Nextage is highly adept at simple picking work, like many cobots, but it also has the dexterity to tighten screws and mount components. We view this as significant in that it shows the potential for higher-value-added operations to be entrusted to cobots.

Exhibit 26: Universal Robots cobot alongside a worker…

Source: Teradyne.

Exhibit 27: …and in a production line

Source: Teradyne.

PHYSICAL MANUFACTURING

Additive manufacturing

US$25-30 bn (2020E base case)

- Lower raw material consumption, quicker time-to-market and allows mass-customisation
- Early commercialisation stage
- Savings example: Airbus production cost of satellites reduced by 20% by using in-house 3D printer as opposed to outsourcing production

Additive manufacturing or 3D printing is the process of making a physical object from a three-dimensional digital model, typically by laying down many successive thin layers of a material. The technology facilitates several aspects of the evolution of the global economy, and more specifically manufacturing, via: (1) reduced raw material consumption; (2) a quicker design to production process; and (3) mass customisation. Within 3D printing, printers and materials are the biggest opportunities, and we believe the industry could move towards a razor/razor blade model as it matures. This means that the installed base could become the driver of a more recurring and profitable opportunity, in the form of materials sales and technology.

The challenges

Speed, energy consumption and further technological progress: (1) slow print speed is an impediment to high-volume production; (2) lack of material science advancement blocks the use in several applications (e.g. metals); (3) high energy costs can affect economics; (4) software development is in the early stages and needs to evolve in order to facilitate the design of more complex products; and (5) there are safety/environmental concerns around melting thermoplastic, which is one of the most used materials currently.

Applications and industries exposed

Similar to other manufacturing innovations such as robotics and vision systems, auto companies were the early adopters of 3D printers and remain the biggest users. The key application for 3D printing is rapid prototyping of new models. Going forward, we believe autos will likely remain the biggest application, but see other end markets playing a major role in the growth of the industry, namely aerospace and consumer goods.

GE is leading the way in terms of commercial applications within aerospace. Specifically, GE is deploying 3D printed fuel nozzles and sensors for the GEnx jet engine. These components serve key purposes, allowing sensors to be mounted on parts that were previously difficult to monitor, the ability to work in hazardous environments (2000 Fahrenheit) and the use of materials not traditionally associated with manufacturing. Furthermore, companies like Siemens are using it as the next step after PLM simulation.

Sizing the revenue opportunity

Additive manufacturing has a potential addressable market of US$25-30 bn by 2020E. Per IDC, the global 3D printing market is worth c.US$11 bn currently, and is expected to grow to c.US$27 bn by 2019, implying a 25% CAGR. We take a more conservative approach in our base case, and assume a 20% CAGR through 2015-20 and a terminal rate of 5% by 2025. This yields a market size of US$40 bn by 2025, implying a CAGR of 14%.

Exhibit 28: Estimating the potential of the 3D printing market
US$ bn

Additive manufacturing	2015E	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
3D printing potential revenue	$11bn	$13bn	$16bn	$19bn	$23bn	$27bn	$30bn	$33bn	$36bn	$38bn	$40bn
% yoy		*20%*	*20%*	*20%*	*20%*	*20%*	*10%*	*10%*	*10%*	*5%*	*5%*
2015 - 2025 CAGR: **14%**											

Source: Goldman Sachs Global Investment Research.

Simplification and weight savings enabled with 3D printing of commercial aviation parts

The challenge: General Electric requires nozzles that hold the T25 sensor which monitors GE's Leap jet engine. Previously, the nozzles, like those used in the Leap engine, were machined from 20 separate parts, resulting in problems with ice accumulation and welding and joint strength. With 19 fuel nozzles per engine and high development costs, GE needed to streamline the manufacturing of the nozzles while satisfying strict aviation regulations.

The solution: With additive manufacturing technology, the newly certified part is made in one solid piece, reducing manufacturing and development time (approximately one year) while improving part performance.

"Once we found a workable solution, it went straight to production. This technology is a breakthrough." – Jonathan Clarke, Program manager for the project.

Exhibit 29: 3D printed component used in GE's Leap jet engines

Source: General Electric.

IN-FACTORY LOGISTICS

Automated Guided Vehicles

c.US$2 bn (2020E base case)

- Autonomous material handling equipment eliminating labour costs
- Early development stage
- Savings example: Harley Davidson reduced costs 7% by introducing AGVs and creating a more efficient production facility

Within manufacturing, automated guided vehicles (AGVs) are used in the automation of material handling, transporting objects through factories and distribution centres. As the technology advances, they should be increasingly connected to the broader IoT network, allowing for just-in-time delivery of components. As a result, the technology should help reduce labour costs and allow for more flexible production that does not need to follow a fixed conveyance line. Egemin, the AGV brand of Kion, estimates the payback time of an AGV system is 2.75 years. We see AGVs as an important development in an increasingly connected and automated logistics system, potentially leading to much lower levels of work-in-progress and inventories.

The challenges

Infrastructure costs, potential new entrants and safety. This technology must first overcome a number of challenges: (1) widespread adoption may require large infrastructure spend on factory layouts to ensure safe use, multiplying the cost; (2) it opens up to competition similar technology used in autonomous cars; (3) similar to autonomous cars, it needs to overcome safety concerns in a likely highly hazardous environment; and (4) the technology still needs to advance and costs need to fall.

The markets disrupted

This technology will disrupt other material handling equipment (such as forklifts). For some suppliers, it may cannibalise their primary offering, as evidenced by large investments from some of the leading players.

Sizing the revenue opportunity

The market for AGVs in industrial use could be worth c.US$2 bn by 2020 and almost US$4 bn by 2025. We assume the current installed base of manned material handling equipment as the potential market for this equipment (Class 2 and 3 industrial trucks). Using industry data, we estimate the proportion of this equipment used in manufacturing and logistics (57%), and forecast global demand to grow at long-run GDP (assumed at 3.0%). Using a variety of other industry sources and company data, we estimate the current AGV installed base is less than 2%; we expect this to grow to c.15% by 2025. We expect pricing to hold up for the next couple of years, as the technology makes significant advances, and to begin deflating once there is broader adoption.

Exhibit 30: Estimating the potential of the AGV market within manufacturing
US$ mn

Automated Guided Vehicles	2014E	2015E	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Comparable material handling equipment manufacturing	342,000	352,260	362,828	373,713	384,924	396,472	408,366	420,617	433,235	446,232	459,619	473,408
YoY growth, %		3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Penetration of AGVs	1.2%	1.6%	2.1%	2.9%	4.2%	6.2%	7.8%	9.8%	11.4%	13.3%	14.2%	15.2%
AGV units sold	4,104	5,540	7,757	10,859	16,289	24,433	31,763	41,292	49,550	59,461	65,407	71,947
YoY growth, %		*35%*	*40%*	*40%*	*50%*	*50%*	*30%*	*30%*	*20%*	*20%*	*10%*	*10%*
Average cost of AGV + installation costs ($'000s)	$65	$65	$65	$65	$64	$62	$61	$60	$59	$58	$56	$55
YoY growth, %		*0%*	*0%*	*0%*	*-2%*	*-2%*	*-2%*	*-2%*	*-2%*	*-2%*	*-2%*	*-2%*
Total AGV sales	$267m	$360m	$504m	$706m	$1,038m	$1,525m	$1,943m	$2,476m	$2,911m	$3,424m	$3,691m	$3,979m
YoY growth, %		*20%*	*20%*	*14%*	*14%*	*8%*	*47%*	*27%*	*27%*	*18%*	*18%*	*8%*

Source: Goldman Sachs Global Investment Research.

Harley Davidson: Automated guided vehicles

Harley Davidson took to transforming its York Vehicle Operations facility, which accounts for more than 60% of the company's motorcycle production.

The challenge: The original factory, laid out on mass-production principles, was becoming inefficient and inflexible. Harley Davidson set as its objective the adoption of lean principles and reduced manufacturing floor complexity.

The solution: One key aspect of this transformation was removing the assembly line production chain and adopting a digital chain (where assembly parts move on flexible automated guide vehicles (AGVs) which are driven by planning needs and software). There was a significant reduction in inventory at hand levels, which currently stand at three hours compared with 8-10 days in the legacy systems, owing to a major cut in the planning cycle, moving from a 21-day fixed plan to only a six-hour time horizon.

Moreover, the low-value-add, repetitive works have been moved to robotic execution, increasing productivity. Incorporation of a real-time performance management system helps in monitoring the entire manufacturing floor via multiple connected devices. This transformation resulted in significant metric improvements for the company: it reduced costs by 7% and productivity rose 2.4%, resulting in a net margin improvement of 19%.

Exhibit 31: An example of an AGV supplied by Siasun

Source: Siasun.

Exhibit 32: An example of an Egemin AGV

Source: Wikimedia.

IN-FACTORY LOGISTICS

Radio Frequency Identification

c.US$2 bn (2020E base case)

- Allow for identifying and tracking objects in complex and connected networks
- Mature technology with new early applications in manufacturing
- Savings example: Griva, a textile manufacturer, achieved a ROI of 30% in 9m from using Alien Technologies' RFIDs to monitor inventory

Radio frequency identification (RFID) technologies are tags that use radio waves to transfer data, to allow the identifying and tracking of objects. The technology has existed since at least the 1970s. Until now, it has been too expensive to be practical for many commercial applications within manufacturing. The technology solves many of the problems associated with bar codes, as radio waves travel through most non-metallic materials, and can be embedded in components. The tags can store data about each component manufactured and allow tracking of their real time locations throughout the production process (e.g. for work-in-progress, supplies and product inventory).

Active RFID tags use a battery and run an imbedded microchip, submitting signals to the reader. They can be scanned over long ranges but cost a dollar or more. Passive tags have no battery. Instead, they draw power from the reader. Manufacturing companies are focusing on passive ultra high frequency (UHF) tags, which cost less than 50 cents today in orders of one million or more. Their read range is typically less than 20 feet vs. 100 feet or more for active tags, but they are far less expensive than active tags and can be disposed of with the product packaging.

The challenges

Cost deflation, compatibility and technological barriers. There are still a number of barriers to widespread adoption within manufacturing: (1) even at 50 cents for a UHF tag, costs need to come down substantially in order for it to be economically viable for widespread adoption – currently their use is limited to only high-value items; (2) the RFID technology must be compatible with the broader IoT system protocols and standards; and (3) the technology still needs to overcome some barriers, such as not being able to send signals through metallic materials.

Applications and industries exposed

RFID are a key enabling technology for connecting factories and managing inventory levels. They are currently used in many industries around the world and on a variety of applications. Club Car, a maker of golf carts, uses RFID to improve efficiency on its production line. Paramount Farms, one of the world's largest suppliers of pistachios, uses RFID to manage its harvest more efficiently. Much of the recent growth has come from, and is continuing to come from, uses in retail apparel, and the largest orders are placed by governments. Food & beverages and textiles are positioned well, owing to the low number of metallic components.

Sizing the revenue opportunity

We estimate the Factory of the Future will offer a c.US$2 bn opportunity for RFID providers by 2020. In 2014, around 7.5 bn total RFID units were sold, with between 3% and 6% of these sales made to manufacturing (mainly UHF tags). Using publically available data from RFID Journal and other industry sources, we are able to forecast trends and pricing. We estimate that the growth rate of manufacturing units sold will be over 20% pa for the next five years. Despite this high rate, this is lower than is expected for the retail industry (the largest end market for RFID technologies, which we expect to grow at a CAGR of over 30%). We hold the average number of readers per 1,000 tags fixed in our forecasts, owing to "reader collision" blocking signals and limiting the number of readers possible in a fixed space. Note that given the growth in different sectors in our base case, by 2020E manufacturing still represents only 4% of total RFID unit sales, and therefore the total market for RFID should be much greater.

Exhibit 33: Estimating the potential of the RFID market within manufacturing
US$ mn

RFID	2014E	2015E	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
RFID units sold (bn)	7.5	9.4	11.7	14.6	18.3	22.9	28.6	34.3	39.5	43.4	45.6	47.9
YoY growth, %		*25.0%*	*25.0%*	*25.0%*	*25.0%*	*25.0%*	*25.0%*	*20.0%*	*15.0%*	*10.0%*	*5.0%*	*5.0%*
% of which in manufacturing	4.5%	4.4%	4.3%	4.2%	4.1%	4.0%	3.9%	3.8%	3.7%	3.6%	3.5%	3.4%
RFID manufacturing units sold (mn)	**337.5**	**413**	**504**	**615**	**751**	**916**	**1116**	**1305**	**1461**	**1563**	**1596**	**1628**
YoY growth, %		*22.2%*	*22.2%*	*22.1%*	*22.0%*	*22.0%*	*21.9%*	*16.9%*	*12.0%*	*7.0%*	*2.1%*	*2.0%*
Average cost of UHF RFID ($)	$0.50	$0.48	$0.45	$0.43	$0.41	$0.39	$0.37	$0.35	$0.33	$0.32	$0.30	$0.28
YoY growth, %		*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*	*-5.0%*
Total manufacturing RFID tags sales	$169m	$196m	$227m	$264m	$306m	$354m	$410m	$456m	$485m	$493m	$478m	$463m
YoY growth, %		*16.1%*	*16.1%*	*16.0%*	*15.9%*	*15.9%*	*15.8%*	*11.1%*	*6.4%*	*1.7%*	*-3.0%*	*-3.1%*
Average number of readers per 1000 tag:	2	2	2	2	2	2	2	2	2	2	2	2
Average cost of UHF reader	$1,000	$950	$903	$857	$815	$774	$735	$698	$663	$630	$599	$569
YoY growth, %		-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%	-5.0%
Total manufacturing RFID reader sales	$675m	$784m	$910m	$1,055m	$1,223m	$1,417m	$1,640m	$1,822m	$1,938m	$1,971m	$1,911m	$1,852m
YoY growth, %		*16.1%*	*16.1%*	*16.0%*	*15.9%*	*15.9%*	*15.8%*	*11.1%*	*6.4%*	*1.7%*	*-3.0%*	*-3.1%*
Total manufacturing RFID sales	$844m	$980m	$1,137m	$1,319m	$1,529m	$1,771m	$2,051m	$2,278m	$2,423m	$2,463m	$2,389m	$2,315m
		16.1%	*16.1%*	*16.0%*	*15.9%*	*15.9%*	*15.8%*	*11.1%*	*6.4%*	*1.7%*	*-3.0%*	*-3.1%*

Source: Goldman Sachs Global Investment Research.

Bosch RFID tags cut inventory time by 97% in China

The challenge: In the Bosch plant in the Chinese city of Suzhou, the yearly task of taking machine inventory used to be a major undertaking. Plant 1 has four manufacturing areas, each with up to 2,500 machines, test benches, and items of measuring equipment. For ABS manufacturing alone, the inventory process used to take up to a month in some cases. Sometimes associates printed out lists to help them manually record machine inventory.

The solution: Now, thanks to smart connectivity, inventory taking takes just four hours. All the machines and equipment items have been fitted with RFID transponders. This allows objects to be identified without physical contact. Now, associates push RFID trolleys fitted with a laptop and antennas through the manufacturing shop (in the future AGVs could also do this too). As they move along, the trolleys use RFID technology to automatically identify machines and devices. This cuts the time needed for inventory taking by 97%, or 440 man hours.

Stanley Black & Decker's Mexico plant

The challenge: Stanley Black & Decker wanted to improve the overall operating efficiency of one of its largest plants in Reynosa, Mexico.

The solution: It implemented real-time location systems (RTLS) on its production lines. RTLS include small and easily deployed RFID tags that provide real-time location and status, thereby allowing better work efficiency, better supervision of inventory, reduced working capital and improved production line throughput. Stanley Black & Decker had a 15% increase in revenue per employee in 2014 and improved equipment effectiveness, resulting in a 300 bp operating profit margin improvement.

Other key technologies (ordered alphabetically)

We briefly highlight five other technologies that could have a dramatic impact on the future of manufacturing:

Augmented reality vision
Augmented reality vision is an upcoming technology that superimposes a computer-generated image on a user's view of the real world. This technology could allow engineers and workers a view of 3-dimensional designs and let them receive visual instruction to complete their tasks, increasing productivity and reducing the likelihood of costly errors. This could disrupt the market for 2-dimensional computer screens used to instruct engineers currently.

In *Profiles in Innovation Vol. 1: Virtual & Augmented Reality*, January 13, 2016, GS analysts estimated that, despite no adoption until 2017, and including virtual reality devices, this market could be worth US$1.5 bn in 2020 and over US$4.5 bn in 2025.

Demand response
Demand response provides an opportunity for factories to play a significant role in their own consumption from the electric grid by reducing or shifting their electricity use during peak periods in response to time-based rates or other forms of financial incentives. Given their large energy use, factories often have the most to gain from any commercial and industrial customer by optimising their energy consumption and helping reduce costs. The latest battery technology can help maximise this potential. Key to this technology is the use of energy storage, which in *The Great Battery Race*, October 18, 2015, GS analysts estimated was a TAM of US$100-150 bn, of which the demand response is worth US$45-71 bn.

Machine learning
Machine learning (or artificial intelligence) is the ability of machines to process data into information and derive knowledge from that information to act independently or augment human decision making. The key difference between machine learning and a smart piece of code or smart connected devices is it is capable of self-learning/improving.

Machine learning has been introduced at a basic level in collaborative robots, and is touted as a key enabler in optimising the IoT. Within IoT ecosystems, machines are able to communicate with each other and adjust/work independently of human interaction.

Machine vision
Machine vision is the technology and methods used to provide imaging-based automatic inspection, gauging, counting and analysis at high speeds, reliability and with greater precision (exceeding the capabilities of the human eye).

This technology, which effectively consists of highly advanced sensors, has the potential to dramatically increase the capability of other technologies such as collaborative robots, AGVs, and other automated production processes.

Nanotechnology
Nanotechnology is engineering on an atomic scale. The analysis or manipulation of atoms and molecules is key to addressing the challenge of extracting higher output from less resource, and is becoming increasingly important in manufacturing. Nano materials are already used in consumer goods such as make-up, and industrial products such as surface coatings. In addition, the semiconductor roadmap provides a dramatic example of this in the relentless miniaturisation and increasing power of electronic devices.

As the limitations of existing technologies become more binding, we believe the importance of this technology will increase, in turn driving an increasing number of nanotechnology applications (e.g. purifying silicon semiconductors). Nanotechnology accounts for a small but growing share of public and corporate research budgets.

Autodesk is using augmented reality to enhance computer aided design (CAD)

Our US technology analysts spoke to Autodesk to discuss the augmented reality used in manufacturing to visualise 3D models in a real-world context, avoiding costly errors and improving collaboration.

The challenge: While CAD software has done much to improve the design process it still has its limits. For example, CAD is still generally constrained by the need to work on a 2D monitor. This limits the ability to view full-sized objects in a real-world context, and hinders true collaboration when many people are working on the same design.

The Autodesk solution: Autodesk is a design software company with US$2.5 bn in annual revenues and with customers primarily in the architecture, engineering, construction and manufacturing verticals. Our analysts spoke with Autodesk's emerging technology division, which is working with Microsoft HoloLens to incorporate AR into CAD. Autodesk's VRED 3D visualisation software product is currently used by auto makers to project things such as doors and colours onto clay car models.

Wide-ranging applications: Autodesk envisions AR improving the design of items as small as videogame controllers or as large as buildings, with the view that having the true 1-to-1 scale that's not possible in 2D can go a long way towards avoiding errors. Autodesk also sees value in looking at a 3D model and having metadata information behind the CAD at your fingertips. Finally, if two people are collaborating on a project, they are better able to work through issues as they go as opposed to working on separate desktops and realising there are issues when they come together. Given the wide range of CAD use cases, we see potential for AR to impact Autodesk's base of 5 mn customers worldwide.

Potential bottlenecks: The computing power of AR systems needs to improve to run large CAD files.

Exhibit 34: Autodesk is working with Microsoft

Source: Microsoft.

Industries

Top-down: >US$500 bn addressable market

- Higher labour costs and increased global competition and putting pressure on manufacturers to automate and making time to market increase in importance as a differentiator
- We see the greatest opportunity from a shift to best-in-class manufacturing for:
  - **Electronics** – Up to US$120 bn
  - **Machinery** – Up to US$110 bn
  - **Food & Beverages** – Up to US$100 bn

Total addressable market could be worth more than US$500 bn

We believe the total addressable market for equipment manufacturers supplying physical automation and software for full connectivity and optimisation of factories could be worth more than US$500 bn, or 10% of fixed investment, in cost savings. We assess this market size on a top-down basis across the relevant industries, based on current levels of automation and digitisation and potential savings achieved in existing technology pilots. This assessment provides a higher value than our bottom-up analysis of the six core technologies we presented earlier, as: (1) our top-down analysis includes other technologies (such as those that are more mature, but where penetration can still be increased or efficiency improved); (2) it aggregates synergies from using more than one of the six technologies profiled; (3) we use a savings approach, which will not necessarily be realised as revenues by equipment providers as some of the value identified will likely be shared with customers rather than manufacturers (especially for technologies where prices deflate quickly).

Approach to our top-down TAM assessment

We believe the size of the total addressable market for all emerging technologies ensuring optimal automation and digitisation of future manufacturing is capped by the potential size of the savings achieved by using those technologies. This would be a best-case scenario, in which the industries adopting these technologies do not retain or pass through to their customers any achieved savings (the latter is what usually happens).

For our top-down assessment, we look at each industry's level of automation and digitisation vs. the best-in-class example of the automotive industry. We expect manufacturing to evolve differently for each global industry. Currently, each is at a different stage of automation and sophistication owing to the competitive dynamics and market pressures it faces. For industries such as automotive, where factories are already highly sophisticated, the incremental value-add of new technologies will be quite low.

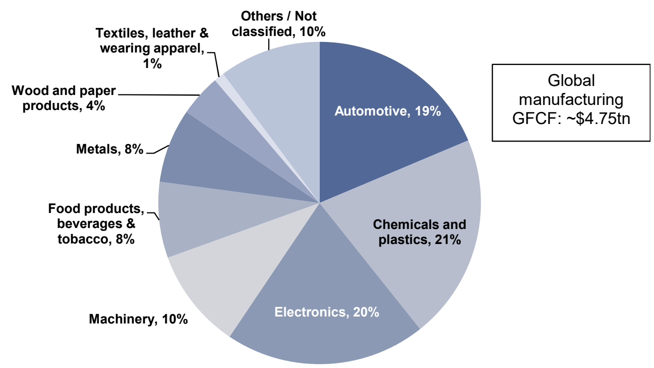
We then collect numerous examples of full automation, digitisation and optimisation achieved in pilots in the eight industries we analyse. Crossing those two data points, we estimate the potential savings achieved, which we assume equates to the maximum possible size of the addressable market of the technologies that allow for those gains.

In more detail, our top-down TAM assessment is based on the following:

- **Assessing the relevant pool of fixed investment.** Manufacturing accounts for around 25% of global gross fixed capital formation (or fixed asset investment). Using data from the World Bank, OECD and other national accounts, we are able to estimate the proportion of fixed asset investment by each manufacturing industry.
- **Assessing the level of existing automation and digitisation**. We capture the varying degrees of automation in each industry by looking at the current penetration of robots (in Japan, Germany, the UK, France and Italy) and software. This is important in assessing the maximum potential for other manufacturing industries if they were to catch up with the more advanced ones, most notably automotive.
- **Assessing the level of savings enabled by full automation/digitisation.** Using Goldman Sachs research, case studies and third-party sources, we estimate a range of gross savings that each industry could generate by introducing and implementing the latest technologies. For some industries such as autos, which have already automated significantly, the extra savings are quite limited; for others, the potential is much greater. We also apply a relevance factor for each technology.
- **Calculating the maximum revenue pool potential for equipment manufacturers.** Given the proportion of investment available, the potential savings for each industry and the degree of automation already in place, we estimate the maximum potential savings and revenue pool available.

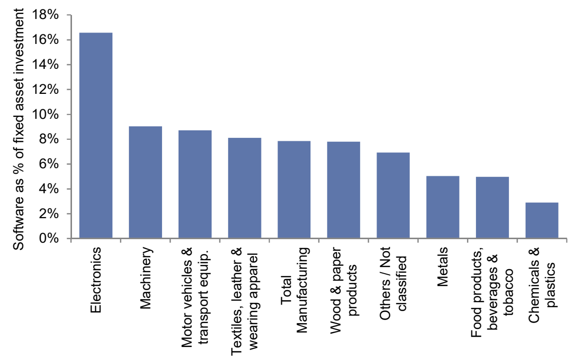
- **Qualifying speed of adoption**. It is unlikely that each industry will automate and innovate to the extent the automotive industry has. Looking at the competitive structure, age of assets and the margin pressure that industries are facing, we also incorporate a metric that aims to capture the likelihood of this maximum revenue pool per industry being realised. Unsurprisingly, the automotive industry is highly likely to adopt new technologies, while the food products sector is less so, for reasons highlighted further on.

Exhibit 35: We look at the key industries that drive fixed investment …
Global fixed investment broken down by industry



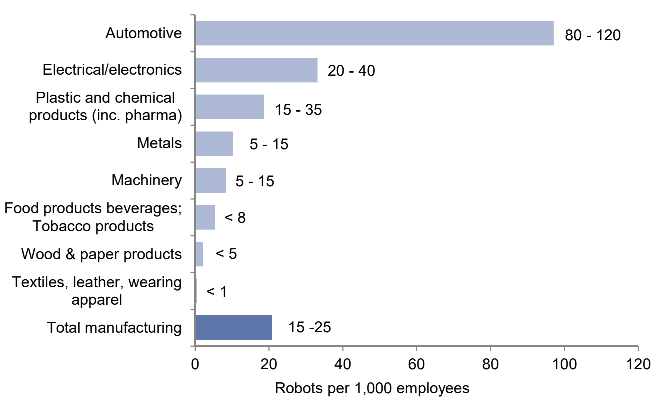
Source: World Bank, OECD, China Statistical Yearbook, Goldman Sachs Global Investment Research.

Exhibit 36: …assessing their software penetration…
Software as % private non-resi fixed asset investment for various industries in the United States (2015)



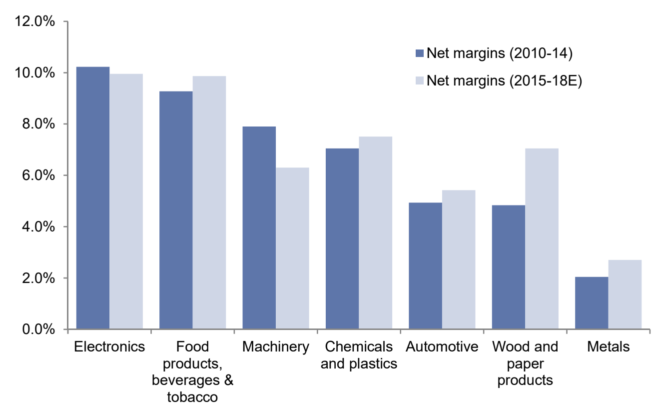
Source: US Bureau of Economic Analysis, Goldman Sachs Global Investment Research.

Exhibit 37: …as well as level of automation…
Robot density per 1,000 employees



Source: Goldman Sachs Global Investment Research.

Exhibit 38: …and urgency of need for optimisation
Net margins in 2010-14 and 2015-18E for selected manufacturing industries



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 39: We used 60+ examples of savings captured by introducing FoF technologies in their current state

Company	Fanuc	FDM	Flextronics	Sub-Zero	Maserati	Continental	Stanley Black & Decker
Business Outcome	Lower downtime	Large savings & faster time-to-market	Reduce energy	Faster time-to-market	Shorten time-to-market	Lower Inventory	Reduce defects
Technology introduced	IoT	3D printing	IoT	IoT	PLM software	IoT	IoT
Description	Monitoring & predictive maintenance	Use of 3D printing to manufacturer component used in drones	Machine level consumption & demand response	Collaboration enhanced across platforms	Use PLM software to design its complex products	Real time supply chain monitoring & interaction	Big data enabled quality checks
Old state	11% unplanned downtime	20 days outsourcing	$8.4mn/factory	15 months cycle	30 months time-to-market	14x inventory turnover	4.9% defect rate
New state	5.8% unplanned downtime	2 days with a ROI of $12,000	$6.9mn/factory	11 months cycle	16 months time-to-market	19x inventory turnover	2.5% defect rate
Improvement	47.8%	10x faster & ROI in 9m	17.5%	23.0%	47.0%	34.8%	48.9%
Result	Savings of $40mn from single customer	Savings of $800,000 cost avoidance over 3 years	Savings of $1mn per factory	15% reduction in cycle time	Helped Maserati produce 3x more cars	Reduced certain component costs by 20%	DPM reduced by 16%

Source: Company data, Goldman Sachs Global Investment Research.

We also perform a scenario analysis to calculate the savings based on the assumption that using labour-reducing technologies (AGVs and cobots), labour-intensive industries (such as textiles, wood and food products) are able to halve their gap with the automotive industry. Using data from five of the ten largest manufacturing countries – Japan, Italy, the UK, France and Germany – we follow five steps: (1) calculate labour intensity (number of employees/output); (2) calculate the reduction in labour needed to halve the difference with the automotive industry; (3) assign high (US$30,000) and low (US$15,000) wages; (4) multiply wages by absolute labour reduction to calculate displaced savings; and (5) divide by output to find the margin impact.

Exhibit 40: Our scenario analysis suggests significant savings potential for textiles and wood products
Analysis of hypothetical scenario in which industries halve their labour intensity (no. employees/output) difference with autos

Savings from labor displacement							
Manufacturing industry	**No. Employees**	**Output ($m)**	**Labour intensity**	**Labour reduction**	**Wages (high/low)**	**Savings in wages($m)**	**% of output**
Food products beverages; Tobacco products	3,773,158	273,462	14	20%	Low	14,827	5%
Textiles, leather, wearing apparel	1,278,993	52,649	24	33%	Low	8,380	16%
Wood & paper products	2,033,371	89,648	23	32%	Low	12,825	14%
Plastic and chemical products (inc. pharma)	3,276,175	401,736	8	0%	Low	0	0%
Metal (exc. Machinery)	3,779,939	290,443	13	18%	High	20,209	7%
Machinery	3,286,976	257,301	13	17%	High	16,978	7%
Electrical/electronics	2,953,577	268,034	11	12%	High	10,629	4%
Automotive	2,548,188	304,233	8	0%	High	0	0%
Others / Not classified	3,168,377	210,498	15	22%	Low	14,053	7%
Total manufacturing	26,098,754	2,148,004	12	16%	Medium	101,344	5%

Source: BEA, OECD, World Bank, Goldman Sachs Global Investment Research.

Note: *These estimates are* ***not*** *indicative of the revenue that we believe will be realised by equipment providers, but represent a maximum cap to those revenues. These estimates are also not fully risk- or probability-adjusted. In most case we use gross cost savings (although we attempt to net the costs of introducing new technologies where we can). While the price of key technologies may have declined significantly in the past few years, we do not fully incorporate the cost of restructuring the fixed infrastructure to accommodate this technology. As a consequence, our estimates are not a full representation of the costs that may be incurred. Industry level data will still vary significantly among countries; see Where will it be built?.*

Exhibit 41: Top-down analysis of bringing each industry's manufacturing to best-in-class

Industry-by—industry potential addressable market in US$ bn

Industries	Current size of industry[1]		Current degree of automation [2]					Potential savings [6]	Maximum opportunity size
Manufacturing sub-sectors	% of global manuf. fixed asset investment	Amount ($bn)	Robot intensity per 1,000 employees [3]	Robot penetration index	Software % of fixed asset investment[4]	Software penetration index [5]	**Automation index**	Savings from FoF technologies	**($bn)**
Automotive	19%	895	97	90%	9%	63%	**76%**	6 - 8%	**50 - 70**
Chemicals and plastics	21%	990	19	19%	3%	17%	**18%**	5 - 7%	**50 - 70**
Electronics	20%	965	33	34%	17%	90%	**62%**	9 - 13%	**90 - 120**
Machinery	10%	485	8	9%	9%	54%	**32%**	17 - 23%	**90 - 110**
Food products, beverages & tobacco	8%	365	5	6%	5%	30%	**18%**	20 - 27%	**70 -100**
Metals	8%	360	10	11%	5%	30%	**21%**	16 - 21%	**60 - 70**
Wood and paper products	4%	200	2	2%	8%	47%	**25%**	18 - 25%	**40 - 50**
Textiles, leather & wearing apparel	1%	50	0	0%	8%	49%	**25%**	20 - 27%	**c.10**
Others / Not classified	9%	440	13	14%	7%	42%	**28%**	8 - 10%	**40 - 50**
Total Manufacturing	**100%**	**4750**	21	21%	8%	47%	**34%**	10 - 15%	**500 - 650**

Industries	Pressure to automate						
Manufacturing sub-sectors	Net margins (2010-14) [6]	Net margins (2015-18E)	Δ net margins	30yr average age [7]	Current age (2015)	% difference	**(100 = very likely)**
Automotive	4.9%	5.4%	0.5%	6.1	6.5	6.3%	85
Chemicals and plastics	7.0%	7.5%	0.5%	8.0	7.9	-1.4%	72
Electronics	10.2%	10.0%	-0.3%	7.5	9.5	27.2%	80
Machinery	7.9%	6.3%	-1.6%	9.3	10.5	13.1%	86
Food products, beverages & tobacco	9.3%	9.9%	0.6%	8.5	8.6	1.4%	68
Metals	2.0%	2.7%	0.7%	11.8	11.4	-3.7%	72
Wood and paper products	4.8%	7.0%	2.2%	8.0	9.2	13.9%	74
Textiles, leather & wearing apparel	n.a.	n.a.	n.a.	9.2	12.2	33.0%	n.a.

Industries	Current technology penetration [7]					
Manufacturing sub-sectors	IoT PaaS software	PLM software	Cobots	3D printing	AGVs	RFIDs
Automotive	◕	◕	◔	◑	◔	◑
Chemicals and plastics	◔	◕	○	○	○	○
Electronics	◑	◑	◔	◔	◔	◔
Machinery	◔	◑	◔	◑	◔	◑
Food products, beverages & tobacco	◔	◔	○	○	◔	◑
Metals	◔	◔	○	○	◔	○
Wood and paper products	◕	○	○	○	◔	○
Textiles, leather & wearing apparel	○	◔	○	◔	◔	◔

Industries	Relevance factor					
Manufacturing sub-sectors	IoT PaaS software	PLM software	Cobots	3D printing	AGVs	RFIDs
Automotive	1.00	1.00	1.00	1.00	1.00	1.00
Chemicals and plastics	0.25	1.00	0.00	0.00	0.00	0.00
Electronics	1.00	1.00	1.00	1.00	1.00	1.00
Machinery	1.00	1.00	1.00	1.00	1.00	1.00
Food products, beverages & tobacco	1.00	1.00	0.75	0.50	1.00	1.00
Metals	0.75	1.00	0.00	0.50	0.75	0.50
Wood and paper products	1.00	0.75	0.50	0.25	1.00	0.75
Textiles, leather & wearing apparel	1.00	0.75	1.00	0.50	1.00	1.00

Notes:
[1] GFCF data from the World Bank, broken up using data from the OECD and China Statistical Yearbook
[2] Robot penetration indexed against automotive; software penetration indexed against electronics
[3] Weighted average of density in Germany, Japan, France, Italy and UK
[4] Software as a % of investments in private non-residential fixed assets in the US; automotive includes other transport equipment
[5] Automotive software penetration adjusted up according to analyst discretion
[6] Net margins of global GS coverage in each industry, note not entire industry and some companies in the sample have exposures to other industries
[7] Average age data is for the US only
[8] Qualitative assessment of penetration at analyst's descretion (actual penetration may be less or greater)

Source: Goldman Sachs Global Investment Research.

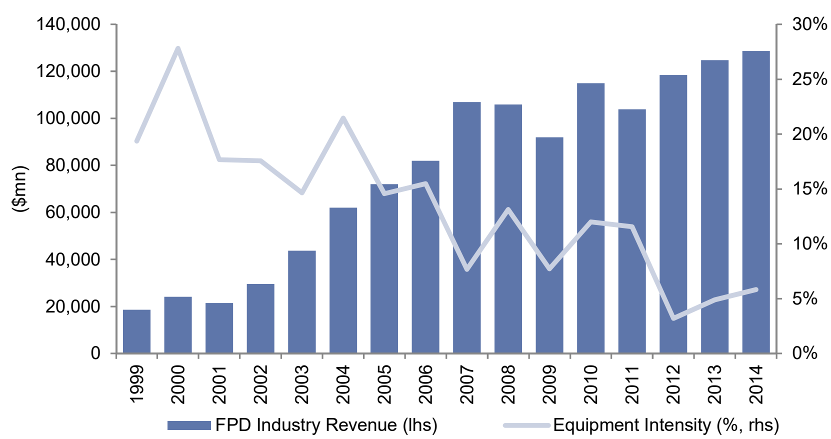
A shrinking addressable market over time

We view the total addressable market as the upper limit of customer budgets (as typically, capex/sales falls over time); accordingly, incremental value for capital goods providers shrinks over time as efficiency-driven innovation progresses and technology prices deflate.

Focusing on the total addressable market and potential business opportunities for capital goods companies, we look at the relationship between IT-related manufacturers and their equipment providers as an example. The life-cycle of IT-related products is short, and we believe the trend in this industry can be viewed as a proxy for other industries.

While markets for IT products such as flat panel displays (FPD) and semiconductors continue to expand, the scale of the markets for equipment used to produce these goods (measured by revenue as a percentage of total end-market capex) has declined to below the historical peak (Exhibit 42). Of interest here, in our view, is that customers such as FPD/semiconductor makers have tended to set investment amounts (or capex-to-sales ratios) for the purchase of capital goods at extremely high levels during the germination period for finished products (more than 20% of sales in some cases). Once this period ends, however, capex tends to enter a downward trajectory as the finished product market expands and matures.

Exhibit 42: Customer budgets have shrunk over the period
Trends in FDP industry sales; % of FPD equipment sales vs. industry sales



Source: Company data, Goldman Sachs Global Investment Research.

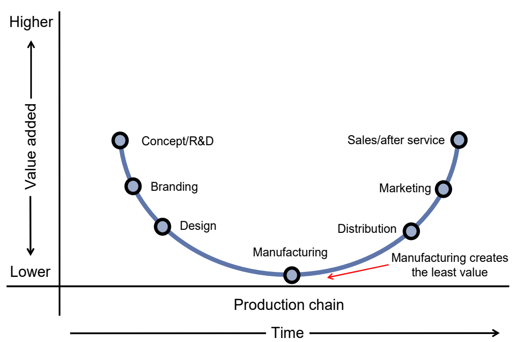
Value-add for the finished products of these manufacturers (customers of capital goods companies) expands as efficiency-driven innovations evolve through development of new technologies, improved yields, economies of scale, and enhanced technical skills among workers. However, selling prices for these products, particularly in IT-related B2C line-ups, nearly always decline, even with substantial evolution in embedded technologies. The performance of today's FPD/semiconductor products is overwhelmingly superior to that of products from 10-20 years ago, and yet the value-added generated by investment in production equipment relative to total finished product is in decline.

FPD/semiconductor manufacturers are entering a mature stage in their industry life-cycle. They are moving towards near full automation in order to remove labour from the production process. However, for capital goods companies, it is apparent that: (1) customers will continue curbing budgets for capital goods beyond what is necessary unless there is ongoing development of new disruptive technologies; and (2) there is likely to be a shakeout of weaker players as capital goods makers compete for these limited capex budgets.

Key for capital goods makers is providing optimal value-added by helping simplify processes to achieve the highest labour cost savings and other efficiencies to which they can tie the value of their products.

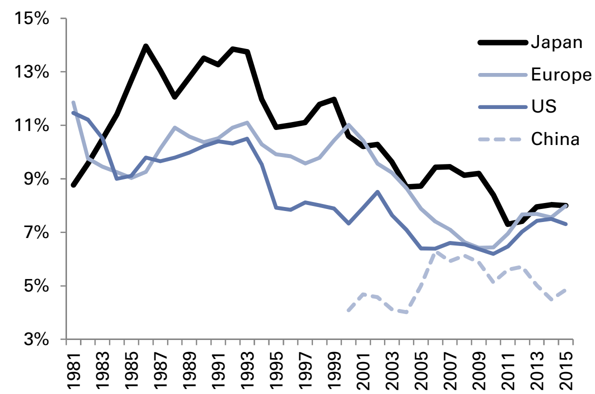
In the smile curve shown in Exhibit 43, which illustrates the general distribution of value-added along the supply chain in the manufacturing industry, production processes are located at the lowest point. In view of the downtrend of capex-to-sales throughout the life-cycle of each product, as mentioned above, it is not easy for capital goods producers to achieve an increase in payments from customers for value added. One solution to this problem is to strive to provide value added to capture investments allocated by customers to other areas. For instance, we think it is important to determine whether or not there are economic rationalisations to be achieved simply by taking fixed operating costs and turning them into depreciable costs.

Exhibit 43: Manufacturing is located at the lowest point of value add in the production process
Smile curve of value added in the production process



Source: *IEC.*

Exhibit 44: Japanese customer budgets entered a downward trajectory once manufacturing had matured
2-year moving average (capex + R&D)/sales for 30 of the largest manufacturing companies today



Source: *Goldman Sachs Global Investment Research.*

A typical example of where capital goods companies have been able to demand a greater share of customer budget was the substantial value-added achieved through introducing industrial robots in the autos industry. The cost of introducing robots is falling each year; we estimate standard upfront costs are now around US$100,000-200,000, including system integration costs. If the depreciation horizon (5-10 years) is taken into account, operating costs fall to a level comparable with labour costs (around US$20,000-30,000 per year). Depending on the size of the customer and production characteristics, the use of robots can have significant advantages over labour in view of their higher productivity and precision, as well as the potential to reduce trade union bargaining power and of course labour costs. In the 1980s, this rationale triggered a sharp increase in the uptake of robots; however, since this 'revolution', the capex-to-sales ratio for the industry has been in decline. For the electronics, food & beverage and machinery industries, we believe FoF technologies are capable of adding significant value and their share of customers' budgets will respond accordingly.

If we scale this analysis up and look at the world's largest manufacturers, using Japan as a case study, we can see how industrial development affects budgets. Since the 1980s, Europe and US customer budgets have been on a downward trajectory. In Japan, during the nascent years of its manufacturing industry, budgets rose and exceeded those of Europe and the US until the broader manufacturing industry matured and budgets also began heading into a downward trajectory. Currently, the (capex + R&D)-to-sales ratio for China's largest manufacturing companies is still at 5%, highlighting where significant opportunities for equipment providers still exist.

Industry-by-industry deep dive

The future of the manufacturing ecosystem will differ markedly for each industry. Influencing factors include: (1) the current level of automation; (2) the market pressures industries are facing; (3) the nature of the products they produce; and (4) other factors such as labour intensity and asset age. Even within each industry, companies are likely to employ different levels of sophistication depending on the products that they manufacture and where the highest leverage in the cost structure stands. While autos has pioneered automation owing to thin margins, even there opportunities remain (e.g. for cross-plant integration). Within underpenetrated industries, we see the highest potential for automation in electronics, food & beverage and machinery.

Automotive – TAM up to US$70 bn

We estimate that around 19% of global manufacturing fixed asset investment goes into the automotive industry, worth around US$900 bn. Regional hotspots include the US, Germany, Japan and China. The automotive industry has pioneered industrial automation from the early 1970s: it is by far the largest market for industrial robots, accounting for 43% of global robotics sales in 2014. Its companies have also been early adopters of the latest technologies highlighted in this report.

In our view, capital goods companies have limited scope to add incremental value in the autos industry given its already highly sophisticated production processes. However, we believe the competitiveness of the industry and the margin pressure that car manufacturers face will continue to place them at the forefront of adopting the latest technologies. Given that the market is dominated by a handful of OEMs, we expect automakers to continue to exert increased pricing pressure on their equipment providers, squeezing capital goods companies. We do not expect OEM capital goods budgets to get bigger, but rather to shrink, reflecting the relentless pressure to reduce costs (with our GS Capex Tracker pointing to a -0.8% capex CAGR for 2015-18E). When making the decision of where to manufacture products, the automotive industry is still highly influenced by tariffs, which are present in all major manufacturing locations.

We believe the two key technologies for this industry given the current levels of penetration are increased usage of automatically guided vehicles and the introduction of collaborative robots.

BMW's automation story

Stage 1: In the mid-1990s, BMW introduced its first large installations of industrial robots and leap-in automation. BMW transformed its production lines from car-body manufacturing to employing hundreds of robots and pushing the level of automation up to more than 80%.

This all came at the same time that substantial developments were made in the computer industry, which also had an impact on Programmable Logic Controller (PLC) technology. The basic automation concept was born to link a centralised PLC together with a number of robots. The robot was completely controlled by the PLC. With much larger installations, machine and human safety became an issue as the PLC capacity became an increasing constraint.

Stage 2: After 2000, Safety PLCs and Decentralised Periphery (DP) were introduced to eliminate this constraint and allow even larger installations with an automation level of up to 97%.

In parallel, the robot controller became more powerful and able to perform additional tasks such as safety-related operations. Software replaced hardware and allowed the robot to operate in a safer way with higher flexibility. At the same time, the mechanics got better, allowing a much higher degree of accuracy. New applications became possible, such as Remote Laser Welding, creating new possibilities for products.

Stage 3: Now, a typical installation at BMW involves between 800 and 1,000 industrial robots able to handle 10-750 kg payloads. Approximately 150 PLCs are connected to the robots and the Master Production Scheduling IT System, allowing one-piece production for up to six different car derivatives on one line. Data-Matrix and Bar-Codes are used to steer the manufacturing of the car body shell. The Master Production Scheduling is held in a Cloud and represents a comprehensive virtual overview of what is happening on the shop floor to guarantee that the customer's car is delivered on time with the correct and individual specifications.

Source: International Federation of Robotics

Electronics – TAM up to US$120 bn

We estimate that around 20% of global manufacturing fixed asset investment is into the electronics industry, worth over US$950 bn. In our opinion, this industry has the greatest opportunities despite its already relatively high levels of automation. If it were to fully introduce the disruptive technologies that we highlight, in particular within the final assembly line, then we believe maximum cost savings to the industry could equate to a TAM of around US$120 bn. This would be a very important contributor in an industry plagued by the challenge of constant product price deflation.

While not to the same extent as in the automotive industry, the manufacturing processes in electronics are already quite mature in terms of automation, and there are powerful customers within this industry. As a result, we predict a similar outcome for capital goods companies in electronics as in the automotive industry: we expect the absolute volume size to remain significant and the industry to be one of the early adopters of new technologies, but capital goods companies' ability to claim some of the profit pool and the growth in customer budgets is likely be quite limited.

While all FoF technologies have significant relevance in electronics, we believe the physical manufacturing technologies (cobots and 3D printing) and in-factory logistics (AGVs and RFID) have the greatest potential.

Machinery – TAM up to US$110 bn

We estimate that around 10% of global manufacturing fixed asset investment is into the machinery industry, worth US$450-500 bn. Similar to the automotive and electronics industries, competition is based on innovation and quality. Machinery also consists of highly tradable goods, where manufacturers have access to global markets. However, volumes are substantially lower than in autos and electronics and machinery manufacturers are not able to take advantage of economies of scale in the same way that those two industries can – this is one of the major reasons why the level of automation is currently relatively low. As costs come down and capabilities improve, we expect to see much greater adoption rates. Starting from a low level of automation, we see machinery as having the potential to be one of the largest addressable markets.

Similar to the automotive industry and electronics, all FoF technologies highlighted are relevant, but we see the most potential for the three with the lowest current penetration: IoT PaaS, AGVs and cobots.

Food products, beverages & tobacco – TAM up to US$100 bn

We estimate that around 8% of global manufacturing fixed asset investment is into the food products, beverages & tobacco industry, worth US$350-400 bn. Food products, beverages & tobacco are manufactured in locations that simultaneously optimise proximity to raw materials and end customers. This is because the products must be fresh and appeal to local preferences. As a result, food manufacturing typically has quite low tradability, although some products such as powdered milk and frozen seafood are heavily exported. As in chemicals (and indeed other process industries), IoT cloud-based platforms for holistic management of plant networks and the use of virtual modelling for plant design and risk mitigation during operations are likely to be the more significant investments in the near term.

In our view, the FoF technologies AGVs, IoT PaaS, and PLM software offer the greatest opportunity. PLM software is used by Coca Cola to design bottles for better CO_2 dispersion and by MWV, a global packaging provider, to reduce the development timeline from 18 to six months.

"The food industry as a whole is probably the next largest sector [for automation] but it is very diverse. Robots are currently mainly being used here in downstream packaging, palletising and logistics and not very much in processes upstream of packaging. There is great potential to use robots in future for handling and processing tasks, such as cutting, positioning, inspection. It is already being done but much less than it could be."

Robotics expert from the International Federation of Robotics Corporation

Metals – TAM up to US$70 bn

We estimate around 8% of global manufacturing fixed asset investment is into the metals industry, worth more than US$350 bn. Metals plants are resource- and energy-intensive and their products are heavy and bulky, so the most important factors for success in those industries include easy access to raw materials, low-cost energy and inexpensive transportation. Similar to chemicals, the longevity of plants delays adoption and some of the technologies highlighted in this report are not appropriate for the industry (as it is characterised by flow type production vs. discrete batches). **We believe PLM software is the most relevant for this industry, but there is also significant potential for AGVs and IoT PaaS.**

Chemicals and plastics – TAM up to USS$70 bn

We estimate that around 21% of global manufacturing fixed asset investment is into the chemical and plastics industry, worth US$950 bn-US$1 tn. Chemicals include bulky, commodity-type products with relatively low trade intensity, but also R&D-intensive pharmaceuticals and cosmetics that have high value density and tradability. The variety of products within this industry requires a number of different production environments, and the size of the opportunity for capital goods providers will vary accordingly.

Chemicals is the largest manufacturing industry in terms of fixed asset investment, and given its size it is a huge market for equipment providers. However, we believe that the chemicals industry will be especially slow to adopt the latest FoF technologies, if at all in some cases. First, a number of the technologies highlighted are directed towards use in discrete manufacturing industries rather than the production of continuous flow liquid or gas processes (e.g. cobots or AGVs). Chemicals scores relatively low on our "pressures to automate" metrics. And second, chemical refineries and plants are particularly risk averse, for two main reasons:

- **The uncertain longevity of new technologies.** According to BASF, the average process plant has a lifecycle of 30 years, compared with 10-15 years for automation hardware and just five years for software. A chemicals plant has to be certain that the technology will last without resulting in downtime.
- **Confidence in cyber-security.** As we are still in the nascent stages of IoT software, the chemical industry has been reluctant to fully adopt the technology. Despite potential productivity gains, in these early days, there is too high a cost of failure to decentralise decision-making, as security breaches raise the possibility of explosions, environmental damage and injuries or fatalities.

Nevertheless, we expect PLM software to be an increasingly important technology for the industry. We also expect an increased adoption of IoT PaaS software; however, this technology is only likely to be used for data analytics/real-time surveillance rather than control actuators (which make decisions) using technologies such as wireless secondary sensors.

Wood & paper products – TAM up to US$50 bn

We estimate that around 4% of global manufacturing fixed asset investment is into the metals industry, worth more than US$200 bn. The manufacturing process is fairly resource-intensive, involving products that have a low value density. This industry is already characterised by high software intensity – above that of automotive and electronics – and it is becoming increasingly automated, particularly in developed markets. **We highlight IoT PaaS software and AGVs as the two most relevant technologies, where AGVs is the least penetrated of the two.**

Textiles, leather & wearing apparel – TAM c.US$10 bn

Accounting for only c.1% of global manufacturing fixed asset investment (worth c.US$50 bn), the textiles, leather & wearing apparel industry is the smallest industry we look at. Textiles, leather & wearing apparel is the most labour-intensive industry in our analysis, and so far, companies have typically responded to rising wages by moving to lower-cost locations. For example, we are seeing dramatic growth of textile industries in countries such as Cambodia, Bangladesh and Vietnam, as companies leave countries with rapidly rising wages, including China. However, given the very low level of automation, **we expect the industry to benefit from labour-reducing technologies: cobots and AGVs. RFID and IoT PaaS are also important technologies.**

Winners & losers

- Increasing factory floor digitisation leaves room for more players in the manufacturing arena, beyond the traditional capital goods companies
- As new players emerge, we are likely to see more M&A, redefining the competitive landscape
- New business models will also emerge, as localisation, customisation, predictive management and control and monitoring are facilitated, but will likely also drive deflationary pricing pressures in traditional hardware

New players, new business models

We expect more players to serve the market for future manufacturing technologies than the traditional capital goods equipment providers that have dominated the past decades. The boundaries between software/connectivity providers and hardware equipment are blurring. As this happens, we expect M&A to increase, as well as new business models to emerge through new aftermarket services and data analytics consulting. Regional balances in manufacturing are also likely to be challenged, with EMs that are pressured on cost leadership likely to adopt some of the newest technologies more quickly.

New players emerging

The flip side of digitisation is that software allows for better optimisation of current asset bases by increasing utilisation rates, reducing the need for capital goods, and introducing a new set of formidable competitors: the SAPs and IBMs of this world. As the world of capital goods goes increasingly digital, the incumbents need to navigate a fine line between the opportunity and the threat of digitisation.

The opportunity sounds huge, but it is not free of challenges. Perhaps the most important one for capital goods companies will be to grow fast enough and reach sufficient size to offset the cannibalisation effect of better-optimised factories resulting in less demand for 'hard' equipment. For instance, increasing the utilisation of a fleet of compressors from 50% to 80% (through connecting it to an IoT PaaS) would reduce the number of compressors needed by close to 40%, but would not materially change the service needed and would involve substantial IT investments. Both servicing and IT investments are not necessarily only provided by the manufacturers of equipment.

Second, some of the FoF-enabling technologies, such as software, are not exclusively provided by traditional capital goods companies; indeed, the likes of IBM, Oracle and SAP are increasingly trying to penetrate markets traditionally served by electrical and machinery makers. Capital goods companies have the advantage of understanding how the physical assets of their customers work, but lag on the software side of engineering skills vs. the big IT providers.

Cisco expands IoT presence with cloud-based service platform provider Jasper

What is Jasper? In March, Cisco completed the acquisition of Jasper Technologies, a cloud-based IoT service platform, for US$1.4 bn. Jasper allows both enterprises and service providers to automate management of IoT services and drive monetisation on a global scale. Jasper currently has over 3,500 enterprise customers and works with 27 service providers in over 100 countries. The company targets a wide range of verticals including automotive, home automation, and manufacturing; customers include General Motors and Garmin. On the service provider side, per a 2014 Infonetics report, Jasper is among the key technologies supporting M2M platforms for AT&T, China Unicom, Telefonica, and Telenor. Jasper delivers its platform through a 'Software as a Service' revenue model.

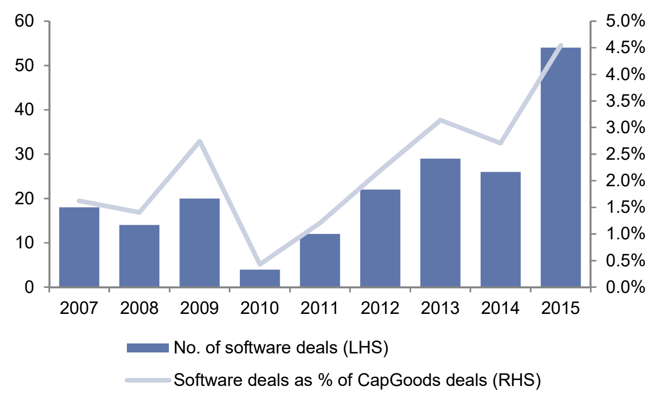
What does it mean for Cisco? Cisco intends to wrap Jasper's platform into a holistic IoT solution by layering in additional services including enterprise Wi-Fi, security for connected devices, and analytics to add-in device management. We view Jasper's platform as complementary to Cisco's existing IoT product suite. Recall that over the past several years Cisco has invested over US$1 bn in this emerging opportunity, which was generating US$2.4 bn in annual sales and growing at 45% per annum (per IoTWF in October 2014).

More corporate action to come

Finally, it will be difficult to drive a meaningful earnings contribution from software and more connected assets in the near term purely through organic actions. This leaves M&A

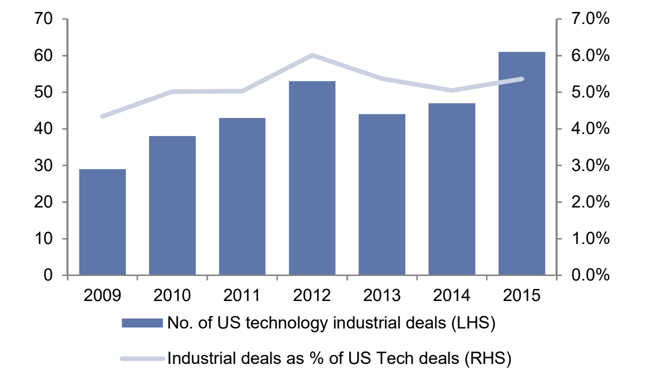
as one of the main levers companies are likely to use to tackle this opportunity. Several deals over the past few years in the capital goods sector highlight that there is already a focus on this: ABB acquired Ventyx and Mincom, two providers of enterprise software solutions for asset monitoring, in 2010/11; Schneider acquired Telvent, a provider of software for asset management, in 2011; Teradyne acquired Universal Robots in 2015; and Amazon acquired AGV maker Kiva in 2012. Within the sector, the ability to generate value from transformative deals has varied significantly by company. We believe the companies that can generate cash more quickly through their current portfolios will be better positioned to benefit from this inorganic opportunity; as tech companies enter the industrial space, we expect to see more M&A from industrials into tech as firms try to stay ahead.

Exhibit 45: Sector boundaries are blurring…
# of deals where cap goods companies acquire software targets



Source: Bloomberg, Goldman Sachs Global Investment Research

Exhibit 46: …as US tech companies target manufacturing
# of deals where US tech acquirer targets industrial targets



Source: Bloomberg, Goldman Sachs Global Investment Research

The emergence of new business models

For equipment makers to succeed in the next phase of manufacturing, a first-mover advantage and leveraging the installed base will be key. Digitisation will affect companies in different ways. In an environment with less growth and more EM competition, installed bases will increasingly be the key competitive advantage for global capital goods companies. Those that already have a high penetration of services and maintenance in their sold equipment have a quicker lead into understanding what revenue streams can be levered/protected by better device connectivity. Taking history as a guide, we believe that whether digitisation turns out to be an opportunity or a threat will ultimately reflect each company's underlying ability to reinvent itself. We see companies that have a good knowledge of their installed base and a superior ability to redeploy capital as better positioned (as highlighted in the Competitive Positioning metrics presented in our report *Preparing for the next industrial revolution*, April 28, 2014). Which players are able to capture the benefits of the exponential creation of data in the industrial space remains to be seen, but three benefits appear almost certain for those that can:

- **Controlling data** will probably mean **more customised value-add client interactions.** Data gives companies capacity to be more proactive in addressing customer issues.
- **More frequent** client interactions most likely mean **more resilient revenue streams…**
- ...while more customised value-add client interactions usually mean **better margins and returns.**

As machines take over, business models will need to evolve quickly. In developed markets, the penetration of PCs, tablets, and smartphones is now almost complete, with 75% of people in the United States having access to mobile broadband internet. This phenomenon has changed the way we work, communicate and consume so much that it is difficult to remember what it was like in the 1990s. As unintuitive as it sounds in the era of Facebook, Google and SAP, the vast majority of capital goods companies still interact with their installed base and customers in the same way we interacted with each other in the 1980s. For the majority of industrial companies, if equipment needs servicing, customers will call an onsite technician. But this is all about to change. What the IT revolution has done to how humans work and communicate over the past 20 years is now happening to machines; and it has the potential to be as revolutionary to how machines operate from day to day as it has been for us. In our view, this is likely to disrupt many business models for the companies that produce and maintain these machines, creating business opportunities for the companies that best utilise the data and, just as it has for consumers, imply deflationary pressure on "like-for-like" products. Innovation will need to be faster and business models more agile, and, most importantly, the way capital goods companies interact with their customers will have to change.

However, when we look back historically, multi-industry capital goods companies have a track record of reinventing themselves and some of them are already on that path again with their latest digitisation-related deals.

IoT allows Kaeser Kompressoren to shift to a more competitive equipment-as-a-service business model

The challenge: Like any traditional manufacturer of capital goods equipment, Kaeser was searching for incremental revenue drivers to optimise its capacity in the face of slowing end markets.

The solution: A few years ago, it began incorporating sensors in its compressors and examining the data it collected in a SAP IoT platform as a potential source of incremental revenue. It started by building a predictive maintenance programme, but ultimately it completely reinvented its way of selling its products while simultaneously increasing its customer base: selling compressed air, instead of air compressors. This shift opened up the compressor market opportunity to smaller customers for which the decision to buy compressors would mean too much of a capital commitment; instead, these customers can tie their investment to their revenues (i.e. pay for the air as they use it). Sensors and big data made it possible for Kaeser to build the platform for this new business. Furthermore, this new business model encouraged the company to be more cost conscious: as the machines are no longer the revenue-producing element and customers pay for uptime, having faultless compressors that do not require any onsite service is the primary goal (i.e. Kaeser makes material savings on service staff).

The expected winners – large installed bases; data analytics leaders

We do not have a clear-cut answer on whether hardware or software providers will win the race to capture value from higher automation. What is clear to us is that hardware makers with large installed bases will have a privileged position and software providers with big data analytical expertise can make meaningful inroads. In the short to medium term, the need for equipment to upgrade capex may benefit the hardware makers, but we believe that over the long run, more of the technologies profiled will make the manufacturing system more optimised, longer lived and ultimately in need of lower capex.

Leading hardware makers could leverage their large installed base and provide production process/product optimisation services based on big data collected from their equipment. Most major Western capital goods companies are already ramping up their software teams and R&D spending in order to be prepared for this.

The largest beneficiaries will likely be the key component makers for enabling input technologies, such as those in the semiconductor/sensor industry, as the billions of machines to be inter-connected will create a substantial opportunity for their product. Providers of integrated Enterprise Resource Planning and Manufacturing Execution System software should also benefit from more data being available, which will drive upgrades of capacity of existing systems.

Where will it be built? Challenging regional establishments

The past three decades have seen unprecedented levels of globalisation as companies from developed economies relocated their manufacturing practices to lower-cost emerging markets.

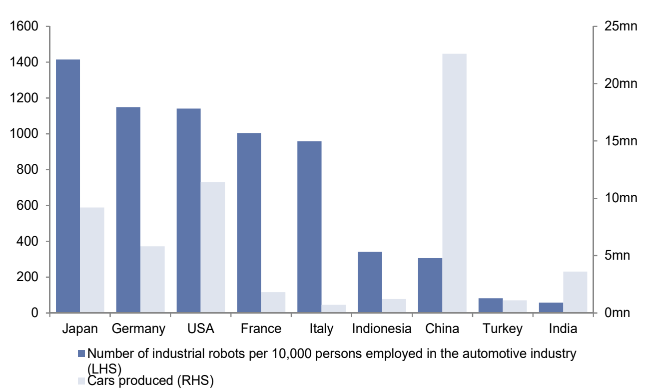
We expect the future of manufacturing to be less labour-intensive, although more skilled labour will be needed. Speed to market will become increasingly important and we expect transport costs as a percentage of total costs to increase. Therefore, some of the motives that fuelled globalisation in recent years are no longer likely to influence decisions. Instead, we expect a critical factor to be manufacturers' need to be closer to their customers. Does this mean we will see a wave of reshoring? Not necessarily, as most of the growth in new customers is still coming from emerging economies.

China: The factory of the world

China is still the largest major manufacturing centre in the world, representing 30% of global manufacturing GDP. Chinese companies have been talking extensively about Industrie 4.0, but we think most companies have yet to complete the 3.0/automation stage. Shanghai Highly Group, for example, one of China's largest compressor manufacturers, started to employ Industrie 4.0 in its production process, but a lack of big data analytical capacity/platform has limited its efforts to move towards intelligent administration and intelligent production.

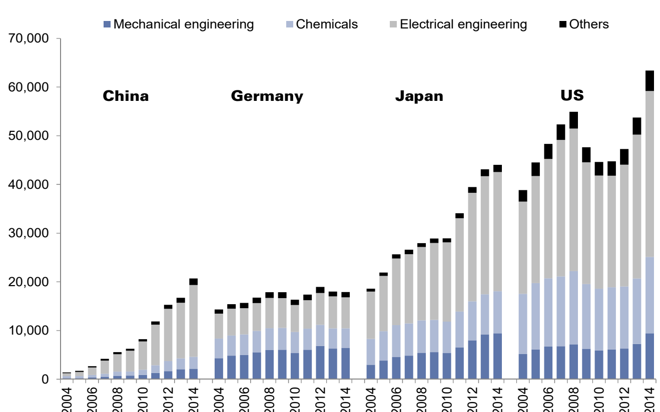
Automation is still low in China, and while the labour cost gap is narrowing, the country still benefits from significantly less expensive talent than in DMs, suggesting a continued incentive for a slow conversion of manufacturing from manual to automated. In our analysis of customer budgets, we note that the capex-to-sales ratio of manufacturing companies is still much lower than that of the mature DM manufacturing companies.

Exhibit 47: Robot penetration varies markedly even in autos
Robots per 10,000 workers vs. cars produced in 2014



Source: IFR, IHS Global Insights, Goldman Sachs Global Investment Research.

Exhibit 48: China's technology gap may be narrowing in electrical engineering but mechanical engineering is still far behind
Patent Cooperation Treaty application by country



Source: World Intellectual Property Organization.

What about the west?

The US and Germany continue to lead several new technological developments, although even in these areas China is catching up. As our GS SUSTAIN team argue in their report *Germany AG: Don't look back* (September 16, 2015), corporate Germany's leadership in 'premium hardware' has been a key driver of its success over the last decade. However, the "premium" element of hardware will increasingly be defined by the software and servicing elements attached to it. This transition introduces new and formidable competitors, changes what constitutes a successful business model, and more broadly puts Germany's competitive advantage "up for renewal". In its core areas of strength, autos, capital goods and consumer durables, Germany's corporates need to lead this technological transition in order to sustain their leadership. The rise and fall of Germany's consumer electronics industry provides an example of the risks involved in not keeping pace with disruptive change.

Asia's Automation Future

Over March 9-29, we hosted a factory automation tour, visiting 26 factory automation-related companies in Japan and China. Below, we highlight examples of how manufacturers in Asia, previously renowned for low labour costs, are in the midst of rapid change to become the factories of the future.

Best in class of Asia part 1: New Chinese factories are among the most automated in the world

China is now experiencing the kind of rapid change that previously forced Japan and other developed economies to increase factory automation. The pace at which it is happening in China is eye-catching. In addition to rising personnel costs and other fixed costs, automation is being driven by demand for higher quality and precision, and limits to economies of scale.

China's auto industry is the most conspicuous example. Typically speaking, the auto industry has the highest automation rate (robot penetration) of all industries. What is noteworthy is that the new auto plants in China actually have the highest penetration rate of robots across the globe.

For example, Nissan's Dalian plant, its newest plant in China (production started in October 2014), has a robot penetration rate of 83%, the highest of any Nissan plant in the world. By contrast, the robot penetration rate at Nissan's Huadu plant, which started production in May 2004, is still around 56%. Local company Geely Auto is aggressively automating/installing the newest machines in stamping, welding, and painting processes at its new Ningbo plant, which was undergoing renewal to make the new model "Pore". The reason for the aggressive automation on these processes is that these are critical determinants of vehicle performance. Geely Auto has installed the newest foreign capital goods/machines instead of Chinese local machines. The plant has monthly production capacity of around 150,000 units and uses more than 100 spot welding robots; a ratio on a par with that of foreign automakers' plants.

Best in class of Asia part 2: Penetration is uneven and initial investment is still large

Automation penetration in China's electronics industry is very uneven. Shortening return on investment periods and decreasing fixed-cost burdens are key factors in the semiconductor fabrication space. Having the newest SPEs/fully automated production lines is critical to make the latest/most advanced nodes, and manufacturing in China is no exception. Yet, the rate of automation is much lower on high-volume products with wider processing nodes (for devices used in autos or conventional electronic applications) and among Chinese companies, as they try to balance the fixed cost burden by leveraging manual labour/assemblies and second-hand SPEs.

Chinese electronic manufacturing service (EMS) companies have strengthened their market presence in recent years. The level of automation in EMS plants is on an altogether different level to that of traditional industries, particularly for smartphones, where annual production runs to several tens of millions of units. Hon Hai, China's largest EMS company, procures thousands or even tens of thousands of production machines from different FA companies every year, i.e. the number of robots in a single-product new auto plant is typically in the hundreds. In contrast, an EMS may have to introduce thousands more robots to make a new product.

Best in class of Asia part 3: Factories of the future may appear sooner than expected

Given China's supportive policies, we think a factory of future may appear in China sooner than expected (even though it may not be justified economically yet). A leading system integrator has stated that it is in discussion with a provincial level government industrial investment fund (Rmb20 bn AUM) to build a highly automated pilot factory, fully funded by the aforementioned fund, to set an example for the manufacturing industry for that region. The factory is supposed to include hardware and manufacturing software that is as advanced as possible and may become a general manufacturing services provider, or a factory that manufacturers in the region can rent in a flexible manner.

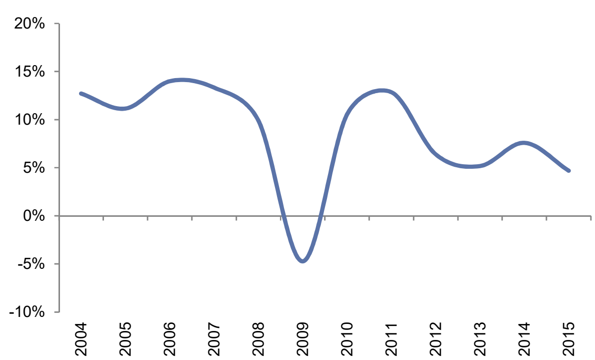
Drivers & barriers

- Rising labour costs, global competition and customers' demand for customisation and immediate access to products are the major forces behind the latest FoF technologies being adopted.
- Still, lack of standards, young asset bases and social pressure from potential unemployment make the road to the optimal manufacturing landscape potentially longer than technological developments alone would allow.

Ten reasons why we are talking about the 'Factory of the Future'

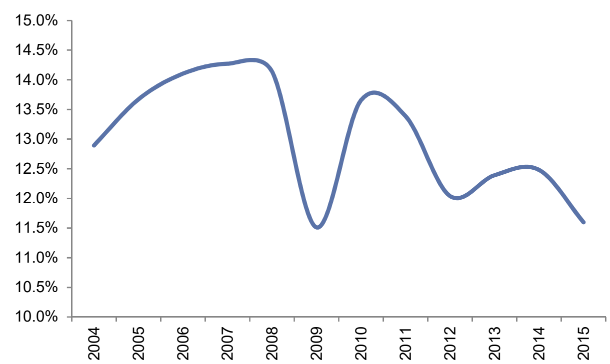
As growth slows post a 15-year super-cycle, all eyes are on the manufacturing sector's margins and returns; we expect these to stagnate over the coming years as operating leverage fades and fixed costs continue to rise (especially labour). Unsurprisingly, the problems have been exacerbated by increasingly unproductive assets, partly owing to legacy assets in DMs and to overinvestment in EMs. Manufacturers will have to increasingly focus on fighting labour cost appreciation in a world where specialised manufacturing talent is becoming scarcer, despite increasingly demanding customers and pressure on companies to return more cash to shareholders. The good news is that more efficient manufacturing practices are now being treated by governments as a priority for nations to stay competitive, and unprecedented developments have taken place in sensing capabilities (the key enabling technology for the Factory of the Future).

Exhibit 49: Slowing growth in manufacturing…
Average of >800 GS covered manufacturing companies' sales growth



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 50: …has put returns under pressure
Average of >800 GS manufacturing companies' CROCI



Source: Company data, Goldman Sachs Global Investment Research

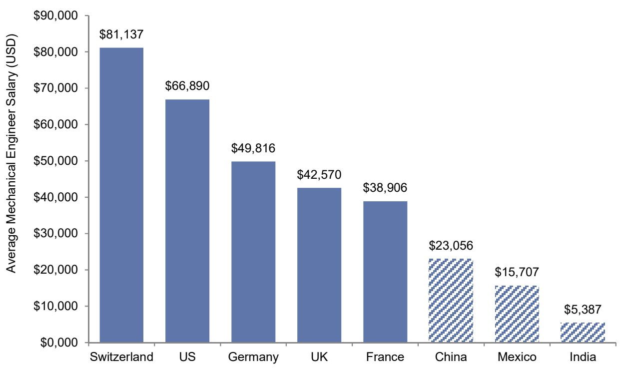
1. DMs need to bring down costs to remain competitive vs. EMs…

The average DM manufacturing hourly labour cost is still more than three times higher than the average manufacturing wage in China. The wave of globalisation over the past three decades has seen a shift of manufacturing to low-cost centres in EM as DM labour costs kept rising. More than half of global fixed investment is now in EMs and the growing threat of EM competition, which is climbing up the value chain, is very real for a number of western incumbents (for example, Chinese rail manufacturer CRRC is now more than 3x bigger than the largest western manufacturer). In the face of continuing labour cost increases, DM manufacturers must adopt the latest technologies and enhance productivity to remain competitive.

2. …but rising EM wages are reducing the 'low-cost location' edge

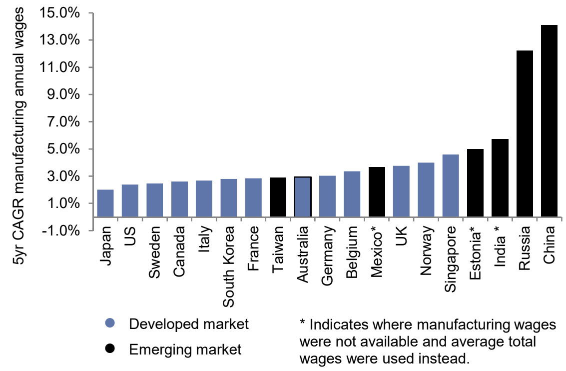
The by-product of economic development and wealth creation has been EM labour cost inflation far outstripping that of alternative manufacturing locations. Although the cost advantage is still significant, we expect it to continue to narrow as wages rise. In order to maintain or increase their share of global manufacturing, EM factories need to evolve to remain competitive. Several are actively targeting higher efficiency (e.g. Foxconn, one of China's largest employers, which now designs, manufactures and deploys its own robots has stated its desire to have a "robot army").

Exhibit 51: Labour costs in DMs significantly exceed EMs...
Annual compensation for a mechanical engineer



Source: PayScale (January 2016).

Exhibit 52: …but in EMs, the cost advantage is quickly narrowing
5-year CAGR of annual manufacturing wages in local currency

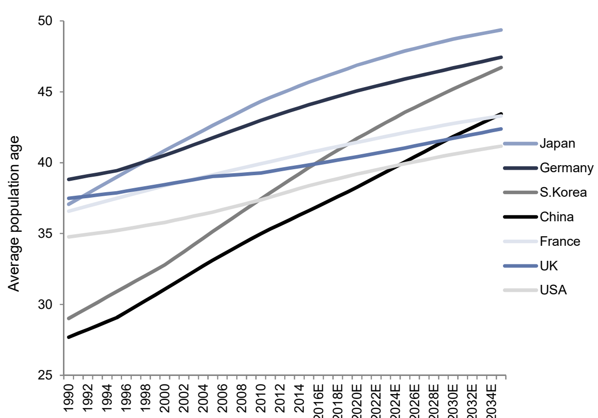


Source: International Labor Organization, Haver, Trading Economics, Eurostat.

3. Specialised manufacturing labour is increasingly scarce

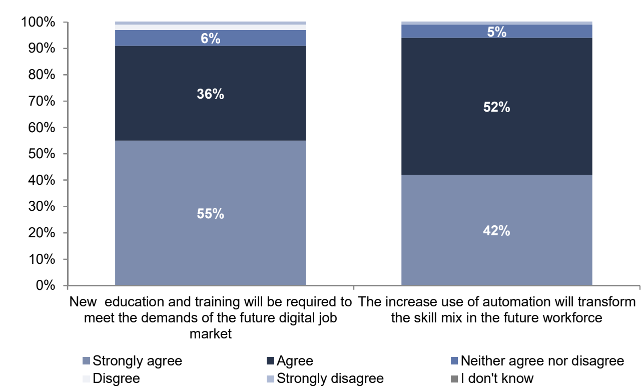
Not only rising labour costs are forcing higher adoption of technologies to streamline manufacturing costs; there is also a growing shortage of skilled manufacturing labour, as noted by 84% of executives interviewed in the US recently by the Manufacturing Institute. They noted that six out of ten open skilled production positions are unfilled owing to a shortage of talent. The scarcity of specialised labour is exacerbated in the largest manufacturing nations by ageing populations and in EMs by a reduced desire among younger generations to work in factories. By 2030, McKinsey expects a shortage of both highly skilled workers (engineers, technicians) and medium-skilled workers (technicians, factory workers) in Brazil, China and India – driven by the rapid growth in knowledge-intensive manufacturing.

Exhibit 53: The labour force is ageing…
Average age of population



Source: UN, Goldman Sachs Global Investment Research .

Exhibit 54: … and skills required are changing
Survey of 250 industry executives regarding the future of talent (2015)



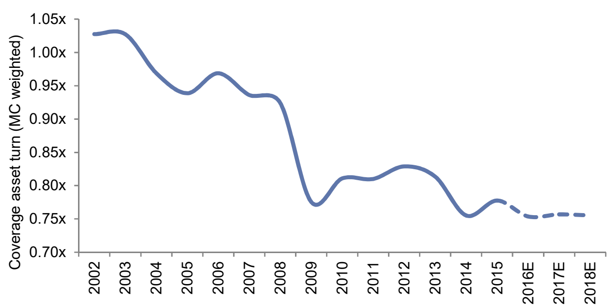
Source: World Economic Forum .

4. Productivity is a differentiator in a world with legacy capacity

The past 15 years saw an unprecedented level of fixed asset investment globally. This was driven primarily by material investment in Chinese infrastructure, and we do not expect it to be repeated over the next decade (see our report *Capex Tracker: No end in sight to the capex slide*, September 18, 2015). Simultaneously, this investment wave drove a new set of low-cost competitors to emerge in key capital goods areas such as electrical equipment, rail and chemicals production. This has led to overcapacity across many global industries, including general industrial manufacturing. One of the key benefits of the upcoming manufacturing technology profiled in this report is not just that it can bring down costs, but that it can increase the total potential output per unit of equipment, allowing companies to improve returns by cutting capacity, but still fulfilling demand.

Furthermore, capital goods companies that serve manufacturing need to move in two interlinked ways: (1) increasingly penetrate their installed bases; and (2) find new services/products to differentiate their offer vs. old and new competitors. The “digitisation” of many products and services is in the sweet spot for this.

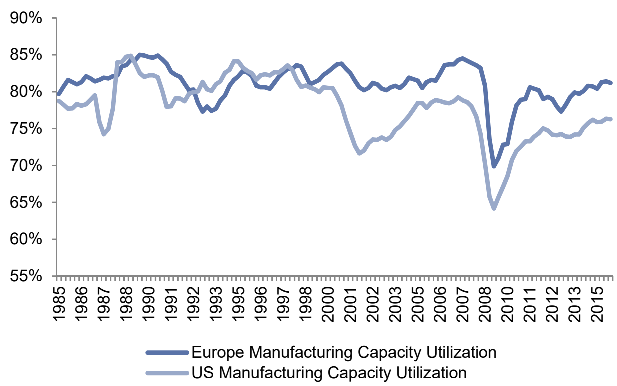
Exhibit 55: Productivity is at a trough…
Market cap-weighted asset turn (sales/GCI) for GS global coverage ex-financials



Market cap weighted asset turn (sales/GCI), GS analyst forecast for global coverage (ex-financials)

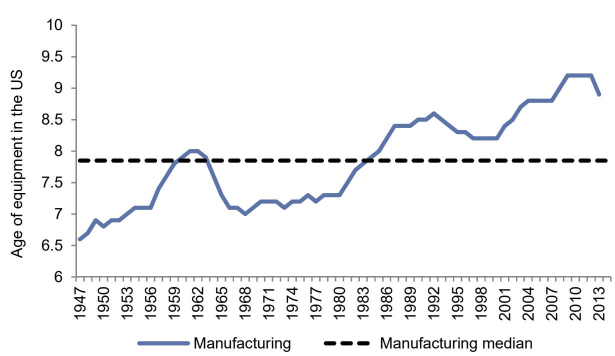
Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 56: …and manufacturing capacity utilisation remains low…
US and Europe manufacturing capacity utilisation



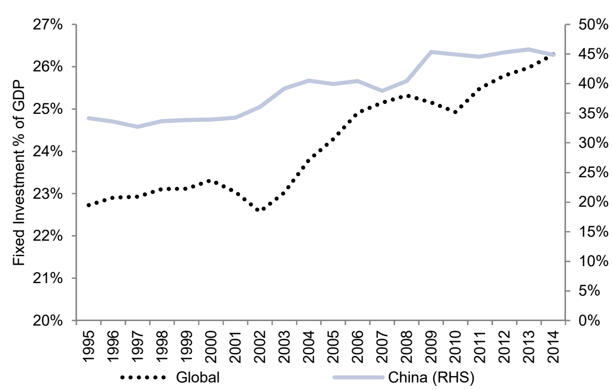
Source: Federal Reserve, Eurostat.

Exhibit 57: …in DM owing to legacy assets…
Average age of manufacturing assets in the US; 1947-2014



Source: BEA

Exhibit 58: ...and in EMs owing to overinvestment
Fixed investment as a % of GDP; global and China



Source: Haver, Goldman Sachs Global Investment Research.

5. There is an increased push to shorten time to market, particularly by eliminating stranded inventories

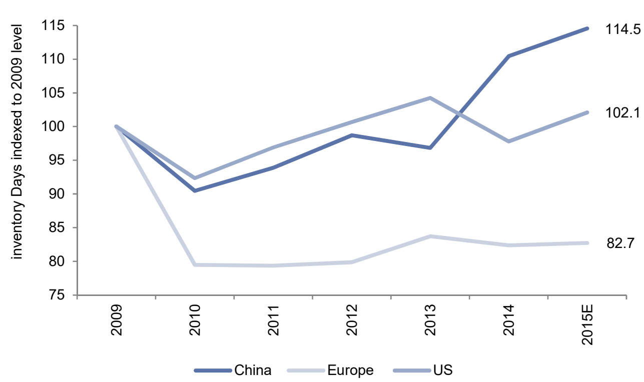
Lengthy product development times are costly and manufacturers are rapidly shortening their time to market. Maserati, an automotive brand of Fiat Chrysler, has reduced time-to-market to 16 months from 30 months by introducing some of the latest FoF technologies. Today's market environment means information comes faster and is more accessible than ever, and that customers now expect products sooner.

Faster time to market also means a lower gap from order to delivery on a day-to-day basis. This is a key source of being able to generate better return on capital for a manufacturer, especially when available capacity is not scarce. Technologies that can integrate communication between suppliers, manufacturers, distributors and the final customers are a powerful tool to eliminate stranded inventories. Atos, an IT services provider, estimates that manufacturing IoT platforms can reduce idle time by up to 58%.

"Industrie 4.0 basically takes the cost of scale close to zero. No matter what lot size you need, the unit cost is about the same. At some point, what will happen is this: You are a consumer and you want to buy a car. You go to the Internet, put your specs together, and send that order to BMW. Someone will check your credit history and your funds. Then, your car will go straight to production and the factory will build it to order. Four weeks from now, you will have a car. No more waiting six months or compromising at the dealership, where they have 50 cars but not the one you want."

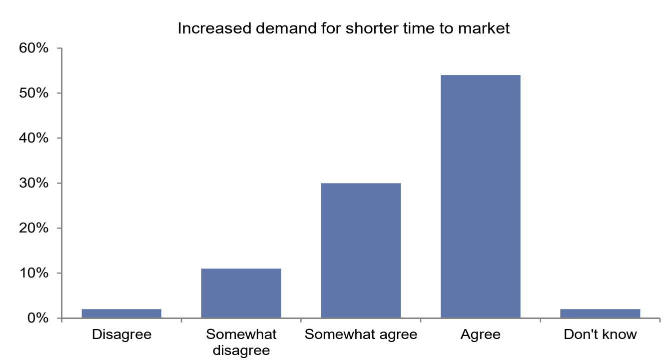
Joe Kaeser, CEO of Siemens, on the future of manufacturing

Exhibit 59: Overall inventory levels have not materially declined outside Europe over the past years
Inventory days across GS manufacturing coverage by region



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 60: Demand is rising for shorter time to market
Survey of 100 companies (2015)



Source: 3Gamma

6. Customers demand unprecedented customisation

Personalisation today is used as a competitive tool to capture sales, and is something that customers look for to distinguish their purchases. In addition, the growth of consumers from emerging markets, encompassing a diverse range of cultural and ethnic groups, increases the complexity of manufacturing in order to appeal to these new large markets. Finally, manufacturers must also prepare for further proliferation of models and greater customisation driven by shorter life cycles.

Exhibit 61: Customers are demanding personalised products
Combinations available for a customer buying a Ford F150 pickup

Equipment options	Variants	Theoretical combinations
Trim	6	6
Passenger compartment	3	18
Power train	2	36
Cargo space	4	144
Engine	3	432
Transmission	3	1,296
Rear axle ratio	7	9,072
Wheels	9	81,648
Tires	8	653,184
Seats	18	11,757,312
Power seats	2	23,514,624
Radio	5	117,573,120
Running boards	4	470,292,480
Rear windows	3	1,410,877,440
Colors	12	16,930,529,280
Interior trim colors	3	50,791,587,840
16 individual options	12,870	**653,687,735,500,800**

Source: Siemens.

7. Focus on safety and security has increased significantly…

The emphasis on worker and product safety has scaled up significantly over the past few years. A more automated, controlled and less labour-intensive environment will reduce the likelihood of accidents and costly litigation. In addition, factories have to be safe from cyber-attacks given the increasingly important role data plays in the manufacturing process.

Exhibit 62: High costs of safety incidents…
Cost to society of work injuries in the UK (£ in 2013 prices)

	Human cost	Financial cost	Total cost
Fatal injuries	£1,153,000	£421,600	**£1,574,600**
Non-fatal injuries	£4,600	£2,900	**£7,500**
7 or more days absence	£17,600	£10,100	**£27,700**
Up to 6 days absence	£330	£550	**£880**
Ill health	£9,900	£8,700	**£18,600**
7 or more days absence	£20,100	£17,300	**£37,400**
Up to 6 days absence	£290	£560	**£850**

Source: HSE.

Exhibit 63: …and increased focus on security
Survey of 3,382 IT executives in Asia-Pacific; % answering "increase 5-10% or more"

Source: Forrester.

8. …and some governments are actively pushing to stay ahead in manufacturing

In a globalised world with lower trade barriers, scarcer demand and more supply, different countries have to fight hard for competitiveness to be suppliers of choice for manufacturing. We have seen numerous initiatives over the past few years that stress this.

For example, Germany has introduced the Industrie 4.0 initiative, representing the fourth industrial revolution, through which it is promoting the concept of 'smart factories'. The use of cyber-physical systems and the communications between components allow for less centralised process management, providing significant quality, time, resource, and cost advantages in comparison with traditional production systems. Industrie 4.0 was a term that originated in industry, but the initiative has received backing by the German government and is a key feature of its High-Tech Strategy 2020 Action Plan.

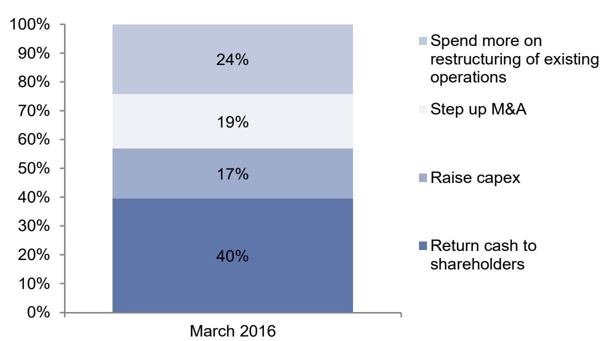
"China Manufacturing 2025" is another example of a government initiative to advance national manufacturing industries. The objective is to move up the value chain, highlighting ten specific industries, centering on five projects: (1) build national/provincial R&D centres; (2) promote intelligent manufacturing pilot programmes; (3) fix the weak link between components, crafts and materials; (4) promote green manufacturing and energy saving; and (5) promote high-end equipment innovation.

In the US, there are several initiatives to promote advanced manufacturing, including the Smart Manufacturing Leadership Coalition, the Industrial Internet Consortium and the Advanced Manufacturing Partnership.

9. Short-term demands from shareholders for dividends and buybacks puts further strain on cash available for organic growth

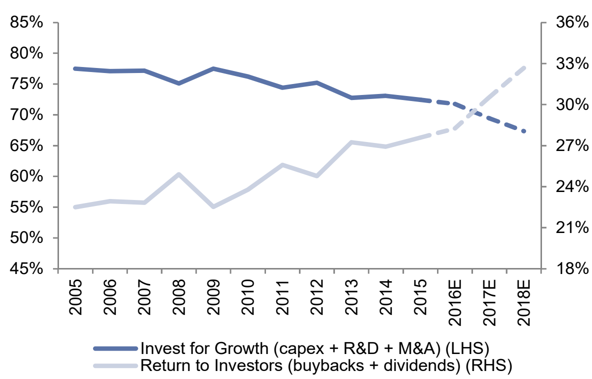
Short-term macro uncertainty and a lack of visibility on growth have led to increasing demand from investors for cash returns from corporates (dividends and buybacks). While this might not be a sustainable means of capital allocation in the long term, it has weighed on short-term considerations for corporates and put further pressure on their ability to optimise FCF generation through more productive capex.

Exhibit 64: Investors prefer dividends/buybacks…
GS European Industrials survey of 57 investors



Source: Goldman Sachs Global Investment Research

Exhibit 65: …and companies are listening to them
OCF used to invest in growth vs. returning to shareholders

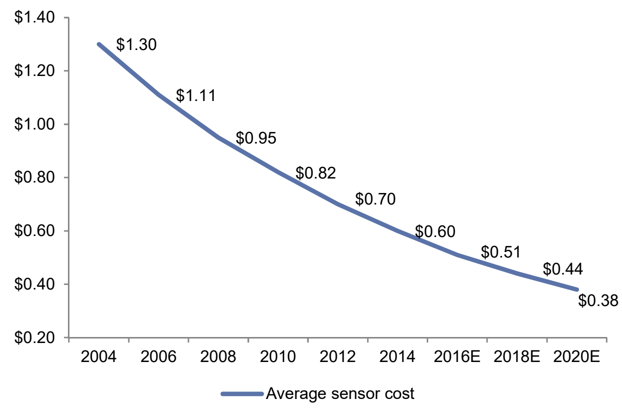


Source: Company data, Goldman Sachs Global Investment Research

10. Finally (and most importantly), key technologies now exist for fully optimised and connected manufacturing

Rapid improvements have taken place in the capabilities of a number of technologies, which have the potential to drive substantial change in factories across the world. While the cost of some technologies has fallen sharply, partly due to the smartphone revolution, widespread adoption is becoming increasingly likely. For example, processing costs have declined nearly 60x over the past ten years, enabling more devices to analyse data. Sensing technology development in particular has meant that many manufacturing industries are at the start of a period of unprecedented change. According to McKinsey, the price of microelectromechanical sensors has declined by 80%-90% over the past five years. Sensors are the key bit of hardware that bridges the digital world with the real world, and declines in sensor prices have also spearheaded declines in the prices of other manufacturing technologies, such as robotics – with claims by some industry participants that prices have declined by up to 10% pa in recent years.

Exhibit 66: In general, the cost of sensors has more than halved over the past decade, with the decline being even more pronounced for specific sensor applications in manufacturing

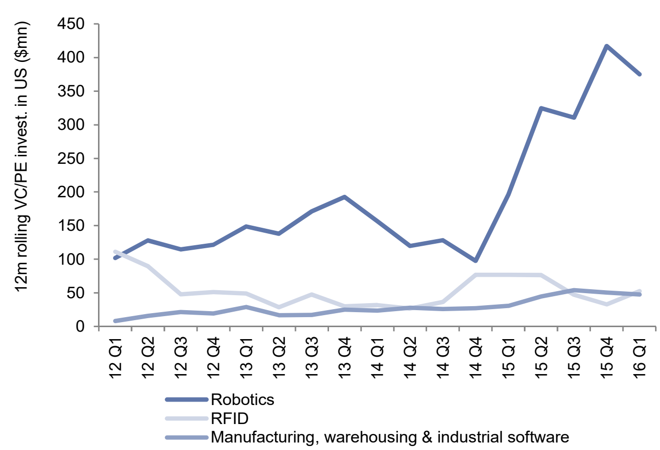


Source: Goldman Sachs Global Investment Research, BI Intelligence.

Venture capital investment in robotics and software is heating up

Venture capital and private equity investments in robotics have picked up in recent years, and manufacturing, warehousing and industrial software investments have also risen significantly, albeit from a low base. Unsurprisingly, given the maturity of RFID technologies, VC/PE investment remains stable. However, this makes up only a small fraction of the US$400 bn+ in venture capital and private equity deals completed in 2014 (where more than 70% were in software-related businesses, healthcare and telecoms).

Exhibit 67: Investment in robotics and software is heating up
12m rolling VC/PE investment in the US (US$ mn)



Source: CBInsights, Goldman Sachs Global Investment Research

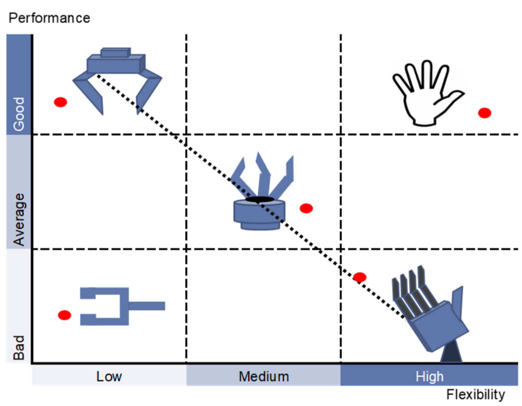
What could derail it?

Manufacturing is entering a decade of significant change and we have tackled some of the latest technology developments. However, predicting the future of manufacturing comes with innate challenges, as no-one can predict the full impact of technological innovation. Technologies are adopted at unpredictable rates and entirely unexpected applications can arise and dominate their uses. Below, we highlight the potential barriers to adoption that could derail the evolution of manufacturing:

- **Lack of one single protocol and standard** has been a recurring concern for a number of suppliers and customers. This includes, for example, a commonly understood programmable robotics language and allowing compatibility/integration between the machines of various suppliers. For example, looking back at the electronics industry, PCs only became widely adopted once the systems were standardised and user-friendly.
- **Lack of incentives owing to excess capacity in manufacturing industries** could prevent adoption of/investment in new technologies. We highlight that while capacity may be not be stretched, pressure on margins is likely to drive disruption in manufacturing in order to increase operating leverage.
- **Limited cost deflation:** There is currently a clear deflationary cost trajectory for many of the key technologies, but there is no certainty that this will continue.
- **Potential effect on employment may generate social and political unrest.** Ultimately, one of the key incentives to automate is to reduce wage costs. In China, for example, over 230 mn people are employed in manufacturing jobs: the social repercussions could be significant if unemployment were to rise rapidly should the labour force not have time to adapt and find alternative work.
- **Longevity of capital goods assets postponing adoption.** The rapid progress of technological innovation in manufacturing could be delayed by the longevity of the capital goods inputs (the average industrial robot lasts 12-15 years). If the benefits of employing new equipment do not strongly outweigh the total costs incurred (including installation costs, prior arrangement redundancy costs and fixed infrastructure adjustments), investment may be delayed.
- **Decreases in demand for traditional industrial capex products** as we shift towards more opex-driven business models (e.g. equipment as a service). Firms may not wish to make the heavy investment needed to automate their factories. We note automation capex will ultimately reduce opex.
- **IP issues could prevent the Internet of Things from reaching its full potential.** The question of "who does the data belong to?" may prevent data from being shared between machines owing to the potential proprietary and security-sensitive information it may contain. Our discussions with companies suggest that data generated from equipment consensually belongs to the client.
- **Development costs might be too high for equipment makers to pursue revolutionary new products.** As Google's recent announcement of the sale of its robotics arm Boston Dynamics suggests, corporates might not be willing to take the burden of multiple years of development costs for products with a lack of prospects for meaningful near-term revenues. This is exacerbated by the threat of slow adoption given relatively new legacy installed bases (2000-13 saw substantial capacity investments) and a conservative set of customers (compared with the less risk-averse and ROIC-sensitive consumer segment).

- **Overautomation.** In addition to a lack of system integration skills and bad selection of FA equipment, we think overautomation is the common cause of bad automation.
  - **Additional overhead costs from over-automation may outweigh the savings from direct labour**, in particular when capacity utilisation falls. As factories increase the pace of automation, overhead costs grow and direct labour costs fall. Increased support costs associated with maintaining and running automated equipment drive overhead costs up even more. The increase in operational leverage owing to a higher proportion of fixed costs hits particularly hard when capacity utilisation falls in a downturn.
  - **Overautomation with the wrong equipment reduces flexibility.** While some of the technologies highlighted in this report combat this challenge, most of today's machines/robots are good at performing one job at very high efficiency levels but with limited flexibility. This is a common argument for not automating. Take a robot gripper as an example. If it only has two positions, the gripper can only grab parts that it has been designed for. If it is to grab different products, the gripper needs to be more complex, more expensive, and often less effective.

Exhibit 68: Overautomation reduces flexibility
Performance vs. flexibility of a robot gripper



Source: Goldman Sachs Global Investment Research.

Automation gone wrong: Increasing overheads and decreasing flexibility

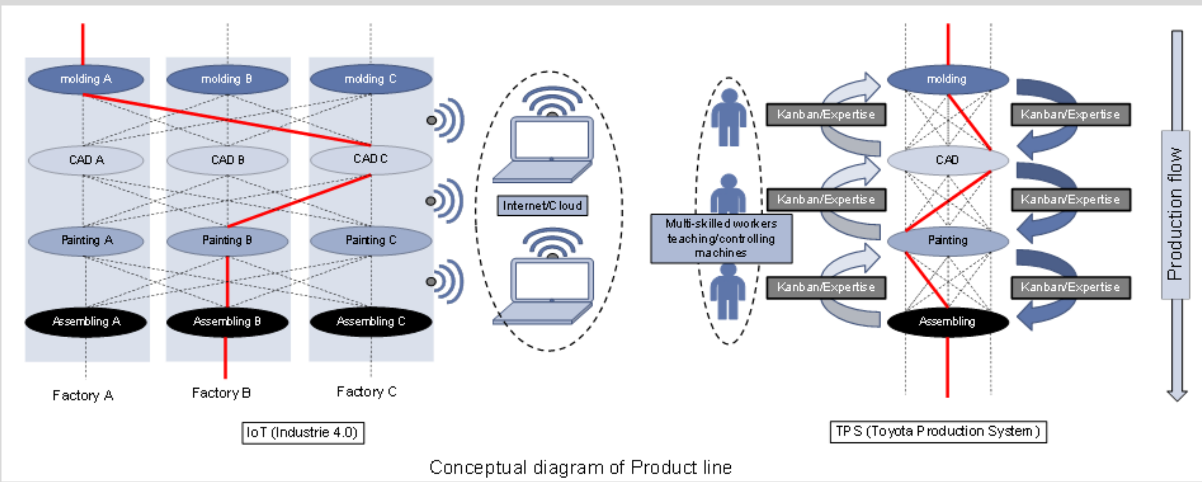
According to a paper by the World Congress of Engineering on Volkswagen's automation strategy, for certain sections of the Golf A5 production line in Germany, it is optimal to limit automation as the additional personnel needed for maintenance already offsets the saved labour cost, and readily available qualified workers produce similar quality while offering much better flexibility. In terms of productivity, the paper finds that in certain sections well-trained manual workers produce a higher percentage of faultless parts, as highly complicated automation systems are susceptible to faults. Even in EMs such as China, over-automation may harm productivity as a result of inexperienced domestic system integrators and an absence of qualified maintenance personnel for the automation equipment. A Chinese local news report stated that in Zhejiang province, where a "robot for human" shift was greatly encouraged, some companies had to set their Japan-made industrial robots aside for two weeks while waiting for the Japanese engineers to arrive to fix technical issues that had arisen.

Appendix 1: Toyota Production System and Kanban manufacturing

IoT ecosystems are not entirely new: Toyota Production System and Kanban manufacturing

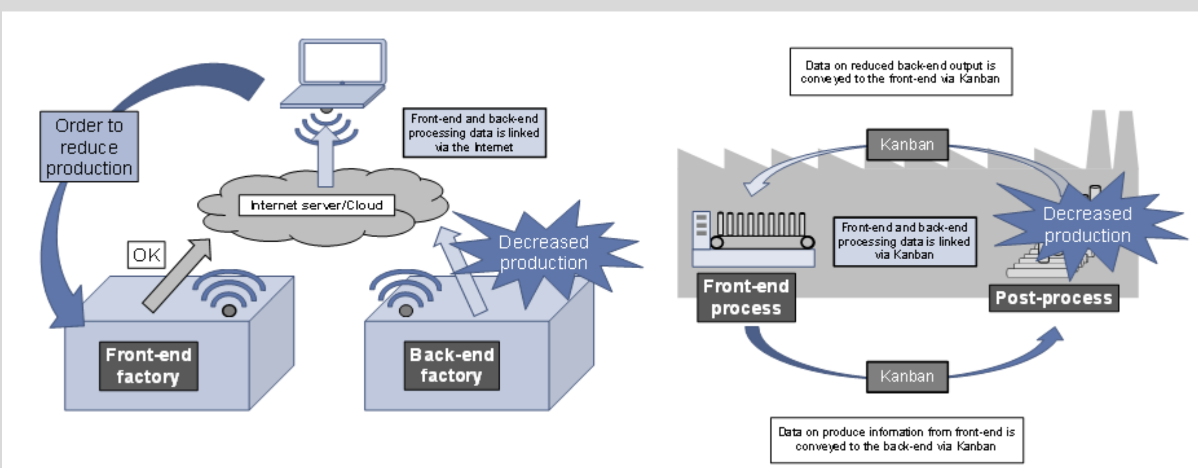
Toyota Production System (TPS) already has many similarities with the emerging digital manufacturing world. TPS achieves a just-in-time system capable of handling small-lot production of a large variety of products by using a Kanban approach and developing multi-skilled workers. What both IoT enabled and Industrie 4.0 systems have in common is that they allow production to be adjusted to changes in demand by using data linking media (IoT in one case and automation based on multi-skilled workers/smart machines in the other). Both Industrie 4.0 and TPS are good at handling changes in demand because information between factories/processes is quickly shared.

Exhibit 69: Comparison of Industrie 4.0 production flow vs. Toyota Production System production flow



Source: Goldman Sachs Global Investment Research.

Exhibit 70: Comparison of production adjustments between factories/processes



Source: Goldman Sachs Global Investment Research.

Appendix 2: Glossary of terms

Exhibit 71: Glossary of terms

Term	Definition
3D Printing	or *Additive Manufacturing;* is the formation of 3D solid objects from a digital motel, typically by laying thin layers of a material
AGV	*Automated Guided Vehicle* ; automatic material handling equipment
CAM	*Computer Aided Manufacturing;* the use of software to help model the manufacturing of a product.
Cloud	Decentralised storage, management and processing of data
Cobot	Lower-cost, smaller and more flexible robots capable of working alongside humans
EAAS	*Everything as a Service;* pay-by-usage/subscription-based models for machinery, transferring capex into opex for manufacturers and creating a perpetuation of revenue streams instead of a one-off asset sale for suppliers.
ERP	*Enterprise Resource Planning;* business-management software that can be used to collect, store, manage and interpret data from many business activities, including: product planning, purchase, manufacturing or service delivery.
IoT	*Internet of Things* ; the network that connects devices and objects. Sensors and software allow for the collection and exchange of data.
IoT PaaS	*Internet of Things Platform as a Service;* Industrial software as a service which is based on the cloud that allows machines to communicate and optimise production.
M2M	*Machine-to-Machine;* refers to the communication and exchange of data between machines and other other devices
Machine learning	or *artificial intelligence;* is the ability of machines to process data into information and derive knowledge from that information to act independently.
Machine vision	Technologies with imaging-based automatic inspection, gauging, counting and analysis at high speeds, reliability and with greater precision (exceeding the capabilities of the human eye).
MES	*Manufacturing Execution Systems;* The central computational system which tracks and documents the transformation of raw materials to finished goods
PLC	Programmable logic controller; a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures
PLM	*Product Lifecycle Management;* using advanced computational methods to create a simulation of a product's production and its life cycle
RFID	*Radio-frequency Identification devices;* technologies that use radio waves to transfer to data for the purposes of automatically identifying and tracking tags attached to objects

Source: Goldman Sachs Global Investment Research.

Disclosure Appendix

Reg AC

We, Daniela Costa, Yuichiro Isayama, Joe Ritchie, Tian Lu, CFA, William Turner, Ashay Gupta, Yuki Kawanishi, Mohammed Moawalla, Jacqueline Du, Samuel H. Eisner, Willy Chen, Toshiya Hari, Stefan Burgstaller, Daiki Takayama, Simona Jankowski, CFA, Wei Chen, Heather Bellini, CFA, Diana Zhao, Alex Karpos, Matthew Cabral, Gautam Pillai, Jessica Kaur, Shateel Alam and Robert D. Boroujerdi, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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