THE THIRD WAVE OF AUTOMATION: CRITICAL FACTORS FOR INDUSTRIAL DIGITISATION

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Abstract: The scope of industrial automation is shifting into a third wave of automation based on extreme information availability, cyber-physical systems and data analytics. This paper present critical factors and way forward for the development of the Swedish industrial automation sector, both users and suppliers. Based on literature and practice studies, and a survey including some 40 respondents, ten factors for realising the third wave of automation was identified with four key factors: Technology, Processes, Business models and Competence. Finally, initial steps on a way forward are proposed for the development of Swedish automation industry and research.

Keywords: automation, industrial digitisation, process industry

1. INTRODUCTION

The global market of industrial automation is large, profitable and growing. The annual revenue is $155bn globally: $72bn in factory automation and $83bn in process automation. The expected growth rate for industrial automation is 50% above growth of general industrial production index (compared to 30% previous years) and the margin is 4% higher in industrial automation than the global industrial average (Credit Suisse, 2012). In the world's largest manufacturing economy, China, there are signs of labour shortages at the low-end that create upward pressure on wages. This is believed to cause automation investment to accelerate.

For planning and control systems (ERP, MES, DCS etc), as an indicator on the situation on industrial automation, the shares and anticipated large growth of the different systems are illustrated in figure 1.

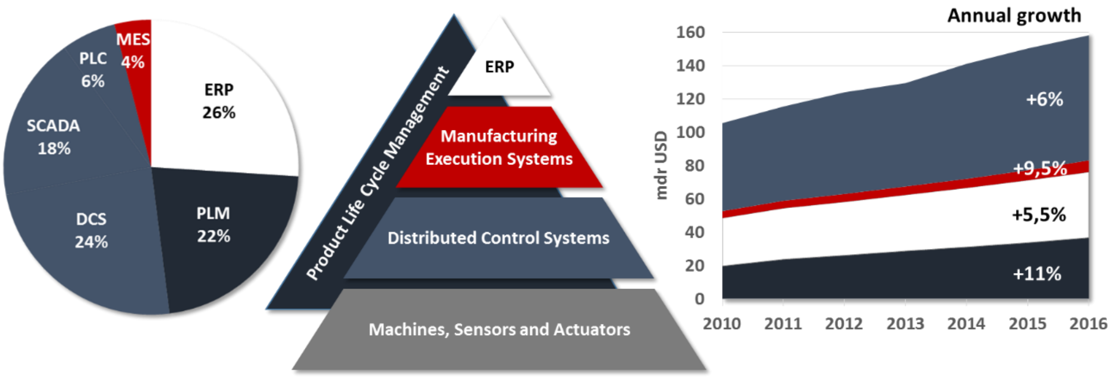

Fig. 1. Shares and growth of DCS, MES, ERP and PLM, respetively.
Source: Blue Institute, Companies data and Credit Suisse (2012).

Meanwhile, the scope of industrial automation is shifting. As the first wave of automation was based on mechanisation and the second wave was based on the use of microprocessors in industrial applications, the current

Third Wave of Automation (Blue Institute, 2013) is based on extreme information availability, cyber-physical systems and data analytics. In response to this third wave of automation based on Internet of things, cloud computing and big data analytics, industries, researchers and governments launch initiatives and development platforms. As stated by Andreessen (2011):

> *"Six decades into the computer revolution, four decades since the invention of the microprocessor, and two decades into the rise of the modern Internet, all of the technology required to transform industries through software finally works and can be widely delivered at global scale".*

The declaration of the German government's large-scale investment Industrie 4.0 reads: *"Germany is preparing the fourth industrial revolution based on Internet of Things, Cyber Physical production systems, and the Internet of Services - in strong industrial applications ..."* SAP, Siemens, Bosch, the automotive industry and research institutions are all involved in the project - from engineers to business management. Four-point-zero refers to the idea that the world has gone through three industrial phases and the fourth coming, based on Cyber Physical Systems, combinations of Internet, embedded digital technology and the management of large amounts of data. Discussions are kept on the nature of transformation. However, in the IT-readiness study by Jentz et al (2013), it appears that no disruptive event transforms industry into smart manufacturing or the forth industrial revolution. They rather observe a gradual shift towards more IT-supported business.

When analysing different manufacturing industries capability and readiness for taking advantage of IT and automation, Booz & Co (2011) presented the 'level of digitisation' as in Figure 2. It was indicated that the automotive and machinery industries lead the way, while the process and basic industries are lagging.

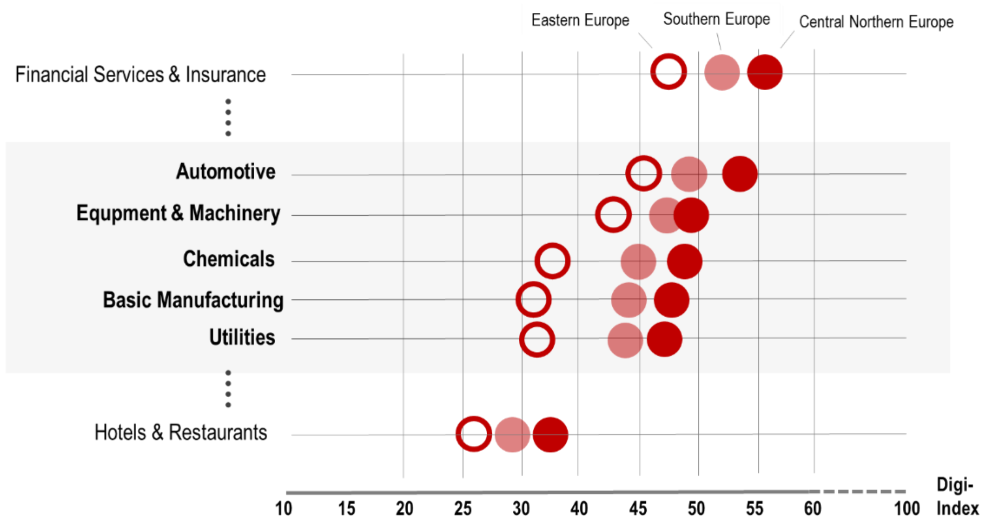

Fig. 2. The level of "digitisation", i.e. probability to take advantage of IT and automation to create financial value. Comparing different industries and regions. 0-100 units. (Booz & Co., 2011).

Based on the background of the increasing digitisation of industries, and the need of identifying critical factors for further development, especially for the process industry, a wide-scoped study was initiated. The purpose was to present critical factors and way forward for the development of the Swedish industrial automation sector, both users and suppliers, enabling this third wave of automation. The results is a synthesis of the thoughts and reasoning surrounding the topmost concerns for the future of Swedish production industry as identified by the survey.

2. METHOD

The objective of the study was to support the strategic development plans for reaching innovative and competitive solutions within process industrial IT and automation. The development should be achieved through the development of cooperation between excellent research, development and innovation environments, leading global automation companies and a leading global process industry acting as demanding customers for dedicated supplier companies. The key question of this study concerned the key factors for taking the next step in digitisation, as identified by the industries stakeholders.

The first step of this study was a broad information collection from discussions with key informants from industry and other organisations, participation in conferences and lectures, as well as open literature gathering and analysis.

Based on this explorative phase, a large number of factors for industrial digitisation was listed by the project team, and synthesised into ten critical factors. The second step included more detailed literature studies, still including a wide span of literature on technology, market, organisation and competence, from both academic and industrial sources. The purpose was to make a qualitative analysis of the study object, as well as detail and revise the findings from the first step. The third step in the process has been to further reduce the number of factors and prioritize those that can have the most impact when it comes to translating IT and automation technology to commercial competitiveness. The method used was a simple and targeted survey. Some 40 respondents were selected based on their knowledge and position in the industry and IT and automation area (senior managers and specialists). The industrial sample was uniquely Swedish and included suppliers and users of automation. Organisations that were included were Innventia, Aspentech, Valmet, Combitech, Prevas, Iggesund, Lovak, ABB, Motion Control, Vinci, Maxima Tecc, Teknikföretagen, Prevas, Stora, Vattenfall, Ragn Sells, Bergen Energi, SP, Bold Printing, Grontmij, Robotdalen, Boliden, SCA, Valmet, Fortum, Eurocon, ÅF, LKAB, Honeywell, AGA, Södra, VLL and Rockwell. The questionnaire presented the ten factors and the participants were asked to point out the top four and to prioritize them with respect to their influence on companies' possibility of reaping the benefits of the third wave of automation. Finally the prioritised factors were revisited and action plans developed by the project team.

3. RESULTS

The first step in the study identified ten factors for realising the third wave of automation: *business models, operation/maintenance, implementation, competence, new business actors, policy/legislation, processes, standardisation, security/integrity and technology*. The factors are a mix of means, requirements and capabilities that was tested in the survey, where the respondents indicated four cornerstones, or critical factors, in development towards industrial digitisation: Technology, Processes, Business models and Competence, as shown in Figure 3.

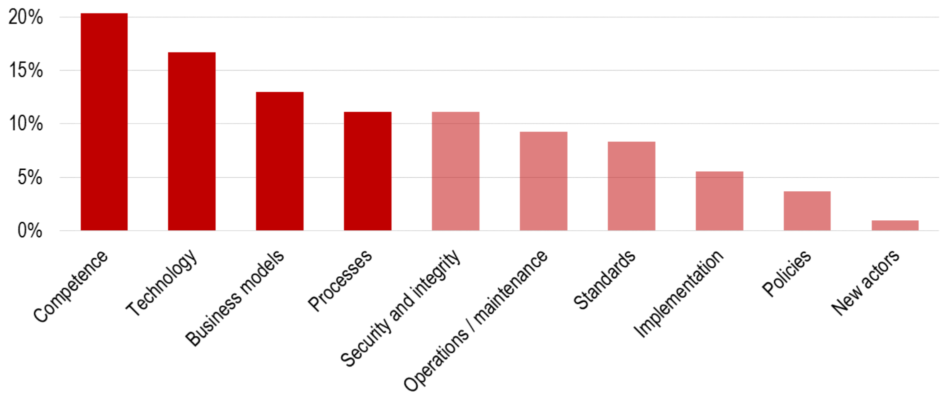

Fig. 3. Priority of the ten factors, based on the survey.

In addition to the four top factors, as further illustrated in figure 4, two notes are worth to be mentioned:

- 'Security and integrity' is highly ranked. One interpretation is that the risks associated with lack of IT security and threats to plants and people are deemed so significant that they can hinder development, rather than enable.
- 'New entrants' is given low importance. One interpretation is that the assessment is conventional and does not take into account that aspects such as Big Data Analytics and the Internet of Things have risen from other environments, but are introduced in the industry. It is very likely that new players will get a foothold in the industrial markets. Still, technology barriers for true process-critical systems will protect established suppliers.

4. PRESENTATION AND DISCUSSION

Each one of these four critical factors is discussed in the following, introducing the state of practice, identified industrial challenges and proposed steps forward.

4.1. Technology

We are awash with new terms and concepts that symbolizes the digital technology and societal digitization. Central are the different types of data sets that help us to new knowledge that can revolutionize the way we do business and live our lives. During the past decade there have been dramatic changes in areas related to such sets: how they are generated, how they are stored and communicated, and how they can be processed and analysed.

Internet of Things. Terms such as the Internet of Things (IoT) or Industrial Internet refers basically to describe the development that takes place when most of the things around us contains some form of computer. The term Industrial Internet was coined by the company GE and refers to the integration of physical machines with sensor networks and software. The commonly used term Internet of Things was coined back in 1999 and can be described as a general reference for uniquely identifiable objects and their virtual representation in an Internet-like structure. Radio Frequency Identification (RFID) was an early example and has been seen as a prerequisite for IoT - if all objects and people were equipped with identifiers they could also be managed and controlled by computers. The research related to IoT is only in its infancy and today directed the largest research efforts towards devices connected to the Internet via low energy radio. The technology required to connect to the Internet and the availability of processing power has become both easier and cheaper. The number of devices is constantly increasing and there is evidence that the increase occurs exponentially. IEEE mentions numbers like a trillion connected devices in 2022 (IEEE, 2014).

Cloud Computing. Cloud Computing describe the different types of computational concepts involving networked computers and enables real-time communication. Cloud computing is really a synonym for distributed computer networks with the ability to execute software applications on a variety of connected computers simultaneously. Google, Amazon, and Apple are all known for their public cloud services offered via the Internet and the most commonly used models for cloud computing services are:

- Software as a Service (SaaS) – gives users access to software and databases.
- Platform as a Service (PaaS) – a computing platform that includes operating systems, databases, web servers.
- Infrastructure as a Service (IaaS) – offers hardware that can be scaled up / down depending on customer needs.

This strategy maximizes the use of computing power and also reduces environmental impact because less power, air conditioning, etc. required to provide a variety of functions. Cloud computing can also provide information and different types of services spread globally in a cost effective and timely manner.

Big Data. Large amounts of data, or Big Data is a term that describes the data sets so large and complex that it is difficult or impossible to treat them with traditional tools available. Challenges in the field is to collect, store, make searchable, share, analyse and visualise data sets. The trend analysis of increasingly large amounts of data is explained by the value in getting more information by analysing related data. For example, the ability to identify correlations to identify business trends, prevent diseases, fight crime, and identify traffic conditions in real time and increasingly also industrial applications. According to McKinsey (2011) more than 30 million sensor nodes are connected to the Internet in the industry and power segments, and the number is growing by 30 percent per year. But this is still a small portion compared to what is measured in production - there are already billions of data points that have the potential for much more. The industry collects more data than any other field of business - close to two Exabytes in 2010 (BIG, 2014). The problem is that the majority of these data sets are unstructured, or even unknown. This industrial “dark data” is data that machines stored in various monitoring logs, perhaps for many years. Such data can be shown to contain significant value if it can be retrieved and analysed using methods that were not available just a few years ago. Big data has spurred a growing need for methods and tools that make it possible to go from unstructured data into relevant information.

Big Data Analytics. Big Data Analytics is to discover and communicate meaningful patterns in large datasets. Widely used visualization methods to communicate these insights. A company can apply analytics to describe, predict and improve outcomes, to optimize decision making, warehousing, marketing and pricing. Operations can be optimised in terms of planning, maintenance, prevent injuries, performance prediction and scheduling. Big Data Analytics is also an absolute catalyst for the industry's business models will be re-evaluated and developed in future years. Big Data Analytics uses mathematics and statistics, the use of descriptive techniques and predictive models to create knowledge from data. The insights from the data sets used to recommend actions or to control various types of decision making - thus is Analytics not so much a matter of individual analysis or analysis steps but rather the whole methodology.

Process-industry specific challenges. During the late 1970s and during the eighties’ pre-globalization period, the process industry were early adopters to embrace the most advanced IT and automation technology. This applied particularly to Sweden where both the pulp & paper and mining industries were precursors, measured by international standards. Collaboration between industry and the Swedish IT and automation industry paved the way for success in the global market. But as the technology renewal progressed and productivity gains were taken home, the development ambitions decreased. Incentives to develop more and better was not clear for individual enterprises. The front line was taken over by other industries and the globalization of the industry would not have been possible without the digital information technology. Production systems on the way to now emerge is now especially characterized by two features, to be adopted by the process industry:

- The amount of information will greatly increase and processed in ever more intricate systems as processes and business models are transformed into economic values.
- Information is closer tied to the physical production flows to the level where they cannot be separated. This means that the product also turns *into* information and its business model throughout its life cycle.

4.2. Processes

One of the key features of manufacturing companies is its ability to adapt, improve, and quick response to changes and disturbances. It is becoming increasingly crucial to make the right decisions, often at very short notice. We see that the digitization of corporate operational processes and across companies' value creation network will create radically new conditions for competitiveness and long-term economic and environmental sustainability.

Digitisation in the supply chain. Increased digitization through all operational processes - across the entire value chain - providing an opportunity for more flexible organizational structure. Information is no longer local, and forecasting and operational planning can be based on integrated information and processes across the company's functional and regional units (Capgemini/MIT Sloan, 2013). Hidden synergies in production and logistics can be realized. Around the turn of the millennium was reported on a number of successful e-commerce and e-supply chain concepts, such as Cisco integrated network of partners, customers, suppliers and employees (Business Intelligence, 2001). The speed of change slowed somewhat for a time, but today has much been realized in technologies and solutions that were predicted during the dotcom boom. In the consumer goods sector, such as Walmart, today it is a very widespread use of advanced forecasting analysis, RFID, wireless equipment, storage systems, visibility and traceability etc (Capgemini, 2013). Maintenance service and customer support is another area that has seen radical step in productivity and value through integrated service management system In the days launched Amazon "anticipatory shipping" where goods are sent to a warehouse or truck in the vicinity of an expected buyer until the order is made for real (Computerworld UK, 2014).

Digitisation in manufacturing operation. Within engineering digitization has thus far been relatively functional. Various functions such as product development, production, purchasing, marketing, etc. have their different digital systems, with different levels of maturity. At the factory level, the use of digital control data existed for a long time, but often in quite isolated parts. It can be seen in the light of the extensive and rather one-sided investments in ERP systems previously made. A large part of production and product planning are supported, however today by digital tools. The application of cloud computing into a manufacturing setting has since 2010 received increasing attention (Li et al., 2010; Meier et al., 2010; Tao et al. 2011). Cloud manufacturing has been formulated as next generation agile manufacturing where a service-oriented approach supports multiple companies to deploy and manage services for manufacturing operations over the Internet (Wang, 2013). Xu (2012) describes two forms of cloud manufacturing: introducing cloud computing technologies into the manufacturing environment and cloud manufacturing as a replication of the cloud-computing environment using physical manufacturing resources in lieu of computing resources.

Digitisation in product and production planning. Digital tools is a means to reach shortened planning times and the flexible configuration of the planning process, which in turn influence the production towards a quicker adaptation to changing circumstances and shortened time to bring a product onto the market (Zülch & Stowasser, 2005). The vision of the Digital Factory (VDI, 2004) is to provide end-to-end transparency in real time, allowing early verification of design decisions in the sphere of engineering and both more flexible responses to disruption and optimisation across a company's production site (Americon and Antonio, 2011).

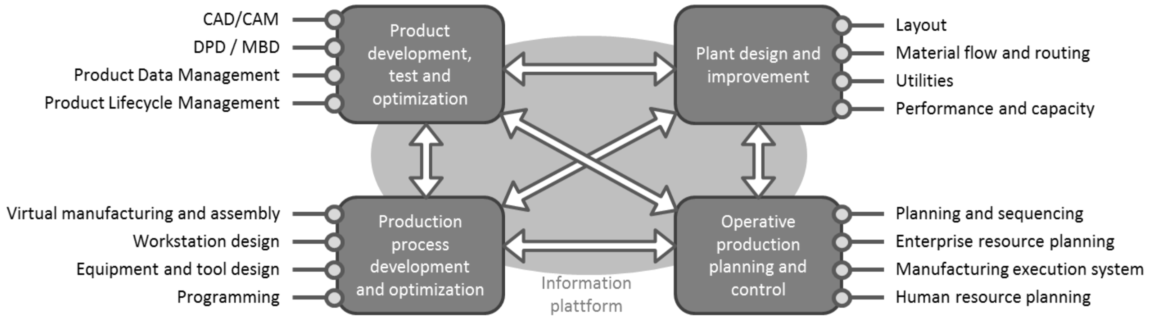

Fig. 5. Four critical elements in the development and operation of the vision around the Digital Plant.

A large part of the factory planning, production- and product-planning is already supported by digital tools. Reviews on industrial implementations are presented by e g Gregor et al (2009) and Wöhlke and Shiller (2005). Industrial engineering was one of the earliest fields to utilise simulation in the analysis, evaluation and optimisation of complex manufacturing activities, and simulation can be applied in virtual models on various planning levels and stages to support product and production planning. In development departments many tasks and decisions which in the past required hardware models or prototypes have been supplemented or completely substituted by digital methods (Wöhlke and Shiller, 2005). Concerning process development and optimization, as well as plant design, many tools are available for specific purposes. However, there is still a lack of open integration possibilities between tools and planning levels, and optimization on a multi-criteria level is required (Kuhn, 2006).

Integration efforts. Finally, in the area of integration to the operative production planning and control, much effort is still needed, and this is perhaps the most immature part of the digital factory vision. Driven by the Internet, the real and virtual worlds are growing closer and closer together to form the Internet of Things and 5G. Moreover, by integrating operational data with development activities, systems can be continuously optimised during production in terms of their performance as well as resource and energy consumption or reducing their emissions, rather than having to stop flows (Vogel-Heuser et al. 2012). This means an integration of the internal and external operations of the companies and to a coherent value chain from raw materials to end customers. From a manufacturing automation perspective, it is known that MES level in Figure 1 has had low priority in terms of investment (while the ERP as a rule are both well implemented and prioritized). This means that there are "holes" in the information chain, both vertically within firms and across the value chain. Research in this area shows that there is a clear correlation between increased integration in a system of values and performance in terms of lower costs and higher quality, delivery and flexibility. But also shows that most companies lack the knowledge and ability to achieve such integration.

Process-industry specific aspects on digitisation. Shah (2005) shows how the process industry value chain are facing a number of challenges and opportunities that digitization may create new values. Challenges include a shift from a product focus to offering-based business, providing lifecycle solutions, to operate in a more dynamic and changing marketplace, to offer customized special products to mass production cost, and to evaluate, report and improve their environmental and social impacts throughout the value chain. Shah (2005) further points out the process industry manufacturing process where flexibility and re-configurability is undeveloped areas where the process industry is not gripped customization fully by e.g. customer-adjustment of the end product. He also points out how this industry's value creation network will look completely different in the future, as it will create entirely new networks. All based on strong drivers such as material shortages, environmental, safety, etc. Information technology is identified as a critical enabler for the creation of tomorrow's process industry. Systems for production system design, modelling and optimization of flow, and planning of value creating flows are identified key areas.

4.3. Business models

Increased competition must be met with increased customer value. Business models' differentiating role becomes more important as competition increases. Meanwhile, the digitisation leads to an increasing amount of data, a conversion of data into information, and knowledge on the value systems including the industry. It creates a foundation of knowledge based on the available information that allows the business models do a better job - more precisely and more dynamically.

This means that there are business models that need to transform the steady improvement in technical capabilities (in digital and production technology) to economic values, competitiveness and sustainability (Gassman et al, 2011). There is also a primary need for business models that provide incentives for industry to invest in the next generation of industrial computing, which in turn is the precondition for a positive development with better resource utilization, etc. It further means that the business models considered as innovations (Teece, 2010) opens up market scenarios where it becomes apparent that the business models are competing rather than the actual products or information services that is the base. But also that the boundaries between corporate strategies and business models become blurred - business models are clearly a part of the strategy.

Defining business models is not a new phenomenon, but the effect of digital technology on them is new. It offers both the adaption of existing models, to make them more efficient, and creation of brand new models. Successful synthesis of digital technology and business concept means that:

- Innovate, transform, and introduce competitive business models is a concern of corporate management, it is an operational as well as a methodology issue of concern for both the suppliers and industry. Business models must account for a holistic approach aligning company's goals and strategy with operational performance.

- The strategy must also have its impact perspective - it can only be done by having the ability to see the entire value system and the company's place in it. Business logic must be understood and taken into account.
- The product development process needs to be integrated, where technology and business concept development are prioritized equal, interdependent, and the design interacts.

4.4. Competence

We have in this study assumed that the technological advances in IT and automation will continue to reform the industrial practice. The technology itself becomes transparent and (theoretically) equally available everywhere. It becomes a question of how the technology is implemented that give comparative advantages. Talent and competence will decide upon the competitive advantage. This applies both to the industry that supplies automation and the industry that uses it.

One of digitisation's consequences is plenty of new forms of work and collaboration, when information can be shared regardless of time and space. Effects that not are not reserved for large or traditional market participants. Bringing ideas into products and markets will be easier. Collaborative manufacturing, Collaborative Engineering, Crowdsourcing, Crowd Funding and Open Innovation are mere examples on concepts of the future.

The Automation Competency Model (ACM) is one example on a competence system developed for the future needs by the Automation Federation in US. It has been developed in response to requirements relatively similar to the Swedish, with retirements and new knowledge needs as drivers. The idea is to form a common platform that all stakeholders - industry, academia, government agencies and individuals - can refer to. It describes the roles and requirements in the automation industry and classifying skills needed from different perspectives.

5. CONCLUSIONS

It is concluded that major gaps that need to be addressed are: (1) low awareness on corporate management level concerning the strategic importance and impact of industrial digitisation, (2) under-investment concerning systems and methods for integration in the value creating systems, (3) low awareness concerning business models' potential to transform technological possibilities to business values, and (4) lack of capabilities, competences and skills for realising the industrial digitisation with full effect.

Ever since computers were first used in industry, the introduction of various schemes to optimize sections of the value chain or processes simultaneously resulted in silos of thought. The paradox is that the more complex the system, the greater the information gap. Tools that make it economically and technically feasible to bridge these gaps are now becoming available. Manufacturing execution systems (MES) are central features of the system structure that unite the production level operating systems, and also create the prerequisite for linking operational data to the development system.

However, investments require sound business cases and also business models that allow for mutually profitable contracts between system providers and industry. This calls for both better calculation methods and competent suppliers to demonstrate a level of profitability, and the need for enhanced business models that provide the right incentives. The investment in solid integration platforms becomes of importance for a development that leads to optimization of complex production / value systems and self-organizing value chains. There is likely a way to ensure that Swedish industry becomes a future-proof production environment.

The way forward can in brief be described in three layers for each of the four cornerstones: (A) measure and assess, (B) educate, spread and inspire and (C) activate. In 'measure and assess', we recommend a benchmark exercise on both company and sectorial level, indicating the current strongholds, weaknesses and potentials on strategic and operative levels. In 'educate, spread and inspire' the initial steps are to form structures for knowledge dissemination and experience sharing. In 'activate' the next steps are based on direct research development and innovation efforts on process, technology, competence and business integration, enabled by digitisation.

Concluding, when industrial automation meets big data and Internet of things, the third wave of automation is created. In the wake follows new opportunities as well as challenges. This paper detail and introduce critical factors and initial steps on a way forward for the development, driven by the Swedish industrial automation industry and researchers, within a common strategic innovation effort.

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