A Survey of Current Challenges in Manufacturing Industry and Preparation for Industry 4.0

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Abstract Evolving business needs and shorter product life cycle demand for new methods and services from production facilities. In the past few decades, research and technology has been advanced at the rapid pace on enterprise level. Technology used at production level is still quite old and has not gained much attention in comparison to enterprise level. Enterprises are interested to invest more resources on production level to overcome problems and satisfy goals of stakeholders. The paper discuss the term Industry 4.0 and why we need changes in our traditional manufacturing systems (due to new business models, companies' competition, and innovation gap). We find-out what are the current challenges faced by organizations with the help of a survey. We also list new opportunities and applications possible by introducing new tools and technologies and provide initial feedback of a scenario from case company. At the end, we discuss how to solve these challenges, scenarios and summarize our paper.

1 Introduction

In the past three decades, there are significant development took place in information technology in general. The developments have revolutionized the way we live our lives and perform business operations/processes at work. The challenge of competition posed by certain countries (China, India) forced developed countries to focus more on innovation, more value, and services. Therefore, there is a trend of growth in budget allocated for next wave of manufacturing as reported by various surveys [1, 2]. Companies are eager to introduce new technologies to improve quality, efficiency of resources, reduce risks, and to remain competitive in the market. These new developments made possible for organizations to serve the customers in new

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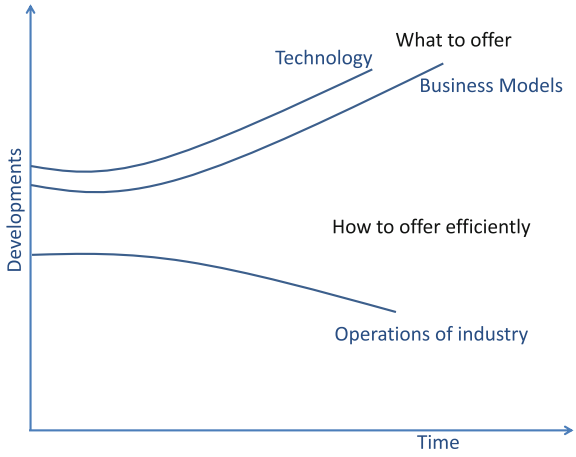

Fig. 1 Relation to develop strategy

ways and generated new business models to create value for customers and revenue for themselves. The Fig. 1 (adapted from [3]) shows the relation between developments in technology, business model, and their application in industrial operations with respect to time. As shown in the figure that there is significant difference in developments of business models, technology vs. development in industrial operations. This also justifies the need to better understand technology, business models and their applicability in organizations to achieve maximum benefits.

New business models have been introduced by various companies in order to provide more value and services to customers [4, 5]. These new business models not only attracted majority of the customers but also created new customers (and their segments) to which values/services can be provided.

A company which fails to cope the technology challenges also face the challenge of introducing new products/services, innovation, and business models. This puts the company in enormous competition where costs have to be reduced each year. A company which employs latest technology coupled with an innovative business model is guarantee for its success. There are many successful examples of big companies and start-ups. Technology has been advanced at rapid pace on enterprise level. Technology used at production level has not gained much attention in comparison to enterprise level. However, these technological developments were not much applied on industrial production level and stands as old as start of the third revolution with basic IT functionalities with monolithic structure. This was due to critical nature of the systems and their potential economic impact on organization operation. If a manufacturing system stops, the whole production line will be stopped and results loss to company. The gap between application level and shop-floor or machine level is also quite obvious. Enterprises are interested to invest more resources on production level to overcome problems.

In this paper, we discuss about industry 4.0. As there is quite potential of improvement at production level, we want to know what are the current challenges faced by companies with the help of a survey. We also provide promising future scenarios and discuss initial results of one of the future scenario in a multinational manufacturing company. At the end we provide a summary and outlook.

2 Industry 4.0 and Future Manufacturing

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, it is driven by German government (Bundesministerium für Bildung und Forschung) [6], and referred as Industry 4.0 (industrie 4.0) [7]. There are various definition exists for industry 4.0 by various groups and companies according to their needs and understanding. They also relate the term with other terms like IoT, Cyber Physical Systems (CPS), Smart Systems, 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 [7] 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". Powerful autonomous physical systems connected with one another and environment will perform operations intelligently (smart systems). These interconnected systems referred as CPS [8, 9] communicate 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 [10]. Such huge amount 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. As stated in [7], in future manufacturing, collaboration is the focal point.

Whether such collaboration exists between CPS, companies, universities, institutions, and other partners, the granularity of such collaboration can vary from cases to cases. Cloud platform and services will play a significant role in this context, allowing systems and partners to work from anywhere, communicate and collaborate in real time cloud environment. Such collaboration exists between our institution and our partners. We perceive the requirements of next generation 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 Research 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 [11–13]. 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. We also want to discuss future scenarios from industry 4.0 perspective and challenges associated with them. We prepared short questionnaire and distributed in ICT 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.

4 Current Challenges

In this section, we provide an overview of current challenges in manufacturing industry. 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 include the feedback from informal interviews, company documents, talks with industrial experts and consultants involved in production environment. These companies belong to diverse industry segments. Although due to different industry segments and complex nature of their businesses, challenges are also diverse but there are also some common challenges. From our results, we discuss top three challenges out of fifteen, in this paper due to space limitations.

4.1 Data Integration

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. Usage of IoT devices increased rapidly in last decade, which also contribute largely in the amount, heterogeneity, and speed of the data generated at the production level.

Such data poses various challenges and demands new methodologies for storing, processing, and management. New algorithms, models, products, and visualizations techniques are required to use and gain the actual benefits from the data. Data engineers are required to analyze 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. 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 landscape heterogeneity are burden in a competitive production environment. Decision made on inconsistent data leads to incorrect decision.

Other challenge is availability of the needed data for analysis purpose. Currently reports are periodically made, pre-defined, and results are exported into other programs, e.g., in Microsoft Excel, for decision making. The significance of real time analysis of production data enable us to make decisions on current data in real time, which leads to cost reduction and improved performance.

If systems are well integrated then above-mentioned problems can be eliminated and hardware, software, and operational costs can be reduced. Such integration is although quite difficult to execute because changes in data structure and understanding of various source data models are needed. If such data have to transfer into other systems then knowledge of system landscape transformation, ETL (extract, transform, and load) methods, and expertise in management are required.

4.2 Process Flexibility

As product life cycle in this decade is shorter than before [14, 15]. 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 [16]. Although such adaptation are performed frequently at various levels, e.g., at process level, changes in database, programs, data types, and even in the production sequences or flow but results in higher costs. Variability management mechanisms are needed for flexibility at various levels in production as it is required in other fields [17]. 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 over 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.

4.3 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. IoT devices will be around 50 billion till the end of this decade [10]. These devices will be used in homes, factories and everywhere. 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 [18]. It is also possible that manufactured electronic products may contain viruses from production facility, when delivered in the market, which results in heavy fines for company or product returns.

5 Future Scenarios and Initial Results

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.

5.1 Process Integration Within and Across Enterprise Boundaries

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. 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 [19] to find out which plant is 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. Other key performance indicators (KPIs) can also be measured, e.g., comparing employee productivity, production capacity, quality metrics, effectiveness, failure rate, and producing products better, faster and in efficient way. 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 Information Access on Hand-Held Devices

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. 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. Customized worker plans can be generated in real time for day to day operations to reduce the possibility of errors and faults. Real-time access of needed information on mobile devices fosters the development of applications using new front-end technologies, e.g., HTML5, SAP Fiori from in-memory database to give personalized experience and enable efficient business interactions. In our case company, production process and product data is delivered on handheld devices to employees working at the shop-floor level at right time. Due to instant availability of data, resources whether machines or human perform their tasks faster based on current data; hence Feedback from the employees was very positive and overall process was also optimized. Some employees complaint about the size and weight of the device. For some jobs handling an extra device was not comfortable. One reason was that they were not used to handle such devices in their day to day operations. Displaying such information on handheld devices in real-time will enable to enhance the performance and reduce the operational costs. Companies can also compare the production data within plants, e.g., by peer to peer comparison of machines or production facilities. Machine states and processes follow to accomplish tasks; all generates data and logs which can be used to find the track the steps performed in a plant. Such data can be compared with data from other plants to learn how to improve or optimal way.

Similarly, in case of faults in machines at production level, e.g., machine faults can be directly reported at ERP level and necessary measures can be initiated immediately saving time needed for production. The production environment display always current KPIs based on real time data.

5.3 Predictive Maintenance

Maintenance of machines is an important area which every organization has to address. Organizations 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. Such

data, e.g., containing machine temperature, vibrations, speed, pressure, state, and other values, 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 in a production environment. Prompt actions can be taken in case of vulnerability to avoid breakdowns. Such actions will increase the reliability of a machine. Predictive maintenance can be performed by seeing when machine is going to fail or which parts should be replaced before machine actually fail.

Machines or hardware 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. 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 Discussion and Suggestions

In previous sections, we list challenges faced by many organizations in their production environment found from our survey. We also provide some motivating future scenarios and initial findings of one of the scenario. Given this state of affairs, there is no silver bullet to solve those challenges at once; solutions are needed to cope with them. We already discussed that poor data management is also the reason for revenue losses as it is also reported in an other survey [20]. In future, database sources heterogeneity will be increased and spread across the globe. Tools and techniques are needed to have a scalable solution which incorporates the requirements within and across enterprise boundaries and to suppliers and other manufacturers. Industry standards should be needed for seamless integration of such heterogeneity.

New tools and platforms are needed to integrate data at production and enterprise level. It will remove the information silos and bring integrated solutions. A holistic security approach is needed to develop a trusted environment for data exchange between partners. Future platforms for collaboration are needed where stakeholder can share and exchange data easily ensuring data security and confidentially of share data. Industry 4.0 demands to introduce new technology to remain competitive in future and requires a complete roadmap and long term investments. A smooth-less transition plays as important role for migration. A comprehensive approach is needed for seamless transition in such projects. During this transition, it is important that

routine processes of factory should continue as before. Planned downtime is less risky, and costs less as compared to unplanned downtime. Although it is quite difficult to estimate the loss due to downtime as it also depends on industry or factors involved, e.g., production loss, material loss, low quality of product manufactured, unproductive resources, and costs involved to overcome all these issues. The overall cost reduces significantly if it is know which part is going to fail and should be replaced. If production is effected or stopped due to unplanned failure, costs are very high, e.g., averaging around 22,000 dollars/minute as mentioned in a survey [21].

We believe that a step-wise approach is needed, first to solve current challenges and to improve current situation. By doing so, it enables production environment to gain quick benefits and make production ready for future scenarios or to gain advantage from industry 4.0. Such step-wise or modular approach can come from service-oriented domain depending on the individual nature of the problem, e.g., for data exchange problem, introducing service bus for data exchange or using wrapper patterns [22] for departments to provide necessary services.

To enable industry 4.0 scenarios firstly concrete problems should be eliminated. As we discussed only few challenges and future scenarios, obviously there are also other future scenarios, e.g., additive manufacturing, cloud manufacturing, self-organizing manufacturing, which will bring also new challenges. Future scenarios mentioned above and others will also bring new aspects of different dimension which should be studied carefully, when implementing or running such project, to keep the organization competitive.

There are various kinds of risks involved in running industry 4.0 projects. One of the hindrances in such projects is related to people. Taking people in confidence and motivating them to participate in Industry 4.0 projects is very important, otherwise they will not allow projects to run successfully. Changing mind-set of people working in the organization is also challenge for industry 4.0 projects. People resist changing the ways they used to follow. So, a clear directive is needed from higher management for activities like data integration or related to industry 4.0 projects. It is also important to increase safety, security, and awareness about industry 4.0 in employees, by training the workforce, as they play a key role to enable new scenarios. Hiring of skilled staff and then keeping the know-how or skilled person with the organization is quite challenging.

7 Summary and Outlook

In our work, we show the importance of industry 4.0 and how it will enable manufacturing industry to improve and optimize processes. Research is focusing to find out what we are new opportunities and other scenarios which are not thought before by collecting data from machine level and integrating systems across the boundaries. In our study, we investigate what are the current challenges industry is facing which should be solved. We also discuss the new scenarios which are possible in manufacturing industry to gain the benefit from industry 4.0. We also give hints briefly

how to solve those challenges and how we can enable new scenarios. Although there is no silver bullet which will solve all problems in industry but still frameworks or step by step approaches are needed to realise scenarios in near future. These new scenarios may pose new challenges which should be considered when realizing such scenarios.

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