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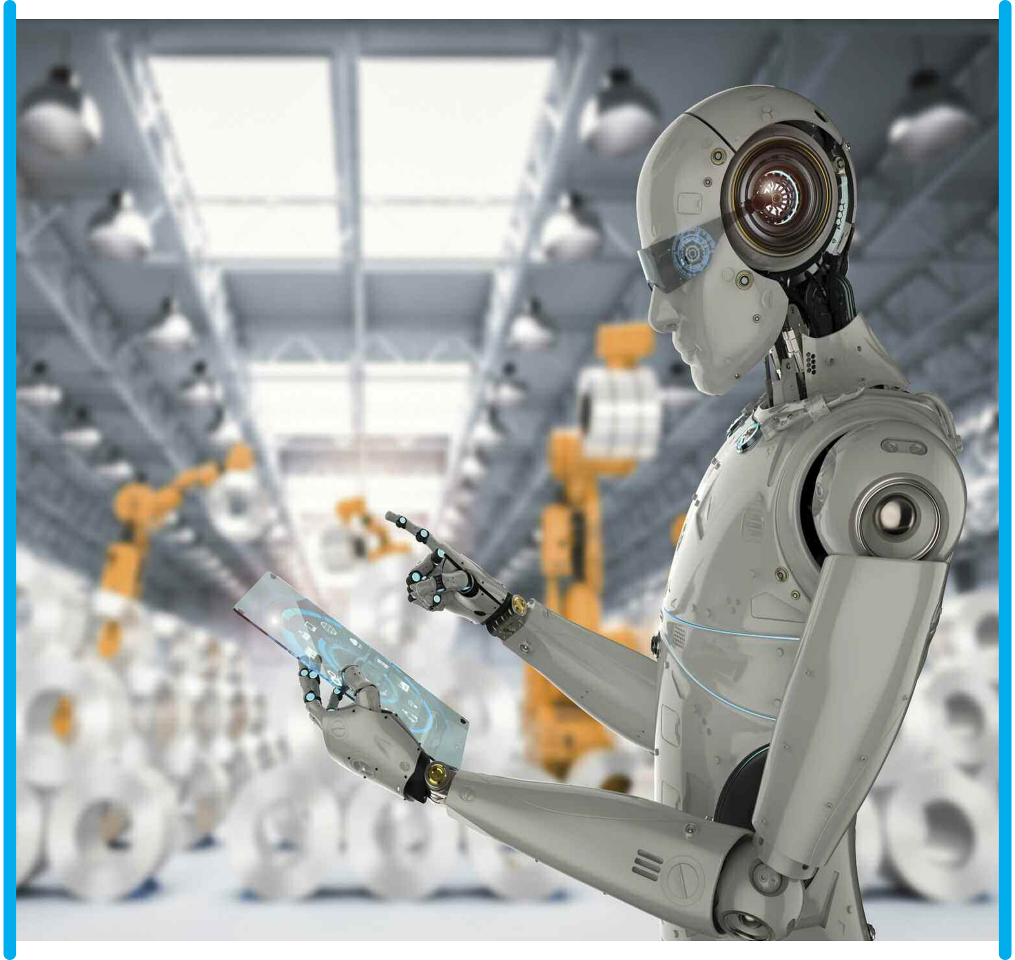
Age of hyperconnectivity and automation



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EXECUTIVE SUMMARY

We are at the dawn of a new super cycle in manufacturing. While advances in artificial intelligence and robotics steal the headlines, it is the combination of those technologies with better and cheaper sensors, internet-of-things platforms and increasingly capable software that will shape manufacturing in the decades to come.

This super cycle – which we are calling the Age of Hyperconnectivity, Nanomanipulation and Machine Automation – will result in significant productivity gains, a disaggregation of the manufacturing value chain and the ability to manufacture customised products for the mass market. It will not be without costs, with the potential for mass unemployment, significant re-onshoring of manufacturing capital to the developed world and concentrated wealth accumulation. Governments and societies will need to find ways of adapting to the structural changes these technologies will bring.

This report, a deep dive on industrial software, is the first in a series of publications that will shed light on the trends underpinning the Age of Hyperconnectivity, Nanomanipulation and Machine Automation. This work links to a number of initiatives across Barclays Research, including *Robots at the gate: Humans and technology at work*, 11/4/18.

We identify five waves within this coming super cycle, the first of which has already begun. We call this the wave of integration and connectivity, which is concerned with the convergence of disparate systems, machines and data sources within the manufacturing IT ecosystem. This trend is already benefitting companies within our coverage, driving IT investment and consolidation of specialist vendors, as well as elevating the importance of software within manufacturing organisations.

The waves that follow will include:

- Accelerated robotic advancement, as robots surpass humans in all physical capabilities.
- Localisation and customisation of production, as technologies including 3D printing become mainstream, forcing out-low cost labour.
- Modular and distributed manufacture, as we move toward outsourced manufacturing-as-a-service.
- Autonomous and synchronised manufacture, with little or no human interaction needed – the birth of dark factories.

Complete realisation of this vision is more than 25 years away, we estimate. In the meantime, we estimate that the addressable Industrial Software market is ~€60bn and will grow at a ~10% CAGR to FY20E. That's well ahead of Gartner's estimate for overall IT spend growth of ~4%.

The industrial software landscape is complex and consists largely of separate functional and vertical silos. In this report, we segment the current value chain into:

- Management systems (Enterprise Resource Planning and Client Relationship Management).
- Design & engineering systems (Product Lifecycle Management including Computer Aided Design, Computer Aided Engineering, Computer Aided Manufacturing, Product Data Management and Digital Manufacturing).
- Manufacturing control systems (Manufacturing Execution Systems, Manufacturing Operations Management).
- Manufacturing operations systems (Supervisory Control and Data Acquisition, Programmable Logic Controllers and Distributed Control Systems),

All of which are underpinned by sensor technology and IoT platforms. Point integration between subgroups of these categories has been ongoing for years. However, the first wave of this super cycle is seeing more strategic combinations of assets (capital goods firms buying into Product Lifecycle Management companies) and wholesale data integrations (including software and capital goods companies rushing to develop the leading IoT platforms).

As explored in our accompanying sector company note, we expect this wave to be a structural tailwind to the industrial software peer group at large over the coming decade at least, as manufacturing firms increase their software spend to remain competitive and boost productivity. The Age of Hyperconnectivity, Nanomanipulation and Machine Automation will fundamentally change the world of manufacturing, as well as the world of work. The industrial software sector offers an attractive way for investors to gain multi-year exposure to this structural digitalisation trend.

CONTENTS

AGE OF HYPERCONNECTIVITY, NANOMANIPULATION AND MACHINE AUTOMATION

Machines to become incrementally smarter and automate large parts of the manufacturing cycle and our lives

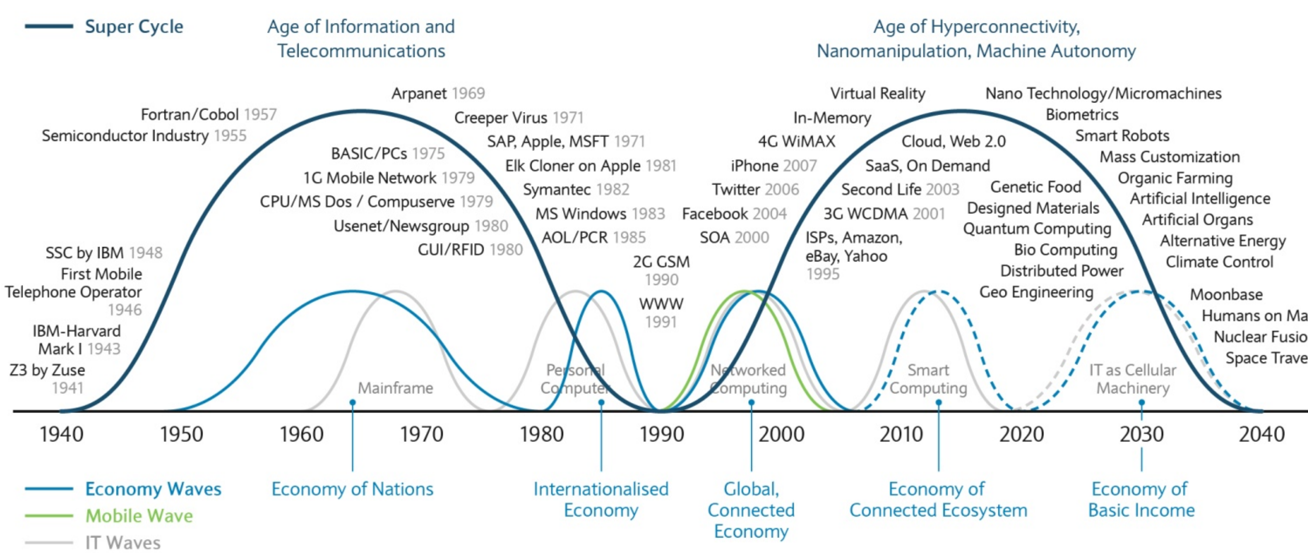
Technological advances have brought us to the beginning of the next super cycle in the manufacturing sector. The combination of industrial software systems, with advanced sensors, IoT networking, AI and advanced robotics, will usher in what we are calling the Age of Hyperconnectivity, Nanomanipulation and Machine Automation.

Rapid advancements in technological capability will see machines becoming incrementally smarter and automating large parts of the manufacturing cycle and our lives. This will result in significant productivity gains, mass customisation and a return to localisation in manufacturing. The value chain will become disaggregated into design, manufacturing, marketplace, and logistics.

The end game will be completely independent, adaptive factories, offering manufacturing-as-a-service. A smart factory is a connected and flexible system which is able to adjust to changing demands and improve through self-optimisation. This will see a new paradigm of mass customisation and the disaggregation of the value chain, which in turn is likely to result in enormous wealth concentration around marketplaces and networks; something already visible in the consumer economy.

FIGURE 1

Kondratieff Waves



Source: SAP, Barclays Research

For manufacturing, the rest of this decade is likely to be driven by increasingly connected ecosystems and smart computing. In this period and beyond, manufacturing IT systems will be impacted by three key drivers:

1. Data intelligence, which is driven by the collapse in the cost of creating, storing, accessing and analysing data. This is combined with ever-increasing connectivity (hyperconnectivity) through fast networks and connected devices.

2. Software advancements, such as machine learning and artificial intelligence, that enable smart automation.

3. Vastly improved manufacturing-specific technologies including 3D printing and other additive manufacturing inputs, advanced robotics and virtual and augmented reality.

There are broad and significant ramifications of this manufacturing digitalisation cycle for all parts of society. For the manufacturers, the increase in connectivity, data, artificial intelligence and machine learning will lead to full automation of the production of low volume and highly-customised products in real time. With an increase in smarter machines and highly adaptive factories, production will increasingly be decentralised.

Disaggregation of value chain will result in completely independent adaptive factories or manufacturing-as-a-service

Why produce a phone in China if a consumer can customise and order it online then receive it from their local 3D printshop? The consequences of this value chain disaggregation, in particular the drop in labour intensity of manufacturing, could have more significant ramifications for society than in previous revolutions.

This cycle will not only drive production automation, it will change the use of production resources and the business model of manufacturers. Adaptive factories will become commoditised production facilities that are rented out as “manufacturing-as-a-service” to companies that design and create a product. The world’s largest manufacturers may no longer need their own factories. On the consumer side this value chain disaggregation is already happening; the world’s largest taxi firm, Uber, has a business model not dependent upon owning cars and the world’s largest accommodation provider, Airbnb, need own no property, and there are many more asset-light marketplace examples.

Manufacturing will be controlled by super aggregators that have limited need for capital or labour

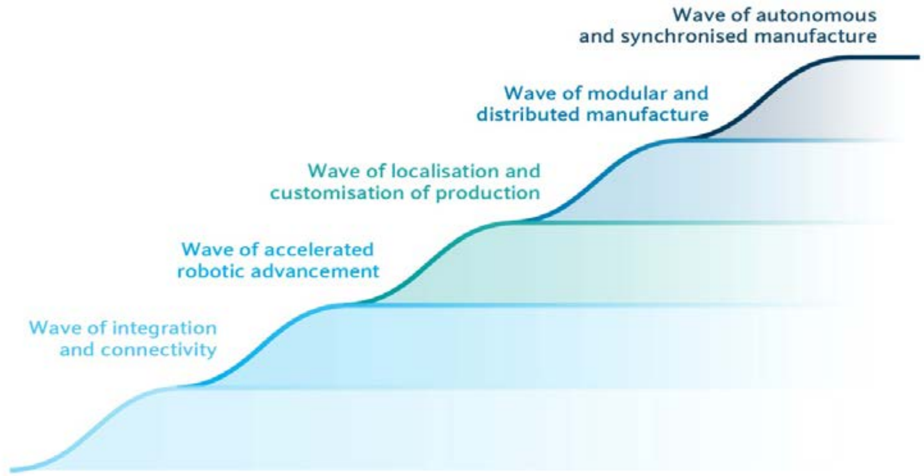
Ultimately, manufacturing may end up being controlled by a limited number of super aggregators or marketplaces that command a network and have limited need for capital or manufacturing labour.

Think big but start small

The potential for smart, adaptive manufacturing is huge but the transition to “manufacturing-as-a-service” will require more open and standardised architecture to enable systems to communicate. This might sound logical and easy on paper, but it will be a complex upgrade cycle as there has historically been a lack of standardisation in manufacturing IT systems. Open source is almost unheard of in the sector, which is dominated by supplier-specific protocols and data formats.

Given this complexity, we anticipate that it will take 20-25+ years to complete the vision of a completely adaptive factory. We see different stages of technology adoption:

FIGURE 2
The five waves of the next-generation of manufacturing



Source: Barclays Research

1: Wave of integration and connectivity

This is the wave that is most relevant to even the medium-term investment cases of the stocks that we cover. It's currently buoying our manufacturingTech coverage companies, and should continue to do so for the coming decade at least.

FIGURE 3

Source: Barclays Research

Taken as a whole, we are currently still only in early stages of automation in large parts of the manufacturing industry. Many systems are still operated in silos, data is either not collected at all or can't be used by other programs, and machines themselves often work in isolation and on only a single step. The first wave is all about bringing those systems into greater harmony.

Manufacturers are well aware that there is a value in data and this is creating an arms race between them to collect, store, analyse and create value out of that resource. The main software systems in an enterprise were developed for a specific department such as the front and back office to manage the commercial side of the business, the engineering department to manage the product development or the production facility to enable basic automation and quality controls. However, these systems don't talk to each other and this creates missed opportunities. Examples of improved integration include better interfacing of design and simulation software; improved links between accounting and cost control and the manufacturing software; huge improvements in production sensors with data feeding back into the production system, etc.

This will all be underpinned by the maturing of enterprise-wide IoT platforms which collect, aggregate and allow for the analysis of data from right across the organisation, critically, connecting not only software data, but sensor data. This integration will take place throughout the enterprise, from design software, through to the manufacturing control systems that make the products, to the costing and inventory software that records business performance, through in many cases to the products themselves once they have left the production facility.

Products are gaining the ability to report back aspects of their performance, enabling iterative changes in design and so on.

While this is a simplified vision of this wave, the reality will involve thousands of small point-to-point integrations. It is already happening in some areas today. Manufacturing processes will increasingly be simulated, resulting in zero-prototype production, reduced waste and higher performance. Production facilities themselves will too be simulated.

2: Wave of accelerated robotic advancement

FIGURE 4

Source: Barclays Research

This wave will see us enter an age in which machines are able to perform any physical task a human can do, but with incredible efficiency and accuracy, and at ever decreasing unit costs. These developments will occur concurrently with the greater integration of systems.

Robotics is already advanced. Just because certain industries continue currently to rely extremely heavily on low-cost human labour, is not to say that humans remain more skilful or capable. Who or what is more impressive, the human who still sews shirts because the unit labour cost is still below that at which a robot could do it, or the welding robot that can complete 88 laser welds in 40 seconds[1]?.

Machines will be developed with capabilities akin to human senses. Sight and hearing are already well advanced in machines, yet touch (smell and taste too, but less relevantly) is behind. This will and is changing and ultimately will make machines superior to humans when it comes to the provision of manufacturing labor.

This should be seen as a transitional phase, or even a golden age, of humans and robots working in harmony. In the language of futurists, this is called multiplicity, describing a hybrid workforce of humans and robots working side by side. Improved software and sensor technology is improving robotic safety systems, meaning robots and humans can work with less separation, further reducing inefficiencies and costs.

This wave will see labour-intensive industries, most notably textiles and clothing, accelerate in their adoption of automation. By the end of this cycle, the production of cars and clothes will not look as fundamentally different as it does today. Again, some development is already taking place in this area, notably for example, with Adidas, which last year was reported to plan the daily production of 800,000 T-shirts using a fully automated Sewbot assembly line[2].

[1] https://www.carmagazine.co.uk/features/car-culture/two-born-every-minute-inside-nissans-sunderland-factory-car-february-2016/
[2] https://www.innovationintextiles.com/automated-sewbot-to-make-800000-adidas-tshirts-daily/

3: Wave of localisation and customisation of production

FIGURE 5

Source: Barclays Research

We expect the next wave to be all about a tipping point being reached, causing massive re-onshoring of production in the developed world.

A major consequence of the shift from labour to capital will be that the unit cost of production labour has less and less of an impact on the total unit cost of a product. This, in turn, means that other costs and factors such as shipping, time-to-market and localised marketing become increasingly important.

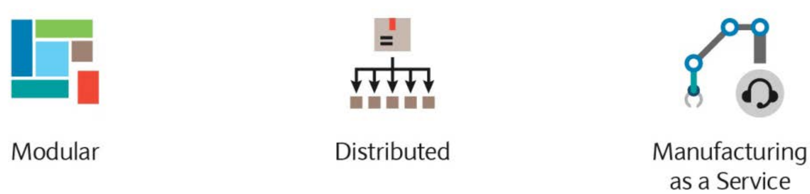
We have already seen early examples of this. When Adidas built its highly automated trainer Speedfactory, it did so near its headquarters in Germany rather than in a low-cost labour location. To solve the issue of last mile delivery, drones will be available while other parts of the supply chain are increasingly automated with smart warehouses and the development of self-driving trucks.

As the same time, direct linkages between ordering and production systems and increasingly-automated manufacture will enable mass customisation of consumer products. This will be underpinned by the coming of age of 3D printing and other additive manufacturing methods. That means customisation will evolve beyond today's selecting between pre-defined options, into free-form product customisation and the integration of the consumer into the design process. Instead of asking a car dealer if you can have red stitches on your steering wheel, you'll sit in your living room with a 3D model of the car projected into the middle of the room and tell your personal robotic assistant that you would like a couple more inches of space between the front and the back seats; the design software adjusts the model, recalculates the price and shows you the results.

Almost any request can be made possible. Clothes could be completely designed or altered and still be delivered within a day because as supply chains would be tightly integrated and production local. Furniture could be completely customised to fit seamlessly into its environment, and delivered shortly afterwards.

4: Wave of modular and distributed manufacture

FIGURE 6



Source: Barclays Research

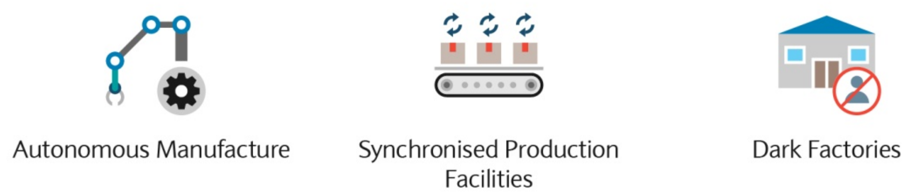
As factory technology becomes ever more capable, it will become increasingly flexible. International standards will likely develop that mean factories can be componentised and built quickly, temporarily or easily retasked for different purposes. Plug-and-play production modules may be developed which are configured in various combinations in factories as needs dictate. Robotic capabilities will be so advanced as to be beyond our current comprehension in terms of what can be produced and how that is accomplished. The most futuristic visions of this trend include what we might call swarm robots; modular, mobile machines that can autonomously arrange themselves to facilitate whatever manufacturing activity is required at that point in time.

Such adaptive factories will become commoditised production facilities that provide on-demand manufacturing for companies that design and conceptualise products, much like we see in the semiconductor fabrication world today. We call this distributed manufacturing.

The world's largest producers will no longer necessarily have any factories of their own. Ultimately manufacturing will just become part of the "sharing economy". This disaggregated and automated supply chain will also create opportunities for new entrants with new ideas. However, IP laws may need to be updated and strengthened as replication of products will become easier.

5: Wave of autonomous and synchronised manufacture

FIGURE 7



Source: Barclays Research

What we consider the final wave of this super cycle of manufacturing, or the end game, is that of fully autonomous production facilities – dubbed dark factories, since humans will be able to switch off the lights and let the robots get on with the job – working entirely in sync with one another.

Thanks to machine learning and artificial intelligence, the software that runs the machines should be able to deal with any issues that arise as part of the production. Robots will be capable of complex problem solving to achieve their goals and therefore should be able to adjust autonomously any aspect of design. At this point, we would no longer expect production facilities, in whatever form they now take, to be standalone entities.

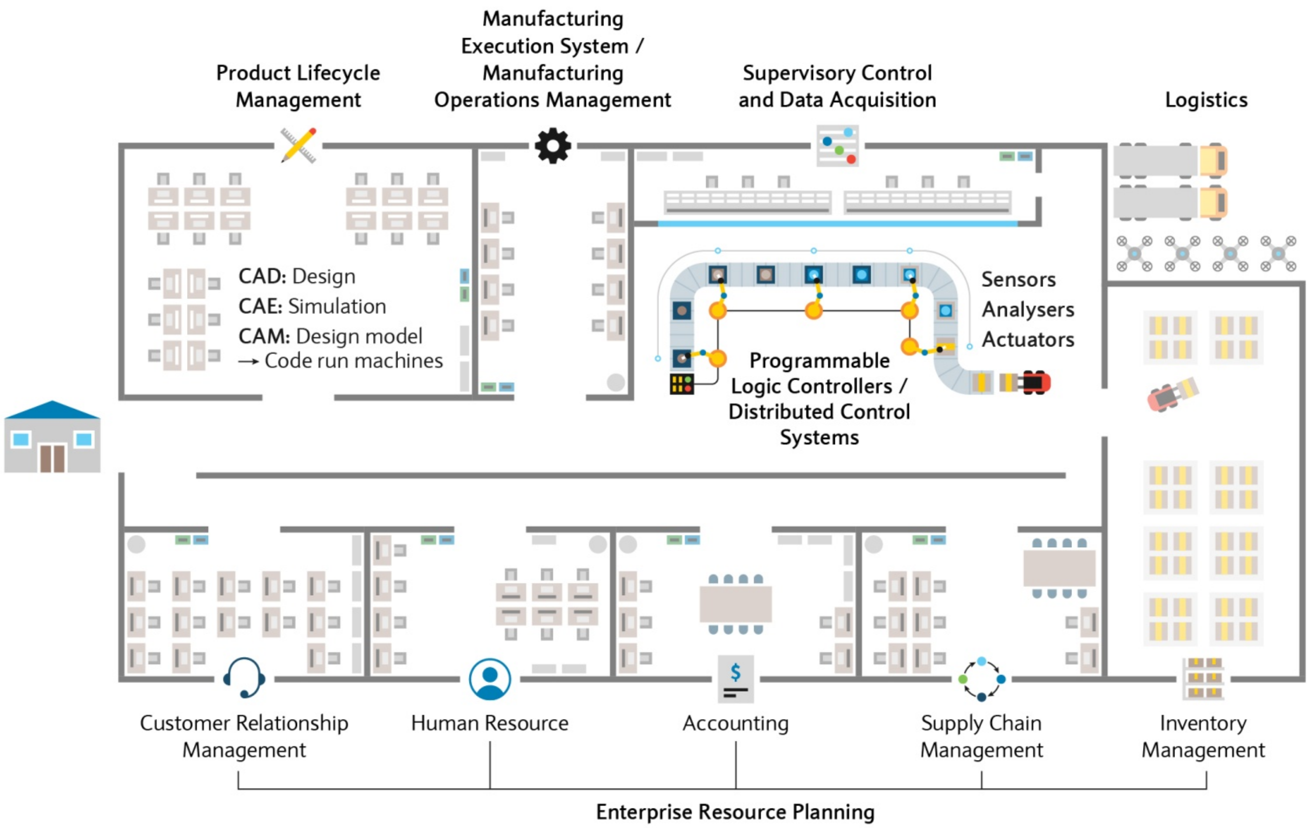
We would expect complete, remote integration globally between factories such that production can be carried out in the most appropriate and efficient way, across distributed manufacturing facilities. The global production system, and the factories within it, organise themselves. There will simply be no need for any human involvement in the operation of production facilities.

SOFTWARE, SYSTEMS AND SUPPLIERS

The industrial software architecture is complex and automation has evolved around functional departments, such as HR, design and manufacturing control. Many of these systems have been adapted and customised over the years, which makes them difficult to replace. As a result, the manufacturing industry sits on relatively old code. Finally, due to the diversity of manufacturing, there are many software suppliers and, although some consolidation has occurred, the underlying programs have rarely been fully integrated.

We show below our manufacturingTech stack. From a functional perspective, we consider five main groups: management (i.e. front and back office); product design & engineering; control; operations. Underpinning the whole we have sensors, intelligent devices and related IoT platforms.

FIGURE 8
Enterprise & Industrial IT Systems



Source: Barclays Research

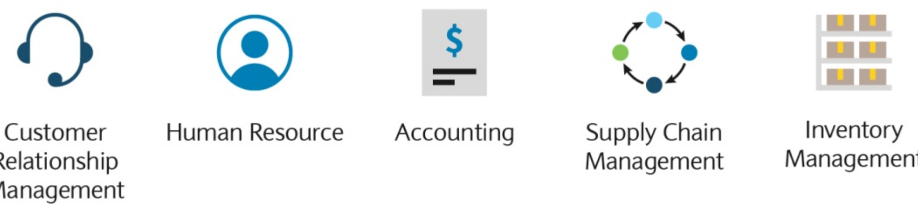
Management IT systems

Enterprise Resource Planning (ERP) is the umbrella term for software systems supporting management in running the day-to-day business. This includes modules such as accounting, Human Resource Management (HRM), Supply Chain Management (SCM), inventory management, procurement and distribution management, as well as Customer Relationship Management (CRM). CRM deals with front office functions and, as this software has a higher need for innovation, it is often seen as a separate category to the more stationary back-office ERP systems.

Although, there are still many suppliers around, the enterprise segment is relatively consolidated and SAP, Oracle and Salesforce dominate the space. The SME space is more fragmented with many local and multiregional vendors.

FIGURE 9

Management IT systems



Source: Barclays Research

Management IT systems integration started 25-30 years ago and this led to the heyday of integration software, or middleware. Vendors including Tibco, webMethods (Software AG), WebSphere (IBM) created unified communication layers to link different systems. Enterprise software reacted to this by making systems more open and there was greater standardisation with the move to the cloud. This resulted in the demise of the middleware players, most of which have been consolidated since. However, further down the industrial software stack this standardisation has not occurred yet and we expect that middleware vendors might see a second wave of demand for their services.

Design & Engineering IT Systems

Similar to ERP, Product Lifecycle Management (PLM) has also always been a bit of a marketing term rather than a common definition, and we see it as an umbrella term to describe the engineering and process lifecycle from conception through design, manufacture, service and ultimately disposal. PLM started to become popular in the '90s, when engineering-focused software companies such as Dassault, PTC and UGS (now Siemens PLM Software) broadened their marketing message beyond CAD/CAM (Computer Aided Design and Computer Aided Manufacturing) to extend their reach beyond the engineering department.

As such, PLM software is an aggregation and integration of the individual stages in product/IP development: CAD to design the product; Computer Aided Engineering (CAE) to test and simulate it; CAM to make it: Product Data Management (PDM) to manage the product data and Digital Manufacturing (DM) to plan the design, production and layout of the actual manufacturing process.

FIGURE 10

Design & Engineering IT Systems

Source: Barclays Research

Most PLM vendors started off in CAD/CAM and have evolved and broadened their portfolios to offer a full PLM offering. Whilst this has resulted in some consolidation, there is a lot of fragmentation still, particularly as this software is highly verticalised. In PLM (CAD/CAE/CAM/DM), the leading vendors are Dassault (CATIA, SIMULIA, SOLIDWORKS, DELMIA), Hexagon (Smart 3D, Vero and MSC), Autodesk (FUSION 360, AUTOCAD, INVENTOR), Siemens (NX, Tecnomatix, LMS, Fibersim), AVEVA (E3D, PDMS), Ansys and PTC (Discovery Live, CREO). For the Architecture Engineering and Construction (AEC) vertical, Nemetschek (Nevaris, Bluebeam, Solibri, SDS/2, and others), Bentley Systems, RIB (RIBTEC, RIB STRATIS, iTWO) and Autodesk (REVIT, CIVIL 3D, INFRAWORKS) are the leading vendors. Leading PDM vendors are Dassault (ENOVIA), Siemens (Teamcenter), SAP, PTC (Windchill) and Oracle. Other vendors active in the space include AVEVA (AVEVA NET) and Hexagon (SmartPlant).

Manufacturing Control IT Systems

Manufacturing Execution Systems (MES) and Manufacturing Operations Management (MOM) software include features such as production planning and scheduling, workflow management, equipment efficiency, production performance calculations, quality management, operations management and manufacturing intelligence.

MES and MOM, as manufacturing scheduling, planning and control tools, are therefore the communication between the top floor and the shop floor. Such systems are often linked to PLM (for design), ERP (for inventory and supply chain) and to SCADA (Supervisory Control and Data Acquisition software for the shop floor) – we discuss SCADA in the next section.

FIGURE 11

Manufacturing Control IT systems

Source: Barclays Research

The terms MES and MOM are used largely interchangeably and, although they are closely linked to manufacturing, they remain part of the enterprise or "carpeted area." MES/MOM systems were introduced in the 1990s to bridge the gap between SCADA and ERP. While SCADA is in its traditional sense responsible for the real-time supervision and control of the production, MES and MOM are all about analysing historical and time-series production data and forecasting future production.

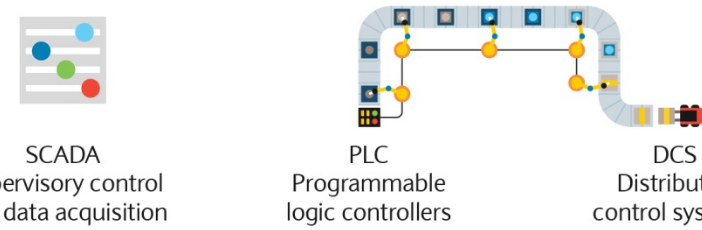
As MES/MOM is closely linked to ERP, PLM and SCADA, the traditional software vendors have all expanded their offerings into this area. Leading vendors in this area are AVEVA (Wonderware), Dassault Systemes (Apriso, DELMIA), Oracle, SAP (Visiprise), Siemens (Simantic) and Rockwell (ProductionCentre).

Manufacturing Operations IT Systems

Operational Technology (OT) is dedicated hardware and software for the shop floor to monitor and control the manufacturing processes through devices such as pumps, valves, sensors, drivers and robots. There exist three main parts – SCADA, Programmable Logic Controllers (PLC) and Distributed Control Systems (DCS) – which have been historically very distinctive. Increasingly there is convergence between these components. Generally

SCADA and PLC are used in discrete manufacturing while DCS is used for the process industry.

FIGURE 12
Manufacturing Operations IT Systems



Source: Barclays Research

Programmable logic controllers are hardware and software to control processes and equipment through pre-programmed parameters for the purpose of automation. PLCs generally manage one standalone machine or piece of equipment and are generally used in discrete manufacturing. The largest vendors of PLC equipment include Siemens, Rockwell Automation, Mitsubishi Electric, Schneider Electric and Omron.

SCADA is a control system that links PLCs together to get a high level overview about a factory process for the purpose of supervision. It consists therefore of software and a network to aggregate and display data. In addition, operators can also issue process commands that are performed by the PLC. Leading vendors of SCADA systems include ABB, Emerson, Honeywell, Schneider and Siemens.

A distributed control system (DCS) is an automated system that controls processes and field equipment. DCS was used for large plants in the process industry such as in the oil & gas industry where a large number of continuous control loops had to be supervised and controlled. Compared to PLCs, which were sold as single components and integrated with a SCADA, a DCS is an inherently integrated solution that includes workstations, control panels (known in the industry as human-machine interfaces) and local control units that are distributed throughout the plant. The largest vendors of DCS systems include ABB, Schneider Electric, Honeywell and Emerson.

Field, Sensor and IoT IT Systems

Sensors and monitoring devices have long been present in manufacturing settings but, as we outline in Appendix I, the data was often stored in so-called historian databases which aren't designed for analysis.

The next generation of sensors collects data in real or near-real time. The sensors themselves are commodity hardware, in our view, but the data being compiled must be able to be visualised and analysed and, therefore, be used to drive real business decisions.

Hexagon is one of the main providers of sensors in our coverage with their metrology division, and over the last 10 years this has been transformed from a hardware to a solutions business.

This development towards solutions combining both hardware and software has given rise to IoT platforms, and it will be no surprise that ERP, PLM, MES/MOM, SCADA and middleware vendors all are coming out with their platforms and trying to convince investors that the whole industry will standardise on theirs.

We are still a little while away from this, but the IoT will enable new solutions and pay per use business models. Below we give some concrete examples:

Industrial IoT could impact field services by marrying CAD data with VR

Industrial IoT (IIoT) is predominately connected to industrial devices or even whole assets. Therefore, it can be viewed as an extension of MES/MOM and SCADA systems, which receive additional data to monitor and manage the shop floor.

IoT could be linked up with PLM for after-market maintenance or predictive maintenance. Think of a tractor which is an expensive capital good for a farmer; after market service is critical for that user, and highly profitable for the manufacturer.

After market service depends on skilled technicians who need a host of data to perform their job. Sensors within the tractor could relay information on the symptoms of any malfunction, enabling faster diagnosis and repair.

Imagine if the engineer sent to look at the tractor were wearing an augmented reality lens and, when the image of a tractor's hydraulic assembly showed up, that lens could automatically marry that with the CAD data that was used to design that assembly. The lens could offer a virtual instruction guide on how to properly work with the assembly in order to correct the problem.

The financial implications of this "guided" service using augmented reality enabled by CAD data could be material as well: perhaps the technician could be a less experienced/less expensive engineer; the cycle time for repair could increase because of less uncertainty and, if that tractor was a connected asset, perhaps the technician would know ahead of time which part would be needed for the repair, saving time.

Industrial IoT could also give rise to the digital twin

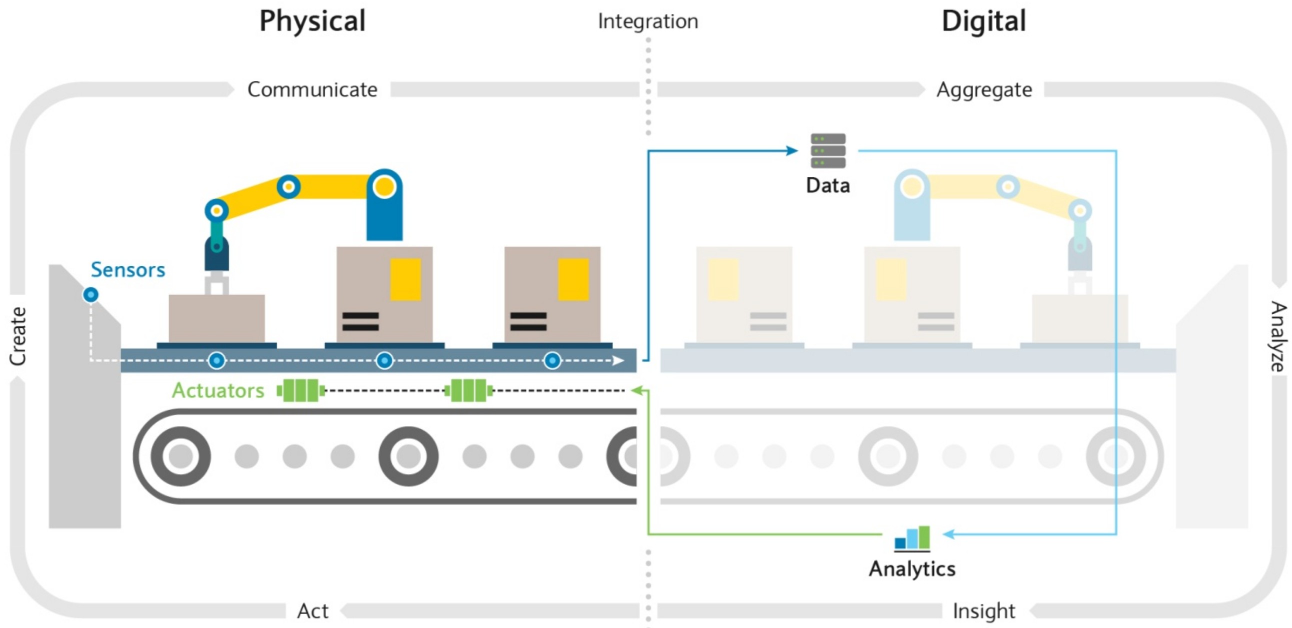
Industrial IoT has also given rise to the concept of the digital twin, which is a representation of a physical asset in a virtual environment. Attaching low cost sensors to physical assets in operation to collect real-world asset data on factors such as heat and vibration allows owners to simulate operations in the virtual environment. With the simulation output, owners can gain a deep understanding of asset performance and the impact that changing factors have on the efficiency, useful life and maintenance needs of the asset. If the owner of the asset is the same as the OEM, the data should optimally be used to inform future product designs or potentially offer new maintenance and service revenue streams to the OEM.

Digital twins of a factory floor connect IoT devices and sensors across a manufacturing system to understand and simulate complex manufacturing techniques to identify problems before they arise. With sensors around the factory measuring all aspects from raw materials, to machines, to WIP and the environment, operators can simulate the factory through a digital twin in near real time.

Through use of the digital twins, intolerable deviations from plan can be caught and altered before irreversible damage occurs. By enabling predictive maintenance IoT and digital twins can reduce machine downtime and reduce costs.

FIGURE 13

Digital Twin of a Factory Illustration



Source: Barclays Research

Consumer IoT primarily impacting the PLM space

While data collected by consumer IoT devices can be of great benefit to the user, such as enabling home automation, health monitoring and remote monitoring, it can also feed PLM systems with information about product usage, performance and quality. That data can be used in further product developments and iterations.

For example, unused functionality can be removed to save costs, or parts with excessive breakage can be identified and improved or new suppliers found. With this, PLM is finally moving from only designing and testing devices to receiving real-world data about how they are used. This is not only helping decision making for engineers that develop new products, but opens up new areas for PLM, such as field support or marketing.

EXCITING END GAME BUT PLUMBING NEEDS WORK

As discussed in the introduction, the prospect of the end game is exciting with the rise of the machines and the potential for humans enjoying more leisure time. The redistribution of wealth will dictate how pleasurable this additional leisure time will be.

Given the complexities of the current industry, and the 40+ years of IT legacy, the transition to distributed autonomous manufacturing will be gradual, requiring a modernised infrastructure to harness the value of the data. This should drive an upgrade cycle in manufacturing and engineering. In this integrated world, the vendors that will win will either be able to support companies in integrating standalone enterprise applications or provide completely integrated solutions. Vendors with standalone applications will only stay relevant if their products are sufficiently differentiated.

Wave of integration and connectivity needs middleware

The current wave of integration and connectivity in manufacturingTech, is being driven by the need for middleware or integration platforms. This is often described as an IoT platform.

As there is not a single vendor with all needed assets, there has been a high level of M&A (see below). Most smart solutions currently available only connect certain elements of the value chain. In the sections below we provide key integration needs and use cases.

FIGURE 14

Industrial Software M&A

Date	Acquirer	Target	Price	Description
Aug-2018	Siemens	Mendix	$700m	Application development platform for MindSphere
Jun-2018	Hexagon	Spring Technologies	na	Software for machine tool simulation/management and verification
Jun-2018	Rockwell	PTC (8.4% stake)	$1,000m	8.4 percent stake in PTC for $1bn
Jan-2018	Emerson	ProSys	na	Plant optimization software solutions
Dec-2017	Oracle	Aconex	$1,200m	Cloud-based project collaboration platform development
Nov-2017	Schneider	IGE+XAO	$155m	CAD and PLM software for electrical installations
Oct-2017	Dassault	No Magic	na	Model-based systems engineering (integrated into CATIA)
Oct-2017	Emerson	Paradigm	$510m	Software solutions to the global oil and natural gas exploration and production industry
Sep-2017	Dassault	Exa	$400m	Computational fluid dynamics (CFD) simulation (integrated into SIMULIA)
Sep-2017	Siemens	Infolytica	na	Simulation software for electromagnetics (EM)
Sep-2017	Silver Lake, GE	Aras Corp (minority stake)	$40m	Product lifecycle management software
Sep-2017	Schneider	AVEVA	na	Reverse merger combining Industrial Software assets from Schneider with AVEVA
Aug-2017	Siemens	TASS International	na	Simulation software primarily focused on autonomous driving
Feb-2017	Hexagon	MSC Software	$835m	Computer-Aided Engineering (CAE) and Simulation Software for Design Validation
Nov-2016	Siemens	Mentor Graphics	$4,500m	Electronic design automation (EDA) software
Sep-2016	GE	Meridium	$495m	Asset performance management (APM) software
Sep-2016	Rockwell	Automation Control Products	na	Centralized thin client, remote desktop and server management software
Jul-2016	Dassault	CST	$240m	Electromagnetic (EM) and electronics simulation (integrated into SIMULIA)
Jan-2016	Siemens	CD-adapco	$970m	CAE for Fluid Dynamics (CFD), Solid Mechanics (CSM), heat transfer and others
Dec-2015	PTC	Kepware	$118m	Developer of communications software for Internet of Things (IoT)
Nov-2015	Siemens	Polarion	na	Application lifecycle management (ALM) enterprise solution
May-2015	PTC	ColdLight Solutions	$105m	Big data machine learning and predictive analytics
Oct-2014	Nemetschek	Bluebeam Software	$100m	PDF-based workflow software for processes and collaboration in the AEC sectors
Jul-2014	Dassault	Quintiq	$340m	Supply chain and Operations Planning & Optimization software
Jul-2014	PTC	Axeda	$170m	Industrial IoT solution
Jul-2014	Hexagon	Vero Software	na	Computer Aided Manufacturing (CAM) software
Jan-2014	Dassault	Accelrys	$750m	Biological, chemical and materials modeling and simulation (integrated in BIOVIA)
Dec-2013	Siemens	TESIS	na	Provider of integration of PLM software with other enterprise applications
Dec-2013	Dassault	Realtime Technology	$244m	3D visualization software
Nov-2013	Autodesk	Delcam	$277m	CAM Software
Jul-2013	Schneider	Invensys	$5,200m	Manufacturer of industrial and electronic control and measurement equipment
May-2013	Dassault	Apriso	$205m	Manufacturing Operations Management software

Date	Acquirer	Target	Price	Description
Nov-2012	Siemens	LMS	na	Provider of test and mechatronic simulation software
Oct-2012	Siemens	Kineo	na	CAM for optimizing robotic movements and path planning for the assembly and disassembly
Sep-2012	Siemens	Perfect Costing Solutions	na	Cost management and estimation software focusing on the discrete manufacturing industry
Aug-2012	PTC	Servigistics	$220m	Service lifecycle management (SLM) software
Nov-2011	Siemens	Vistagy	na	CAD/CAE/CAM for advanced composite materials
Apr-2011	PTC	MKS	$300m	Software application lifecycle management (ALM)
Jul-2010	Hexagon	Intergraph	$2,125m	Provider of CAD and geospatial intelligence software (GIS) included the PPM business
Apr-2010	Dassault	IBM's PML business	$600m	IBM's Product Lifecycle Management (PLM) business including sales and client support
Jun-2008	SAP	Visiprise	na	Provider of manufacturing execution system (MES) software
May-2008	Autodesk	Moldflow	$265m	Injection Molding Simulation Software
Apr-2008	Rockwell	Icuity Software	na	Enterprise Manufacturing Intelligence (EMI) software
Mar-2008	Ansys	Ansoft	$832m	Electronic design automation (EDA) software
May-2007	Oracle	Agile Software	$495m	Product lifecycle management (PLM) software solutions (became Oracle Agile PLM)
Jan-2007	Siemens	UGS	$3,500m	Product Lifecycle Management (PLM) software and services (became Siemens PLM)
Dec-2006	Nemetschek	Graphisoft (54.3%)	$125m	CAD software for the architectural and building industry professions
Dec-2006	SAP	Factory Logic	na	Lean Manufacturing software
May-2006	Dassault	MatrixOne	$410m	Collaborative PLM solutions
May-2006	Rockwell	GEPA	na	Industrial automation change management software
Oct-2005	Autodesk	Alias Research	$182m	Developer of 3D graphics technology
Jun-2005	SAP	Lighthammer	na	Manufacturing intelligence software provider
May-2005	Dassault	ABAQUS	$413m	Nonlinear finite element analysis software (integrated into SIMULIA)
Feb-2003	Rockwell	Interwave Technology	na	Manufacturing Enterprise Solutions (MES) integration
Jan-2002	Rockwell	Propack Data	na	Manufacturing information solutions for regulated industries

Source: Company Data, Barclays Research

Integrating CAD + CAE

CAD and CAE (or simulation) are both categories of PLM and are already closely integrated. As we explain in this report, it is the CAD data which is fed into the simulation software in the first place. However, it is worth noting that, as these have historically been provided by different companies, there is a handover that needs to take place.

The design and simulation of a product is typically done one step after the other, in a batch process; in other words, the CAD data is handed off to the simulation engineer in order to simulate, and then any changes go back to CAD team. Closer, or real-time, integration of simulation inside of a CAD tool can allow for optimisation and design to happen simultaneously.

This is, we believe, the thought process behind a number of notable acquisitions shown above, including the Siemens acquisition of CD-adapco and Dassault's acquisition of Exa.

There have other developments here without acquisitions – specifically, Ansys and PTC announced they will be integrating Ansys' Discovery Live into PTC's Creo. We think this integration could help democratize simulation for Ansys, and provide PTC with upgrade opportunities for its large CAD base. Furthermore, the integration of Discovery Live could help PTC competitively as Ansys is considered best in class, Ansys could get a broader distribution channel to seed the market for simulation.

Integrating ERP + PLM

ERP and PLM systems use similar data sets, but for different needs. In PLM the focus is on component specifics and how this is used to create the product or service (engineering focused), whilst ERP is focused on the cost or logistics of the item (transaction focused).

The main interaction between the two systems is via the Bill of Material (BOM). The BOM tends to be different for ERP and PLM systems. Engineers will use an Engineering BOM (eBOM), representing a design/product specified by engineering (and managed by PLM), while the rest of the organisation will work with a manufacturing BOM (mBOM), representing the way the design/product will be produced (and managed in ERP).

FIGURE 15
Integrating ERP + PLM

Source: Barclays Research

Having one BOM would be an ideal scenario, but often departments do not agree, resulting in a separate eBOM and mBOM and a third-party data exchange connecting the two. Historically, the power has been with ERP and closer integration is needed for bespoke mass production – for example, if one customises a bicycle purchase, there is the need for real-time re-pricing of different options. This requires an integrated BOM. This need was, for example, behind the $2.4bn acquisition of CallidusCloud by SAP, which was able to add sales quote management or CPQ (Configure, Price, Quote) software to its offerings.

Most PLM and ERP vendors have developed data management platforms to provide integration between ERP, PLM and MES systems. However, as these systems are often not open enough, there has been limited standardisation and manufacturing and engineering companies tend to have multiple platforms in place.

Integrating PLM + MES/OT + sensors

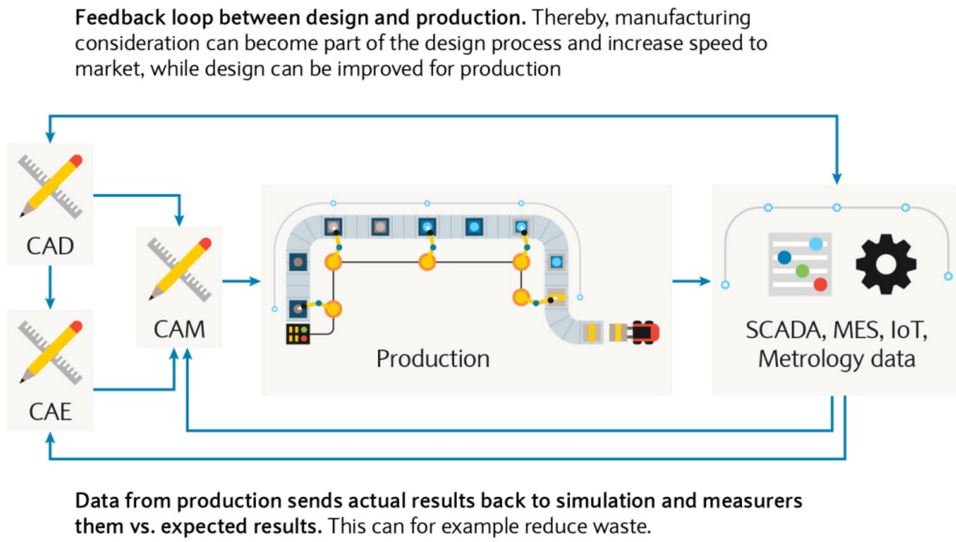
PLM and MES (in combination with OT) are both product focused, one for design and simulation and the other for production. Both systems developed over time independently, but there are significant benefits to integrating them.

In essence, an integration of both parts creates a feedback loop between virtual design and physical production. Therefore, manufacturing considerations can already be addressed in the design phase, which improves time to market and makes ramping up production more efficient.

In addition, feedback from the shop floor can help to improve the product design and increase quality. Overall efficiency gains can be won through ongoing improvement of the design process and the CAE and CAM software and by reducing waste. PLM-MES integration was a key consideration for Hexagon in its acquisition of MSC as can be seen from the graph below.

FIGURE 16

Integrating PLM + MES/OT



Source: Barclays Research

The way to integrate both systems is similar to the integration or ERP with PLM. Bespoke or out of the box solutions can be used, and there is a small number of vendors that are providing both software components as an integrated solution. The integration of PLM with MES was also partly behind the AVEVA/Schneider Software deal and the strategic emphasis these companies place upon the digital twin concept.

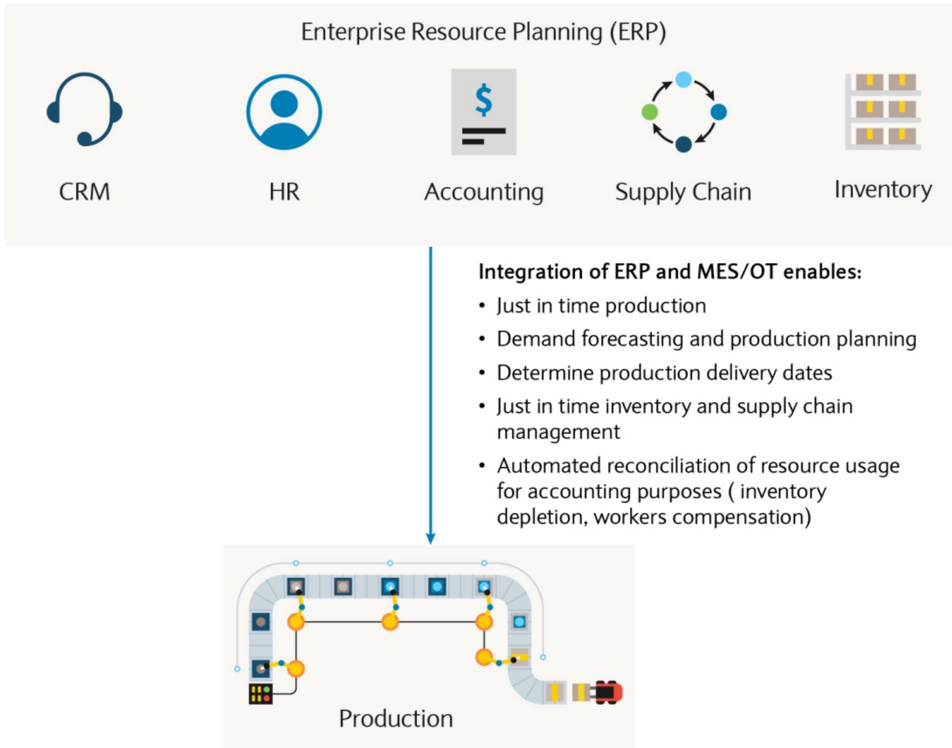
Integrating ERP + MES/OT

When integrating and ERP and MES system, the transactional data from the ERP system such as client orders, deliveries from suppliers and inventory can be used by the MES for real-time adjustments to the production effort. This could, for example, be in reaction to new or cancelled client orders.

In addition, it supports demand forecasting and production planning as well as business models around just-in-time delivery, where goods are only produced following a client order. On the other hand, the real-time data and production schedules from the MES system can be used on the ERP side to forecast more precise product delivery dates and can provide early warnings if inventory is being used quicker or production is slower than expected.

FIGURE 17

Integrating ERP +MES/OT



Source: Barclays Research

Integrating platforms

Given the silos within the manufacturingTech infrastructure and the increased level of data available from sensors, there is major strategic value in being the provider of the data architecture or data platform underpinning this integration. It is therefore no surprise that vendors from all over the manufacturingTech ecosystem have focused on data management and, increasingly, are morphing into IoT platforms.

The market remains fragmented with 500+ IoT platforms and most of these are nascent with <$10m in revenues. As the applicability is partly related to the connected data streams and installed base, we find that traditional players score at the top, the notable exception to this being C3 IoT, founded by Tom Siebel in 2009.

Given the huge data need for IoT platforms, this is a typical cloud play, supporting Microsoft (Azure IoT) and Amazon (AWS IoT). Other leading vendors include SAP (Leonardo), IBM (Watson IoT Platform), C3 IoT and PTC (ThingWorx). PTC acquired ThingWorx in 2013 for $113m, and we suspect this was the reason behind the $1bn strategic investment of Rockwell in the company (for an 8.5% stake).

This group is followed by the cap good IoT platforms, some smaller IT companies and Oracle. On the IT side there is Software AG (Cumulocity IoT), Atos (Codex IoT) and Oracle (IoT Cloud). For Software AG, this is a core strategy to reinvent the company and it has signed an interesting joint venture called Adamos with DMG MORI, Dürr, ZEISS and ASM. Other players in this follower group include Siemens (MindSphere), GE (Predix), Bosch (IoT Suite), Hitachi (Lumada), Schneider (EcoStruxure) and Cisco (Jasper and Kinetic).

The market is nascent at this stage, but hugely strategic and this is reflected in the revenue opportunity, We therefore anticipate that this will remain a highly competitive part of manufacturingTech over the coming years.

ASSESSING THE ADDRESSABLE MARKET

Below we discuss the addressable market for Industrial Software, in which we include spend for the manufacturing, natural resource and construction verticals.

From a top down perspective, worldwide IT spend was around €3.2trn in 2017 according to Gartner; of this, ~€320bn was related to software, while from a vertical perspective the IT combined spend for manufacturing and natural resources was €495bn and €75bn for the construction vertical (or together 18% of the total).

Assuming a similar split of software revenue in the manufacturing, natural resource and construction vertical to the overall industry, we estimate an addressable market of €58bn. According to the World Bank [3], the total industrial market by revenue, including construction, is ~€19trn.

This indicates that the current software spend by these industries is small relative to revenue and has significant room to expand if software solutions are able to reduce other costs within these industries or enable additional revenue sources. We estimate that the Industrial Software market will grow at a ~10% CAGR to FY20E, ahead of Gartner's estimate for overall IT spend growth at ~4%.

We complement our top down addressable market analysis with a bottom up analysis. We analyse each major software category on a standalone basis to derive an overall software spend.

FIGURE 18

Total addressable market

~€12bn	~€27bn	~€14bn	~€5bn
ERP and CRM	PLM	MES and SCADA	AIM

Source: Barclays Research

The largest addressable market within Industrial Software is the PLM vertical, which according to Technavio is close to €27bn. The largest players within this are Dassault (~11% share) followed by SAP (~8%), Siemens (~8%), Autodesk (~6%), PTC (~5%), and Ansys (~5%). We calculate these shares for Dassault, PTC, Ansys and Autodesk using their total revenue bases adjusted for FX, while for SAP and Siemens we use industry sources to determine[4] the market share.

The second largest category is MES and SCADA at €14bn, which is based on MES market data from Frost & Sullivan and SCADA estimates from marketsandmarkets[5]. For the MES category we have market share estimates from Frost & Sullivan, which indicate 10% share for ABB, 9% for AVEVA and 6% for Siemens.

[3] https://data.worldbank.org/indicator/NV.IND.TOTL.KD

[4] *http://beyondplm.com/2017/08/31/cloud-plm-raise-stakes/* and https://www.engineering.com/PLMERP/ArticleID/8529/Great-ERP-worse-PLM-What-SAP-PLM-needs-to-sharpen-its-competitive-edge.aspx

[5] https://www.marketsandmarkets.com/Market-Reports/scada-market-19487518.html?gclid=EAIaIQobChMI34W2kquI3gIVF57VCh0YhgD5EAAYASAAEgK2g_D_BwE

The ERP and CRM category is the third largest. Based on ERPNews[6] and Appsruntheworld[7] data, we estimate that the ERP and CRM markets were €41bn and €24bn respectively, in total. Applying the same split as the 18% IT spend for manufacturing, natural resources, and construction of the total spend to this, we calculate that the addressable ERP and CRM market within these verticals is €12bn. The largest players within this category are SAP, Oracle and Salesforce.

The smallest category is Application Infrastructure & Middleware, which includes middleware as well cloud, IoT and analytics applications. Based on Gartner, this market is ~€26bn; assuming that again 18% is within the manufacturing, natural resources, and construction verticals, this indicates an addressable market of ~€5bn. The largest providers within this category are IBM and Oracle.

Overall, our bottom up addressable market analysis indicates an addressable market of €57bn, very close to our top down model.

[6] http://www.erpnews.com/erp-market-size-expected-exceed-49-billion-2020/
[7] https://www.appsruntheworld.com/top-10-crm-software-vendors-and-market-forecast/

COMPANY PROFILES

Some of the companies profiled in this section are not under coverage by Barclays Research (as indicated next to the company names). Information about these companies is being provided for information purposes only and is not an investment recommendation by Barclays Research.

ABB | Zurich, Switzerland (covered by James Stettler)

Background: MES

Industrial Automation (formerly Process Automation) has become the group's core automation division (excluding Robotics) and – with the addition of B&R – is seeking to shrink the gap to global leader **Siemens**. Whereas Siemens is the global market leader in discrete automation, ahead of Rockwell, Schneider, Mitsubishi and Omron, ABB holds the No. 1 position in process automation with a global share of ~20% in 2015 ahead of Honeywell, Siemens and Emerson with about 15% each, according to ARC. Following the acquisition of B&R, ABB aims to become a leading global full solution automation vendor across the entire spectrum (excluding PLM and ERP).

Including B&R, management calculates pro-forma sales of $15bn across the broader automation space, including products, software, solutions and services, putting it second behind Siemens but ahead of Schneider and its US and Japanese peers.

ABB aims to challenge the global automation leader, building on its global No. 1 position in process automation, the significant installed base in robotics (No. 2 behind Fanuc), electrical equipment and its widened digital offer. B&R, which is a small vendor in discrete automation compared with Siemens (>€35bn installed base in PLCs), has an open platform approach that has led the company to outgrow the market by wining business with large OEMs as well as end users, ranging from VW, BMW, Nestlé to Roche.

ABB Digital is being expanded and the company has partnered with Microsoft to develop integrated digital platforms based around Microsoft's Azure cloud platform. ABB has seen a positive customer reaction to the new digital offer 'ABB Ability' and has rolled out over 180 industry specific digital applications. The company sees its installed base of 6,000 installed solutions, 70,000 control systems and 70m digitally enabled and connected devices as a key starting point. The aim is to support customers on all three levels: planning/design/simulation - building - operation. As are its competitors, ABB is seeking to move from upfront one-off payments on software to subscription-based contracts. One of the most advanced areas here is for Asset Health, and the company has already changed the business model on some of its SCADA and process control offers. In terms of planning software, ABB is already selling RobotStudio on a subscription basis and B&R adds automation studio for virtual commissioning and installation.

Arcstone | Singapore (private, not covered)

Background: MES and IoT

Arcstone was founded in 2013 by Willson Deng in Singapore. The company was founded with the vision to solve the most common issues in manufacturing and supply chain fuelled by Industrie 4.0. Willson realised that many traditional MES systems were not build for a fast changing environment and that the move from mass production to mass customisation puts a heavy strain on manufactures. Therefore, he founded Arcstone to solve this. The company developed a next generation MES system leveraging IoT to optimise practices across the shop floor and make use of data, thereby reducing cost and waste as well as increasing quality. While the company started with innovating the MES, its ultimate goal was to solve inefficiencies around the supply chain as it believes there are bigger problems to solve.

The company's platform consists currently of three components - arc.ops, arc.link and arc.quire. The backbone of the platform is arc.ops, which is the MES that provides users with a holistic view of the manufacturing process. Arc.ops includes various modules that allow manufacturers to monitor the production, track productivity and control processes. These modules include planning and scheduling, batch tracking, workflow tracking, work-in-process inventory monitoring, workstation control, automated KPIs, and analytics. The main differentiation of Arcstone's MES to traditional offerings is that it is highly is configurable, as an end user can change and configure the software themselves, while traditional MES require a significant proportion of bespoke developments.

Data from the shop floor is acquired through arc.quire. The integration software acquires data through legacy sensors and systems such as PLC, SCADA, machines and IoT based digital interfaces such as vibration, distance and heat sensors.

Integration and data exchange with other software systems is done via arc.link. Compatible other software systems include ERP, legacy MES and PLM. According to the company, for 90% of its customers ERP integration is a must to coordinate with sales, inventory, bill of materials, customer orders. Integration leads to a significant reduction in man hours and manual work, while reducing the risk of errors. At the same time, a PLM integration is depending more on the customers as some, for example contract manufacturers, don't even have one. For others this is more relevant, for example for companies that work a lot with prototypes. For some customers, the will augment the existing MES solution with theirs and therefore an integration with the legacy MES is needed.

Next year the company plans to launch arc.net, its supply chain offering, to tackle the inefficiencies around manufacturer's supply chain.

The company's go to market strategy is currently mainly based on partnerships with government entities, system integrators and consulting groups with 90% of customer request being inbound.

Ansys | Canonsburg, USA (covered by Saket Kalia)

Background: Simulation and Digital Twin Technology

Ansys is the leading engineering simulation software company that aids across the product lifecycle through the use of pervasive simulation across a variety of industries. The company has positioned itself to capitalize on emerging trends, such as additive manufacturing and digital twin technology. Ansys' products can simulate a variety of physics such as fluids, structure, electromagnetics, semiconductor power, embedded software and optical.

Ansys was founded in 1970 and is headquartered in Canonsburg, Pennsylvania originally under the name Swanson Analysis Software and is a leader in simulation software. The company was founded by John Swanson after working at Westinghouse doing finite element analysis by hand. He left the company to pursue building software to aid in the analysis and ultimately the company he created went public in 1993. Through the 2000's the company acquired several other simulation specialists to build out its multi-physics portfolio of offerings.

Some of the bigger acquisitions were Fluent for its fluid dynamic tools and Anasoft and Apache for their speciality in electronics and semiconductors respectively. The full suite of offerings allows Ansys to offer simulation technology to propel customers to the next stage of growth. For example, an automotive manufacturer no longer only needs to simulate the aerodynamics of a vehicle but also the onboard electronics and how an autonomous vehicle would behave in the wild.

At the beginning of 2017 Ajei Gopal become CEO and has overseen tuck-in acquisitions that continue to expand the physics Ansys solutions can simulate, namely 3DSIM and Optis. In addition, new products such as Ansys Discovery Live were recently released to provide real time simulation technologies to designers who historically didn't have access to simulation technology. The tool shows designers how design changes will impact the structure in real time and is allowing a products time to market to accelerate.

Ansys has also developed key partnerships with companies like PTC, Synopsys and SAP to embed Ansys solutions in partner's products. Most recently, Ansys and PTC announced that Discovery Live would be embedded into the PTC CAD product to allow for real time simulation in the CAD tool.

The company employs ~3,200+ people globally with about 1,000 working in R&D. Ansys' revenues are 3x larger than the nearest competitor and its products are used by 97 of the Fortune 100 Industrial firms and more broadly, 45,000 customers worldwide. Ansys generates ~75% of its revenues from 4 verticals: high tech, aerospace & defence, automotive and industrial equipment.

Autodesk | San Rafael, USA (covered by Saket Kalia)

Background: CAD, PLM

Autodesk is a design software company that has three main focus areas: 1) Architecture, Engineering & Construction; 2) Product Design & Manufacturing; and 3) Media & Entertainment. Although one of the biggest opportunities Autodesk sees is the digitalization and optimization of the construction site, there are also growth opportunities in manufacturing where they generate at least 25-30% of revenues.

Autodesk was founded by John Walker in 1982 as the company developed what would be its flagship product AutoCAD. In 1989 the company crossed $100M in revenue and through the 90s Autodesk built out its capabilities to better serve various industries, including manufacturing. Today AutoCAD is the largest revenue generating product for Autodesk.

Since 2014 Autodesk has been undergoing a transition to a subscription model. In 2016 Autodesk discontinued the sale of perpetual licenses and has since introduced incentives to convert legacy maintenance users to the subscription model. One incentive is industry collections which provide users in each vertical a broad solution set relevant to their respective industry.

Autodesk leverages indirect channels with ~1,600 resellers worldwide which generated ~70% of FY18 revenues. Recently Autodesk has placed a greater focus on their own e-store, which should increase the mix of direct sales in coming years.

Andrew Anagnost, previously SVP and Chief Marketing Officer, took over as CEO in 2017. He has overseen some tuck-in acquisitions, but most notably has continued his active role in transitioning the company to subscription.

In 4Q18 Autodesk initiated a restructuring program to refocus the business on key drivers of the future such as a subscription model, digital transformation and its 3 business sub segments: manufacturing, construction and production. With the restructuring Autodesk reduced its workforce by ~13% or ~1,150 workers.

Aspen Technology | Bedford, USA (publicly listed, not covered)

Background: PLM

Aspentech is the market leader in process simulation for the chemical and oil & gas industries and, therefore, a key competitor to the SimSci business which now forms part of AVEVA's engineering portfolio. Such software is sold prior to or alongside the plant design software sale and is a mathematical model concerned with the chemical process of, say, turning crude oil into refined fuel. Therefore it models how various processes and factors (heat for example) impact the chemical process. This is separate to the 3D model of the physical plant itself, and helps facilitate such a process. Over time, Aspen expanded from pure process simulation to focus on process optimisation. Therefore, while the core of the software sits within the PLM suite, parts of Aspen's offering extends the MES/MOM layer of the manufacturingTech stack. Today, Aspen is listed on the NASDAQ with a market capitalisation of ~$7bn.

Begun as a joint research project between MIT and the US Department of Energy in 1977, Aspen stands for Advanced System for Process Engineering. The premise for the project was that computer engineering and simulation was being applied to construction, mechanical and electrical areas, but was suitable also for chemical processes. Following the energy shortages of the decade, the government came together with MIT to use simulation technology as a way to produce fuel and chemical components more efficiently and more cost effectively than was currently the case. The software was designed to be used right across the process manufacturing industry, rather than purely for specific chemicals or processes, and to replace the plethora of in-house bespoke systems that were being used at the time. In 1981 Aspen Technology was founded to commercialise the technology. The business was first listed in 1994, but went on a spree of acquisitions (over 25), which led the business into a very turbulent period. In 2002, it acquired Hyprotech for $99m, a process simulation business in upstream oil & gas production. However, a year later, the FTC ruled the acquisition illegal – they were primary competitors, with only SimSci also in the market – and disposals were made to Bentley and Honeywell. The company went through more tumult between 2008-10 along with management changes. CEO Antonio Pietri, was appointed in 2013, leading the company's growth and margin expansion. In 2014, ApsenTech opened a new headquarters in Bedford, Massachusetts. In 2017, it launched aspenONE Asset Performance Management, a new solution in the data management space. In 2018, an alliance with Emerson was formed to co-develop in a number of areas.

AVEVA | Cambridge, UK (covered James Goodman)

Background: PLM and MES

AVEVA is a UK-based software company with its headquarters in Cambridge. The group has a broad portfolio of software across computer aided design, process simulation, asset performance management, supervisory control and data acquisition and manufacturing execution systems, as well as consulting services. It was listed on the London Stock Exchange in 1996 and is in the FTSE250 index.

AVEVA's genesis was a government-funded computer aided design project (CADCentre), established in 1967 in Cambridge. This was an initiative of the UK government to develop CAD techniques and promote its usage across British industries, its funding requirements fulfilled by the Ministry of Technology. The group created an object-based engineering database called Dabacon and launched its core Plant Design and Management System (PDMS) in 1976. CADCenter went on to become a private company in 1983 with the government diluting its ownership and this was followed by a management buyout in the year 1994. CADCenter listed in 1996 and changed its name to AVEVA in 2001.

AVEVA made various acquisitions over the years; the first one being in 2004 when the group acquired the global leader in software for marine and shipbuilding design, Tribon Solutions. This allowed the company to venture into marine solutions, now called AVEVA Marine. This was followed by iDesignOffice in 2009 which specialised in instrumentation engineering technology for plant and marine solutions.

The MARS business of Logimatic group was acquired in 2010 and was merged with AVEVA's nascent Enterprise Solutions offering called AVEVA NET. In 2011, the group expanded into 3D data capture after it acquired LFM, the software division of Z+F UK. In order to build on its 3D structural detailing capabilities, AVEVA acquired Bocad, a provider of building information modelling software in 2012. The risk management software provider 8over8 was acquired by AVEVA in 2015 for its offerings in oil & gas, mining and other industries.

Most notably, of course, in early 2018, AVEVA merged with the industrial software business of Schneider Electric, which resulted in Schneider Electric becoming the largest shareholder in the group with ~60% ownership. The merger created a substantially larger global business, now with a customer base of 16,000+ spread across 10+ industries in 80 locations worldwide.

The heritage AVEVA's core product is E3D (Everything3D), which is the successor to PDMS. PDMS and its successor E3D are iteration of AVEVA's CAD tool and work on the proprietary database technology. E3D was launched in 2012, as the first major relaunch of the company's core product, incorporating both additional organic and acquired functionality. In total, AVEVA's engineering tools accounted for ~90% of revenue.

AVEVA NET, an internal data management tool, was also launched by the heritage business in 2002. This tool was used to aggregate a wide range of asset management information from multiple sources like tag data, location information, reference documents and laser scans into a 3D visualisation environment. It accounted for ~10% of revenue.

Schneider Software was a broader mix of sizable, acquired businesses. We identify four main product offerings, namely Wondercare, Citect, SimSci and Avantis.

Wonderware is the main product and we estimate this accounts for ~50% of the total Schneider Electric software portfolio. It provides Supervisory Control And Data Acquisition (SCADA) software. SCADA software collects and displays data from remote locations in order to control equipment and conditions on the factory floor. It is a full system and includes hardware components (sensors) which collect the data. Wonderware pioneered a Human Machine Interface (HMI) designed to be used with the Windows operating system and this was the success behind the company. It was founded in 1987 and in 1998 it was bought for $375m by Siebe (Siebe and BTR plc formed Invensys in 1999). Citect is another SCADA software product and Schneider acquired this in March 2006 after a bidding war and bought the business for $80m.

Process simulation (mainly SimSci) we estimate accounts for ~20% of revenues and are steady state process simulation tools for process design and operational analysis. These tools help engineers create optimal process designs, analyse plant operation, develop performance improvement and monitor and optimise operations. This is mainly sold into the chemical, petroleum, gas and polymer industries. SimSci was founded in 1967, IPO'd in 1996 and two years later with disappointing earnings it was bought by Siebe for $145m. Spiral Software was founded in 1998 and is an operations planning and scheduling tool for the oil industry. It was bought in October 2012 by Invensys and merged with the SimSci business.

Avantis is an asset performance management tool that we estimate accounts for a further ~10%. This product set is designed to maximise the return on the owner operators' assets. Tools include maintenance scheduling, supply chain optimisation, diagnostic data tools and predictive applications around asset failure.

Bentley Systems | Pennsylvania, USA (private, not covered)

Background: PLM (AEC)

Bentley Systems, founded in 1984 by Keith and Barry Bentley, is a design software company, focused on the Architecture, Engineering & Construction (AEC) vertical. The company provides a range of software across the lifecycle of assets such as bridges, skyscrapers, airports and power stations from design through to operations and asset performance. The company is based in the US and is private, however, its shares can be bought on invitation on the NASDAQ Private Market. Siemens has, over the years, acquired a 9% stake in the business. The companies have a strong partnership, including a €100m innovation investment programme. In the most recent initiative, Bentley is integrating Siemens's Teamcenter and MindSphere products with its engineering and project management tools to create a digital twin offering for the engineering and construction industry.

The company's first product in 1984 was PseudoStation, a software that allowed for low cost terminals to access Intergraph (now owned by Hexagon) design files, instead of using the more expense Intergraph workstations. In 1985 the company released its first version of MicroStation, which was an early, stand-alone CAD system that could now be used on an early PC. Alongide ProjectWise and AssetWise, it remains today one of three key products of the company. Microstation is a 2D and 3D design software primarily used for the architectural and engineering verticals. ProjectWise, as the name suggests, is a project management and collaboration tool for the design through construction to handover of infrastructure assets. AssetWise is a product data management software to facilitate capital planning, efficient maintenance, risk reduction and legislative compliance.

In addition to organic growth, the company has also expanded via considerable M&A. Since the first acquisition of IdeaGraphix in 1997, the business has completed over 30 business acquisitions.

Cadence Software | San Jose, USA (publicly listed, not covered)

Background: EDA

Cadence is an electronic design automation (EDA) player focused on the design of semiconductors, printed circuit boards, and other electronic products. The business is broken into five segments.

The business Cadence has historically had the most leadership in is Custom IC Design and Verification, which is related to designing electrical systems using analog power with a product called Virtuoso. The other business where Cadence has built market share is in Functional verification, where products like Palladium for hardware-accelerated verification are leaders. Another area (though smaller) is System Interconnect and Analysis, which is essentially tools to design printed circuit boards (PCBs) using a toolset called Allegro.

Other businesses include Digital IC Design and sign-off, and Intellectual Property. On Digital, the three main sub-segments here are logic design, physical implementation, and sign-off, which are all geared towards digital semiconductors. Intellectual Property (IP) is usually standards-based design snippets that can be used in designs to accelerate time to market – here we have seen Cadence make acquisitions like Tensilica and nusemi to help build the business.

Like its peer Synopsys (profiled below), roughly 90%+ of revenue is coming out of backlog giving Cadence high visibility near term.

C3 IoT | Redwood City, USA (private, not covered)

Background: IoT

C3 IoT was founded in 2009 by Tom Siebel, who is the Chairman and CEO. Prior to C3 IoT, he founded Siebel Systems in 1993, and this CRM business was sold to Oracle in 2006 for $5.8bn.

The business was originally focused on software to help electric grids manage energy flows to homes. However, the 2014-'15 oil price slide resulted in its client ending software purchases. With a $70m cash injection from TPG Growth, C3 re-launched in 2016 focusing on collecting and analyzing data from sensors and industrial machines. The company was renamed from C3 Energy to C3 IoT and since has developed in a full stack cloud based IoT development platform. It expanded from the energy sector to address the manufacturing, oil and gas, aerospace and defense, transportation, healthcare, retail, commercial services, and public-sector enterprises.

It is a platform that enables companies to design, create and deploy enterprise IoT applications. In addition, it provides a tool-kit and pre-build SaaS IoT applications to deliver predictive maintenance, sensor health, supply network optimization, inventory optimization, energy management, and AI-based CRM.

The company delivered just over $80m in revenues last year (April '18) and this was 60% growth on the prior year. Bookings were up 130%. The company was valued at $1.4bn in the March '17 funding found. It raised a further $100m in January '18 but there have been no details on the valuation.

Dassault | Vélizy-Villacoublay, France (covered Gerardus Vos)

Background: PLM

Dassault Systèmes is a European software company founded in 1981 as a subsidiary of Dassault Aviation Group. The company is headquartered in France and develops design, simulation and product lifecycle management software. In 1996 the company spun out from its parent and went public in France with a listing also on the NASDAQ, where it delisted voluntarily in 2008 and remains to date listed on the Euronext Paris. The Dassault family remains the largest shareholder with a ~41% stake.

The company was originally founded to develop the next generation of computer aided design (CAD) software called CATIA. To support the commercial and distribution side of the business, the company entered into a marketing, sales and support agreement with IBM. The agreement supported Dassault's growth and lasted for nearly 30 years until in 2010 Dassault acquired the PLM, service and client support business from IBM for $600m.

While the company's origin was in the aviation industry, it expanded significantly in automotive industry during the 1980's and won customers such as BMW, Mercedes and Honda. The company continued in the following years to expand into other verticals such as assembly, consumer goods, high-tech, shipbuilding and energy.

Following its IPO in 1996, the company acquired SolidWorks in 1997 for $310m and split the company into two divisions: The "Process-centric" segment included Product Lifecycle Management solutions to focus on the whole end-to-end product cycle; this segment included CATIA. The "Design-centric" segment focused on design-only solutions and included the newly acquired SolidWorks brand. In 1998 Dassault acquired IBM's Product Data Management solution and created on the base of this asset the ENOVIA brand to manage product data from CATIA. In 1999 the ENOVIA brand was expanded with the acquisition of Smarteam, a product data management solution with focus on SMBs.

In 2000 the company created the DELMIA brand, which focused on digital manufacturing simulation, and consolidated the acquisitions of Deneb, Delta and SafeWork all in the year 2000. In 2005 the company acquired AVAQUS for $413m, a nonlinear finite element analysis software solution, which was integrated into the newly created SIMULIA brand, covering several simulation domains. In 2006 the business continued with its M&A expansion with the acquisition of MatrixOne, a collaborative PLM solution, for $410m, which was integrated into the ENOVIA brand. In 2007 Dassault created the 3DVIA brand, a 3D visualisation software for consumers and professionals. This followed by the acquisition of Seemage, a provider of 3D interactive product visualisation software.

In 2008 the company launched an online offering of its PLM offering with PLM 2.0 and introduced the next version of its PLM solutions with V6 (included brands CATIA, DELMIA, SIMULIA, ENOVIA). During this phase the company made a series of acquisitions to support its online offering including the acquisition of Engineous Software, a provider of process automation, integration and optimisation, for $40m.

In the following years the company built out its existing business with a series of smaller acquisitions including Greensoft (2010), Exalead (2010), Enginuity (2011), Intercim (2011) and Netvibes (2012), before in 2012 it launched 3DEXPERIENCE platform to expand its PLM offering and include user experience to enable better product delivery. In the same year it created the GEOVIA brand, a simulation solution for extraction related activities like mining, with the acquisition of Gemcom Software for $360m, a leader in mining simulation software. In 2013 Dassault acquired Apriso, a provider of manufacturing operations management systems, for $205m to close the loop between design and manufacturing. Apriso was integrated into the DELMIA brand. In the same year, Dassault also acquired Realtime Technologies (RTT), a 3D visualisation software provider, which later became the 3DEXCITE brand.

In 2014, the company continued with its acquisition driven expansion with two major acquisitions. The first one was Accerlyrs for $750m, a provider of biological, chemical and materials modelling and simulation, which became the BIOVIA brand. The second was Quintiq for $340m, a provider of supply chain and operations planning & optimisation software, which was integrated into the DELMIA brand.

In 2016 it expanded DELMIA's product offering with the acquisition of Ortems, a provider of software for production planning and scheduling. In the same year it also announced the acquisition of CST, a provider of electromagnetic and electronics simulation software, for $240m, which was integrated into the SIMULA brand. In the following year, the SIMULA segment was strengthened by the acquisition of Exa for $400m, a software provider for Computational fluid dynamics (CFD) simulation. Shortly after, it acquired No Magic, a model-based systems engineering software provider, which was integrated into CATIA. In 2018, it also acquired a majority stake in Centric, a PLM vendor in the fashion and retail space.

Hexagon | Stockholm, Sweden (covered Gerardus Vos)

Background: PLM and Metrology

Hexagon is a Stockholm based software and capital goods group providing products to design, measure and position objects, which are used by various end users like surveyors, construction companies, security companies, defense related industries and government agencies.

Hexagon was founded in 1992 when a consortium of private individuals acquired a major shareholding in the stock exchange listed company Eken Industri & Handel AB, which was subsequently renamed Hexagon. In 1998 current Chairman, Melker Schorling, started to build his stake in Hexagon and he brought in current CEO Ola Rollen in May 2000.

Mr Rollen streamlined the conglomerate and changed the business via acquisition. In May 2001 the first major acquisition was made when Hexagon acquired US based Brown & Sharp, which forms the basis of the Metrology division, which later became Manufacturing Intelligence. The next significant acquisition was made in late 2005 with Leica Geosystems, which forms the core of Hexagon's Geosystems division. In 2007 Hexagon acquired NovAtel, which become part of Positioning Intelligence. In mid-2010 with the acquisition of PLM software vendor Intergraph, it formed the PPM division and Safety & Infrastructure. In 2017 the latest large acquisition followed with MSC Software in the simulation space.

The company split its business into two segments: Geospatial Enterprise Solutions (GES) and Industrial Enterprise Solutions (IES) with each having several sub divisions. GES and IES represent each roughly half of the company's revenues.

Geospatial Enterprise Solutions includes sub divisions Geosystems (Leica), Safety & Infrastructure (part of Integraph) and Positioning Intelligence (Novatel). Geosystems represents ~75% of the segment's revenues and produces a wide array of measurement and positioning systems used in construction and transportation. Safety and Infrastructure represents ~20% of the segment's revenues and provides incident management and geospatial software solutions to help customers manage, enhance and protect life, infrastructure and property. Products are mainly sold to the governments. Positioning Intelligence represents ~5% of the segment's revenue and provides receivers, casings, antennae and so-called "middleware", which is integrated into high-precision positioning applications (GNSS).

Industrial Enterprise Solutions includes sub divisions Manufacturing Intelligence (Brown & Sharp, MSC) and PPM (part of Intergraph). Manufacturing Intelligence represents ~70% of the segment's revenue and provides a range of stationary and portable industrial measuring systems, mainly sold into the automotive, aerospace and general manufacturing industries, and design and engineering software. PPM represents ~30% of the segment's revenue and provides PLM software to the oil & gas, chemical and power industries.

Nemetschek | Munich, Germany (publicly listed, not covered)

Background: PLM (AEC)

Nemetschek, founded in 1963 by Prof. Georg Nemetschek, is a Munich based company providing software for the architecture, engineering and construction (AEC) industry. The company has several brands, products and end markets. Core of the offering is used by AEC professionals for the design and build of real estate and infrastructure. These segments represented 63% and 29% of group revenues in FY17. Beyond that the company has a small offering (2% of rev) for the management of buildings and for the visualisation, 3D modelling and animation for the Media & Entertainment end market (6% of rev). The company went public in 1999 and is listed in the Prime Segment on the Frankfurt stock exchange.

The company was founded as an engineering firm with the name Ingenieurbüro für das Bauwesen. The company quickly made use of emerging computer technology, and was in 1968 the first company in the construction industry that made use of computers. In 1977 it developed its first software, which uses magnetic strips to perform calculations. In 1980 the company released its first computer-aided engineering software (CAE), which remained a unique offering of the company for many years. In 1981 Nemetschek Programmsystem GmbH was founded for the distribution of the company's software offering. In 1982 the company started to expand internationally, first to Switzerland and Austria. In 1984 the company launched one of its core products, a CAD system, for architects and engineers called Allplan. In the following years the company continued to expand internationally and continuously improved its Allplan CAD offering.

In 1998 the company started with its inorganic growth strategy with four acquisitions, Frilo, Glaser, Bausoftware and Crem, and has remained since then very acquisitive.

Following the first acquisitions, the company went public in 1999 on the Frankfurt stock exchange and acquired two further companies, Maxon and Auer. In 2000 the company expanded by acquiring Vectorworks, in 2006 it acquired Graphisoft and Scia, in 2013 Data Design System, in 2014 Bluebeam, in 2016 Solibri and SDS/2, in 2017 dRofus and RISA and in 2018 MCS Solutions.

One of the key differentials of Nemetschek's acquisition strategy is that Nemetschek AG itself acts as a holding company for the brand it owns and does not integrate the acquired companies. Instead the acquired brands operate independently with each brand has its own CEO and CTO. Everything that is important for the operations and product developments remains within in a brand, which the company argues is attractive for smaller firms that they acquire. According to the company, this has given them competitive advantages in M&A transactions compared to competitors. It is interesting to note that in the headquarters in Munich there are only around 30 employees across controlling, finance, HR and strategy.

Oracle Corporation | Redwood City, USA (covered by Raimo Lenschow)

Background: ERP and PLM

Oracle is a relatively small player in PLM through its Oracle IoT Cloud and IoT Applications offering. The core to its PLM applications is the $500m acquisition of Agile Software Corp in '07. Agile was mainly focused on product collaboration and product data management and integrated with many 3rd party CAD and ERP systems. It was focused on the high-tech, life sciences, industrial manufacturing and consumer packaged goods sectors. Agile bought Cimmetry Systems in 2005, which was an enterprise visualisation tool. The key brands for Oracle PLM still are Agile, Cimmetry and AutoVue. Today, the company's PLM portfolio includes solutions for product ideation, development, commercialization, quality management and project portfolio management. The company's PLM solutions are used by more than 2,000 companies across multiple industries. In addition, it has the aforementioned IoT platforms.

Oracle also provides broader Supply Chain Management (SCM) solutions outside of PLM, including procurement, planning and order management. We also note that the company's manufacturing vertical specific portfolios are called Oracle Manufacturing Cloud and Oracle Smart Connected Factory (SCF). Oracle Manufacturing Cloud provides manufacturing and supply chain materials management with embedded analytics. Oracle SCF provides a solution to monitor factories (production performance, maintenance predictions, assets, quality etc.) in a global view to improve the 360 degree view of the manufacturing operations. These vertical solutions bring together the company's products across major enterprise applications such ERP, PLM and SCM, packaged for the industrial manufacturing vertical.

Oracle has continued to expand its vertical specific solutions for industrial and manufacturing companies. Recently, the company announced the acquisition of Textura, a provider of cloud-based contract and payment management solutions specifically for the construction industry for $663m. Oracle then followed this up with the acquisition of Aconex, a cloud-based solution that manages team collaboration for construction projects, for $1.2bn. These two solutions are part of the company's Construction and Engineering vertical business unit, a cloud-based project control and execution platform that manages all phases of engineering and construction projects. These solutions are also integrated with Oracle Primavera (acquired in 2008), a suite of cloud and on-prem solutions for project, cost, time and risk management across industries. We also note the company's acquisition of Opower, a provider of customer engagement and energy efficiency cloud services to utilities, for $532m.

PTC | Needham, USA (covered by Saket Kalia)

Background: CAD, PLM, SLM, and IoT

PTC is a design software company that helps companies design products through the product lifecycle through their two business units: 1) solutions group, and 2) IoT group. The solutions group includes products that compete in the CAD, PLM and SLM space. IoT is the faster growing segment which includes IoT and VR solutions which has a focus on industrial factory use cases.

PTC was founded in 1985 by Dr. Samuel Geisbergand and is headquartered in Needham, Massachusetts and originally incorporated itself as Parametric Technology Corporation. The company released Pro/Engineer which was the first parametric modelling (3D) software in the market and was first adopted by John Deere. PTC then went public in 1989. In 1992 IndustryWeek announced Pro/Engineer the Technology of the Year. About 5 years later, PTC began selling its PLM product Windchill. In 1999, PTC crossed the 25,000 customer market with a significant presence in the industrial sectors.

Throughout the 2000s PTC made a series of acquisitions to expand its solution set. In 2005, PTC acquired Arbortext for technical publishing technology and Aptavis for technology in the retail and apparel space. In 2006 PTC acquired MathSoft for engineering calculation and ITEDO for 3D illustration software. Then PTC acquired CoCreate in 2007 for direct modelling technology. In 2008 PTC acquired Synapsis to collect performance data and run analytics and in 2009, the company acquired Relex for access to reliability engineering software

In 2010, James Heppelmann became CEO and the company rebranded Pro/Engineer to what is now known as PTC Creo. Perhaps the most transformative acquisitions by Mr. Heppelmann include what now make up the IoT group today, most notably Thingworx, acquired in 2013.

In 2014 PTC acquired Axeda Corporation to build on Thingworx for its IoT connectively solutions and ATEGO for exposure to aerospace, transportation and automotive industries. In 2015, PTC acquired ColdLight for its machine learning and analytics functionality and Vulforia from Qualcomm Connected Experiences for Augmented Reality, along with Kepware in 2016 for its connectivity solution for industrial environments.

Today PTC employs 6,000+ people and works with 750+ partners and resellers. 32% of FY17 revenues were from industrial customers with reference accounts like John Deere, Caterpillar, Manitowoc and ABB. Federal Aerospace and Defence makes up 16% of revenues with reference accounts such as Boeing, Lockheed Martin and NASA. PTC also made a formal commitment to return 40% of FCF to shareholders.

RIB Software | Stuttgart, Germany (publicly listed, not covered)

Background: PLM (AEC)

RIB Software, founded in 1961 in Stuttgart as Recheninstituts im Bauwesen, provides software for the architecture, engineering and construction (AEC) industry. The company's software is used for model based design and construction of real estate and infrastructure. The company is listed on the Frankfurt Stock Exchange

The company was founded as an engineering firm and made early use of emerging computing technology for the construction industry, for example to compute relevant figures for bridges. In 1968 the company developed a software to calculate the visibility of planned roads and extended into other areas such as tunnelling and hydraulic engineering. In 1979 the company introduced IDEALOG, a software that was used in Germany for AVA (Ausschreibung, Vergabe und Abrechnung), a standardised method for tendering, awarding and accounting for building work.

In the 1980s the company consolidated its software offering with STRATIS for road construction and civil engineering and with RIBTEC for structural engineering. It also introduced ARRIBA, which we understand is the follow up solution for IDEALOG for AVA. ARRIBA was used for tendering, awarding and accounting for building work. During that time all the software was converted to run on Windows.

In 2004 the company started its international expansion and established and R&D center in Guangzhou, China. In 2009 and 2010 the company opened 10 new regional offices, three in the US, two in China, and one each in Dubai, India, Australia, Singapore and Hong Kong.

In 2009 the company introduced German version of iTWO, which is a cloud-based 5D building information modelling (BIM) solution. It is 5D as it is not only used for the virtual design (3D) but also cost and time. In 2010 the company launched the English and Chinese version of iTWO. In 2011, the company is listed on the Frankfurt Stock Exchange.

Since 2012 the company has expanded its business through M&A, starting with three acquisitions in 2012: MC², a US based developer of construction estimating software, ProjectCentre, Australia-based SaaS construction software developer, and U.S. COST, a US based construction software vendor. With this acquisition, RIB expanded its geographical footprint in key construction markets. In 2013, RIB purchased majority stake in the German based Cosinus Information Systemes GmbH, a provider of ERP software the building and construction verticals. In 2014, it acquired Docia, a Denmark-based SaaS company for construction collaboration, and a majority stake in Iceprice, a provider of an e-com platform for the construction and building verticals. In 2015 RIB acquired Soft SA, a Spanish construction software company, which gave it access to Spanish speaking markets (Spain and Latam). In 2016 it purchased a 25% stake in the Hong Kong based construction software company called Exactal, which it enlarged incrementally to a 100% stake in January 2018. In 2018, it also acquired a 51% stake in Datengut Leipzig GmbH, a provider of mobile solution for the construction industry, and 80% of MS Gesellschaft für Informations- und Managementsysteme mbH, a provider of facility management solutions.

Rockwell Automation | Milwaukee, USA (covered by Julian Mitchell)

Background: MES

Rockwell Automation is an industrial company based in Milwaukee, WI, focused on discrete, and to a lesser extent, process automation It has two operating platforms – Architecture & Software, and Control Products & Solutions.

The original base of the company, and a key brand it retains today, is the Allen-Bradley electric equipment business, which was founded over 100 years ago. Allen-Bradley expanded into industrial controls in the mid-20th century, and it has been one of the global leaders in Programmable Logic Controllers (PLCs) for several decades. Allen-Bradley was acquired by conglomerate Rockwell International in 1985. The resultant entity within Rockwell International, Rockwell Automation, launched a number of major products during the 1990s, including the Logix controller, which has remained largely unique since its launch, as it is a controller which is able to operate in both process and discrete environments, on the same platform.

Rockwell International split in the early 2000s, as aerospace supplier Rockwell Collins was spun off, leaving Rockwell Automation as the 'RemainCo'. Rockwell Automation has focused on its core automation offering, and it divested its motors / Power unit to Baldor Electric a decade ago. The company has made a push into the 'Connected Enterprise' (a concept driving a new wave of automation investment by customers, driven by the increasing number of smart assets on the plant floor which generate data), and expanded its software offering, in an effort to accelerate organic sales growth.

Rockwell's approach to the Connected Enterprise remains focused on 'open standards' (rather than a more 'monolithic' approach, as well as 'simplification' (having a focused product offering, and linking with partners who share an open approach). ROK claims to be one of the global leaders in MES software, but even after several years of double-digit growth, its sales base is still slightly less than $100m. Around one third of its MES sales sit 'on top' of other manufacturers' control products, underlining one advantage of this 'open' approach.

CEO Keith Nosbusch had run ROK since the spin-off of Collins, and he stepped down in 2016, being replaced by Blake Moret (who had run the CP&S segment). Earlier this year ROK took a ~$1bn stake in PTC (as well as a Board seat), potentially signalling a greater willingness to use inorganic means to accelerate the top-line.

SAP | Walldorf, Germany (covered Gerardus Vos)

Background: ERP and PLM

SAP was founded in 1972 and is headquartered in Germany. The company was founded to provide standard application software for businesses processing. Over the time the company grew to one of the largest software companies in the world, providing a wide range of enterprise applications. The company is listed on the German stock exchange.

ERP and PLM systems communicate through the Bill-of-Material or BOM, which tend to be different between ERP and PLM. Engineers will use an Engineering BOM (eBOM), representing a design/ product specified by the engineering (and managed by PLM), while the rest of the organisation will work with a manufacturing BOM (mBOM) representing the way the design/product will be produced (and managed in ERP).

In 2017, SAP relaunched its Leonardo platform, which was previously an IoT platform, as a platform take advantage of data analytical tools such as artificial intelligence (AI), machine learning, advanced analytics and Blockchain. Given the above it is clear that SAP wants to dominate the data exchange but is less focused on the design, control and engineering tools, although it has offerings.

Software AG | Darmstadt, Germany (covered Gerardus Vos)

Background: IoT and middleware

Software AG, founded in 1969, is a German software company, providing a wide range of software solutions. Adabas & Natural (A&N) is the legacy offering of the company, and includes the database software, Adabas, for mainframe and programming language Natural. Digital Business Platform (DBP) includes the company's middleware, business process, IT transformation, analytics and IoT offering. The company is listed on the Frankfurt Stock Exchange.

While A&N is the company legacy division, DBP was created through acquisitions in combination with some existing integration assets. In 2005 Software AG acquired Sabratec and Casabac and strengthened its integration portfolio. In 2007, it acquired its integration competitor webMethods. In 2010, Software AG acquired US based Data Foundations, a provider of master data management systems. In 2011, the company acquired Terracotta, a provider of software for in-memory databases. Many smaller acquisitions followed and the next meaningful acquisitions were in 2013 with alfabet, a provider of software for planning and optimisation of IT infrastructure, and Aparma, a provider of streaming analytics. All the acquired assets in combination with the existing integration assets formed the basis for Digital Business Platform. After a period of lower M&A activity the company acquired AI company Zementis in 2016, Cumolocity (IoT platform in 2017), and Trendminer (self service analytics for time series data; used on top of historians). All the above acquisitions formed the basis for Digital Business Platform.

In 2017, Software AG announced the launch of a JV with some leading capital goods venture called ADAMOS (ADAptive Manufacturing Open Solutions). ADAMOS is based on the IoT platform of Software AG and includes a digital market place, in which partners can sell apps to each other.

Siemens AG | Munich, Germany (covered James Stettler)

Background: PLM, MES and OT

Siemens offers an automation portfolio, product lifecycle software and technology-based services covering the value chain from product design to manufacturing. The company generated revenue of about €1.2 billion from digital services and around €4.0 billion from software solutions in FY2017, representing growth of 20% (11% ex-Mentor) vs. the company's estimated growth of 8% for the overall market. Siemens is raising R&D expenditure (6.2% of sales in FY2017) by €400m to €5.6bn in FY2018 - major part earmarked for 1) automation, 2) digitalization, 3) decentralized energy systems and 4) the new venture unit 'next47'. Out of the €5.2bn in R&D funds spent last year, around €1.2bn was dedicated to software and digital solutions.

The company has strengthened its portfolio through large deals in the area of software (~€9bn spent to date including mendix) and is #1 in Digital Manufacturing PLM software and #1 in discrete factory automation. Digital Factory has built up a ~€2.6bn+ software portfolio, starting with the acquisition of UGS (2007, PLM software), LMS (2012, simulation software), CD adapco (2016) and Mentor Graphics (2017, electronic design software). Siemens sees particularly significant opportunities in China, where the penetration of software remains low.

mendix: Siemens announced the acquisition of Boston-based mendix ('a leader in low-code application development', *www.mendix.com*, 400 employees, founded in 2005) for €600m to drive the expansion of the digitalization business, in particular the Mindsphere IoT platform. Mendix is expected to register growth rates of more than 40% until 2022 in a 'highly attractive' market according to Siemens. The business is subscription based with gross margins of ~80% in line with software companies and over 90% recurring business. Siemens plans to merge MindSphere and Mendix platforms together, with the aim to shorten the release times of the software and application development by more than 50%. Mendix currently has more than 50,000 application developers, and Siemens expects the number to double soon.

Mentor Graphic: Founded in 1981, US-based Mentor Graphics claims to be a leader in electronic design automation software in the area of electronic board and chip design. Mentor's products are used in the design and development of a diverse set of electronic products (integrated circuit and system-on-chip design), including transportation (auto ~20% of sales), electronics, Internet of Things (IoT) platforms and systems, computers, medical devices, industrial electronics, manufacturing systems and wireless communications infrastructure. The company generated revenue of $1,200m in FY2016 with an adjusted EBIT margin of 20%, implying EV/sales on the transaction of 3.5x and EV/EBIT at 17.5x. Having built a leading position in PLM software (second behind Dassault Systèmes), Siemens aims to combine its offer to its core customers, including automotive, not just software for prototype design (UGS, LMS and CD-adapco) and electronics design.

CD-adapco: US-based, privately held CD-adapco is the second-largest CFD focused provider of engineering simulation software, support and services. With over 30 years of experience, the company has 19,000 software users, working at 3,200 different companies. Siemens paid $970m on an EV basis (~5x historical sales and ~24x historical EBIT, assuming a margin of 20%). The company seeks to scale up the business by rolling out the product suites across its own client base. Simulation & analysis forms part of the greater PLM market, split roughly equally between FEA (finite element analysis) and CFD (Computational Fluid Dynamics). **Ansys** is the global leader in CFD market, while **Dassault Systèmes** is the global leader in FEA market. The acquisition of CD-adapco gives Siemens access to only part of the simulation market, as the company still lacks a presence in the FEA segment.

Synopsys | Mountain View, California, USA (publicly listed, not covered)

Background: EDA

Synopsys is the largest EDA company in the world, focusing on digital IC design, customer verification, intellectual property, FPGA design, and customer IC design among others. Like Cadence, the business is split into segments, which we discuss further.

The largest segment is Core EDA, which includes a host of tools in digital IC, custom IC, field programmable array, and verification products. We believe there are several industry standard tools here as well like Design Compiler and PrimeTime, as well as other important tools like IC Compiler and IC Validator – all of them funnel into a broader platform called Galaxy.

Core EDA also includes verification tools, which include multiple software and hardware solutions. On software, VCS, CustomSim, FineSim Spice are well known tools in the industry. On hardware, ZeBu is an emulation tool that competes with Cadence's Palladium as we discussed above.

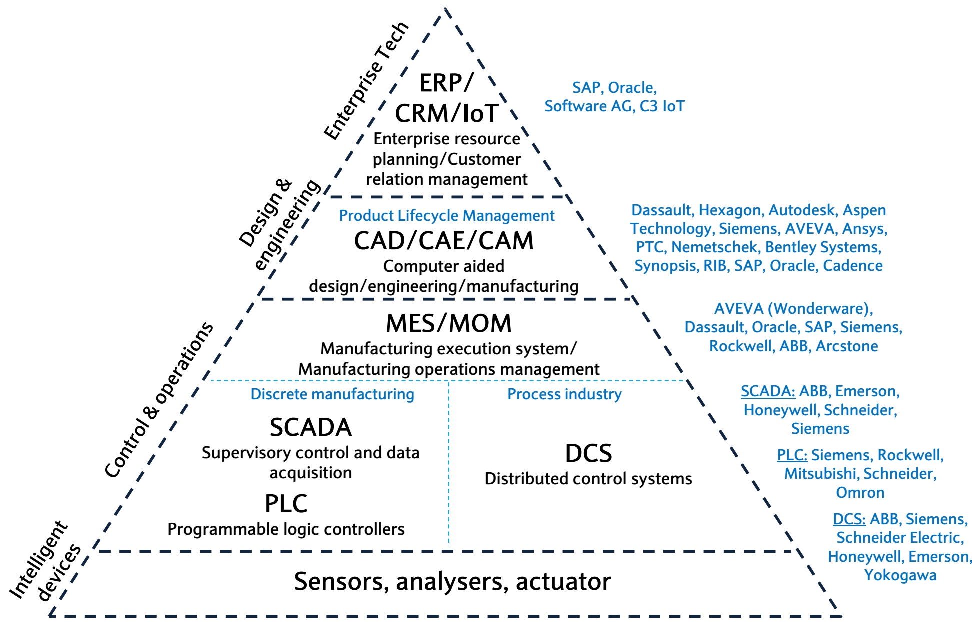
Other segments include IP, Systems, and Software Integrity which includes standards-based IP known as DesignWare. The company also acquired Coverity for security testing software code. The last segment is Manufacturing solutions, which includes tools like Sentaurus for TCAD, and Yield Explorer Odyssey and Yield Manager for managing yield in semiconductor manufacturing.

Like Cadence, Synopsys generates 90%+ of revenue from backlog, and is headquartered in California. Of note, Synopsys' largest customer is Intel (covered by Barclays analyst Blayne Curtis), which made up ~18% of total revenue in FY17. The company was co-founded by Aart de Geus, where he serves as Co-CEO alongside Chi-Foon Chan.

APPENDIX I – INDUSTRIAL SOFTWARE STACK IN MORE DETAIL

FIGURE 19

Barclays manufacturingTech stack



Source: Barclays Research

In this appendix, we cover the individual components of the ManufacturingTech stack in more detail.

Management IT systems – ERP, CRM

The front and back office depend on the Enterprise Resource Planning (ERP) system, which consists of an accounting module at its core, as well as many other applications to run a company including Human Resource Management (HRM), Supply Chain Management (SCM), inventory management, business intelligence and Customer Relationship Management (CRM). CRM is often considered separately.

Enterprise Resource Planning (ERP)

The enterprise resource planning is the core management software and used for planning, monitoring and reporting of a business. Generally the key part of it is the financial module, where companies record all transactions for management accounting and also financial reporting. Furthermore, the module is used for financial planning, budgeting and cost management. In addition, there are many other modules, such as human resource management where a company manages its workforce and processes the payroll and other HR-related functions. Within the supply chain management module, a company manages its suppliers and orders. This software is needed to place orders, manage orders and pay orders according to T&Cs. This sounds simple, but in reality, given the involvement of several departments within the procurement process, this is highly complex (i.e. the people that place, receive and pay are all different and might never speak to one another). The inventory management tool is used to monitor the use and depletion of inventory within the production or distribution, with the aim of minimising working capital needs. There are many other modules that support the management of a business; these largely depend on the type, sector and the size of a business.

Customer Relationship Management (CRM)

The CRM is used to manage the relationship with a company's customers. This starts with basic details, such as contact details and past orders, however, more modern systems also monitor the performance of the sales force, warn if customers have not been contacted for some time, provide analytics, record customer preferences and are used to keep track of customer interactions and information that is provided. It also is used for marketing purposes and supports senior management through more informed decisions.

Design & Engineering IT Systems – PLM, CAD, CAE, CAM, PDM, DM

In the design & engineering or product development department, there exist a range of software that is used to design products (i.e. create a virtual model, which is multidimensional) and then simulate their behaviour and robustness under stress. In addition to that, there is software that converts the designed and simulated model into instructions for machines to speed up the production process; this part sits halfway between the engineering department and the production. PLM is and umbrella term and contains the following components.

Computer Aided Design (CAD)

CAD is a software that helps engineers in the initial design stage of a product development based on computational geometry and computer graphics. Engineers can create a virtual model of a new product within the software in 2D or 3D. The software enables engineers also to design the inner workings and skeleton of a product. The software captures product specification such as materials, tolerances, dimensions. CAD is used to create products in the marine, automotive, aerospace and construction, as well architecture sectors. The goal is to improve the productivity of engineers by providing them with a tool to manage the increased complexity of products, improve quality and create a product model that can be used further down the manufacturing process to speed up the overall process. In addition, the product model can be used in virtual simulation called Computer Aided Engineering (CAE), which we discuss in the next section, and as input into Computer Aided Manufacturing (CAM) software for the manufacturing process. CAD software varies largely by end market, while the term CAD is generally used for all sorts of end market, electronics and construction have their own terms with Electronic Design Automation (EDA) also called Electronic Computer Aided Design (ECAD) and Architecture, Engineering, and Construction (AEC) software.

Computer Aided Engineering (CAE)

CAE is basically a range of software that helps in engineering analytical tasks and simulation of products in the development stage. Input for the CAE is the model that was generated in the CAD. The CAE software is generally specific for the material analysed and can be broadly categorised into Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD) and Multibody Dynamics (MBD). FEA simulates how a structure reacts to forces, vibrations, heat, pressure and other physical effects; for example, the simulation of a phone dropping from several heights until it breaks. CFD simulates fluids (like liquids or gas) against structures; for example, the simulation of the airflow over the spoiler of a race car to optimise the aerodynamics. MDB simulates mechanical systems consisting of several moving parts interacting with each other under the influence of external forces; for example, the impact of the vibrations on a combustion engine. The overall goal is to analyse the robustness, performance, durability of a product under various scenarios such different temperature, pressure, component interactions and forces. Findings will be incorporated into the development process to optimise the product.

Computer Aided Manufacturing (CAM)

CAM is a software that controls and instructs machines in the manufacturing process. CAM uses model data that was created in CAD and simulated in CAE as an input. CAM software is used to generate the code to run Computer Numerical Control (CNC) machines. CNC machines generally include machines that work with structures such as mills, lathes, engravers, surface grinders, welders, electrical discharge manufacturing. While CAM is sitting already in the manufacturing side of a product lifecycle, it is considered to be part of the PLM side as it is essentially just an extension of the CAD/CAE software to allow a faster production process. Before CAM, CNC engineers had to programme the machine manually, which was work intensive depending on the product complexity and this process was more prone to errors.

Product Data Management (PDM)

Product data management (PDM) is a system within PLM that is responsible for storing and managing the product data that is created during the design process. Key reasons for having a separate storage system for design data are firstly to store data in a way where it can easily be found and reused by a person not originally involved in the design process (so that the knowledge remains within the company and not within the engineering team only) and secondly that the data in the PDM is linked to parts and items in such a way that is actually makes the manufacturing process easier and faster.

Manufacturing Control IT Systems – MES and MOM

Manufacturing Execution Systems (MES) or Manufacturing Operations Management (MOM) cover tasks such as production planning, scheduling and quality management.

Manufacturing Execution Systems (MES) and Operations Management (MOM)

MES and MOM software, while technically not sitting directly on the shop floor, are very close to the manufacturing process and are responsible for the operational management, while operational technology is about controlling and monitoring the actual production. The operational management often sits physically over the shop floor; however, it remains part of the enterprise or “carpeted area”. It is primarily used for discrete manufacturing and is essentially a middleware sitting between the ERP system on the enterprise level (IT) and the operational technology (OT) directly on the shop floor. MES and MOM were introduced in the 1990s to bridge the gap between SCADA and ERP. While SCADA is, in its traditional sense, responsible for the real-time supervision and control of the production, MES and MOM are about analysing historical and time series production data and forecasting future production. So MES and MOM include features such as production planning and scheduling, workflow management, equipment efficiency, production performance calculations, quality management, operations management and manufacturing intelligence. The terms MES and MOM are largely interchangeably and even industry insiders often fight about the precise definition. Some argue that MES is a subset of MOM, while others believe it is the same thing. Originally, the system sitting between IT and OT was called MES. The term MOM came into existence later as its proponents argued that the system had to develop into areas beyond “execution” and therefore the definition had to be broadened to include new systems, such as quality controls. While some providers used MOM as the new marketing name for the expanded MES, some kept using the term MES.

Data management for MES/MOM and SCADA

Production data is generally stored in time series databases. While production data can be stored also in relational databases, they are generally not optimised for time series data and result in limited functionality. Historians were traditionally the variety of time series database technology that was used in manufacturing. They work well with industrial software such as PLC and DCS and were designed to capture time series data related to the production process such as vibrations, pH level of water, speed of production, amount of ingredient added, etc. In addition, they were optimised to write data very fast and compress data to save storage space. While historians remain the most widely used database technology in manufacturing, the technology also remained unchanged for the last couple of decades. As a result it is challenging to integrate them with modern applications, other data sets that give context to the analysed data and there is a limited amount of skilled staff available that are specialised on this niche. In addition, the read speed of historians is very slow as they were optimised to write fast and capture data mainly for regulatory purposes and less for analytics. In order to overcome this shortage, 'data connectors' can be used to integrate a data historian with an IT application or an IoT platform. The data connectors are pushing certain data sets into the database of the IT application and IoT platform.

The alternative to historians is open source, more modern time series databases, which were developed by big tech companies in order to store user data, such as likes, time spent on certain pages or number of clicks. While such databases haven't been developed to capture production data, they are well suited to do so. They are easily scalable, can capture significantly more data than historians, are faster, can be more easily integrated with modern applications, are open source and don't require an expensive licence, and finally can also easily be integrated with other data sources such as production schedules, client orders, shifts, information about employees on the shop floor, etc. However, currently there is a very low installed base that is limiting the application development for open source time series database.

Manufacturing Operations IT Systems – PLC, DCS, SCADA

Operational Technology (OT) is dedicated hardware and software for the shop floor to monitor and control the manufacturing processes through devices such as pumps, valves, sensors, drivers and robots. There exist three main parts - SCADA, Programmable Logic Controllers (PLC), Distributed Control Systems (DCS) – which historically have been very distinctive, but increasingly there is convergence between these components. Generally SCADA and PLC are used in discrete manufacturing while DCS is used for the process industry.

Programmable Logic Controller (PLC)

Programmable logic controllers are hardware and software to control processes and field equipment through pre-programmed parameters for the purpose of automation. PLCs generally manage one standalone machine or piece of equipment and are generally used in discrete manufacturing. PLCs can range from small brick-size devices with tens of input/output (I/O) points to rack size devices with thousands of I/O. They can come with built-in human machine interface, but generally come as standalone controllers and need to be integrated and linked with other equipment; the advantage is that PLCs generally can work with equipment from other providers as they are provider-agnostic.

Supervisory control and data acquisition (SCADA)

SCADA is a control system that links PLCs together to get a high level overview about a factory process for the purpose of supervision. In addition, operators can also issue process commands that are performed by the peripheral controllers (PLC). With SCADA, a manufacturing firm can access widespread and remote controllers and supervise them in a central manner. As the controllers are often from various manufacturers, SCADA was designed in a way that it could access the data through standard automation protocols and therefore integrate parts even when they came from different providers. It was designed for real-time monitoring and control and therefore historical data analytics is not part of SCADA's core functionality; this functionality is often found in MES. However, over time the functionality of SCADA software was extended and now frequently includes more advanced features such as data collection and reporting that were traditionally only found in MES; the term for this is SCADA with MES functionality.

Distributed Control System (DCS)

A distributed control system is an automated system that controls processes and field equipment. DCS was used for large plants in the process industry such as in the oil & gas industry where a large number of continuous control loops had to be supervised and controlled. Compared to PLCs, which were sold as single components and integrated with a SCADA, a DCS is an inherently integrated solution that includes workstations, control panels (known in the industry as human machine interfaces) and local control units that are distributed throughout the plant. One of the main advantages of a DCS system is that if any one of the distributed controllers fails, the remaining plant can continue to operate despite the failed station. While DCS are distributed, the entire system of controllers is connected to a network to monitor the overall process.

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Materially Mentioned Stocks (Ticker, Date, Price)

ABB Ltd. (ABBN.S, 19-Oct-2018, CHF 20.99), Overweight/Neutral, A/CD/CE/D/E/J/K/L/M/N/T

Alfa (ALFAAL.L, 19-Oct-2018, GBp 137), Equal Weight/Neutral, J/L/Q

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Ansys, Inc. (ANSS, 18-Oct-2018, USD 153.81), Underweight/Positive, CE/J

Autodesk Inc. (ADSK, 18-Oct-2018, USD 137.29), Overweight/Positive, CD/CE/J

AVEVA (AVV.L, 19-Oct-2018, GBP 26.78), Overweight/Neutral, J/K/M/N

Dassault Systèmes (DAST.PA, 19-Oct-2018, EUR 115.70), Equal Weight/Neutral, J

Hexagon AB (HEXAb.ST, 19-Oct-2018, SEK 458.90), Overweight/Neutral, CD/J

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