Internet of Things and the Future of Manufacturing Industry

** R. Jayaraman*
*** Avisek Basu*
**** Suryadipta Chakraborty*

Abstract

Manufacturing companies are evolving into highly interconnected, multimodal, aggregated, agile networked entities knitted together by IT systems. The latest development in IT, the Internet of Things or IoT, is slowly beginning to change the traditional methods of manufacturing. Next on the horizon is the Industry 4.0 (I - 4.0) model, which will be created by using a mix of cloud computing, wireless connectivity, AI, and computer integrated manufacturing. The underlying automation is provided by the IoT, using sensors, which collect data, and feed into an interconnected grid of multiple action nodes which will drive production, productivity, and efficiency. In this paper we address the issues that will govern the adoption of IoT in manufacturing. We show that the I - 4.0 will be highly dependent on IoT, will use data analytics using big data and AI to process large volumes of data to provide agile output. The cost considerations which will form a key part of the transition to the I - 4.0 era are also discussed using a model.

Keywords: Artificial Intelligence, IoT, Manufacturing

Acronyms used in this paper

AI - Artificial Intelligence	MRP - Materials Requirement Planning
AWS - Amazon Web Server	O/B - Outbound
CBA - Cost Benefit Analysis	OM - Operations Management
CRM - Customer Relationship Management	OVC - Operations Value Chain
DC - Distribution Centre	PoS - Point of sale ETA - Estimated Time of Arrival
ETA - Estimated Time of Arrival	PPC - Production Planning and Control Unit
FG - Finished Goods	RDC - Regional Distribution Center
GPS - Gloabl Positioning System	RFID - Radio Frequency Identification
I - 4.0: Industry 4.0	SCM - Supply Chain Management
I/B - Inbound	SIM - Simple Integrated Messaging
IoT - Internet of Things	SKU - Stock Keeping
IT - Information Technology	S&OP - Sales and Operation Planning
MHR - Machine Hour Rate	WH - Warehouse
	WMS - Warehouse Management System

I. INTRODUCTION

I – 4.0 is on the way. Adopting I – 4.0, manufacturing plans to take advantage of the developments in the fields of AI, big data, cloud computing and storage, IoT,internet-basedconnectivity and super speed

Manuscript received March 15, 2018; revised April 10, 2018; accepted April 15, 2018. Date of publication May 6, 2018.
* R. Jayaraman is with S. P. Jain Institute of Management and Research, Mumbai, Maharashtra, India- 400 058. (email: jayaraman@spjimr.org)
** A. Basu, Analytics Advisory Associate Manager, Accenture Solutions Private Limited, Bengaluru, Karnataka, India- 560 076. (email: pgpm2017.avisek@spjimr.org)
*** S. Chakraborty, Analytics Specialist, Accenture Solutions India Private Limited, Bengaluru, Karnataka, India- 560 076. . (email:pgpm2017.suryadipta@spjimr.org)
DOI: 10.17010/ijcs/2018/v3/i3/129621

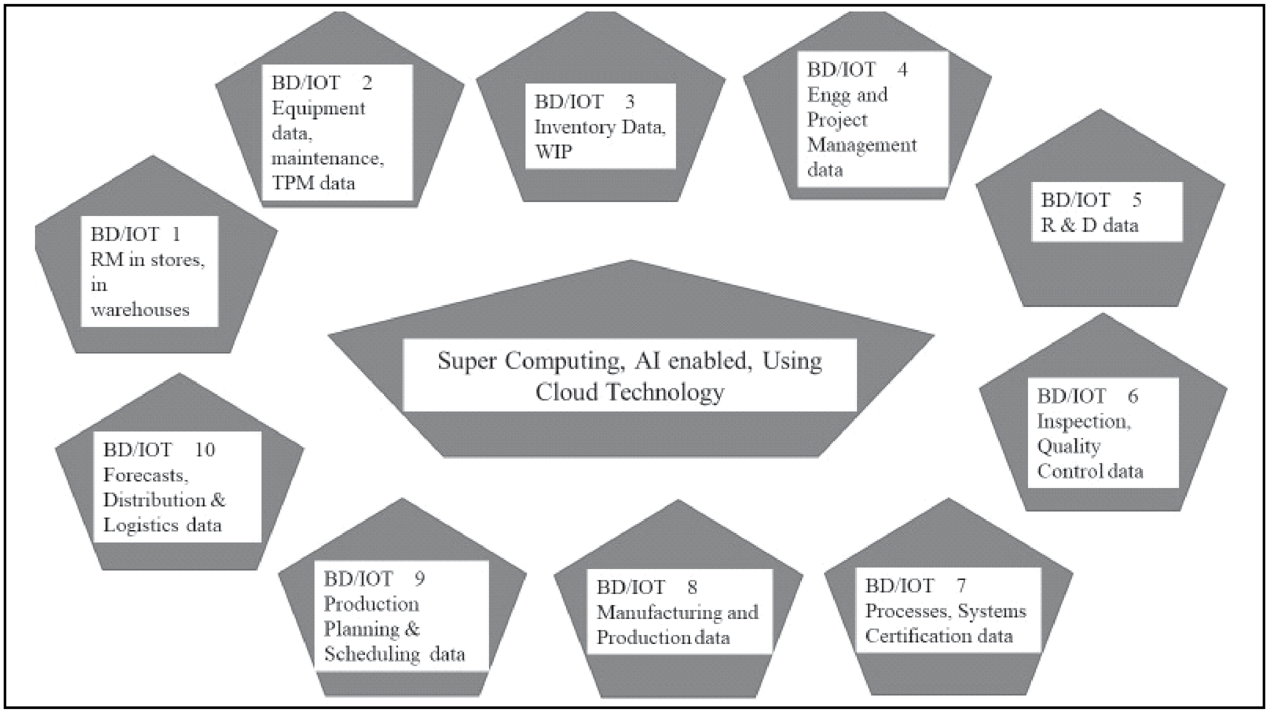

Fig. 1. Showing the Big Data Blocks (BD/IOT) Connected by IOT in the Operations Value Chain diagram I – 4.0 OVC

computing to create agile organizations which can address market needs pro-actively and reactively. To get a clear picture of what each of these I – 4.0 building blocks will do, refer to fig. 1.

Fig. 1 shows the construct of the future I – 4.0 operations value chain (OVC), an integrated whole, which works as a single unit. Big data is collected in various value adding blocks of the OVC using IoT sensors, the data is then stored in cloud storage devices. Using the stored and flowing data using AI based neural software, super speed calculations are done to identify production parameters at various production centers based on which the quality and quantity of the output are controlled. The ten value adding centers shown in fig. 1 are only representative. There could be other, like, vendors links, other departments like sales and marketing etc. AI contains the algorithms developed for the specific OVC, and can be dynamically recalibrated, to represent periodic changes in priorities and decision rules. Optimization bases could also be changed using AI programs. Cloud storages are needed to house the mega volumes of data captured by several IoT devices and manipulated by the AI devices to run the OVC. The voluminous data and its processing can be done only at super speeds if the outputs from the processing are to be fed to the IoTs embedded in the OVC to be responsive in micro to nano seconds (for example, for current speeds of supercomputing) [34]. The IoT devices provide two functionalities – sensors collect data and the same is transmitted using the wireless connectivity provided by these devices. The internet overlay, apart from connectivity, can also be tapped as a source of information and data, a feature which can be suitably be deployed to improve output parameters as needed. In sum, the future I – 4.0 OVC will be data rich, consist of a networked architecture which enables instantaneous and continuous interconnection between the various OVC centers, which is equivalent to a manually run OVC, where many individuals perform these functionalities. The difference is in the scale of data, handling of massive amounts of data, manipulation at speeds of light, and running a responsive and agile OVC. This is a big difference in terms of time, variety, market pulled production, single piece flow production, and agility.

II. PURPOSE OF THIS RESEARCH

The purpose of this research is to understand the dimensions of I – 4.0 in terms of how IoT can be used to promote seamless manufacture, running fully integrated operations using data analytics and AI. The possible use of IoT in discrete manufacturing can be studied by proposing a system architecture for deployment. It is proposed to understand the architectural features at three levels of IoT use in a manufacturing environment. We then use two *use cases* to illustrate the applications of IoT in industry. These *use cases* have been carefully chosen to provide a holistic view of how the architecture can be deployed in practice. Finally, it is proposed to analyze and distil insights for deployment of I – 4.0 in the different value adding centers of an OVC, as also to develop a cost-benefit model for selection of IoT devices to be deployed.

III. METHODOLOGY

We have used the *qualitative research methodology* to achieve our purpose. Using literature available in websites, website search, analyzing use cases culled from websites and other data we have developed our insights and architectural designs for the deployment of IoT, for understanding how IoT can work in certain environments and its general deployability in I – 4.0 type of situations. We sifted current data from many websites to know about the costs and benefits of systems that use IOT, based on which we have developed a CBA model for a cost – benefit analysis.

IV. STRUCTURE OF THE PAPER

The paper is structured as follows: after an introduction, followed by the *purpose of this research* and the *methodology used* sections, we examine the structure of the IoT architecture, followed by a description of two use cases. Based on the ideas developed in the use cases, we describe the deployment of IoT in an OVC. This is followed by the development of a cost-benefit model for IoT. The paper ends with some of our thoughts and predictions as to how IoT will evolve in the future.

V. OPERATIONS AND SUPPLY CHAIN MANAGEMENT

For the sake of convenience, we can look at a manufacturing company as a group of three chains of activities in fig. 2:

Fig. 2. Three Chains of Activities

The manufacturing and related activities of a company can be understood as in-company operations. Inbound operations and outbound operations can then be called as the *Supply Chain.* In classical terminology of operations management, inbound operations are the *upstream* and outbound operations, the *downstream* part of a company's total operations value network. The framework of the Operations Value Chain (OVC) is shown in Table I.

The OVC is a simple way of listing all the activities that the company performs as a part of the in-company operations. Obviously, OVCs of two companies can be different. In a non IoT scenario, the activities in each of the value adding blocks in the OVC is planned and

TABLE I.

THE OVC IN A TYPICAL MANUFACTURING COMPANY SHOWING INBOUND, IN-COMPANY, AND OUTBOUND OPERATIONS VALUE CHAINS.

Inbound Operations	In-company Operations			Outbound Operations	
Sourcing and Procurement	**Product and Process design**	**Execution**	**Checks & Control**	**FG Inventory**	**Post Processing**
Inward material receipt and storage, inspection, returns of non-acceptable quality	Technology scanning and planning, engineering, design and project management	PPC, scheduling, monitoring, and follow-up	WIP	Finished goods storage and inspection	Transport outbound, distributors. wholesalers, retailers
In-plant inventory	Processes and services delivery design and documentation	Manufacturing and service delivery	In-line inspection		After sales services
Issue of materials	Systems, standards, and specifications	Control quality, costs, continuous improvement, performance measurement, performance analysis	Defectives management		Customer feedback, complaints, management of complaints, customer returns

Source:R. Jayaraman

controlled by the supervisors in each ofthese blocks, integrated into a working whole usually by the Production Planning and Control (PPC) department. The PPC forms the bridge between the sales/marketing functions and the in-company operations functions to ensure that market demands are met in all respects by the OVC. In an IoT scenario, many of the manual functions are done by IoT devices. The value adding centers in inbound operations can be:

Order placement/procurement on/from strategic suppliers' vendors
Inbound logistics (including loading, securing, insurance, documentation)
In transit storages (warehousing)
Arrival at the premises of the buyer
Vendor performance monitoring and feedback, continuous improvement
Identification of strategic sources of supply, appointment of strategic suppliers
Performance monitoring of strategic sources, sensei

Similarly, the value adding centers in outbound operations can be characterized as follows:

Loading of finished goods in outbound vehicles, securing, insurance, documentation
Storage in warehouses, distributors, wholesalers, retailers
Information management

To develop an IoT system architecture, we need to examine the various elements that form the OVC. For example,

❖ Smart in-plant RM inventory management
❖ Production planning and scheduling
❖ Performance measurement and smart quality inspection
❖ Smart inventory management of FG

Customer feedback data collection and action management are some of the application areas. Similarly, the following can be considered for detailed examination in the supply chain:

❖ Smart procurement
❖ Automated warehouse management
❖ Retail inventory management
❖ Smart after-sales service
❖ Out-bound logistics planning
❖ Empanelment of strategic suppliers and vendors
❖ Performance monitoring of suppliers / vendors
❖ Cost control

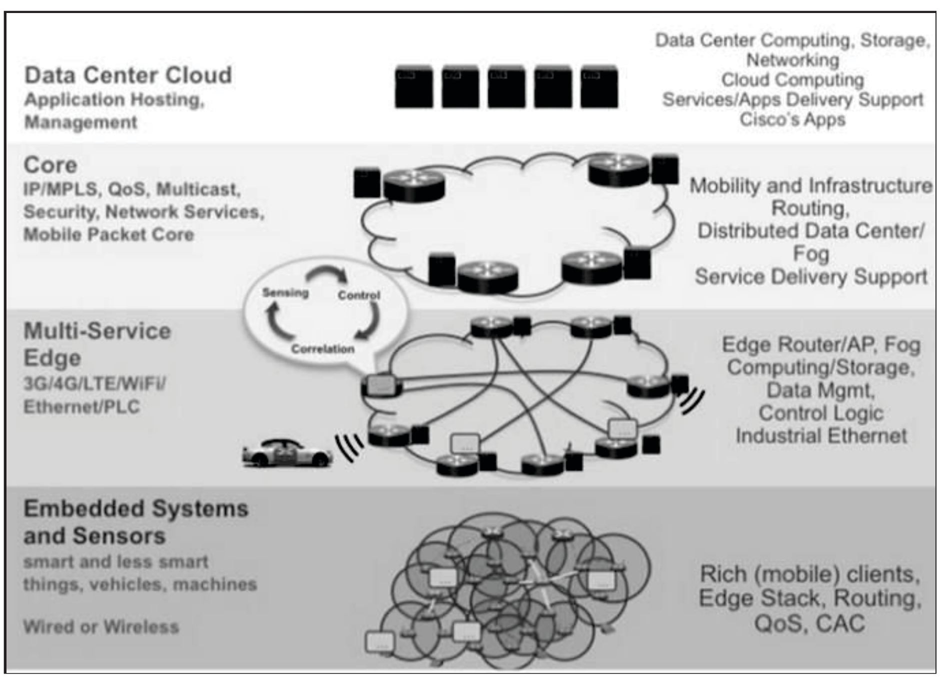

Fig. 3. IoT solution framework

Source: https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html

VI. AN IoT ARCHITECTURE FOR AUTOMATION AND OPERATIONAL EFFICIENCY – SMART INVENTORY

A typical IoT solution architecture is shown in fig. 3.

❖ Sensors collect different kinds of data from various sources where embedded systems are physically located.

❖ The data collected by the sensors go to the router which is connected to another router which connects to the internet.

❖ There is a cloud server which manages the database and applications which users access through internet via a variety of devices.

❖ The analytics tools used in the whole IoT ecosystem are hosted in either cloud or a local network which fetches data stored in the cloud server.

❖ The cloud server (e.g. AWS, MS Azure) used in the IoT ecosystem is generally equipped with storing very large amount of data and hence, IoT solutions generally deal with Big Data.

❖ In view of the complexity and amorphous nature of the data, and the very short time demand for responses between equipment, supercomputing speeds will be needed.

IoT can be used in various operations and supply chain management functions.There can be a host of IoT architectures that can be in use and these can be customized according to usage. We have tried to develop an IoT architecture for smart inventory management in a hypothetical discrete manufacturing company. The proposed solution is built and explained in three levels of detail.

In-company level : This is, for example, one retail store or one DC or one factory of a company that is implementing this architecture.

Supply Chain node level : This is an aggregation of all DCs, retail stores etc. that are operated by one company in the supply chain network.

Aggregate level : This is an aggregation of all companies operating in a supply chain. A combination of the in-company and the supply chain node levels.

The one common factor that links all the three levels is the inventory held in each of these blocks of operations. The overall effect of the IoT enabled architecture to control the company operations is to minimize/optimize inventory levels across the spectrum, to provide the best services to customers. Hence, the name "Smart Inventory".

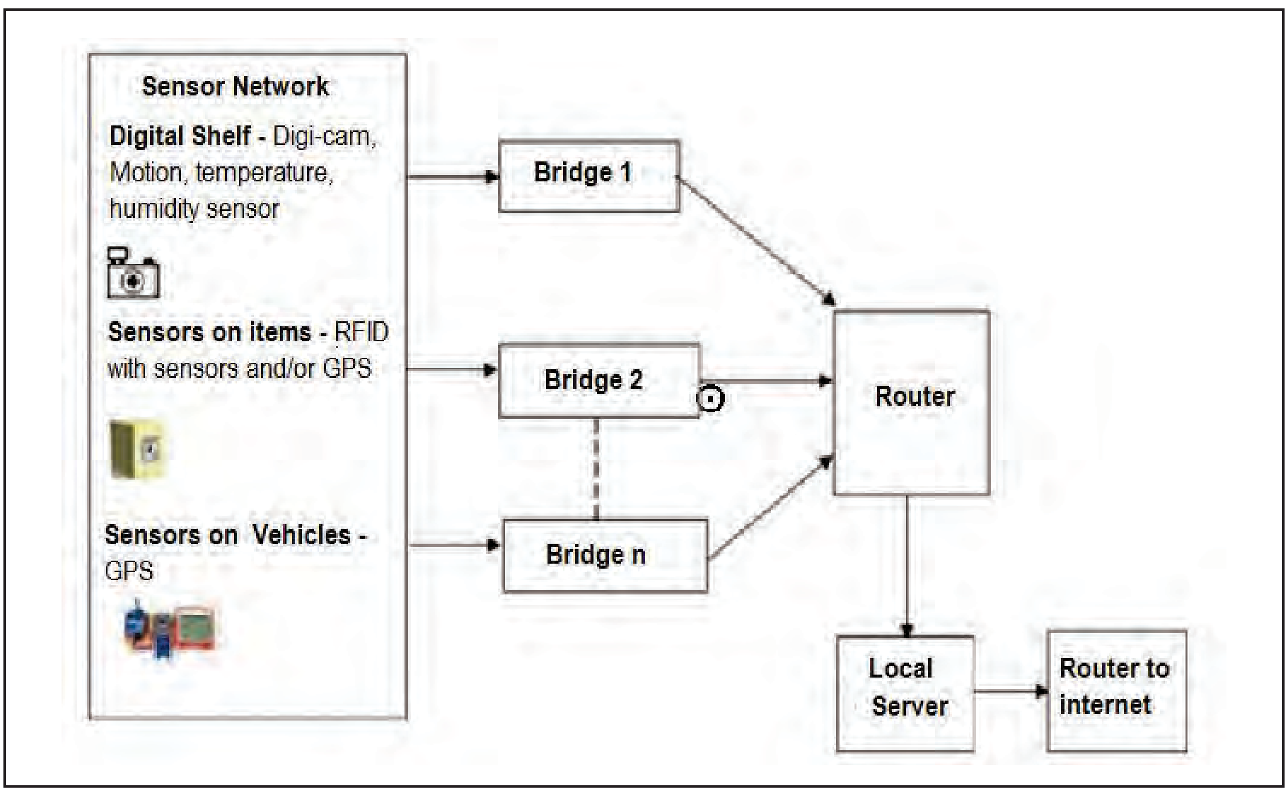

Fig. 4. IoT architecture at company level (e.g. a retail store)

A. In-company Level

At this level it will be a network of sensors, bridges, routers, and local data servers. The pictorial representation will look as shown in fig. 4.The idea here is that the value creating centers are physically close-by, belong to the same owners, are under one corporate umbrella and hence, amenable for close co-ordination, monitoring, controls, and management. In such an environment the design of the IoT architecture is centrally managed, designed, and operated by a central entity within the company, usually the IT department. As many bridges as needed can be installed, and the data from the bridges are to be collected as shown,and processed through the internet. Connection cable distances are not unduly long, can be laid in a short time, and are easy to control, especially for fault detection.

B. Supply Chain Level

At this level it is a network of routers from different points of the company's network of nodes connecting into a cloud (intra company portal), which will also be connected to routers from different geographical locations of vendors, strategic suppliers, external storage locations, like, warehouses as well as the GPS of the on-route transport vehicles. The pictorial representation will look like as shown in fig. 5.

The intra-company level portal is accessed remotely from a central location. Since the vendors and suppliers can be located in different geographies, and there can be a large number of them, the data storage and transmission requirements will need a separate cloud server to receive, manipulate, and transmit data. This part of data activities through IoT can be subject to the usual problems associated with handling data over long distances and nodes over which little control can be exercised by the company. Hence,firewall specifications, procedures for operating IT systems and the IoT architecture have to be designed not only from traffic load concerns, but also to deal with security concerns.

C. Aggregate Level

At this level it will be a network of companies from different points of the supply chain network, from different geographical locations (fig. 6), which will connect to the internet and share a common portal via a VPN that only this network of companies can access. This portal will give real time visibility and also will have

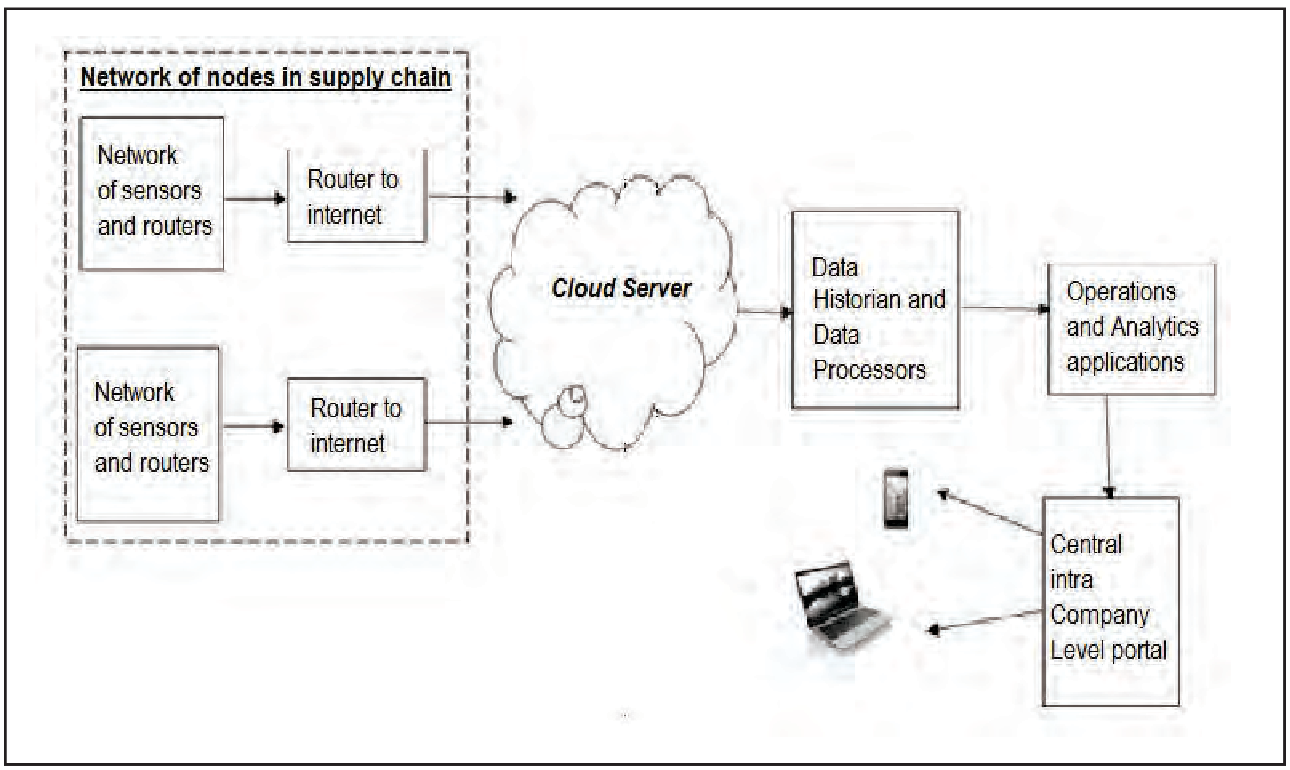

Fig. 5. IoT architecture – supply chain level

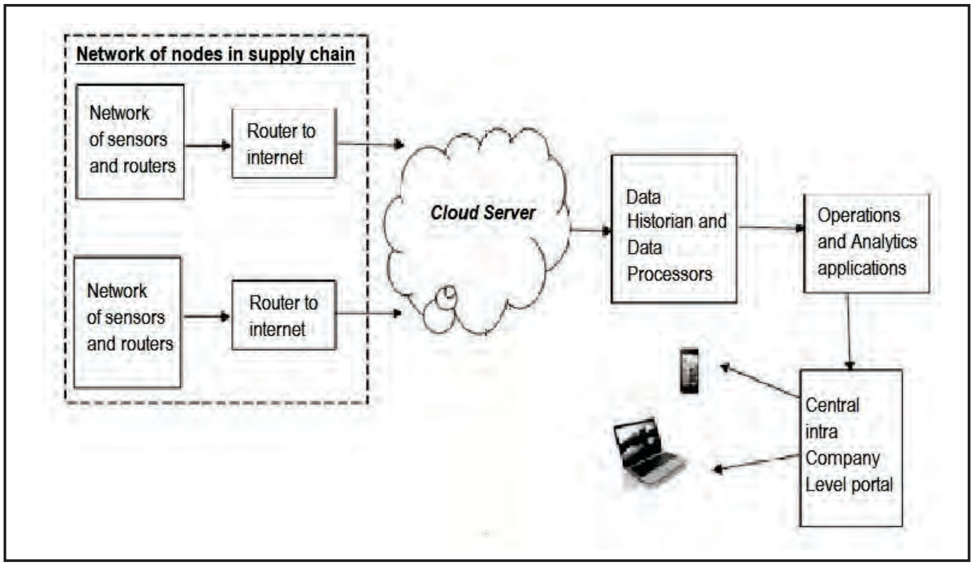

Fig. 6. IoT architecture – Aggregate Level

an application (replenishment ordering application) which will order materials based on certain rules/cognitive intelligence of its own (AI based).

The architecture here is more open, in the sense of covering a wider geography, a larger base of applications, a variety of decision rules, many types of AI applications for making decisions by the computers in the system based on the data that is added from the various cloud servers. The number of cloud servers is entirely a function of the availability of these devices, as, currently, mainly due to cost and security concerns, cloud servers are not many, and their availability is restricted. Hence, establishing connectivity with cloud server locations can be a serious cost consideration.

Using the concepts described above, it is possible to develop a generic approach for the use of IoT in OM and SCM. However, before proceeding to do so, we will describe two "use cases" which illustrate the application of IoT in two world famous companies. Both are manufacturing companies, one a tool manufacturing company, and, the other, INTEL, the world leading computer chip maker.

VII. IMPLEMENTATION STORIES OF IoT IN MANUFACTURING - USE CASE I : SANDVIK COROMANT

Sandvik Coromant is a Swedish company that supplies cutting tools and services tothe metal cutting industry. It is headquartered in Sandviken, Sweden and is represented in more than 130 countries with some 8,000 employees worldwide. It does business with industries such as aerospace, automotive, die and mould, medical, oil and gas, power generation, small part machining, and wind power. With its deep knowledge and experience, it provides meaningful insights and innovative solutions to the problems of its clients. Its toolbox of services is designed to increase efficiency, profitability, sustainability, and knowledge in the field of metal cutting [22].

A. Need of IoT for Sandvik Coromant

Sandvik Coromant have always thought of themselves as much more than just a metal cutting tools supplier. They work closely with manufacturing customers to provide reliable tools and tooling solutions. For providing these services and innovative solutions, they have constantly upgraded their technological capabilities. The company has developed a team of "yellow coats" who are the technical experts who provide training and troubleshooting to customers in more than 150 countries. Team members also conduct on-site visits, where they provide recommendations to improve the customer's manufacturing process.

With the continued growth, a new challenge for Sandvik Coromant was created. There was increasing demand for the "yellow coats" to provide the services and recommendations, but "yellow coats" couldn't be everywhere at once. Now, the question was, how to scale the team's services quickly, without having an impact on quality? IoT provided the answer. Sandvik Coromant has taken this opportunity to create a scalable service model that delivers the same world-class quality of service and technical expertise that its customers are used to, still having "yellow coats" available when needed [23].

B. Implementation Details

Using Azure IoT Suite, Cortana Intelligence, and Dynamics 365, Microsoft helped Sandvik Coromant to develop its service model with a predictive analytics solution that ties all of the elements of the supply chain and fabrication processes together.

The IoT Suite collects, computes, and analyses data from sensors embedded in all of the tools across the shop floor, monitoring every aspect of their performance, as well as detecting the existence of any bottlenecks in the overall supply chain or manufacturing. Then, with Cortana Intelligence, Sandvik Coromant uses that analysis and makes recommendations on how to optimize the manufacturing process and creates a predictive maintenance schedule that is designed to help avoid unscheduled shutdowns. Finally, the solution integrates master data from the CRM system with meta data from the shop floor system and the machining system and makes them available through CRM, which can then provide feedback, and support in predicting when to change or order a tool [23]. Fig. 7 shows the service model for this solution.

VIII. USE CASE II : INTEL USES IoT FOR BUILDING SMART MANUFACTURING SOLUTIONS

Intel is using IoT to tap data from many sources and to analyze it for smarter, faster, and better-informed

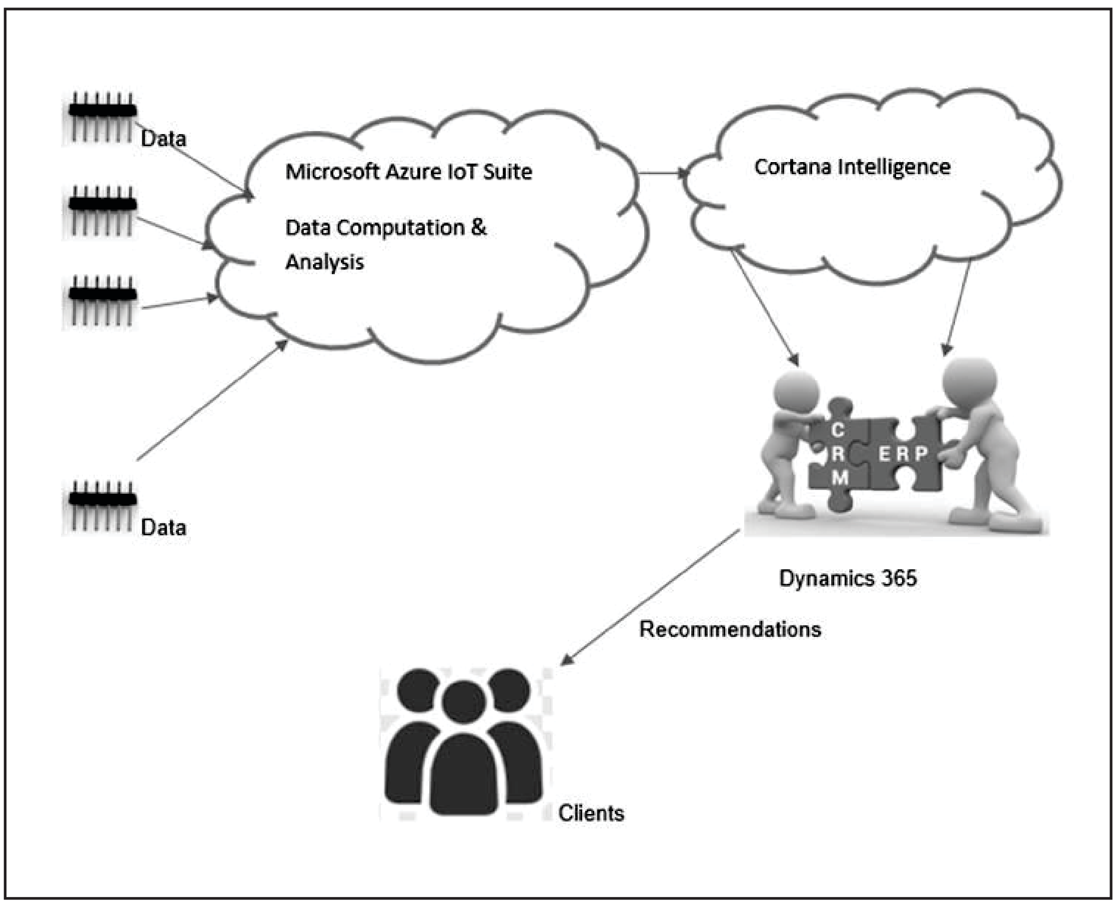

Fig. 7. Sandvik Coromant's Service Model for Predictive Analysis

business decisions. The manufacturing process in Intel has been transformed from the old, traditional way to smart manufacturing, for example, [35] and [36]. In this new way of manufacturing, there is an increase in connectivity, which helps to yield more data and, using analytics, derive actionable intelligence. The Intel IoT Platform offers a defined, repeatable foundation for how IoT devices will connect and deliver trusted data to the cloud. It provides connectivity, manageability, interoperability, security, and analytics capabilities to enable high-performance manufacturing [37].

A. How Intel is Increasing Manufacturing Performance With IoT

The key objectives of Intel are increasing production line performance and improving the bottom line using data that is generated throughout the production cycle to help make decisions, solve business problems, and identify opportunities. Data is generated almost every moment. Ability to store, analyze, and extract useful information using conventional methods from the generated massive data files is a big challenge. Also, getting information into the right hands at the right time is made more difficult by large number of factory automation networks that do not talk to each other.

B. IoT Based Solution Overview

An IoT platform with analytics capabilities has been implemented which provides solution for the above-mentioned challenges. A brief overview of the solution follows:

1) Data Acquisition: Tools and sensor networks send factory data to industrial grade IoT gateways that filter and secure the information before sending to the data store platform.

2) Data Collection and Aggregation: The data store platform, based on the Hadoop core, collects data from throughout the factory, including structured data from existing databases, and unstructured data from tool sensors, log files, and SMS text messages. It then cleans, extracts, transforms, and consolidates the data.

3) Data Analytics: The data is analyzed by analytics software and high-level factory applications running on the data store platform.

4) Data Visualization: The results of the analysis are presented to users via intuitive visualization capabilities in the business intelligence layer of the network.

C. Solution Benefits

Through the use of IoT technologies and big data analytics in its factories, Intel demonstrated benefits in many areas.

1) Increased manufacturing throughput: The production line can run for longer periods of time due to shortened planned maintenance resulting from preventive maintenance measures that reduce the number of routine part replacements.

2) Improved Efficiency: Image analytics are used to identify good units from defective units roughly ten times faster than the manual method.

3) Reduced Downtime: Tool failures are avoided through the use of preventive maintenance to identify worn parts that need to be replaced in advance of planned maintenance[38].

A schematic diagram of the IoT architecture used by INTEL is shown in fig. 8. More details and information about the IoT systems being used by INTEL are available in [24, 25].

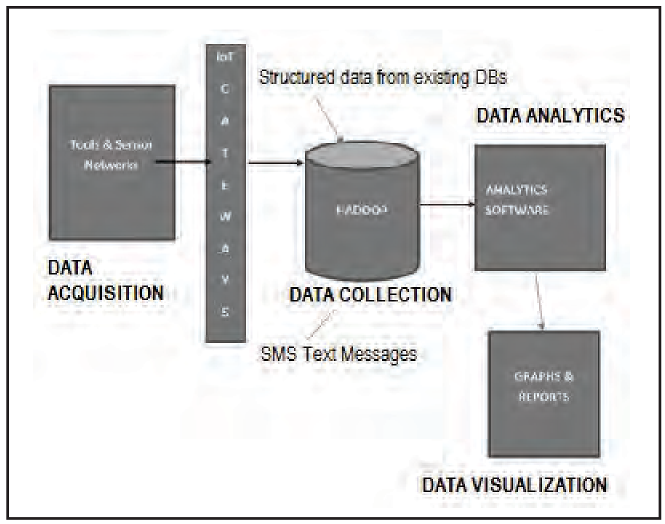

Fig. 8. Solution architecture for smart manufacturing solutions

The two use cases discussed provide an idea of what can be achieved by using IoT as a business development and efficiency improvement tool. No doubt these are just the beginnings but the potential is demonstrated.

IX. OPPORTUNITIES FOR INTERNET OF THINGS IN OM and SCM

As a part of our study to understand the IoT, we examined the contents of many websites to obtain the latest information and data on the developments in the field of Smart Manufacturing. Various terms are used – Industry 4.0, automated manufacturing, integrated manufacturing, and so on. The main ingredients that have led to this evolution are: IoT, big data, data analytics, cloud computing, super speed computing, AI, algorithms, machine learning, internet, universal connectivity, and interoperability between various softwares. As a result of our study we have come up with the compilation in table II, which illustrates theapplications of IoT in the various value adding centers of the OVC.

The compilation, a result of the research done by

TABLE II.
ILLUSTRATING THE APPLICATIONS OF IOT IN VARIOUS VALUE ADDING CENTRES OF THE OVC

IoT Benefits in Manufacturing Operations					
Operations function	**Where**	**What**	**Why**	**How**	**Benefits**
Smart In-plant RM inventory management	In factory / Store area	Intelligent and automated management of inventory to ensure just-in-time supply of parts to decrease inventory carrying costs by 20% - 50%	Inventory carrying cost of parts and components represents a fair proportion of total cost incurred by any manufacturing company. Hence, reducing inventory levels and thus, inventory costs are important to increase operational efficienc.y	Used intelligent camera technology to monitor the fill level of a supply box and wirelessly transmit the data to an inventory management system that automatically reorders supplies.	1. Optimal usage of bins and other WH resources 2. Less space in inventory racks/pallets- release of WH capacity 3. Maximum transparency of bin data - automated replenishment ordering system 4. Continuous stock inspection and counting 5. Real time data collection on usage of inventory. Analytics on collected data can help find improvement opportunities.
Production Planning and Scheduling	In-factory Production Line	Automated production planning with real time collection of machine data from IoT devices	Inefficiencies in production planning increased production cost, decrease fill rate, and service level at various points of supply chain of any manufacturing company. Efficient production planning and execution can help companies reduce costs and increase fill rate and indirectly lead to customer satisfaction.	Real time data collected from production line machines can help in analysing MHR, machine utilization levels and breakdown information etc. to help translate S&OP level plans to shop floor level. Production scheduling can be improved by automated job allocation to work stations and workforce.	1. Improved asset utilization 2. Possible reduction in idle time 3. Possible reduction in flow time and cycle time 4. Improvement in production capacity with the same facility
Performance measurement and smart quality inspection	In-factory production line	IoT sensors collecting data on production performance and quality	Manufacturing companies have to employ separate processes and resources to measure performance of production and inspect quality of production which forms a part of production	IoT devices can collect huge amount of production data to measure performance metrics cycle time, throughput rate, flow time). IoT sensors like intelligent digital camera (for physical	1. Automated QEWS (Quality Early Warning System) analytics can give out machine performance data like temperature, speed, air flow, humidity for

			cost. Also, destructive tests eat up more cost. IoT solutions (like video analytics by Eigen Innovations) can reduce the need for resources and time required for process and quality control which will increase throughput of the production line.	inspection) can be used for basic quality checks. Sensors in machines (e.g. heat sensors) can give out machine performance data that were previously inaccessible, thus making performance measurement automated and easier. Reduction of human intervention and tie required are the reasons for cost reduction in QA and PMS processes.	predictive maintenance, and improve uptime. 2. Automated Quality inspection and testing reduces costs through ML algorithms embedded in IoT solutions to identify sources of poor qualtiy and take proactive actions. 3. Reduction in quality and performance measurement resources and hence, cost.
Smart inventory management of FG	In-factory and warehouse inventory of finished goods	IoT based inventory management systems can track inventory status, manage replenishment orders, and track every unit of inventory for better visibility.	Lack of visibility of inventory decreases service level and increases read time and sometimes, increases operational costs due to inventory obsolescence. Better visibility can address all these issues increasing profitability of operations and customer satisfaction.	1. Increasing data stored in RFID tags and communication real time locational information to centralized inventory management system. 2. Digital shelf collecting data of of inventory levels at retailer end or PoS. 3. Robo carts to manage customer orders at PoS and tracking inventory levels and velocity of movement of different products/SKUs to manage replenishment orders accurately.	1. Lower average inventory levels leading to decrease inventory carrying costs 2. Higher inventory visibility leading to increase in fill rates. 3. Analysis of PoS data can lead to better supply planning
Transport and O/B logistics planning	Planning of outbound logistics post production and storage at factory/ HO	IoT based systems helping in-factory planning for outbound logistics. Helps in capacity planning, utilization sensing, route optimization	Dearth of information about containers makes the job of staffers at WH or factory cumbersome involving errors and to-and-fro reworks (>10 km walk a day/worker). Also, logistics planning can be done better from a central location rather than independently from different locations.	1. Capacity estimation and visibility through connected containers and central systems conveying info to handheld devices with workers. 2. Outbound logistics capacity planning in case of big manufacturing firms in case of sudden or gradual increase in load. 3. Route optimization (with traffic monitoring) from factory to WH or RDC and giving drivers the info for cost reduction per delivery and reduction in time to deliver.	1. Logistics cost reduction 2. Better fill rate due to more accurate logistics capacity planning. 3. Lesser time-to-delivery increases responsiveness.
Smart Procurement	In-factory or central location as per business strategy	Automated planning and greater collaboration in procurement function	Lead time in procurement increases time-to-market. Also, overall profitability takes a hit due to less-than-optimized spend planning.	1. Connected WH or smart manufacturing help generate data regarding spend, and purchased item usage 2. Predictive and prescriptive analysis can give when to plan procurement and where to purchase from depending on past data. 3. Usage data directly conveyed to the suppliers to plan supply of upcoming orders beforehand.	1. Better collaboration with product development team and suppliers 2. Better procurement planning reduces time-to-market 3. Faster procurement cycle and better procurement planning can increase utilization and productivity of factory by reduction of idle time due to

				unavailability of RM	
Automated WH management	Warehouse	Automated and better management of warehouse operations	Optimized WH management can increase replenishment cycle at distributor or retailer end. Increased WH cost hits profitability of company and its supply chain partners.	1. Tracking of I/B and O/B products through sensors and RFIDs for better picking, sorting and allocation planning. 2. IoT based handheld devices to provide information to staffers where to pick from, where to put away or where to load. 3. Connected logistics planning and integration of WMS software with IoT based systems to increase accuracy of WH operations. 4. Product defects to be detected early on and appropriate actions can be taken.	1. Accuracy of container loading at WH to decrease replenishment cycle at distributor / retailer end. 2. Lower cost of operations at WH through proactive actions for defective delivery (I/B) or prevention of defective delivery (O/B). 3. Lower effort of staffers at WH for similar or increased level of performance.
Retail Inventory Management	At retailer location	Automated inventory management through IoT based systems.	Better inventory management can increase fill rate at retailer end reducing potential loss of sales and increasing customer satisfaction.	1. Smart or digital shelf connected with order management applications ordering automatically as required based on availability at shelf and demand sensing application integrated with it. 2. All inventory levels at retailer locations to be visible at company level. 3. Sensor based RFID tags to help in storing regulatory compliance information at item level.	1. Demand forecasting or demand sensing to be more accurate with usage data. 2. Real time tracking of inventory levels and automated replenishment ordering system to increase fill rate and decrease loss of sales at retailer level. 3. Will help indirectly to increase responsiveness of the supply chain and increase customer satisfaction.
Smart after-sales services	At consumer/ customer location	Automated after sales services at customer/product location through IoT based systems generating automated service requests.	After sales service is a major part of customer satisfaction management. Hence, automated after sales can reduce effort at customer end for after sales requests and increase customer satisfaction and loyalty.	1. IoT based asset tracking systems (different systems for different products, example - BMW integrated SIM system) generate usage data and predictive analytics generates probable time for after sales service requirements from past data. 2. It can be an integrated SIM based system/ se nsor-based system. 3. Service centers / showrooms to manage portal for live products and automated service resource planning for better and faster after sales service.	1. Reduced after sales service time requirements- reduced cost of supply chain. 2. Better customer satisfaction - customer loyalty
O/B Logistics Management and Asset tracking	In-transit vehicle and inventory	IoT based in-transit aasset tracking for better visibility	Lack of visibility in O/B logistics assets and in-transit inventory creates a sub-optimal logistics	1. Connected containers to generate data of exact location, ETA, ambience inside on real time basis.	1. Better O/B logistics planning to optimization of vehicles reducing

and logistics planning	planning increasing cost of supply chain. Also takes up time for rework in case of special cases in-transit inventory with ambience requirements.	2. Automated warning system in case of breach in ambience 3. Connected vehicles to increase central visibility through location and route data	cost of transportation 2. Increase quality of delivery through proactive actions taken through automated warning systems 3. Route optimization to reduce logistics cost and time-to-deliver and lower carbon emission.

Source: Authors' study

the authors,in consultation with several references from literature (see table II), is only illustrative, and not exhaustive. However, the many areas that can benefit from IoT, and related application devices, are indicative of the many changes that will be driven by IT in manufacturing. The primary driver will be cost-benefit, whichwe will examine next.

TABLE III.
REFERENCES USED AS A PART OF THE RESEARCH FOR THE COMPILATION OF TABLE II.

Operations function	References
Smart In-plant RM inventory management	[8], [9],[10]
Production Planning and Scheduling	[1], [2], [3], [4]
Performance Measurement and smart quality inspection	[7]
Smart inventory management of FG	[8], [9], [10]
Transport and O/B logistics planning	[11], [12], [13], [14]
Smart Procurement	[15], [16]
Automated WH management	[17], [18], [19]
Retail Inventory Management	[8],[9], [10], [20], [21]
Smart after-sales services	[32], [33]
O/B Logistics Management and Asset tracking	[5], [6]

X. COST BENEFIT ANALYSIS (CBA) OF ADOPTION OF IoT BASED SYSTEM IN MANUFACTURING INDUSTRY

In this part of our study we have tried to develop a framewor, using which we can analyze the business case for adoption of IoT in manufacturing. As per our research, we can say, as on date, there are four industries which have majorly benefitted from adoption of IoT, and these are depicted through the pie-chart shown in fig. 9.

Evidently, manufacturing has benefitted the most so far, and can lead the deployment of I – 4.0 in the near future. I – 4.0 has been used by the German car maker Mercedes Benz in a plant in Germany [39].

In the first part of this framework, we have tried to

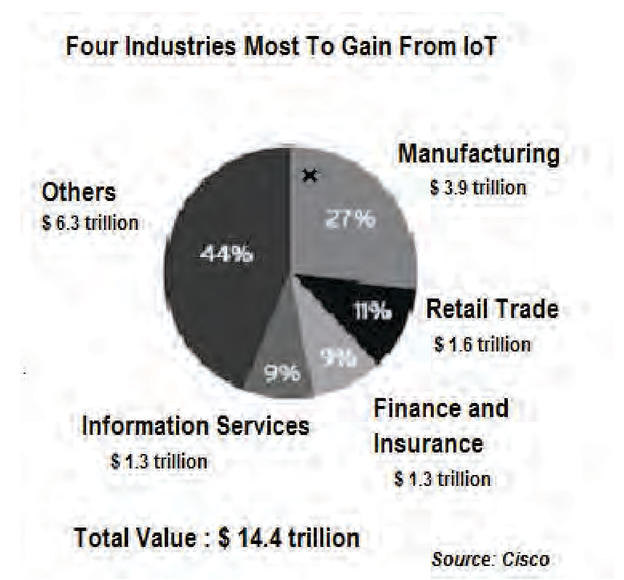

Fig. 9. Major industries that have benefited from IoT

exhaustively as possible to take into account when any company is in the process of evaluating cost-benefit of IoT adoption in their operations. These are covered in equations 1 through 3 for cost, and equations 4 to 6 for benefits. Equation 7 gives the cost – benefit determinant.

There are many operations and supply chain functions where IoT can make a huge impact as is shown in the tables I, II and III. Hence, it is not possible to make a one-jacket-fits-all framework for this purpose and for this reason, in the second part of this framework, we have taken a hypothetical case of IoT adoption for increasing efficiency of operations through predictive maintenance in a manufacturing company and have come up with a CBA framework. The objective is that this framework and the its construction can help to develop similar frameworks where IoT is being adopted for different reasons.

As mentioned earlier, in the first part of the study, we have come up with a list of cost objects and benefit objects for all possible uses of IoT known at this point. The list is as follows:

A. Cost of IoT Adoption

❖ Cost of sensors
❖ Cost of RFIDs
❖ Cost of infrastructure and peripheral devices
❖ Cost of software development
❖ Cost of data storage capacity development
❖ Cost of integration with analytics applications
❖ Cost of software installation and implementation
❖ Opportunity cost of integration with legacy systems
- *Loss of working hours during migration*
- *Loss of sales during migration*
- *Loss of quality/performance drop during migration*

❖ Cost of training personnel
❖ Cost of low productivity in operationalization period

B. Benefits of IoT

❖ Increase in sales due to increase in fill rate, customer satisfaction, service level
❖ Cost savings due to reduced miles in logistics
❖ Cost savings due to predictive maintenance, increased utilization of machines, andgreater productivity.
❖ Cost savings from increased process efficiencies, reduced operating cost
❖ Cost savings due to reduced understocking of RM, smart procurement

C. Framework for Cost-Benefit Analysis for IoT Adoption in Predictive Maintenance

1) Cost Breakdown

Cost of IoT Architecture

a) Hardware:

IoT Sensors :₹ 32.50 per sensor with N number of sensors (or ₹ 2,113) (Note: the prices of sensors are falling continuously, and this trend is likely to continue [26].
Standard devices - assumed as already present in the architecture [26].

b) Software

IoT Cloud Solutions: ₹ 33,048.00 per month for P number of months
Enterprise Solutions / Applications – assumed as already present in the architecture [27].

c) Network

Wireless Routers: ₹ 1,600.00 per router, M number of routers
Cost of IoT Architecture = 33*N + 33000*P + 1600*M **(1)**

d) Cost of Development & Integration

Cost of software development: ₹ A hour cost to be born for X number of development hours

Cost of integration with existing applications: ₹ A per hour cost to be born for Y number of integration hours

e) IoT deployment

Cost of deployment = ₹ C (fixed cost)
Cost of loss of production/service delivery = ₹ D per hour to be borne for T number of deployment hours **(2)**

f) Cost of Training

Cost of training personnel = ₹ B per personnel with Z number of training personnel

Therefore, total cost = Cost of IoT Architecture + Cost of Development & Integration + Cost of IoT deployment + Cost of Training = 33*N + 33000*P + 1600*M + A*(X+Y) + C+ D*T+B*Z **(3)**

Assumptions

❖ By standard devices we mean desktop, tablet, and cell-phone. We assume these are already available.
❖ IoT cloud solutions - data storage, data processing, and analytics
❖ ERP systems or the required applications are assumed

to be available where the insights derived from IoT solutions are integrated and presented.

2) Benefits Breakdown

Assumptions

Suppose, in this case, the IoT implementation is being done for predictive maintenance.

a) bReducing unplanned downtime
Loss during an unplanned downtime at MHR (Machine hour rate) for R hours (Average number of reduced unplanned downtime per year) = ₹ MHR*R

b) Reducing unnecessary maintenance
Loss during an unnecessary maintenance at ₹ K per maintenance for L times (Average number of reduced unnecessary maintenance per year)

Reduced MTTR (Mean time to repair) and Increased MTBF (Mean time between failures):

Since the analytics embedded with IoT adoption will give insights about what kind of failures may occur, a company can be better prepared for the reduced number of repairs that are needed. Hence, the MTTR will be reduced. Also, due to predictive maintenance, MTBF will increase.

Assume the machine generates ₹ Y revenues per hour and time to repair has been reduced by H1 hours per repair with N repairs per year.
Benefits from reduced MTTR = ₹ Y*H1*N **(4)**
Suppose, increase in MTBF = T_f
Then, Benefits from increased MTBF = MHR * T_f **(5)**

Therefore,
Total benefit = Savings from reducing unplanned downtime + Savings from reducing unnecessary maintenance + Benefits from increased MTBF and reduced MTTR
= MHR*R + K*L + Y*H1*N + MHR*T_f **(6)**

Now comparing the cost with the benefits from the above two equations, we should ideally justify that, the total cost as calculated should be less than the estimated total beneft.

From equations (3) and (6) we have,
33*N + 33000*P + 1600*M + A*(X+Y) + C+D*T+B*Z) <MHR*R + K*L+ Y*H1*N + MHR*T_f **(7)**

Satisfaction of this inequality would show the business case for IoT adoption. Similar frameworks can be developed for evaluation of business cases for IoT adoption for other purposes.

XI. WHAT IS AHEAD FOR INTERNET OF THINGS (IoT)

The future market and the extent of benefits derived from IoT are onlyincreasing. As per research, there will be 34 Billion IoT network devices by 2020 with 24 Billion IoT specific devices and 10 billion traditional devices (PCs, Tablets, Smartphones etc.), which shows that there is a big potential market waiting to be addressed by benefits that IoT can provide. Businesses and governments are to be the top adopters of IoT in the near future. But, as is with every prosperity, the prosperity of IoT also comes with a veiled threat of increased propensity to be attacked or breached by hackers and vested interests. We have tried in this part of the study to analyze what the future of IoT can look like in the manufacturing industry.

A. Objective of Using IoT Ecosystem

Broad objectives of developing an IoT ecosystem to run businesses are to remain mostly same as they are today. Four basic objectives are:

- ✓ Improving customer services, keeping customers happy and delighted by meeting demands
- ✓ Lowering operating cost
- ✓ Increasing throughput / productivity
- ✓ Expanding into new markets, creating new product offerings from Voice of Customer.

B. Probable Future Developments

1) Cyber-physical systems: With the development and testing of new algorithms and software architectures, developers and software architects are expected to be able to create ecosystems that can inter-connect millions of devices around the world. These ecosystems will help companies to track business processes and flow of goods through the supply chain in real time. In the near future, the need of flow of information and goods in tandem will be more than ever, and that is where these systems will help. These ecosystems will also help companies implement methodologies like lean manufacturing in a faster manner. With more information available across the supply chain, companies will be able to decrease inventory costs, and in turn lower working capital requirements.

2) Manufacturing of IoT devices : Proliferation of IoT systems and devices will also drive growth in IoT devices manufacturing companies. Since, there will be a very large number of devices required in near future as per research, we can safely imagine a surge in growth numbers of IoT device manufacturers in the short term. It remains to be seen how this growth is sustained in the longer term.

3) Rise of new service providers to manufacturing industry: As IoT ecosystems will require a different approach to collection, communication, processing, and analysis of insanely large volume of data, special skillsets will be required to develop, run, and maintain these IoT systems. In the near future, it is quite logical for manufacturing firms to not build these capabilities in-house and outsource these functions to service providers. This need of outsourcing will give rise to new service offerings (may be by new firms or existing technology/consulting firms) in the market. Services will include:

❖ Low-level device control and operations such as communications, device monitoring, and management, security, and firmware updates.

❖ IoT data acquisition, transformation, and management.

❖ IoT application development, including event-driven logic, application programming, visualization, analytics, and adapters to connect to enterprise systems.

4) New analytics approaches: Due to availability of large amounts of data, every manufacturing firm is bound to invest more in making sense of the data and creating insights from the data for various objectives. Large amounts and very high velocity data will require different forms of approach to analytics systems that will be applied to this data. In-house analytics capability will most likely become a staple for every manufacturing company in future.

5) IoT to drive proliferation of Artificial Intelligence in business: Other than generating data, IoT will also open doors for companies to develop and build AI based systems which will automate processes like production planning, resource allocation, MRP etc. For example, Hitachi is already using AI based robots called 'robot boss' to manage its shop floors at some of its factories. This trend will only proliferate. AI based systems will become commonplace in manufacturing which will be integrated with IoT ecosystems.

6) *IoT to address cargo theft issues:* Accurate tracking of cargo and goods through the supply chain will protect companies from supply chain risks like cargo theft or inventory pilferage. Item level tagging and container level tracking will enable this.

7) IoT to ensure consistent quality : IoT based systems will enable companies to track processes and components used at every unit of production through off-shore production sensors and live connected video to ensure maintenance of quality. Also, sensors at product level will be able to ensure correct quality parameters and, in case of non-compliance, generate warning signals for corrective systems to come into action.

Caution: DDoS attacks to inflict more losses than ever

In October 2016, the first IoT malware was found to be in existence. Hackers attacking IoT systems through malwares which inflict Distributed Denial of Services (DDoS) throughout the system or in part of the system, will be able to cause more damage than ever to companies. Companies must create systems secure enough to minimize these losses from advanced cyber-crime.

XII. CONCLUSION

IoT is a network of intelligent computers, devices, and objects that collect and share huge amounts of data. We have focused our study on IoT limited to the manufacturing industry. The Industrial Internet of Things (IIoT) is the use of IoT technologies in manufacturing. With the current trend of automation and data exchange in manufacturing technologies, I - 4.0 is the new era. With I - 4.0, the need of generating, collecting, and analyzing data has increased drastically and IoT is being increasingly used to fulfill this need. IoT helps to set up a connected factory which, in turn, brings new possibilities for optimization and reduced waste in all stages of production.

We have discussed in our study the various areas where IoT is being used and what benefit it brings. Briefly stating, in manufacturing under I - 4.0, all stages of the value chain are connected and communicate with each other. This is achieved via IoT, which helps in the efficient use of resources, optimized processes, and a high degree of automation. IoT is transforming the

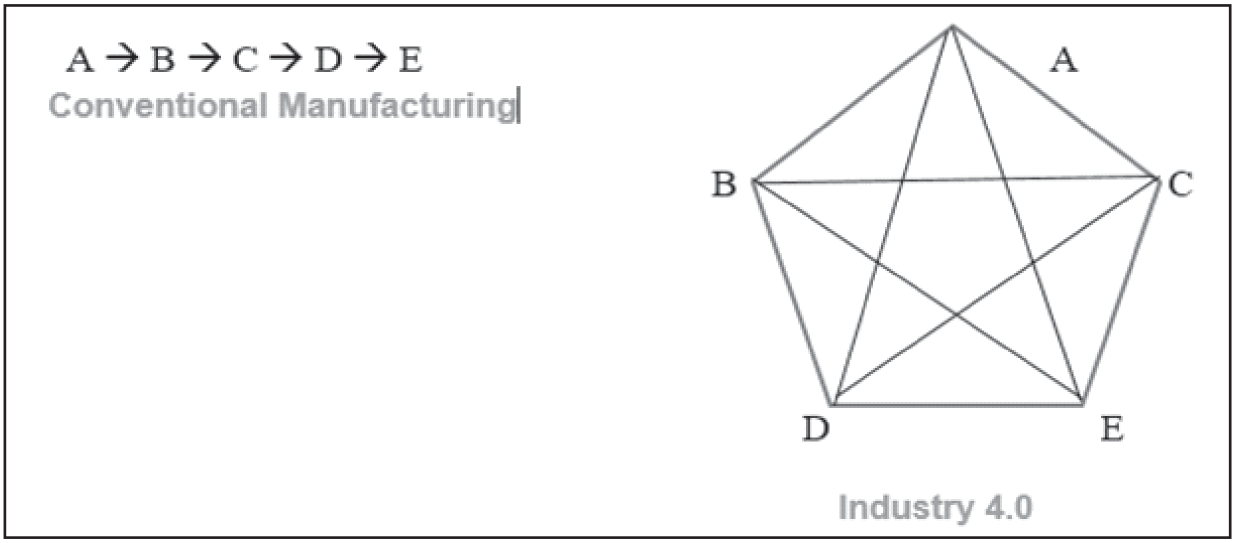

Fig. 10. Comparing conventional and I-4.0 manufacturing

manufacturing industry, the biggest benefit being a significant increase in optimization of processes and better, more fact-based decision making.

In fig. 10 it is shown how in I - 4.0 all the stages of the value chain are connected, unlike in conventional manufacturing. The development of 'networked' and 'integrated' organisations will be a significant outcome of I – 4.0.

❖ With cloud-based solutions it is possible to collect and process data from machines, factories, and even individual tools within the company. The data can be analysed by using advanced algorithms in order to gain learnings and optimise processes. With instant access to information and data, new collaboration opportunities are made possible between people in different parts of the organisation and different parts of the world. IoT as a silo is a means to collect and store data from various devices. When it is equipped with analytics, artificial intelligence, ERP, and CRM solutions, it does all the possible analysis from the gathered data and updates the enterprise systems for better decision making. With the growing opportunities we have analysed the future roadmap of IoT [28], [29], [30], [31].

❖ Though IoT is not a mere hype and does provide useful benefits, the decision of implementing it requires further analysis, as shown in (7).

XIII. FURTHER WORK

IoT and I-4.0 are subjects which are at the cusp of an explosion. We have only seen the beginnings, and there is a lot more to come. An important feature of I – 4.0 will be how each one of these developments, i.e., IoT, cloud computing, AI, internet, super speed computing, universal connectivity, moves forward in the near future. For example, there is talk about net neutrality being phased out. What effect this can have on I – 4.0 is not clear. Similarly, a lengthening in the Moore's Law time horizon, i.e., instead of doubling every two years, if things were to double in twenty years, then I – 4.0 can be adversely affected. Availability of silicon chips is a pre-requisite. Thus, there is a lot of uncertainty in this field and the future should unravel many new developments, offering huge scope for further work.

REFERENCES

[1] MaRS, ON, Canada,"Tech. Adoption Lifecycle (TALC)," 2009. [Online]. Available: https://www.marsdd.com/mars-library/technology-adoption-lifecycle-talc/

[2] Gartner Inc., Stamford, USA. [Online]. Available: https://www.gartner.com/document/3768572?ref=TypeAheadSearch&qid=c389c9a183a2834b670bfc

[3] S. Ezell, "IoT and Smart Manufacturing,"Inform. Technology and Innovation Found., 2016. [Online]. Available: http://www2.itif.org/2016-ezell-iot-smart-manufacturing.pdf?_ga=1.261819661.1089858538.1464487061

[4] N. Joshi,"What's IoT doing in Manufacturing?" 2016. [Online]. Available: https://www.allerin.com/blog/whats-iot-doing-in-manufacturing

[5] Accenture,"Smart Prod. Finding a Way Forward: How manufacturers can make the most of the Ind. Internet of Things."[Online]. Available: https://www.accenture.com/t20160119T041002Z__w__/us-en/_acnmedia/PDF-5/Accenture-804893-Smart-Production-POV-Final.pdf
[6] D. K. George,"TagBox is turning up the heat in the country's cold chain monitoring space." 2017 [Online]. Available: https://yourstory.com/2017/08/tagbox-turning-up-heat-in-cold-chain-space/
[7] D. Bigos, "Quality Control: A transformational opportunity with IoT,"2016. [Online]. Available: https://www.ibm.com/blogs/internet-of-things/quality-control-opportunity/
[8] O. Guy, "Three ways IoT is transforming inventory management,"Newton, MA, USA, 2017. [Online]. Available: http://internetofthingsagenda.techtarget.com/blog/IoT-Agenda/Three-ways-IoT-is-transforming-inventory-management
[9] Everything, "Inventory Manage." [Online]. Available: https://evrythng.com/solutions/inventory-management/
[10] ClearSpider, "How the Internet of Things (IoT) will Transform Inventory Mana." [Online]. Available: http://www.clearspider.com/internet-of-things-inventory-management/
[11] EFT, "The Internet of Things (IoT) in Supply Chain and Logistics," London, UK, 2016. [Online]. Available: https://events.eft.com/iot/
[12] M. Lacey, H. Lisachuk, A. Giannopoulos, A. Ogura. "Shipping smarter: IoT opportunities in transport and logistics," 2015. [Online]. Available: https://dupress.deloitte.com/dup-us-en/focus/internet-of-things/iot-in-shipping-industry.html
[13] SupplyChain247, "How the Internet of Things is Improving Transportation and Logistics," NJ, USA. [Online]. Available: http://www.supplychain247.com/article/how_the_internet_of_things_is_improving_transportation_and_logistics
[14] Dream Orbit,"Most Useful IOT for Logistics Appl. Areas in Transportation. "[Online]. Available: http://dreamorbit.com/most-useful-iot-for-logistics-applications-areas-in-transportation/
[15] D. Sahu, "The reinvention of procurement through Internet of Things," [Online]. Available: http://wiprodigital.com/2017/06/15/reinvention-procurement-internet-things-iot/
[16] CPO Rising, "What will the Internet of Things mean for procurement? In a word: Collaboration." [Online]. Available: http://cporising.com/2015/03/30/what-will-the-internet-of-things-mean-for-procurement-in-a-word-collaboration/
[17] Samsung, "Smart warehouse," [Online]. Available: https://insights.samsung.com/2016/06/24/creating-a-smart-warehouse-with-the-internet-of-things/
[18] Falcon Autotech, Delhi, India, "Smart tech is your warehouse's new care taker."[Online]. Available: https://www.falconautoonline.com/smart-warehousing-technology/
[19] HCLTech, Noida, India [Online]. Available: https://www.hcltech.com/brochures/travel-transportation-and-logistics/smart-warehouse
[20] TechTarget,"IoT Agenda." [Online]. Available: http://internetofthingsagenda.techtarget.com/blog/IoT-Agenda/Three-ways-IoT-istransforming-inventory-management
[21] Teamextension. [Online]. Available: https://teamextension.blog/2017/06/28/iot-is-helping-you-change-the-inventorymanagement-system/
[22] Wikipedia,"Sandvik Coromant," [Online]. Available. https://en.wikipedia.org/wiki/Sandvik
[23] B. Edson, "Azure IoT Suite helps Sandvik Coromant stay on cutting edge within "digital manufacturing," Microsoft, 2016, https://blogs.microsoft.com/iot/2016/09/12/azure-iot-suite-helps-sandvik-coromant-stay-on-cutting-edge-within-digital-manufacturing/
[24] Intel, "IoT Security and Scalability on Intel IoT Platform." [Online]. Available: https://www.intel.com/content/www/us/en/internet-of-things/iot-platform.html
[25] Intel, "Turn data at the edge into real value." [Online]. Available: https://www.intel.com/content/www/us/en/embedded/solutions/iot-gateway/overview.html
[26] Atlas, "The average cost of IoT sensors is falling." [Online]. Available: https://www.theatlas.com/charts/BJsmCFAl
[27] Microsoft Azure, "IoT Hub Pricing". [Online]. Available: https://azure.microsoft.com/en-in/pricing/details/iot-hub/
[28] OpenMind. [Online]. Available: https://www.bbvaopenmind.com/en/10-predictions-for-the-future-of-iot/
[29] Norton, "5 predictions on the future of the Internet of Things." [Online]. Available: https://us.norton.com/internetsecurity-iot-5-predictions-for-the-future-of-iot.html

[30] M. Loffler, and A. Tschiesner, "The internet of things and the future of manufacturing," McKinsey & Company. [Online]. Available: https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-and-the-future-of-manufacturing
[31] E. Puzey, "The future of IOT in manufacturing." [Online]. Available: http://www.supplychain247.com/article/the_future_of_iot_in_manufacturing
[32] AI-connected vehicles with Watson Assistant," [Online]. Available: https://www.ibm.com/internet-of-things/industries/iot-automotive
[33] M. Wilson, "BMW and IBM team up for cloud-connected CarData network", 2017.[Online]. Available:https://www.ibm.com/blogs/cloud-computing/2017/06/bmw-ibm-cloud-cardata/
[34] Wikipedia, "Supercomputer. "[Online]. Available: https://en.wikipedia.org/wiki/Supercomputer
[35] SmartManufacturingLeadershipCoalition, "Smart Manufacturing - A New Ind. Revolution,"2014. develop a list of cost objects and benefit objects as https://www.youtube.com/watch?v=Hcq4e9D4uL8
[36] GE, "SmartManufacturing: The brilliant factory." [Online]. Available: https://www.youtube.com/watch?v=SfVUkGoCA7s
[37] Intel, "The internet of things starts with Intel inside," [Online]. Available: https://www.intel.in/content/www/in/en/internet-of-things/overview.html
[38] Intel, "Intel and Dell Increase Manufacturing Performance with the IoT." [Online]. Available: https://www.intel.com/content/www/us/en/internet-of-things/blueprints/iot-increase- manufacturing-performance-blueprint.html
[39] YouCar, "Car Factory: Mercedes-Benz Industrie 4.0," 2015. [Online]. Available: https://www.youtube.com/watch?v=fdXRTKy_TrM
[40] R.Jayaraman, Operations Value Chain Diagram

About the Authors

Prof. R. Jayaraman is Professor (Operations and Supply Chain Management) with S.P. Jain Institute of Management and Research, Mumbai, Maharashtra, India.

Avisek Basu is Analytics & Modeling Associate Manager with Accenture, Bengaluru, Karnataka, India.

Suryadipta Chakraborty Functional consultant with the Analytics Advisory, Accenture, Bengaluru, Karnataka, India.