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Introduction to Industry 4.0

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1.1 Introduction to Industry 4.0

- The manufacturing industry is currently subject to huge change. This change is caused by various ongoing global megatrends such as globalization, urbanization, individualization, and demographic change, which will considerably challenge the entire manufacturing environment in the future.
- The Industry 4.0 is the ongoing automation of traditional manufacturing and industrial practices, using modern smart technology.

1.1.1 Need of Industry 4.0

- Various possibilities for increasing the profit in the industrial manufacturing are almost exhausted and new possibilities have to be found.
- Namely, the production costs were lowered with the introduction of just-in-time production, by adopting the concepts of lean production and especially by outsourcing production to countries with lower work costs.
- When it comes to the decreasing costs of industrial production, Industry 4.0 is a promising solution. According to some sources, Industry 4.0 factory could result in a decrease of:
    - production costs by 10-30%
    - logistic costs by 10-30%
    - quality management costs by 10-20%.
- There are also a number of **other advantages** and reasons for the adoption of this concept including:
    - a shorter time-to-market for the new products,
    - an improved customer responsiveness,
    - enabling a custom mass production without significantly increasing overall production costs,
    - more flexible and friendlier working environment, and
    - more efficient use of natural resources and energy.

1.1.2 Definition of Industry 4.0

- Industry 4.0 is the term assigned to the present technological trends such as automation, exchange of data among the interconnected devices, and interoperability. Industry 4.0 is also referred to as the 4th Industrial Revolution.
- Different researchers have different perceptions on the true meaning of Industry 4.0. Some of the definitions by different authors are given below:
- As per **Klaus Schwab (2016)**,

"Industry 4.0 is differentiated by a few characteristics of new technologies, for example: physical, digital, and biological worlds. The improvement in technologies is bringing significant effects on industries, economies and governments' development plans. Schwab pointed out that Industry 4.0 is one of the most important concept in the development of global industry and the world economy."

- As per **Schumacher, Erol & Sihn (2016),**

"Industry 4.0 is surrounded by a huge network of advanced technologies across the value-chain. Service, Automation, Artificial Intelligence Robotics, Internet of Things and Additive Manufacturing are bringing in a brand new era of manufacturing processes. The boundaries between the real world and virtual reality is getting blurrier and causing a phenomenon known as Cyber-Physical Production Systems (CPPS)."

- As per **Mrugalska & Magdalena (2017),**

"The modern and more sophisticated machines and tools with advanced software and networked sensors can be used to plan, predict, adjust and control the societal outcome and business models to create another phase of value chain organization and it can be managed throughout the whole cycle of a product. Thus, Industry 4.0 is an advantage to stay competitive in any industry. To create a more dynamic flow of production, optimization of value chain has to be autonomously controlled."

1.2 Core Idea of Industry 4.0 (Through The Industrial Revolutions)

The Industrial Revolution has resulted in the all-round development of economic and social structures in different phases. The development is shown in *Fig.1.4*.

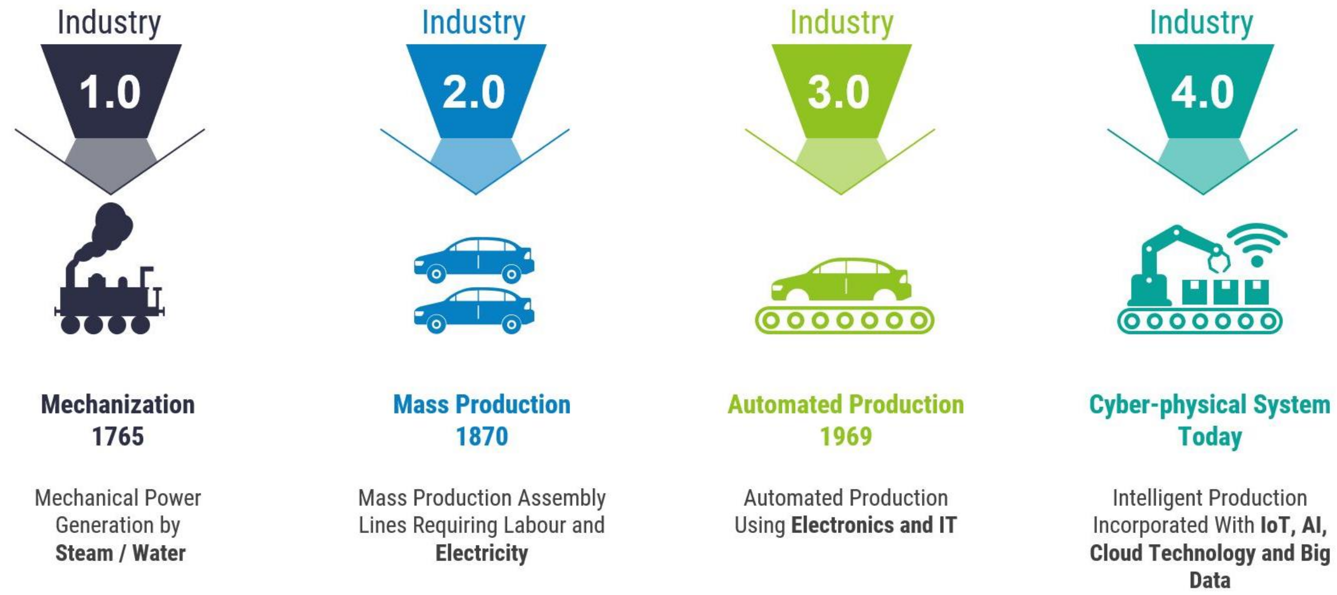

Fig.1.1 – Industrial Revolutions: Phases of Development

- The **first industrial revolution** began with the mechanization and mechanical power generation in the 1800s by the steam or water. It brought the transition from manual work to the first manufacturing processes; mostly in the textile industry Improved quality of life was the main driver of the change.
- The **second industrial revolution** was triggered by electrification that permitted industrialization and mass production but without the possibility of product's customization.
- The **third industrial revolution** is characterized by digitalization with the introduction of microelectronics and automation. In manufacturing, this facilitates flexible production, where a variety of products is manufactured on flexible production lines with programmable

machines. Such production systems however still do not have flexibility concerning production quantity.

- Today we are in the **fourth industrial revolution** that was triggered by the development of Information and Communications Technologies (ICT). Its technological basis is smart automation of cyber-physical systems with decentralized control and advanced connectivity (IoT functionalities). The consequence of this new technology for industrial production systems is the reorganization of classical hierarchical automation systems to a self-organizing cyber-physical production system that allows flexible mass custom production and flexibility in production quantity.

1.3 Origin of Industry 4.0 Concept

- The Germany has one of the most competitive manufacturing industries in the world and is even a global leader in the sector of manufacturing equipment. The Industry 4.0 concept first comes from Germany.
- Industry 4.0 is a strategic initiative of the German government that supports the development of the industrial sector. It is also an action towards sustaining Germany's position as one of the most influential countries in machinery and automotive manufacturing.
- The basic concept was first presented at the Hannover fair in the year 2011. The main idea is to exploit the potentials of new technologies and concepts such as:
    - availability and use of the internet and IoT
    - integration of technical processes and business processes in the companies
    - digital mapping and virtualization of the real world
    - Smart Factory (including smart means of industrial production and smart products).

1.4 Industry 4.0 Production System (A Smart Factory)

- *Fig.1.4* represents the Industry 4.0 smart factory. The core process is digital to physical conversion in a reconfigurable manufacturing system. Reconfigurable manufacturing systems are the latest advance in the development of a manufacturing system.

Manufacturing Systems:

- The first step was **fixed production lines** with the machines dedicated to the performance of specific tasks so only one product could be produced.
- Next step was **flexible production systems** with programmable machines that allowed the production of a variety of different products but offered no flexibility in the production capacity.
- As the results of the latest development are **reconfigurable manufacturing systems** able to adapt their hardware and software components to follow ever-changing market requirements of type and quantity of the products.
- Between Industry 4.0 manufacturing technologies, additive manufacturing, such as 3D printing, is often mentioned as one of the key technologies. In combination with rapid

prototyping methods including 3D modeling, a direct digital thread can be established from design to production, facilitating a shorter time from the idea to the product.

- Until now, however, additive manufacturing processes cannot always reach the same quality as a conventional industrial process and some new materials still need to be developed.

Machines:

- Machines in Industry 4.0 factory are Cyber-Physical Systems, physical systems integrated with ICT components. They are autonomous systems that can make their own decisions based on machine learning algorithms and real-time data capture, analytics results, and recorded successful past behaviors.
- Typically, programmable machines {CNC and NC) are used, with a large share of mobile agents and robots able of self-organization and self-optimization.

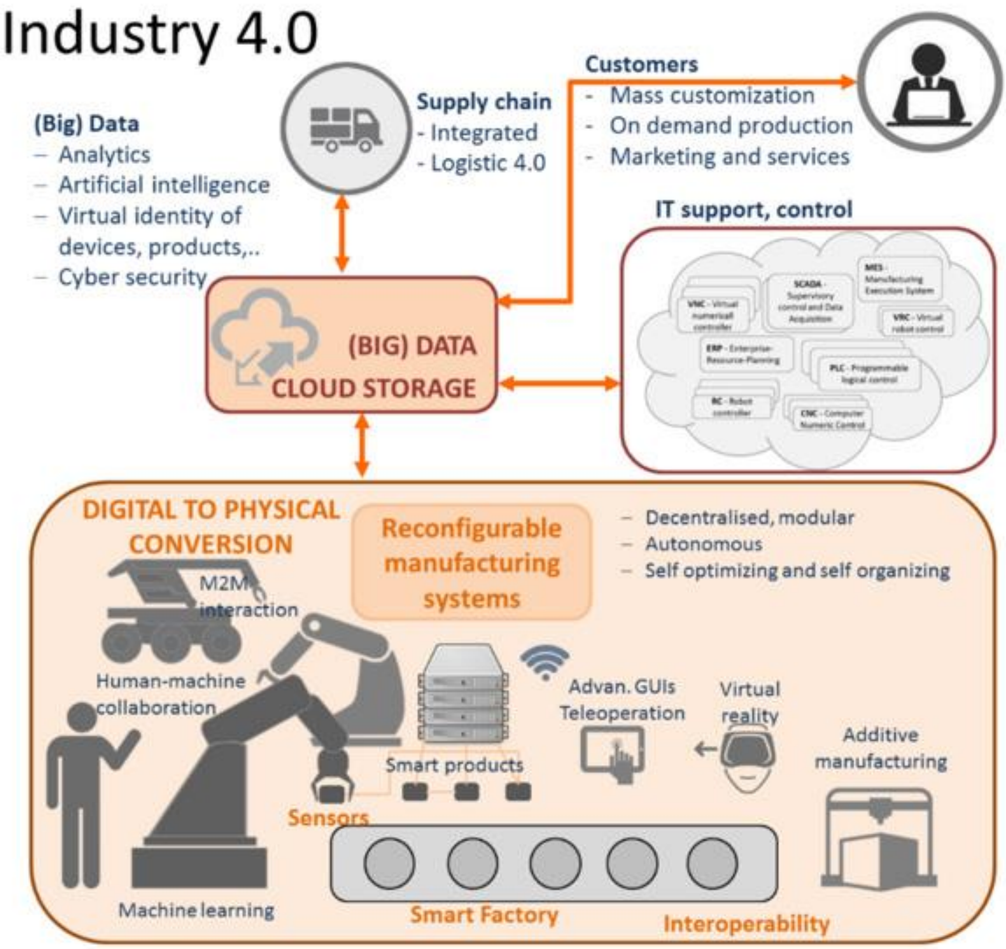

Fig.1.2 – Industry 4.0 Smart Factory

Products:

- Products in such factory are also 'smart', with embedded sensors that is used via a wireless network for real-time data collection for localization, for measuring product state and environment conditions. Smart products also have control and processing capabilities.
- Thus they can control their logistical path through the production and even control/optimize the production workflow that concerns them. Furthermore, smart products are capable of

monitoring their own state during the whole life cycle, including during their lifetime/application.

- This enables proactive, condition-based maintenance that is especially valuable for products embedded in larger systems (like for example power converters in electric grids)

Data:

- In Industry 4.0, the production elements have virtual identity alongwith their physical representation. A data object is stored in the data cloud. Such virtual identity can include a variety of data and information about the product, from documents to 3- D models, individual identifiers, current status data, history information and measurement/test data.

Interoperability and Connectivity:

- Important elements of the Industry 4.0 concept are also interoperability and connectivity. A continuous flow of information between the devices and components, Machine-To-Machine interaction (M2M), manufacturing systems and actors should be established.
- Hereby the machines, products and factories can connect and communicate via the Industrial IoT (mostly based on the wireless network). Another important topic is Human-To-Machine (H2M) collaboration that is necessary as some production tasks are too unstructured to be fully automated.
- A lot of research effort is currently also invested in so-called **collaborative robotics**. Here human workers and especially designed compliant robots work together in the execution of complex and unstructured work tasks at the manufacturing production line.
- Such tasks were done completely manually before. Advanced user interfaces are developed for new forms of M2H communication. They often include teleoperation and are based on augmented reality environments.

IT Support:

- Software tools are crucial for operating of the Industry 4.0 smart factory. *Fig.1.4* shows the well known pyramid structure of support software of modern production systems.
- On the **business level**, the **Enterprise Resource Planning (ERP)** tool is implemented. ERP is a business management software used for business planning, order processing, supply chain management, sales and distribution, accounting, HR management, etc.
- Usually, commercially available solutions are implemented. For Example: SAP, MS, Oracle, etc.

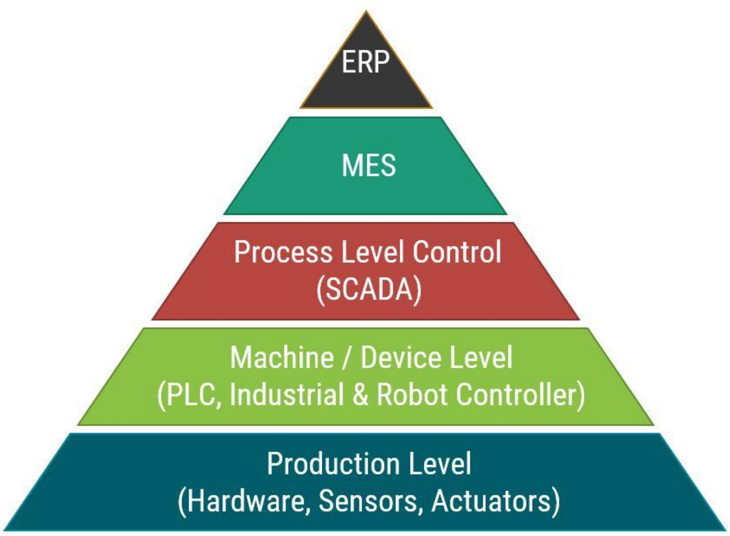

Fig.1.3 – Automation Pyramid in Modern Production System

- The **second level** in the traditional automation pyramid is **Manufacturing Execution System (MES)**. It supports production reporting, scheduling, dispatching, product tracking, maintenance operations, performance analysis, workforce tracking, resource allocation and similar. It covers aspects such as management of the shop floor and communication with the enterprise (business) systems.

- Most of the software solutions available on the market are centralized and not distributed to the shop floor elements. This is a major limiting factor when flexibility is needed due to the dynamics of customers' order flow and/or changing production environment, including shop floor configuration.
- The next operative level is **process level control** based on **Supervisory Control and Data Acquisition (SCADA)** control system. SCADA is a computer system collecting & analyzing real-time data and it monitor, control & optimize industrial plants.
- Next, the **machine/device level** has a naturally distributed control level. **Programmable Logic Controller (PLC)** is used for controlling or regulating a machine or system.
- At the **field/production level**, the **field devices** receive and output signals, communicating with the machine controls. It includes hardware, sensors and actuators.
- ERP and MES tools represent basic software in the company and are used since the nineties. Both systems have typically a modular structure but are centralized in their operation and thus have limited capability for dynamic adaptation of the production plan.
- Nevertheless, already implemented conventional ERP and MES systems should not be seen as main obstacles to the introduction of the Industry 4.0 concept but more as a step towards it. Namely, already the introduction of a common MES tool requires advanced IT infrastructure on the shop floor level and this is also a precondition for further development towards a smart factory.
- The next important issue is information integration among ERP, MES and other software tools used in the company. Problems such as database integration and communication protocols need to be resolved.
- It can be concluded that for the Industry 4.0 the classical automation structure does not present the best solution as it is not flexible enough for adapting to the dynamic changes in the order flow and at the shop floor.
- Distributed MES solution, where most of the functions are decentralized, is expected to be more suitable for the reconfigurable production systems, For full support of reconfigurable systems, a continuous flow of information (vertical and horizontal integration) between all elements (shown in *Fig.1.4*) should be realized.

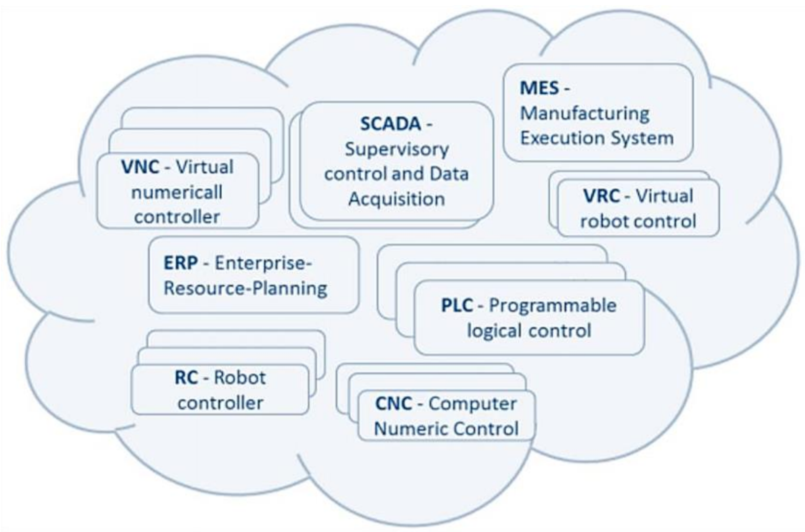

Fig.1.4 – Industry 4.0 IT Support and Control Elements

1.5 Current State of Industry 4.0

- Before implementing new concepts, the following preconditions should be fulfilled:
    - Stability of the production has to be guaranteed during the transition phase.
    - Stepwise investment should be possible as most of the industrial processes cannot bear big one-time investments.
    - A good know-how protection is necessary. Closely connected is the cybersecurity issue.
- Furthermore, the industry concept is not just limited to the production system but it includes the complete value chain (from suppliers to the customers) and all enterprise's functions and services. It is clear that it is not easy to fulfill these criteria, therefore only some 'islands' of the Industry 4.0 concept currently exist.

1.5.1 Readiness for Industry 4.0

- To evaluate the current state the German organization 'Verband Deutscher Maschinen- und Anlagenbau' (VDMA) has conducted a study on the readiness of Germany companies for Industry 4.0 based on following six dimensions:
    1) Strategy and organization (investments, innovations management)
    2) Smart factory (equipment and IT systems, data capturing and usage, digital modelling)
    3) Smart operation (integration of value chain, cloud storage)
    4) Smart products (physical components, virtual identity)
    5) Data-driven services (ICT functionalities, prediction and optimization of business outcomes,..)
    6) Human resources (employees skills, continuous education)
- A survey was conducted of **268 companies** from Germany with more than 20 employees. The results showed that,
    - **56.5%** of all participating companies are not fulfilling any requirements concerning Industry 4.0 readiness.
    - **20.1%** of the companies are assessed to be on Level 1 (beginner), which means that the company is involved in Industry 4.0 through pilot initiatives in various departments and investments.
    - Only **0.3%** of companies (8 companies from 268 that were participating) are ranked on Level 5 (top performer). This means that they have already implemented the Industry 4.0 strategy and have sufficiently addressed all six evaluated dimensions.

1.5.2 Real-world Smart Factories

<u>SEW Eurodrive</u>

- It is a German company. The basis of their approach is manufacturing logistic based on so-called 'mobile assistants'. The mobile assistants are autonomous mobile platforms that move through the shop-floor carrying material, half-products and tools.

- In the attached Radio-Frequency Identification (RDIF) chips mobile assistants also carry all information concerning the required manufacturing processes. When a new customer order arrives the mobile assistant collects the necessary material and autonomously brings it from workstation to workstation, according to the order of necessary manufacturing processes.
- At the workstations that are cyber-physical systems, the mobile assistant connects to the machine and provides the necessary information. At the workstations based on manual human work, the communication with the worker is established via user interface running on a tablet.
- As a result, the productivity of the SEW company has been increased and the workers were relieved from most of the heavy manual labor connected with transporting and displacing of material and half-products.
- The only limitation towards complete automation in this company is a human factor. For example, when constituting working teams for a specific product it needs to be considered who can most efficiently work together. Such decisions can of course not be automated.

GE's Brilliant Factory

- General Electric's "Brilliant Factory" already uses IIoT technology in some of its manufacturing plants and aims to introduce smart technology ultimately within the company's 400 manufacturing and service plants.
- GE aims to transform their traditional manufacturing plants by digitally connecting teams designing products to the factory floor, other supply chain partners and, finally, to service operations.
- Subsequently, the company aims to build a continuous loop of real-time data sharing, enabling faster, more accurate decision-making, which results in an increase in productivity. This digital thread that they want to create will allow GE to design, manufacture and service their products better. Indeed GE is targeting KPI (key performance indicators) of 20% increase in uptime and 10% rise in throughout.
- As an example, GE recently developed an app for use in the company's turbo-machinery businesses. The mobile app connects the factory floor with engineering, allowing the engineers to verify that the factory can feasibly manufacture the virtual products, which are still in the design phase. How this works is that when a designer creates virtual construction of a part, for instance a CAD drawing, the app will provide real-time feedback, such as whether the thing can be made and, if not, which features should be adjusted. When a pilot is successful, GE will roll out the smart system across factories with similar requirements.

Airbus: Smart Tools and Smart Apps

- Another example of a real-world smart factory is the aircraft manufacturer Airbus's plant. Airbus is working in with National Instruments to create what they describe as the factory of the future.
- The first phase of the smart system targets the reduction of mistakes and wasted time and materials, a lean manufacturing concept. Savings are achieved by giving workers real-time "toolbox talk" information on the job they are tasked to complete. This toolbox information is fed online on demand to the worker's mobile device. This ensures that the workers know

exactly what is required and that they are using the correct tools, at the right setting and they know exactly what steps they should be taking at any given time.

- This use of educational technology has many use-cases within industrial maintenance and reduces the costs of having highly skilled, experienced maintenance engineers onsite.
- Instead, online augmented reality tutorials in collaboration with sensors on smart tools will transmit information via Wi-Fi to workers who are for example, routing a cable loom in an aircraft, letting them know when they are within a few millimeters of a device to be connected and of the precise connections and wires to attach.
- In another scenario, which is common in manufacturing, and something that robots are not very good at either, smart tools detect the amount of torque used, say, to tighten bolts. Over-tightening or under-tightening bolts and screws is a common cause of material failure, but with smart tools this should allow workers to apply the correct amount of torque while at the same time allowing engineers to analyze the data, detect whether the task was done correctly and, if necessary, take action.

1.6 How is India Preparing for Industry 4.0

- India is steadily increasing its share of Global Manufacturing GDP. All leading countries are embarking on major initiatives to promote manufacturing by adopting the advancements in Internet and Information Technology.
- German government announced “Industry 4.0” while governments in China and India have their own focused programs, “Made in China 2025” and “Make in India” respectively. Idea is to encourage multi-national, as well as national companies to manufacture their products in India. The Government is focusing more on enabling policies and improving infrastructure for certain key sectors.
- ***According to IBEF, the Government of India has set an ambitious target of increasing the contribution of manufacturing output to 25 per cent of Gross Domestic Product (GDP) by 2025, from 16 per cent currently.***
- Industry 4.0 is expected to transform manufacturing in India by bringing operational efficiencies to manufacturing industries like automotive, electrical and electronics.
- Several **initiatives** has been taken in India as follows:
  - Major Indian states are taking initiatives to adapt to Industry 4.0. Andhra Pradesh has taken an initiative to capitalise on the IoT potential in the country. The state government has approved the first-of-its-kind IoT policy with an aim to turn the state into an IoT hub by 2020 and tap close to 10% market share in the country.
  - India’s first smart factory, moving from automation to autonomy, where machines speak with each other, is being set up in Bengaluru. It is making progress at the Indian Institute of Science’s (IISc) Centre for Product Design and Manufacturing (CPDM) with an investment from the Boeing Company.
  - Various Indian companies are increasing their focus and partnering with other companies for developing new IoT and M2M solutions, the Digital India initiative from

the Government of India is expected to enhance the focus on IoT in tackling the domestic challenges.

- Bajaj Auto was one of the first automotive enterprises to initiate automation in the industry. It commenced the process of automation in 2010, today it uses 100-120 "Cobots" (Collaborative Robots) in its production facilities. Maruti Suzuki manages 7 process shops and 5 assembly lines by around 1,700 robots. Ford has managed to operate the assembly lines and body shop of its Sanand Plant by 437 robots.
- Smart Advanced Manufacturing and Rapid Transformation Hub (SAMARTH) - Udyog Bharat 4.0 is an Industry 4.0 initiative of Department of Heavy Industry, Government of India. The initiative aims to raise awareness about Industry 4.0 among the Indian manufacturing industry through demonstration centres. Currently there are four centres:
    1) Center for Industry 4.0 (C4i4) Lab Pune;
    2) IITD-AIA Foundation for Smart Manufacturing;
    3) I4.0 India at IISc Factory R & D Platform;
    4) Smart Manufacturing Demo & Development Cell at CMTI.
- In India, Flipkart is looking at robotics to improve efficiency in its 13 warehouses in India. The brain behind this is Gurgaon based startup Grey Orange Robotics.

1.7 References

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