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Smart factory: A methodology for adaptation

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ABSTRACT

The purpose of this paper is to find from literature, (a) why 'smart factory' is an appropriate development to the factory system now, and (b) what is a smart factory, and what are its constituents and governing principles of design. The findings are used to propose a methodology for retrofitting or designing a smart factory. In the first step, the prevailing factory system and its weaknesses are identified. In the next step the technological developments, that are conducive to form the smart factory, which outperforms the existing factory system, are reviewed. In the third step the smart factory definitions are analyzed and in the fourth step the constituents, governing design principles, as identified from the literature are collected, analyzed and categorized. In the final step, we used the findings to propose a methodology to retrofit an existing factory or design a new smart factory. The literature concerning 'smart factory' is abundant, and a strict selection scheme was used, to choose the literature for the study. This might have eliminated some relevant literature. Smart Factory is a disruptive development to the existing factory system, and as such the findings first assist to identify the 'advanced knowledge in science and technology' that is needed for success (sensors, IoT, storing and processing a huge amount of data and data analytics). It then identifies various possible technologies that can constitute to specific smart factory implementations and guide with the design principles. The value of this research is the proposed methodology, which can guide anyone planning to move forward in the smart factory path.

Keywords— *Internet of Things (IoT), Industrial Internet of Things (IIoT), Smart manufacturing, Cyber-Physical Systems (CPS), Cyber-Physical Production Systems (CPPS), Industry 4.0, Smart factory*

1. INTRODUCTION

A great worldwide endeavour is underway, to use the Internet of Things (IoT) and smart analytics in technologies in the manufacturing industries and, consequently, to improve the overall performance, quality, and controllability of manufacturing processes. The integration of all IoT technological advances in computer networks, data combination and analytics to all manufacturing factories is referred to as a smart factory [1]. It is a fully connected and flexible system that can use a constant stream of data from connected operations and production systems to learn and adapt to new demands [2].

'Smart Factory' can be defined as a factory of connected and intelligent machines, where waste, defect, and downtime is almost equal to zero. These highly productive factories move materials more efficiently across the factory floor, made possible in part by data seamlessly moving from sensors on machines to servers to services [3]. Smart Factory is seen as the panacea for all the difficulties and limitations of conventional factories. This research is aimed at reviewing the published literature to identify (a) why smart factory is the appropriate development now, for the factory system of manufacture (b) what are the constituents of a smart factory and (c) how retrofitting or developing a new factory has to be handled. Section 2 reviews the traditional factories and their limitations. Section 3 describes the technological developments that make the development of 'Smart Factories' appropriate at this time. Section 4 analyses and collates the descriptions of smart factories and establishes a comprehensive list of constituents before describing an inclusive description (definition) of a smart factory. Section 5 describes narratives describing smart factories, constituents of smart factories and their design principles. It then proceeds to describe a methodology to implement retrofitting or designing a new facility so that it will be a smart factory.

2. CONVENTIONAL FACTORY

A conventional factory, with its origin during the 18th century, is an industrial site, consisting of buildings and a large collection of machinery, where workers operate machines to manufacture goods. The technologies employed were continuously improved with continued new developments in science and technology. Factories manufacturing chemicals are often called plants and have most of their equipment, consisting of blowers and ducts, pumps and piping, tanks, pressure vessels and chemical reactors, located outdoors and operated by personnel in control rooms. Such a plant will have several machine units made up as an assemblage of several components that get worn-out and eventually break. Maintenance in these factories consists of actions necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition. This is often achieved by replacing components that have reached the near-end-of-life condition or broken down completely, during an overhaul.

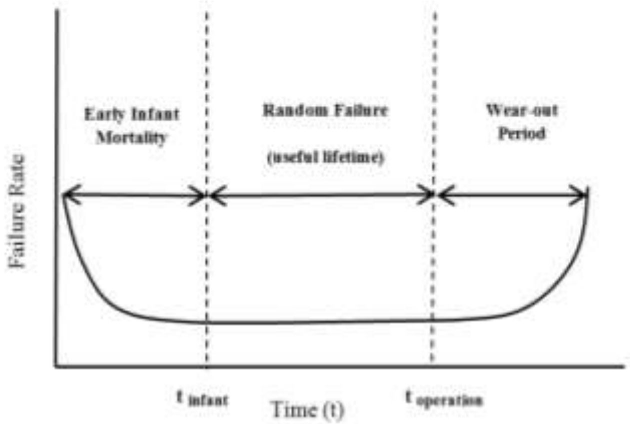

Fig. 1: Cumulative operating time versus failure rate

Traditional maintenance considers that the operation of a population of devices can be viewed, as shown in Figure 1, comprising 3 distinct periods:

(a) An 'early infant failure' (burn-in) period, where the chance of failure is high at the beginning and decreasing rapidly over time.
(b) A 'random failure' (useful life) period, where the chance of failure remains constantly low over time.
(c) A 'wear-out' period, where the chance of failure increases over time.

Historical data are collected in the form of time to failure or mean time to failure (MTTF) and components are assumed to reach the 'wear-out' period when their time in operation approaches the MTTF. During the shutdown of a plant for maintenance, it is customary to replace such components that are in the wear-out period to increase the reliability of the plant. However, these components will often have some useful life left in them.

2.1 Limitations of conventional factory

Operation of a conventional factory can be regarded as an endeavour to maximize the state of functioning (Sofu) and minimize the state of failure (Sofa) of the plant in the safest possible manner. Every activity, including resource allocation and data collection, is tailored to minimize 'Sofa'. Maintenance was classified as (a) breakdown maintenance (b) preventive maintenance and (c) planned maintenance for general work and condition-based maintenance for special units. Maintenance personnel called the 'running maintenance team' were kept on 'stand-by' to attend breakdowns. Preventive maintenance routinely checked the plant and changed the lubricants routinely to prevent breakdowns. Based on historic data planned maintenance works were carried out to refurbish or replace worn-out components nearing their life expectancy derived from crude measurements and historical data. Historic data itself was collected as aggregate parameters like the time to failure (which is used to estimate the mean life of a component) rather than a large amount of data about each component at short time intervals. Spare units of critical components also were kept in waiting for replacement during the break down maintenance or planned maintenance. This approach has stabilized the operation and maintenance and, efficiency levels were established as targets to represent good performance (for example more than 330 days of operation of a cement plant in a year). The limitations can be summarized as follows:

(a) Organization of the maintenance as breakdown, preventive and planned maintenance.
(b) Running Maintenance Team waiting as stand-by.
(c) Spare components waiting as stand by.
(d) Shortage of spare units and emergency purchases.
(e) Data collection in summary form which lacks continuous analysis of data and optimization.
(f) Limited opportunities to detailed data analysis for finding root causes, due to the summary format of data collection.
(g) The bulk of the maintenance work is post-event.

The problem is further exacerbated by the rapid obsolescence of products and the emergence of new products, high-quality standards, short delivery and decreasing costs [4]. Conventional factories and their supply chains face challenges in keeping up with ever-shifting fashion. Conventional factories have the safety, environmental and sustainability issues [2]. 'Fixed Routing' is a major limitation where the production line is fixed except when manually reconfigured by people with system power down. There is no communication among machines, products, information systems and people and the field devices are separated from the upper information systems. In the current thinking, this is considered as a major drawback. Another major limitation is due to the fact that 'any malfunction of a single device will break the full operation since every machine is preprogrammed to perform the assigned functions only' [5].

2.2 Analysis

The situation needs some disruptive development that will destroy the existing methodologies and procedures and introduce better and autonomous new ones based on advanced technologies that make very much reduced waste, defect, and downtime. Smart factory is the result of this new development based on advanced technologies namely (a) sensors to generate more operational data (b) Internet of Things (IoT) for effective communication (c) cloud and dedicated computing to handle huge amount of data (d) deviation from traditional processing and (e) integrated management. The following sections describe them.

3. TECHNOLOGICAL DEVELOPMENTS

This section describes the advanced technological developments identified in the preceding analysis, which form the basis for the desired disruptive development for the present factory system.

3.1 New Opportunities to generate data (Sensors)

The sensor is a device that detects events or changes in the environment, and transforms signals from different energy domains (such as radiant, mechanical and thermal) to the electrical domain and provides a corresponding output [6]. It detects or measures a physical property and records, indicates, or otherwise responds to it.

In 2004 Kanoun and Tränkler [7] anticipated the following two areas of development:

(a) Maintenance-free sensors with long life expectancy and low electric power consumption.
(b) Increased use of multisensory and wireless systems and miniaturization.

In 2018 Schütze, Helwig and Schneider [8] report of smart sensors, which generate the data and allow further functionality from self-monitoring and self-configuration to condition monitoring of complex processes. In short sensor technology of today has advanced to provide sensors to (a) continuously generate data for every aspect of the manufacturing process (b) track real-time movements and locations of raw materials, work-in-progress and finished goods, and high-value tooling (c) be placed on equipment to drive predictive and cognitive maintenance analytics and (d) geo-fence dangerous equipment from operating in close proximity to personnel. In this context geo-fence is a virtual geographic boundary, defined by GPS (Global Positioning System) or RFID (Radio-frequency Identification) technology that enables software to trigger a response when a mobile device enters or leaves a particular area.

3.2 Opportunities provided by communication capabilities and IoT

Internet, as known to everyone, is a global computer network providing a variety of information and communication facilities. The internet of things, IoT, is the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data. This is a revolutionizing development that has the potential to change way factories operate and people conduct their day-to-day lives. In other words, this can be part of the disruptive technology desired for developing smart factories.

Patel and Patel [9] express the vision of IoT in the following way: Internet of Things (IoT) is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/services and reach common goals. In the context of a factory, the things/objects can be blowers and ducts, pumps and piping, tanks, pressure vessels, chemical reactors, and their constituent components like shafts and bearings. With the latest development of RFID technology, IoT has been paid more and more attention because it could provide a promising opportunity to build powerful industrial systems and applications. This is achieved by leveraging the growing ubiquity of RFID, wireless, mobile and sensor devices embedded in the object, logic object and internet-based information infrastructure. The Internet of Things (IoT) is a significant element of Industry 4.0 that creates comprehensive network infrastructure to create virtual systems and physical objects using the internet [10] leading to operations that can be performed more efficiently, accurately and intelligently [11].

3.3 Opportunities for storing and processing a huge amount of data

Advancement in sensor technology has opened the floodgates for the influx of huge amounts of industrial data. Industrial data is growing twice as fast as any other sector. Yet today, less than 3% of the data is tagged and used in a meaningful fashion [12]. With the use of advanced sensor technologies modern manufacturing systems increase the complexity in generating huge amounts of continuously generated data. This data contains valuable information useful for several use cases such as knowledge generation, optimization of key performance indicators (KPI), diagnosis, prediction, and feedback to design or decision support [13]. Technology for storing and handling this data also is developing faster. The following sub-section provides a brief description of technologies in these two aspects.

3.4 Fundamental deviation in data processing, use of data

In order to figure out huge data and its impact imagine a journal bearing carrying a running shaft in a factory. The wear in the bearing is the parameter that tells whether it is in the operable condition or is reaching the wear-out period. When no continuous data is available, as, in the conventional factory, routine change of lubricant and the MTTF from the historical data are the two things to rely upon. Imagine a condition where the wear is taken twice every hour. This is a large amount of data about a single component. But this provides opportunities to decide the daily wear rate reflecting the condition of lubrication providing a better way to manage than the routine change. The measurement of wear permits the estimation of the remaining life. This can facilitate to plan the spare part and bring the maintenance team in time to minimize the downtime. But this needs two things: (a) availability of large data and (b) processing capability or analytics to compute different monitoring constructs to assist in the efficient operation. In other words, a fundamental deviation in collecting data and processing data is required.

Collection of continuous data provides opportunities for viewing single and subsets of data under different classifications. In this context, classification can be seen as a systematic arrangement of data. For example, the continuously collected data from the journal bearing above can be used to calculate (a) the average wear per week (b) overall wear rate per day to estimate the life available (c) the impact of the environmental change (say the dusty condition) by considering the data during the period (d) the requirement of lubricant change indicated by increased wear on the daily and weekly basis and so on. It is worth noting here that a single item of data can belong to several different groups under different classifications. The classification of data for different constructs results in establishing different analytics. Making the journal bearing may include it sending a photograph of itself to the maintenance team when it is entering the 'end-of-life' stage of its life. Thus the data processing and use of data have to be part of the disruptive technology and undergo a fundamental deviation. It should adopt the processing techniques highlighted earlier in section 3.3 about 'Opportunities for storing and processing a huge amount of Data'.

3.5 Opportunity for better management

Groover [14] identifies that production systems have two constituents namely (a) facilities and (b) manufacturing management systems. Facilities consist of the factory, production machines and tooling, material handling equipment, inspection equipment and computer systems that control the manufacturing operations. Manufacturing Management Systems are the procedures and systems used by the firm to manage production and solve the technical and logistics problems associated with designing the product, planning the processes, ordering materials, controlling the work-in-process as it moves through the plant, and delivering the product to customers. Four functions are performed in this category: business functions, product design, manufacturing planning, and manufacturing control. Collection of the huge amount of data and associated analytics greatly enhance the ability to utilize the facilities to the full and seamlessly integrate the manufacturing management systems to assist production and minimizing waste and downtime while maximizing sustainability.

3.6 Analysis and summary of findings

Section 3 summarizes the technological developments that are needed and developed to make 'smart factory' a feasible concept. Subsection 3.1 summarizes the developments in sensors which form the origin of the 'huge amount of data' that is the lifeblood of the smart factory. It describes multi-sensor measurement to ensure reliability and correctness of the data and, a feature extraction unit to reduce or optimize the dimensionality of the measurement space. Subsection 3.2 summarizes the Internet of Things, IoT, and the opportunities arising from IoT. The huge amount of data generated by the sensors is transmitted to the computer through the IoT. Subsection 3.3 discusses the opportunities for storing and processing a huge amount of data that has been transmitted through the IoT. Subsection 3.4 discusses the processing and use of the huge amount of data in different ways that facilitate autonomous management of the connected machines and units in a smart factory. Subsection 3.5 identifies the four parts business functions, product design, manufacturing planning, and manufacturing control that have to be integrated and the facilities developed integrating the technological developments. Having thus seen the summary of the influencing factors for the 'Smart Factory' it is necessary to look at 'What is a Smart Factory'. Section 4 describes what a smart factory is? and section 5 describes the methodology adopted to retrofit a smart factory.

4. WHAT IS A SMART FACTORY?

Smart factory is the incorporation of latest technologies in its development to have the self-x capabilities, where x stands for characteristics such as description, awareness, management, organizing, controlling, directing, healing, correction, auto-discovery, re-configuration, predicting, comparing, maintaining, organizing etc., which in turn makes manufacturing reliable, safer, economical, sustainable and high quality. Section 2 identified the shortcomings of the conventional factories and Section 3 identified the technologies that can alleviate some if not all of the shortcomings. This follows the technology transfer model Research → Development → Design → Production as proposed by Ramanathan [15]. In this model, research findings are first developed sufficiently for incorporation into the design of goods and services. Then the design phase starts which leads to commercial production. Smart Factory concept is between the development and design phases and hence the definition of it in terms of constituents and the level of their incorporation in designs are fuzzy. Another important aspect about technology transfer identified by Bennet and Vaidya [16] is the 'basic knowledge of science and technology of the recipients'. The nature of the smart factory requires competence in what is traditionally called multi-disciplinary. The level of competence of the implementers thus has a significant influence on the constituents of any specific implementation of smart factories. The following subsections explore the description of the smart factory by different authors, constituents of smart factories and design principles of smart factories.

4.1 Description of smart factories by authors

The literature has listed many descriptions for 'Smart Factory'. When reading through them one could immediately realize that they are goal oriented descriptions answering the 'what' question than the 'how' question. Table 1 shows some of these descriptions.

Table 1: Description of smart factory by authors

Author	Description of smart factory
Jay Lee [1].	The combination of all new IoT technological advances in computer networks, data integration and analytics to bring transparency to all manufacturing factories
Elvis Hozdic [4]	Integrating between the numerous industrial and non-industrial partners who build virtual organizations resulting in an effective and flexible production solution.
Radziwon et al. [17]	A manufacturing solution that is related to automation, known as a combination of software, hardware and mechanics, which should lead to optimization of manufacturing resulting in a reduction of unnecessary labor and waste of resource.
Deloitte Development[2] .	A self-optimizing performance across a broader network, self-adapt to and learn from new conditions in real or near real time and autonomously run entire production processes

4.2 Constituents of smart factories

According to Deloitte Development LLC [2], the components needed to enable a successful smart factory are largely universal, and each one is important: data, technology, process, people, and security. Following these five clusters were formed.

4.2.1 Data: Data is the lifeblood of the smart factory. Through the power of algorithmic analyses, data drive all processes, detect operational errors and provide user feedback. When gathered in enough scale and scope, it can be used to predict operational and asset inefficiencies or fluctuations in sourcing and demand. Combining and processing the resulting data actions are what make them valuable. To power the smart factory, manufacturers should have the means to create and collect on-going streams of data, manage and store massive loads of information generated.

4.2.2 Technology: For a smart factory to function, assets defined as plant equipment such as material handling systems, tooling, pumps, and valves should be able to communicate with each other and with a central control system. The control system can take the form of a manufacturing execution system, which is an integrated, layered hub that functions as a single point of entry for data from across the smart factory and the broader digital supply network, aggregating and combining information to drive decisions. Organizations have to consider other technologies including transaction and enterprise resource planning systems, IoT and analytics platforms, and requirements for edge processing and cloud storage.

4.2.3 Process and Governance: One of the most valuable features of the smart factory is its ability to self-optimize, self-adapt, and autonomously run production processes which can fundamentally alter traditional processes and governance models. An autonomous system can make and execute many decisions without human intervention, shifting decision-making responsibilities from human to machine in many cases, or concentrating decisions in the hands of fewer individuals. The connectivity of the smart factory may extend beyond its four walls to include increased integration with suppliers, customers, and other factories.

4.2.4 People: In a smart factory people are expected to still be key to operations. However, there can be profound changes in the operations and IT/OT organizations, resulting in a realignment of roles to support new processes and capabilities. Some roles may no longer be necessary as they may be replaced by robotics (physical and logical), process automation, and AI. Other roles might be augmented with new capabilities such as virtual augmented reality and data visualization.

Organizational change in management could play an important role in the adoption of any smart factory solution.

4.2.5 Cyber Security: By its nature, the smart factory is connected and thus cybersecurity risk presents a greater concern in the smart factory than in the traditional manufacturing facility and should be addressed as part of the overall smart factory architecture. In a fully connected environment, cyber-attacks can have a more widespread impact and may be more difficult to protect against, given the multitude of connection points. It was observed that existing technologies and terminologies were given specific features and meanings when they were applied in smart factory applications. Therefore, the existing terminologies towards smart factories have been reviewed. With their additional features and meanings, they have become the active constituents of smart manufacturing. They could be clustered into the above five constituents.

Table 2: Technology/Terminology and References

Technology/Terminology	Reference
Intelligent	[18][19],[20],[21]
Energy saving efficiency	[22],[23], [24],[25],[20],[22], [26]
Cybersecurity	[27],[28],[29],[22]
Real-time Communication	[20],[30],[31]
CPS/CPPS	[32],[20],[22], [25], [33], [34]
Virtual Reality and Augmented Reality	[22] [35] [36]
IoT/IIoT	[20],[22], [37], [38]
Data analytics/big data analytics	[25],[39],[40],[25][41],[42], [43], [44]
Data visualization	[45] [46]
Operation Planning	[47]
IT-based production management	[20]
Smart Materials	[23],[48],[49]
Advanced manufacturing	[50],[51],[52] [25]

Table 2 illustrates a collection of these technologies and terminologies, which were found in the references accompanying them. For example, one terminology is intelligent technology which means the ability to change its action based on its own experience. Another term is energy saving efficiency which is a technology where the energy necessary to provide a product or service can be reduced. Cyber security is one of the five constituents as discussed earlier in section 4, it is when data should be secured from cyber threats. In addition, real-time communication is a technology, which enables users to exchange data with systems in real-time and this can be put with the technology cluster. Virtual Reality (VR) creates 3D images using a computer and the interaction in that space with the help of electronic devices, for the user to feel as if he or she has been immersed in a synthetized environment. Augmented Reality (AR) is a technology that can superimpose a computer-generated 3D numerical format in the real world but not interact with it. VR and AR are categorized under the people cluster because there are changes in the operations supporting new processes and abilities. CPS/CPPS (Cyber Physical Systems /Cyber Physical Production System) are technologies used to solve and work with physical mechanisms or components. This is placed under the process and governance cluster. IoT/IIoT (Internet of Things /Industrial Internet of Things) enables communication between the physical and internet-enabled devices, which can be used to improve the existing manufacturing systems. IoT/IIoT is also placed under the process and governance cluster.

Additional terminologies such as big data is a technology that can analyze large sets including real-time data that are difficult to analyze by traditional methods. Data analytics is dealing with data into actions and insights within a manufacturing system. This terminology is clustered under the data cluster. Indeed, big data can be understood as being part of this technology which also makes it under the data constituent cluster. Data visualization represents data with the help of graphs and other visual representations which can lead to graph patterns to analyze the data. The authors agreed that data visualization should be the process and governance cluster. Furthermore, operation planning is when all the activities of the organization are planned to achieve the final objective. In other words, connecting everything happening within the organization through the help of IT. This terminology can also be placed on the process and governance cluster. The IT-based production management includes computer-aided design (CAD), computer-aided manufacturing (CAM), computer aided technology (CAx) etc. These are the tools that allow designing, analyze and facilitate the design and production. Therefore, the CAx tools are included in the technology cluster. Smart materials can sense the change in environment with the help of sensors and take the corrective actions using actuators, as well as they provide data for analysis as well, which may lead to improved part design.

Smart materials can be considered as a process and governess cluster. Finally, advanced manufacturing terminology which is, for instance, additive manufacturing that is a technology that can print a 3D image into an object with the help of a laser beam, an electron beam which is a technology cluster.

In summary, the clustering has been done according to the author's subjective judgment by determining the most suitable cluster because there are some items that could have been possibly placed in another cluster; nevertheless, they are placed in a specific cluster. However, the authors fully acknowledge that one might argue that the respective items might fit into another cluster as well based on the individual background and experience.

4.3 Design principles of smart factories

The constituents that are clustered from section 4.2 are aimed to act as the capabilities to enable smart manufacturing to comply with the six design principles of Industry 4.0 scenarios. The design principles will help designers to build new smart factories or upgrade. Most of the literature is focused on the design principles of the smart factory [53], [54], [55], [56] and these principles are :

4.3.1 Interoperability: Being able to allow communication through interfaces between the components/sub-systems of a manufacturing system, allowing it to work with or use parts of another component of subsystems.

4.3.2 Virtualization: Creating an artificial factory environment with CPS similar to the actual environment and to be able to monitor and simulate physical processes. Such an environment can be created by the Information transparency in CPS and the aggregation of sensor data [57].

4.3.3 Decentralization is the ability of Smart Manufacturing systems and technologies to make decisions on their own and to perform their tasks autonomously including global production goals [57].

4.3.4 Real-time capability or Responsiveness is the ability to automatically and in real-time collect manufacturing system data via a network of sensors such as IoT and immediately provide the derived understandings [58].

4.3.5 Service orientation: Manufacturing industries and organizations focus on profit from selling the service rather than selling the product [56]. Cloud computing plays an important role in enabling the on-demand provision of services[59].

4.3.6 Modularity: is the design of the system components. It is when system components are combined and separated easily and quickly. It allows the system to respond to changing customer requirements and to avoid the internal system malfunctions[60].

5. DEVELOPMENT OF SMART FACTORIES

After understanding the definitions of a smart factory and its five constituents. As well as the terminologies that describe smart factory systems in the previous tables, it is time to develop a vision for connecting the various aspects. This vision creates the foundation for smart factory implementation.

5.1 Analysis of literature

In analyzing the development of smart factories some authors identified a diverse set of practices for adapting the smart factory. Indeed, the systematic nature of smart factory implementation creates uncertainty about the particular adaptations that may be needed with regard to other technologies, processes, and workforce capabilities. This uncertainty is due to the very high cost, however, the benefits of investment will increase in an uncertain time in the future. Our analysis of the literature about implementing smart factories revealed seven main steps underlying a successful smart factory implementation which is discussed in the following section. To the best of our knowledge, this paper is the first attempt to collect and present the methodology for implementing a smart factory in this form.

5.2 Proposed methodology

The methodology for smart factory adaptation went through seven stages (1) Situation Analysis (2) Breakdown Prevention Analysis (3) Sensor Selection (4) Data Transmission and Storage Selection (5) Data Processing and Analytics (6) Autonomous Action Network (7) Integration with the Physical Plant Units. Each of the seven steps is described below.

Situation analysis starts with the process description with the associated plant units. Then historical data of these units could be appraised through performance analysis of the plant units. This would identify the units that have robust performance and need little change and the vulnerable units that can be subjected to process improvement. In the next stage, breakdown prevention analyses the vulnerable units identified earlier which are investigated for rectifying their vulnerability. As making them smart is the way forward in making them robust, the needed self-x characteristics are identified. This self-x characteristic may be the notification of the remaining life of a journal bearing for example. The next stage is to establish the monitoring needed to incorporate the specific self-x characteristic. A suitable sensor is selected for this monitoring. This follows the estimation of the amount of data that would be generated and the choice of the communicating method. The important next stage is where the generated a large amount of data is arranged in suitable classes (data processing) and subjected to various analyses. The analyses would reveal conditions where remedial or reactive actions are needed to keep the unit operational or to minimize the downtime and safety risks. This needs an autonomous or self-acting network of activities. Once this network of activities or actions is established the last stage is to integrate the process with plant units. This will make the vulnerable units in the conventional plant more robust due to self-monitoring and autonomous remedial action. Figure 2 shows the hypothetical model for retrofitting a smart factory.

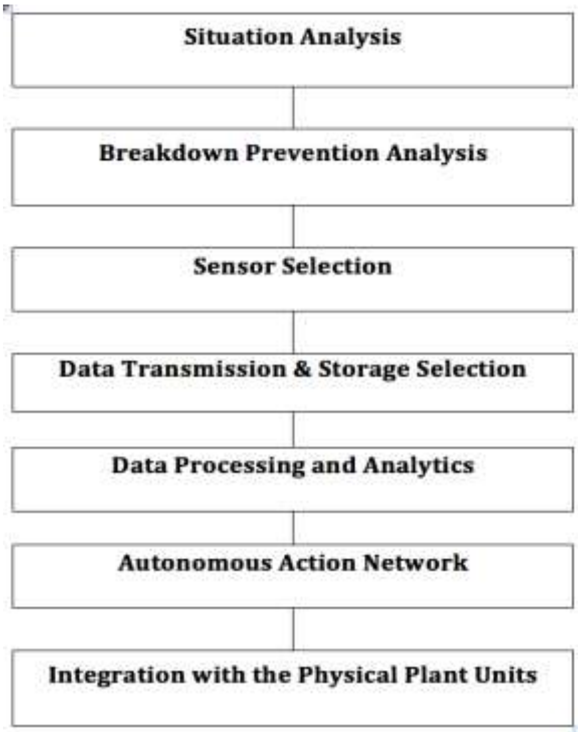

Fig. 2: Hypothetical Model for Retrofitting a Smart Factory

6. CONCLUSION

With the sensor technology and evolving information technologies, such as IoT, big data, and cloud computing together with artificial intelligence technologies, we believe the smart factory concept can be implemented in retrofitting existing factories or designing new factories. The smart machines and products can communicate and negotiate with each other to reconfigure themselves for flexible production of multiple types of products. The massive data can be collected from smart artifacts and transferred to the cloud through the internet protocols. This enables the system-wide feedback and coordination based on data analytics to optimize system performance. The above self-organized reconfiguration and data based feedback and coordination define the framework and operational mechanism of the smart factory. To achieve these benefits, companies can follow the proposed seven-step methodology to build or retrofit a smart factory with the five constituents that are matching the six principles discussed earlier. The methodology is hoped to shape a vision of the future manufacturing.

7. REFERENCES

[1] Lee Jay, “Smart Factory Systems,” Informatik Spektrum, May 2015.

[2] Deloitte Development LLC, “The smart factory Responsive, adaptive, connected manufacturing, A Deloitte series on Industry 4.0, digital manufacturing enterprises, and digital supply networks.” 2017.

[3] Verzijil Diederik et al., "Smart Factories Capacity Optimisation." Business Innovation Observatory, Contract No 190/PP/ENT/CIP/12/C/N03C01, European Commission, 2015.
[4] Hozdic Elvis, "SMART FACTORY FOR INDUSTRY 4.0: A REVIEW," International Journal of Modern Manufacturing Technologies, vol. VII, no. No.1/2015, p. 28, 2015.
[5] Shiyong Wang, Jiafu Wan, Di Li, and Chunhua Zhang, "Research Article Implementing Smart Factory of Industrie 4.0: An Outlook," Hindawi Publishing Corporation, vol. 2016, p. 10 pages, 2016.
[6] Dr Sergey Y. Yurish, "Sensors and Sensor Systems: Design and development for smart phones and IoT." International Frequency Sensor Association, 21-May-2017.
[7] Kanoun O. and Tankler H., "Sensor Technology Advances and Future Trends," IEEE Transactions on Instrumentation and Measurement, vol. 53, no. No 6, Dec. 2004.
[8] S. A., H. N., and S. T., "Sensors 4.0-smart sensors and measurement technology enable Industry 4.0," Journal of Sensors and Sensor systems, vol. 7, pp. 359–371, 2018.
[9] Keyur K Patel, Sunil M Patel, and PG Scholar, "Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges," p. 10, 2016.
[10] Trappey A.J.C, Li X.K, and Lee I.J.Y., "IoT patent roadmap for smart logistic service provision in the context of Industry 4.0.," J.Chin.Inst.Eng., vol. 40, pp. 593–602, 2017.
[11] Jia X., Q. Feng, T. Fan, and Q. Lei, "RFID Technology and its Applications in Internet of Things(IoT).," in In Processing of 2012 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet), Washington, DC, 2012, pp. 1282–1285.
[12] "IDC report-THE DIGITAL UNIVERSE IN 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East.".
[13] Kevin Nagorny, Pedro Lima-Monteiro, Jose Barata, and A.W Colombo, "Big Data Analysis in Smart Manufacturing: A Review," Int.J. Communications, Network and System Sciences, vol. 10, pp. 31–58, 2017.
[14] Groover Mikell P., Automation, production systems, and computer-integrated manufacturing, Fourth edition. New York: Pearson Education, 2016.
[15] Ramanathan K., "An Overview of Technology Transfer and Technology Transfer Models," 14-May-2018. [Online]. Available: http://tto.boun.edu.tr/files/1383812118_An%20overview%20of%20TT%20and%20TT%20Models.pdf.
[16] David Bennett and Kirit Vaidya, "Meeting technology needs of enterprises for national competitiveness," International Journal of Technology Management, vol. 32, no. 1/2, p. 112, 2005.
[17] Radziwon A., Billberg A., Bogers M., and Skov E., "The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions," Procedia Eng, vol. 69, pp. 1184–1190.
[18] "Robotics and Intelligent Systems: A Virtual Reference Book." [Online]. Available: https://www.princeton.edu/~stengel/RISVirText.html. [Accessed: 19-Sep-2018].
[19] Shuhui Qu, Raymond Jian, Tianshu Chu, Jie Wang, and Tian Tan, "Computational reasoning and learning for smart manufacturing under realistic conditions," in 2014 International Conference on Behavioral, Economic, and Socio-Cultural Computing (BESC2014), Shanghai, China, 2014, pp. 1–8.
[20] Park J and Lee J, "Presentation on korea smart factory program," in Proceedings of the international conference on advances in production management systems, Tokyo, Japan, 2015.
[21] "Smart tooling, smart machines and smart manufacturing : working towards the industry 4.0 and beyond.," in Proceedings of the 21st international conference on automation and computing, Glasgow, Scotland, 2015, pp. 11–12.
[22] Kang HS, Lee JY, Choi S, and et al, "Smart manufacturing: past research, present findings, and future directions.," International Journal Precis Eng Manuf 2016, vol. 3, pp. 111–128.
[23] A. Fytrou-Moschopoulou, "Energy-efficient Buildings: Multi-annual roadmap for the contractual PPP under Horizon 2020," Build Up, 21-Sep-2015. [Online]. Available: http://www.buildup.eu/en/practices/publications/energy-efficient-buildings-multi-annual-roadmap-contractual-ppp-under-horiz-0. [Accessed: 19-Sep-2018].
[24] D. Trombley and E. Rogers, "Benefits and Barriers of Smart Manufacturing," 2014.
[25] Davis J., "Cyberinfrastructure in chemical and biological process systems: impact and direction.," Arlington, VA, NSF workshop report.
[26] Jennifer A. Nekuda Malik, "US expects energy savings through smart manufacturing," MRS Bulletin, vol. 41, no. 1, pp. 10–11, Jan. 2016.
[27] GD Abowd, M. Ebling, G. Hung, and et al, "Context-aware computing," IEEE Pervas Comput, vol. 1, pp. 22–23, 2002.
[28] "Smart Process Manufacturing Engineering Virtual Organization Steering Committee.," Smart process manufacturing: an operations and technology roadmap. [Online]. Available: https:// smartmanufacturingcoalition.org/sites/default/files/spm_ _an_operations_and_technology_roadmap.pdf (2009, accessed 29 March 2017).
[29] Cheng K., "Keynote presentation_2: Smart tooling, smart machines and smart manufacturing: working towards the industry 4.0 and beyond.," in Proceedings of the 21st international conference on automation and computing, Glasgow, Scotland, 2015, pp. 11–12.
[30] Kibira D, Morris K, and S Kumaraguru, "Methods and tools for performance assurance of smart manufacturing systems.," J Nat Inst Stand Technol, p. 8099, 2015.
[31] Korambath P, Wang J, Kumar A, and et al, "A smart manufacturing use case: furnace temperature balancing in steam methane reforming process via Kepler workflows," Procedia Comput Sci, vol. 80, pp. 680–689, 2016.
[32] Leita˜o P, AW Colombo, and S. Karnouskos, "Industrial automation based on cyber-physical systems technologies: prototype implementations and challenges.," Comput Ind, vol. 81, pp. 11–25, 2016.
[33] "Cyber-physical systems: design challenges.," in Proceedings of the 11th IEEE international symposium on the object and components-oriented real-time distributed computing, Orlando, FL, 2008.
[34] Monostori L, "Cyber-physical production systems: roots, expectations and R&D challenges.," Procedia CIRP, vol. 17, pp. 9–13, 2014.
[35] Esmaeilian B., Behdad S, and Wang B, "The evolution and future of manufacturing: a review," J Manuf Syst, vol. 39, pp. 79–100, 2016.

[36] S. Choi, K. Jung, and S. D. Noh, "Virtual reality applications in manufacturing industries: Past research, present findings, and future directions," Concurrent Engineering, vol. 23, no. 1, pp. 40–63, Mar. 2015.
[37] Wang M, Zong RY, Dai Q, and et al, "An MPN-based scheduling model for IoT-enabled hybrid flow shop manufacturing," Adv Eng Inf, vol. 30, pp. 728–736, 2016.
[38] Alberti AM and Singh D, "Internet of Things: perspectives, challenges and opportunities," in Proceedings of the international workshop on telecommunications, INATEL, Brazil, 2013.
[39] Yu C, Xu X, and Lu Y., "Computer-integrated manufacturing, cyber-physical systems and cloud manufacturing concepts and relationships.," MAnuf Lett, vol. 6, pp. 5–9, 2015.
[40] Ku¨ hnle H. and Bitsch G., "Foundations & principles of distributed manufacturing.," Berlin: Springer, pp. 55–70, 2015.
[41] K. A., "Smart manufacturing," Int J Prod Res, vol. 14, pp. 1–10, 2017.
[42] Schabus S and Scholz J, "Geographic Information Science and technology as a key approach to unveiling the potential of industry 4.0: how location and time can support smart manufacturing," in Proceedings of the 12th international conference on informatics in control, automation and robotics, Colmar, 2015, pp. 463–470.
[43] Shin SJ, Woo J, and Rachuri S., "Predictive analytics model for power consumption in manufacturing," Procedia CIRP, vol. 15, pp. 153–158, 2014.
[44] Kusiak A, "Smart manufacturing must embrace big data," Nature, vol. 544, pp. 23–25, 2017.
[45] Stanley B. Gershwin, "The future of manufacturing systems engineering," International Journal of Production Research, vol. 56, no. 1–2, pp. 224–237, Jan. 2018.
[46] Guodong Shao, Seung-Jun Shin, and Sanjay Jain, "Data analytics using simulation for smart manufacturing," in Proceedings of the Winter Simulation Conference 2014, Savanah, GA, USA, 2014, pp. 2192–2203.
[47] Teramoto K, Wu D, and OTA K, "A Framework of Accuracy Assured Machining for Smart Manufacturing," Memoirs of the Muroran Institute of Technology, vol. 65, pp. 35–39, Mar. 2016.
[48] Sinha S., "Advanced/smart manufacturing: from nanoscale to megascale.," IEEE Potentials, vol. 35, pp. 7–8, 2016.
[49] Dazhong Wu, Connor Jennings, Janis Terpenny, Robert X. Gao, and Soundar Kumara, "A Comparative Study on Machine Learning Algorithms for Smart Manufacturing: Tool Wear Prediction Using Random Forests," Journal of Manufacturing Science and Engineering, vol. 139, no. 7, p. 071018, Apr. 2017.
[50] Davis J, Edgar J, Graybill R, and et al., "Smart manufacturing. Annu Rev Chem Biomol Eng," vol. 6, pp. 141–160, 2015.
[51] "Anderson A. Report to the President on ensuring American leadership in advanced manufacturing.," Executive Office of the President, 2011. [Online]. Available: https://obama whitehouse.archives.gov/sites/default/files/microsites/ostp/ pcast-advanced-manufacturing-june2011.pdf.
[52] Park HS and Tran NH, "Autonomy for smart manufacturing.," J Korean Soc Precis Eng, vol. 31, pp. 287–295, 2014.
[53] Khan M., Wu X., Xu X., and Dou W., "Big data Challenges and Opportunities in the hype of the industry 4.0.," In Proceedings of the IEEE International Conference on Communications (ICC), Paris, France, pp. 1–6, 21-May-2017.
[54] Vogel-Heuser B. and Hes D., "Guest Editorial Industry 4.0 Prerequisites and Visions," presented at the IEEE Trans. Autom. Sci. Eng., 2016, vol. 13, pp. 411–413.
[55] Mohammed M. Mabkhot, Abdulrahman M. Al-Ahmai, Bashir Salah, and Hisham Alkhalefah, "Requirements of the Smart Factory System: A Survey and Perspective." MDPI, 01-Jun-2018.
[56] Hermann M., Pentek T., and Otto B., "Design Principles for Industrie 4.0 Scenarios: A Literature Review," Working Pap, 2015.
[57] Cyplik P. and Patecki A., "RTLS vs RFID-partnership or competition?," LogForum 7. 2011.
[58] Tyrin I. et al, "Multi-agent system 'Smart Factory' for real-time workshop management: Results of design & implementation for Izhevsk Axion-Holding Factory.," in Proceedings of 2012 IEEE 17th International Conference on Emerging Technologies & Factory Automation (ETFA 2012), Krakow, 2012, pp. 1–4.
[59] Yao X., Jin H., and Zhang J., "Towards a wisdom manufacturing vision," 2015, vol. 28, pp. 1291–1312.
[60] "Smart factory: The requirements for implementation of the industry 4.0 solutions in FMCG environments-case study," Scientific Journal of Logistics, vol. Log forum 14(2), pp. 257–267, 2018.

