A Perspective on Industry 4.0: From Challenges to Opportunities in Production Systems

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Abstract: Industry 4.0 and smart factory are the terms frequently used for next generation production systems. Advancement of Information technologies paved the way for evolution of production systems. To remain competitive in the market, enterprises want to utilize these technological advancements in order to solve current challenges and serve customers in new ways which were not imagined before. In order to provide new services quickly, new methods and technologies have to be introduced at manufacturing level. The paper briefly discusses industry 4.0 and settings (arrangements) for co-innovation. This paper also describes what are the current challenges faced by companies with the help of a survey. The paper proposes an approach from strategical to operational level for the implementation of industry 4.0. In this paper, we also provide new opportunities, scenarios, and applications enabled by introducing new tools and technologies for industry 4.0. At the end, the paper provides summary and glimpse of the future work.

1 INTRODUCTION

Advancement in Information Technology (IT) made it possible to bring production systems at new levels. These new developments enable organizations to improve current environment and allow them to serve the customers in new ways by using new business models to create value for customers and revenue for themselves.

Companies are eager to introduce new technologies to improve quality, efficiency and effectiveness of resources, reduce risks, and to remain competitive in the market (Falk et al., 2015; Tassey, 2014). A company which fails to cope the technology challenges also face the challenge of introducing new products/services, innovation, and business models. This places the company in fierce competition where costs have to be reduced each year.

New business models have been introduced by various companies in order to provide more value and services for customers (Kallenbach, 2015; Figalist, 2015). These new business models not only bonded majority of the customers but also created new customers (and their segments) to whom value-added services can be provided. An innovative business model coupled with the latest technical tools guarantees the success of a company. There are many successful examples of big companies and start-ups. For example, Amazon (originally, a book-selling company) understood what are the demands of customers and potential markets, now become one of the major IT services provider challenging the position of the IT companies which are in business over many decades.

Technology has been advanced at the rapid pace on enterprise level. However, these technological developments are not applied on industrial level and it still stands as old as the start of the third revolution with basic IT functionalities and monolithic structure. There are solutions on enterprise level which can be applied at production or shop-floor level. However, organizations are hesitant to use them on the shop-floor level. This is due to critical nature of the systems and their potential economic impact on operations of organization. If a manufacturing system stops, the whole production line may have to be stopped which costs the loss to company (items produced per hour). Therefore, Technology used at production level is still quite old and has not gained much attention in comparison to enterprise level.

In this paper, we discuss about industry 4.0 and settings for co-innovation in future manufacturing. We describe the current challenges faced by compa-

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nies at production systems with the help of a questionnaire. These companies belong to diverse segments of industry. We also provide promising future scenarios that can improve the efficiency of production systems. We present an approach for industry 4.0 which will guide us for the steps needed to be taken for industry 4.0. It will also describe how we can enable future scenarios (discussed in this paper) and simultaneously help to solve current challenges in production systems. At the end we provide a summary of the paper and outlook.

2 INDUSTRY 4.0 AND CO-INNOVATION IN FUTURE

The first industrial revolution started in the end of the 18th century with the introduction of mechanical machines. The second industrial revolution started in the beginning of the 20th century with electricity and mass production. The third industrial revolution started in early 1970s with introduction of electronics and Information Technology (IT). This was the beginning of automation of manufacturing processes and programmed machines to take the production responsibilities. In order to compete with other uprising countries (like India, China) and offer more value to the customers, developed countries started to apply advance technologies on production level. In USA and some other countries, such initiatives are termed as fourth industrial revolution, Internet of Things (IoT), or next generation systems. Whereas in Germany, this initiative is driven by German government (Bundesministerium für Bildung und Forschung), and referred as Industry 4.0 (industrie 4.0) (MacDougall, 2014). The industrial revolutions are depicted in the Figure 1.

There are various definition exists for industry 4.0. Various groups and companies define the term according to their understanding and perspective of discussion. There are also inter-relating terms like IoT, Cyber Physical Systems (CPS), Smart Systems, Digitalization, and Digital Factory.

We define Industry 4.0 as a revolution enabled by application of advanced technologies (like IT) at production level to bring new values and services for customers and organization itself. The will also bring flexibility and quality in production systems to fulfill demands of new innovative business models and services quickly (service oriented architecture and network communication at production level). The digitalization and virtualization are tools to bring end-to-end services throughout a product life-cycle (design till recycle) and in a cost effective way for customers. A formal definition of industry 4.0 is defined in (Kagermann et al., 2013) as follows:
”Industry 4.0 will involve the technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes”.

Various terms are used in above definition. Here we briefly explain these terms. Powerful autonomous physical systems connected with one another and environment will perform operations intelligently (smart systems). These interconnected systems referred as CPS (Lee et al., 2008; Tseng and Hu, 2014) communicates each other to fulfill the tasks. Cyber-Physical Production Systems comprise smart machines, warehousing systems and production facilities that have been developed digitally and feature end-to-end ICT-based integration, from inbound logistics to production, marketing, outbound logistics and service. The IoT is a network of devices. These devices can be small, e.g., sensor in a fridge or it can be a robot working inside a car manufacturing factory. The No. of IoT devices till 2020 will be around 50 billion, an estimate by Cisco (Cisco, 2015). The significant number of connected devices opens up the door for new opportunities and new use cases in every field. Industry and academics will find new use cases and services which can be offered to various industries. Although currently IoT use cases at production level are less and organizations does not know how we can take advantage from it. Collaboration will get more focus in future from industry 4.0 perspective as reported in (Kagermann et al., 2013). In the following, we present one of the future scenarios from industry 4.0 perspectives.

2.1 Co-innovation Opportunities

Recent developments in IT have paved the way for the next industrial revolution. Next industrial revolution is going to change our eco-system. As stated in (Kagermann et al., 2013), in future manufacturing, collaboration will be the focal point. Whether such collaboration exists between CPS, industries or other partners, the granularity of such collaboration can vary from cases to cases. Services either from cloud computing or fog computing (term initially coined by Cisco (Bonomi et al., 2012)), will play a significant role in this context, allowing systems and partners to work, communicate and collaborate from anywhere in real time.

There exists variety of collaboration possibilities for development of future products, e.g. within companies, research institutions, or combination of both. Every collaboration requires adaptation of the strate-

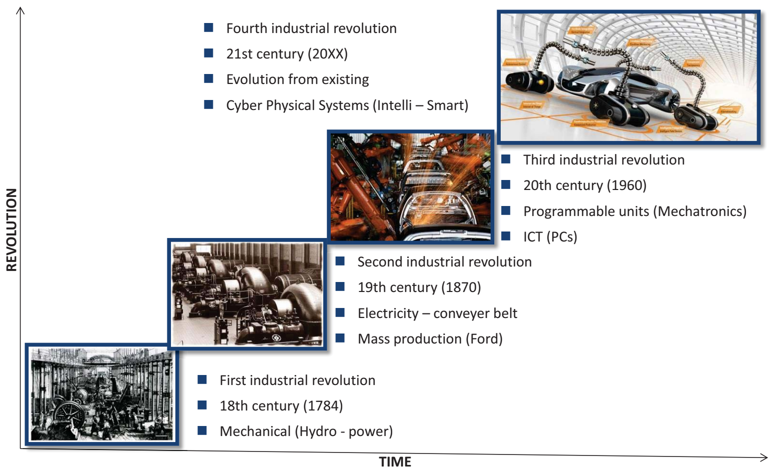

Figure 1: Industrial revolutions.

gies, as collaboration strategies between company-to-academics will be different than company-to-company collaboration strategy. For collaboration, partners decide about the scope of the collaboration, governance strategy, coordination, confidentiality, intellectual property rights, deliverables, duration, milestones, matters relating sharing of results, terms, and termination of the collaboration.

For collaboration between companies, companies can collaborate for a common shared goal to gain mutual benefit. Such collaboration can exists between companies to design a new product, using other company infrastructures based on new business models, or between partners to optimize logistics in manufacturing. There are also challenges involved, e.g., finding and sparing suitable resources for such collaboration from their routine operations. Although it is quite possible that companies fear to participate in such collaboration project because of the fear that they may disclose their business knowledge or companies competitive advantage will be compromised.

Industries want to collaborate with academic institution to increase the research and development in the companies. By collaborating with research institution, companies gain access to current innovative research areas from academics and can use the knowledge to co-innovate products for future or introduce new flexible processes in their organizations.

Research institutions gain access to sources of business relevant innovations and work on real world problems and case studies. Academic institution students will find placement opportunities for internships and potential employers afterwards. Industrial partners can help the academic partners to get the proprietary state of the art technology in terms of hardware and software licenses. Industries can transfer the innovation from research prototype or proof of concept to commercial realization of a product or deployment in a real environment. Companies will attract new potential employees in form of students by hiring them as internees or research students who already know about the processes of the company.

Such a collaboration exists between our institution and our partners. We perceive the challenges of our partners facing and better guide what services they can offer in future in diverse topics. An example of such collaboration in the context of industry 4.0 is to find-out what are the requirements of next generation manufacturing systems and services (like seamless integration, secure services, and smart systems) and conduct the research on industry 4.0 with the help of industrial partners. We investigate solutions for current problems and how new and innovative services/systems can be created and evaluated for next industrial revolution.

3 APPROACH

As in real industrial context, all issues can not be addressed at once, therefore, an approach is needed to accomplish the goals. This approach should address the current problems, and pave the way for industry 4.0.
In this section, we propose a high-level approach which consists of nine phases. This approach can be used for any pilot project. The approach is iterative in nature. The overall approach is depicted in the Figure 2. For the detailed understanding of our approach, we describe its phases as follows:
In Goals and objective phase, organization set the goals and objectives what an organization want to achieve in a project. All steps made in a project should help to achieve the objectives of the project

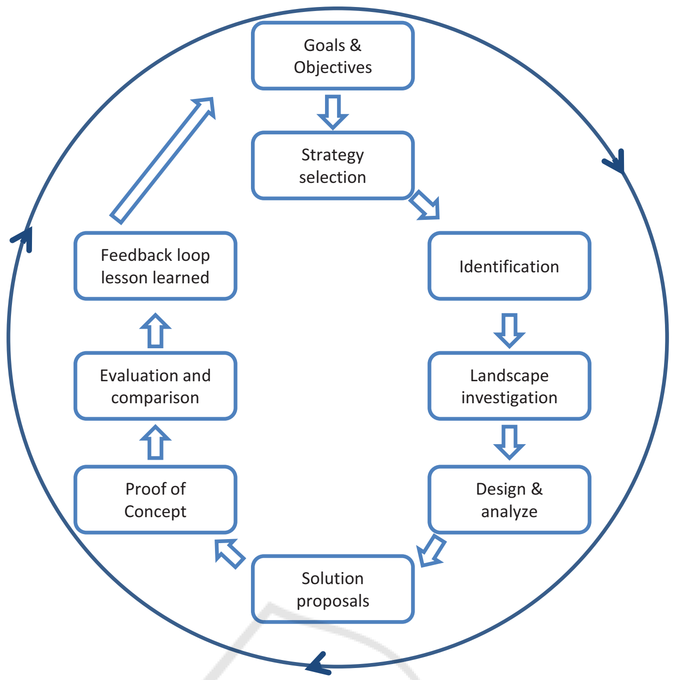

Figure 2: An approach for Industry 4.0

and therefore the goals of company.
In strategy selection phase, organizations decide how they want to proceed and select which strategy they want to apply. What are concrete steps needed to be taken in order to achieve goals and objectives described in previous phase. New business models can be introduced or developed in this phase (Madu, 2013).

In identification phase, high-level requirements will be collected. Partners and stakeholders will be identified for the project. Collaborative workshops will be conducted to identify pain points and opportunities. From stakeholders perspective, the purpose is to identify roles, responsibilities, and tasks in the project.

In landscape investigation phase, detailed information about the current landscape will be collected.

In design and analyze phase, gathered information will be analyzed. This step will also bring better understanding of landscape and helps to design the solution.

In solution proposal phase, solution will be proposed. Various solutions are possible for a project which will be compared and finalized in this phase. For the selected solution specific guidelines will be prepared. Here sanity check is also performed to realize the project, whether the organization have required capabilities or not.

In this phase, proof of concept of the selected solution will be executed.

The evaluation phase is to review the outcomes of the project. Here post implementation situation will be evaluated whether the defined objective and goals are achieved or not.

Feedback loop phase is for the continuous improvement purpose. Experience gained will be documented and suggestion will be prepared in case of rolling out project on larger scale. It also includes suggestions or guidelines to improve overall process for other projects.

In this part, we will describe strategy selection phase in detail. There are various perspectives and methods available and organizations can choose from them depending on the nature of problem. As for industry 4.0 changes are required at various levels, so it is important for an organization to decide where they want to focus first in a project. One of the strategies is to address the areas where company is currently facing challenges or having problems. There are various perspectives, namely outside-in or inside-out perspective (Day and Moorman, 2010). In outside-in perspective, customers are focal point. Organizations look for what are customer trends and requirement, which innovative services or value added benefit they can provide to customers and on basis of such questions and requirements they design their strategy and build business models. Typical examples of outside-in perspective are offering new business models, products, and services e.g. which data companies or external customers required from production useful for mutual benefit (without losing competitive advantage).

In inside-out perspective, organizations look inside the organization for opportunities how can they better utilize resources and processes to provide new services and products to meet customer's requirements. In inside-out perspective, organizations focus on organization itself and to solve internal challenges first, e.g., solving data silos issues, providing real-time data access, standardization, and process optimization, which afterwards, will help to enable industry 4.0 scenarios and benefits. Organizations also have to decide which strategy they want to employ in projects top-down, bottom-up or hybrid one. In future, we plan to describe activities (conducting workshops, interviews) in each phases in detail with the help of a case study.

4 CURRENT CHALLENGES AND METHODOLOGY

For our research in this paper, we use one of the qualitative techniques called case research strategy. As industry 4.0 and smart manufacturing is relatively new research area, practice based problems, and poses new challenges, case research strategy is a best candidate for it as discussed in (Benbasat et al., 1987; Eisenhardt, 1989; Eisenhardt and Graebner, 2007). In this paper, we want to know and understand the stakeholder's expectations, requirements and the potential challenges industry 4.0 poses in the natural settings. Since current challenges, future expectations from industry 4.0 have been limited investigated and lack of case data in production environment from companies. To find-out, what the top challenges manufacturing industry is facing, we prepare a short questionnaire and distributed it in an information technology exhibition. We also get insights by informal interviews, various company's documents, and talks with industrial experts and consultants regarding current problems and challenges in production environment. Although due to different industry segments and complex nature of their business, challenges are also diverse but there are also some common challenges.

We describe top five current challenges faced by companies at production level in this paper. These challenges are also relevant to the evolution of industrial automation and manufacturing.

4.1 Data Challenge

In our data-driven world, we generate data in various ways. In production environment, data is generated and collected from different machines sensors, process data, product data, quality data, plant data, logistics data, data from partners, and infrastructure data; all contribute into explosion in data size.

Such data poses various challenges and demands new methodologies for storing, processing, and management of such data. New algorithms, models, products, and visualizations techniques are required to use and gain the actual benefits from the data. Data engineers are required to analyse such data and to find correlation between data streams and to gain new insights from the data which were not thought earlier. Specifically, there is a problem in which plethora of intermediate solution exists for data management within a company; it ranges from storing and exchanging data in form of printouts, emails, excel sheets, proprietary applications, and using heterogeneous database solutions between various departments or production halls. Lack of standardized approach for data management is still one of the concerns in big companies. For example, redundant data is stored in various departments of the company, in different data formats with minor extensions or enrichments. Such data silos raise the amount of data redundancy, inconsistency, and different interpretation of data. Software licenses, updates, hardware, and skilled personnel costs to manage such data landscape heterogeneity are a burden in a competitive production environment. Decision made on inconsistent data leads to incorrect decision.

4.2 Data Exchange with Partners

Companies have to exchange data within their factories or departments and make sure the availability of data for other processes in time. External partners also share their data with companies to keep processes optimized, e.g. material logistics data to keep the stock level as minimum as possible. There is also trend that instead of selling manufactured products, companies share their infrastructure or production facilities with other companies for revenue gain. Data transparency is also required in this case where other companies uses infrastructure as a service. Companies have to share the progress status of such products manufactured at their production facilities with other companies and for further processes carried out on products if needed. There is a gap between production level and ERP level. A close integration between shop floor and ERP level is often missing. Traditionally, data is not exchanged between shop floor and ERP level in real time and independently. Transferring of data between various systems at production level causes delay. In some scenarios, physical product is transferred on the conveyer belt but updated information was not loaded to carry out operations on the product which results in higher costs. Production status of a product is missing and often not in real time; hence status transparency lacked. Normally, even in state of the art factories, they have only three states to update the status of the product, namely production started, in progress, and finished, and are not well integrated with ERP systems. So, a monitoring solution from factory is needed considering which information to provide, in which granularity, user roles, as same information or process may be applied on the other products. There are also issues due to data exchange with partners in a collaborative environment, e.g. sharing the process status of products and current state of the processes applied on products. Companies also have to consider that sharing information with partners does not result to lose competitive advantage or sharing critical insights. Similarly, in case of machine faults at production level are not reported at ERP level and current state of the production does not reflected. Necessary measures for machine repairs cannot be initiated because of delay in reporting.

4.3 Training and Skill Development

Normally, especially in Germany, companies are facing shortage of skilled staff due to various factors. One of the major factors is aging population. People used to work in production are retiring and also taking production knowledge and experience they gained during their jobs. Other issue is to keep the hired persons within organization, as younger ones wants to have incentives, promotion or prefer to change jobs frequently. As majority of the workforce consists of old people who do not want to learn technologies or hinder to have change in their routines work. Introducing new techniques, gadgets, or changing their way is quite challenging as they resistant to such changes. This challenge becomes manifold in case of industry 4.0 scenarios where changes are eminent factor.

4.4 Process Flexibility

As product life cycle in this decade is shorter than before (Hofreiter and Huemer, 2010; Hofmann and Bick, 2015). Individualized and customized products also become reality. Such individualization and customization requires flexibility at production level in a cost effective manner. In order to provide such flexibility, production environment should be adaptable at the process level. Technology, currently used at shop floor level is inadequate and does not support the process flexibility (Zhang et al., 2013). Traditionally, processes and systems at production level are developed and managed isolated over the time in various departments. Change management at production level is quite challenging. As processes span in various departments, a clear process ownership is also missing in case of adaptation or changes. Change structure is also needed because sometimes it is not possible to keep the required change in the specific area and will impact the whole landscape due to dependencies. In case of changes, required changes are transferred in form of printouts or using email communication. Often these changes are handled individually in each department without any specific standards which raises the complexity and costs of managing such changes. There is a need to bring process standardization and synchronizations between various company departments to provide flexibility in an effective manner.

4.5 Security

Security is also a top concern now and it will be the major concern in future for industries. Industries want to keep their people, products, and production facilities environment secure from security risks. The trend of using smart devices in production is increasing. On one hand connectivity of these devices provides great advantages to ease our lives. On the other hand it poses greater risk from security perspective. Monitoring of such devices, used in production, is also a challenge from software and hardware perspective, which is often ignored. All devices whether industrial machines, computer, tablets, or smart phones needs to be updated on regular basis whether to avoid threats or due to configuration changes installed in these devices spread across the geographical location or inside factory. Keeping track of updates and management of such devices is a tedious task too. As some of IoT devices used at production level have very limited processing capabilities which requires new tools or methods, and measurements, to keep the devices secure instead of tradition methods. Serious measures are needed to restrict the threats posed by the malfunctioning or hacked devices. There are already various examples already happened where production facilities are targeted, e.g., security holes exploited in programmable logical controllers deployed in factories (Zetter, 2011). It is also possible that manufactured electronic products may contain viruses from production facility when delivered in the market, which may result heavy fines for company or product returns.

5 FUTURE SCENARIOS FOR INDUSTRY 4.0

Manufacturing industry has to cope with various challenges as mentioned in previous section. Despite of those challenges, in the following, we present some of the future scenarios from industry 4.0 perspectives. The scenarios also reflect the challenges mentioned in previous section. In first scenario, we discuss that more integration of processes are required within enterprise between ERP and shop-floor level and also across enterprise boundaries for optimal and collaborative environment. Second scenario highlights the importance of real time information access to make decision. Lastly, last scenario shows the importance of predictive maintenance in a production environment.

5.1 Integrated Processes

Product life-cycle involves series of processes, from design to production, service and feedback from customers. These processes can belong within the same enterprise or distributed across enterprise boundaries.

Process integration is quite challenging in this case due to various technologies, interfaces, standards, methods and unique characteristics in each enterprise involved. Involving customer's feedback or customization direct in manufacturing process will lead to improvement in the product and higher customer satisfaction.

Integrated processes across the enterprise will enable to optimize and make decisions in real time. Logistics can be well optimized and out of stock or over production cases, both results in revenue losses can be eliminated. Suppliers can access to live data at shop-floor level and know when to provide the required material for better resource planning and will reduce unplanned outage or overstock situations. Existing processes can be optimized and will be executed faster.

In case of companies having more than one manufacturing facilities, whether in same geographical location or scattered around the globe, cross plant manufacturing and planning makes more sense if data from facilities is available and integrated. Production load can be distributed from one plant to the other plants for optimal resource usage. Business processes can be analyzed across plants (Lodhi et al., 2014) to find out which plant is performing better and what we can learn from one plant or how we can develop best practices for specific industry or products for the whole organization. There is also a trend in which instead of selling end products, companies sell their know-how or other services.

A company can allow other companies or partners to use state of the art manufacturing facility, competency and knowledge know-how as a service to develop their own product. In this case integrated process across enterprise boundaries is a real challenge where companies have to exchange information and applying processes at hired facility in a secure and confidential way.

5.2 Real-time Data Access to/from Shop-floor Level

Real-time data access in a production is very vital whether it is related to products, processes, or machines operating in the factory. Traditionally, real time information access for processes was not available at shop floor level. In case of change in processes or actions, workers or machines have to wait until instructions are manually transferred or data is loaded in the production system. Future factories demand a close integration between ERP and shop-floor and real time access of data at production level for real time execution and vice versa. Data collected from machines and business processes is filtered, analyzed, and then delivered in required format to provide insights which in return will help to give better process control, optimize, and reduce overhead costs.

5.3 Predictive Maintenance

Maintenance of machines is an important area which every manufacturing company has to address. Manufacturing companies try to carry out planned maintenance based on different strategies like operating hours, number of products processed, or after a certain time. A machine condition monitoring system can be introduced to avoid unplanned maintenance. Machines equipped with sensors generates huge amount of data and records the operating condition in which machine operates. Historical data collected regarding machines operating conditions can play a vital role. Current state of the machine is compared with historical data and with other data in different dimensions (product quality, and wastage data). Models can be developed to predict which part of machine or machine is going to fail or vulnerable (Lee et al., 2015; Wang et al., 2008).

Machines manufacturers can collect data from machines to provide remote diagnostics and offer maintenance services from their locations. Such data can also be useful for them to know in which conditions their machines are operating and what they can learn from such data. For example, machine manufacturers can develop next generation of machines for specific industry or buyers segments by understanding their operating needs based on history. Remote setting of parameter or operating conditions or providing early warning in case of machine is over used or wrongly used as compared to what it is made for. They can also send their maintenance staff to repair or diagnose the problem. Such data can be collected by the machines and transmitted to the machine manufacturer. Other option is such data is collected by the production facility and then those enterprises can collaborate to produce or offer better services.

6 SUMMARY AND OUTLOOK

Industry 4.0 and smart manufacturing started to show their importance in manufacturing industry. In our paper, we provide an iterative approach for industry 4.0 projects. In our study, we investigate what are the current challenges. We also discuss the new scenarios which are possible in manufacturing industry to gain the benefit from industry 4.0. Although, we listed only current challenges but in future these new scenarios may also pose some challenges. In future, we want to explain our approach in detail and to develop a industry 4.0 project prototype (proof of concept) to demonstrate the utility of our approach.

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