Internet of Things: technologies and applications in healthcare management and manufacturing

Mémoire

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Internet of Things: technologies and applications in healthcare management and manufacturing

Memoir

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Résumé

L'Internet des Objets (ou IoT) s'appuie sur des objets connectés dotés de capteurs et technologies capables d'échanger des données entre eux de manière indépendante. Ces nouvelles technologies offrent aux entreprises et à toutes les organisations des moyens pour l'acquisition et le traitement intelligent de l'information (Industrie 4.0) pour demeurer compétitives.

Ce mémoire vise à analyser la contribution de l'IoT dans les soins de santé et production, mettant l'accent sur l'Industrie 4.0 et la maintenance prédictive, particulièrement en maintenance, sur la base d'œuvres littéraires récentes publiées au cours de la dernière décennie.

L'objectif principal de ce mémoire est de comprendre l'IoT, d'exposer ses potentiels et sa stratégie de déploiement dans différents domaines d'applications. Même, le but est de comprendre que l'IoT ne se limite pas à l'application de la maintenance des systèmes de production mais aussi du bien-être des patients, c'est pourquoi j'ai choisi ces deux domaines importants où l'IoT peut être appliqué (santé et production) pour ce travail de recherche.

Cette thèse aidera à explorer comment l'IoT transforme le système de santé. J'explique comment l'IoT offre de grandes avancées dans ce système. Je donne quelques exemples où ses concepts souhaiteraient être implémentés pour améliorer la qualité des soins des patients et quelques études récentes.

Outre, je clarifie l'impact de l'Industrie 4.0 sur la production, notamment en maintenance, en lien avec la maintenance prédictive rendue possible par l'IoT. Je fournis une vue d'ensemble de l'Industrie 4.0 et de la maintenance prédictive. J'aborde les fonctionnalités de l'Industrie 4.0 et présente ses technologies de pilotage susceptibles d'améliorer les domaines de processus de production, tels que la réduction des temps d'immobilisation, les coûts de service, etc. J'attire l'attention sur les implications de la maintenance prédictive dans l'Industrie 4.0 en décrivant son fonctionnement et comment les fabricants peuvent l'exécuter efficacement, avec des exemples à l'appui.

Abstract

The Internet of Things (or IoT) relies on connected objects embedded with sensors and other technologies capable of exchanging data with each other independently. These new technologies provide businesses and all organizations with the means to acquire and intelligently process information (Industry 4.0) to remain competitive.

This thesis aims to analyze the contribution of IoT in healthcare and manufacturing, with a focus on Industry 4.0 and Predictive Maintenance, specifically in maintenance, based on recent literary works published over the last decade.

The main purpose of this thesis is to understand what IoT is, to highlight its potentials and its deployment strategy in various areas of application. Similarly, the goal is to understand that IoT is not limited to the application of the maintenance of production systems but also of patients' wellbeing which is the reason why I selected these two important areas where IoT can be applied (healthcare and manufacturing) for this research work.

This thesis will help explore how IoT is transforming the healthcare system. I explain how IoT offers great advances in the healthcare system. I give some examples of where its concepts would like to be implemented to improve the quality of care of patients and some recent studies.

In addition, I clarify the impact of Industry 4.0 in manufacturing especially in maintenance, in connection with predictive maintenance made possible by IoT. I provide an overview of Industry 4.0 and predictive maintenance. I discuss the capabilities of Industry 4.0 and present its driving technologies that can improve all areas of production processes such as reducing downtime, service costs, etc. Moreover, I draw attention to the implications of predictive maintenance in Industry 4.0 by describing how it works and how manufacturers can run it effectively, with supporting examples.

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List of abbreviations and acronyms

ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
API	Application Programming Interface
ATM	Automated Teller Machine
AWS	Amazon Web Services
AMQP	Advanced Message Queueing Protocol
BDC	Banque de développement du Canada
BLE	Bluetooth Low Energy
BMI	Body Mass Index
CM	Cloud Manufacturing
CoAP	Constrained Application Protocol
CPS	Cyber-Physical Systems
CPPS	Cyber-Physical Production Systems
EHR	Electronic Health Record
EPC	Electronic Product Code
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HIE	Health Information Exchanges
HTTP	HyperText Transfer Protocol
H-IoT	Health-related internet of things
IaaS	Infrastructure as a Service
IBM	International Business Machines
ICT	Information and Communication Technologies
IDC	International Data Corporation
IIoT	Industrial Internet of Things
IoT	Internet of Things
IEFT	Internet Engineer Task Force
IM	Instant Messaging
IPv6	Internet Protocol version 6
IrDA	Infrared Data Association
LAN	Local Area Network
LR-WPAN	Low-Rate Wireless Private Area Networks
MAC	Medium Access Control
MIT	Massachusetts Institute of Technology
mDNS	Multicast DNS
MTTF	Mean Time To Failure
MTU	Maximum Transmission Unit
MQTT	Message Queue Telemetry Transport
M2M	Machine to Machine Communication
OMG	Organisms Genetically Modified
PAN	Personal Area Network
PC	Personal Computer
PHY	Physical Layer
PTC	Parametric Technology Corporation
P&G	Proctor & Gamble
QoS	Quality of Service
REST	Representational State Transfer
RFID	Radio Frequency Identification Development

SaaS	Software as a Service
SCM	Supply Chain Management
SDK	Software Development Kit
TCP	Transmission Control Protocol
TI	Texas Instruments
TPM	Total Production Maintenance
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
UWB	Ultra-Wide Band
WAN	Wide Area Network
WBAN	Wireless Body Area Network
WI-FI	Wireless Networking (WLAN products that are based on the IEEE 802.11 standards)
WSN	Wireless Sensor Network
XMPP	Extensible Messaging and Presence Protocol
3D	Three Dimensional
3G	Third Generation (mobile communication system)
6LowPAN	IPv6 over Low power Wireless Personal Area Networks

Dedication

I hereby dedicate my research paper to almighty God who has been my guardian throughout my research process and by his grace I was able to complete my master's degree program.

Also, I dedicate my research work to my beloved mother (Mrs. Magne Emilienne Pochangou) for encouraging and supporting me to further my education and to accomplish my research with truthful self-confidence.

I am also dedicating my work to my loving brothers (Mr. Fonkam Teda Paterne and Mr. Navot Fonkam) for their contribution and support.

Lastly, to a true and loving one (Gbenga Damilare Bakare) who also supported, encouraged and motivated me when I almost gave up.

Words are not enough to express how I am grateful to have you all in my life, I pray God bless you all in your endeavours in life.

Acknowledgements

I would like to acknowledge my supervisor, Professor Daoud Ait-Kadi without whom I would have never had the opportunity of learning enormously with interest.

I am expressing my sincere gratitude for he has really assisted me greatly during my program. Thank you for your patience, continuous support, insightful comments and advice that have tremendously helped me throughout my research. I would not have imagined a better mentor for my master's degree program.

I also extend my sincere gratitude to my family members for their contributions.

Thank you all for your support.

Introduction

Imagine a world where almost everything is interconnected and automated. In an effort to address the concerns hindering the progress in healthcare and manufacturing, IoT systems will need to be adopted. In essence, this suggests that IoT promises to pave the way for new services, applications and transform a wide range of fields as it will certainly make things a lot smarter. My research paper aims to demonstrate that IoT has the potential to impact the healthcare and maintenance world positively, for instance, by promoting better patient care outcomes, by enhancing operations' productivity and efficiency and others.

This research work will address the applications of IoT in healthcare and manufacturing field—with emphasis on maintenance based on Industry 4.0 and predictive maintenance. This work is a collection of several readings/sources based on articles, books, documents and some online information. Some examples will be given to back up the theories of IoT and for a clearer knowledge of its importance in society. Likewise, this work will help understand how IoT assists in tackling problems faced in the world, whether be in the case of health emergencies, business operations, maintenance of equipment, road traffic management, energy conservation, agricultural problems, etc.

This memoir is divided up into five parts. The first part will give an overview of IoT by talking about its history, by giving a concrete definition of this technological innovation and an understanding of how it operates. Second, the advantages and disadvantages as well as the domains (or areas) where IoT can be applied will be discussed. Third, different technologies and protocols that enable the deployment of IoT systems into today's world will be elaborated. Then, the fourth and last part will describe the various ways IoT influences the healthcare and manufacturing field, especially on how Industry 4.0 impact maintenance with predictive maintenance solutions. Finally, some example cases will be provided to support this technological advance that is, IoT in healthcare along with some real-world examples of Industry 4.0 and predictive maintenance in the manufacturing (maintenance) field.

Part I: What is the Internet of Things (IoT)?

1. About the Internet of Things

This first part will provide an understanding of IoT, from its origins to how it operates and delivers services.

1.1 Origins of IoT

According to (Borgia, 2014, p.1,3) [9], the origin of IoT can be credited to Kevin Ashton, a member of the Radio Frequency Identification (RFID) Development community and one of the founders of the original Auto-ID Center at MIT, who introduced the term IoT in a presentation held at Proctor & Gamble (P&G) in 1999. (Claveria, 2019) [13] said this visionary technologist challenged businesses to imagine a world where the Internet will permeate all aspects of people's lives. Computers will be able to sense things for themselves using RFID and sensor technology and will give real-time feedback without human intervention.

As stated by (Alqahtani, 2018, p.1) [3], in 2003, the Auto-ID center released the electronic product code (EPC) network. The EPC enabled tracking objects moving from one location to another. This gave an idea for the IoT implementation, where microchips can be used to create a network for mainstream commercial means. The radio frequency identification (RFID) implementation further cemented the opportunities for developing the IoT as a new IT paradigm in both academic and industrial environments.

That being said, as noted by (IMDA, n.d., p.1) [74] and by (Evans, 2011, p.3) [22], it is only sometimes between the years 2008 and 2009 IoT became more relevant to the practical world because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics.

1.2 Definition of IoT

First, let’s discuss separately what Internet and Things mean. According to (GCFGlobal, 2019) [30], the Internet is an increasingly important part of everyday life for people around the world. It is a global network of billions of computers and other electronic devices. With the Internet, it's possible to access almost any information, communicate with anyone else in the world, and do much more.

On the other hand, based on (Borgia, 2014, p.2) [9] article, a “thing” can be any real/physical or virtual object (e.g., RFID, sensor, actuator, spime, smart item) but also a virtual/digital entity, which moves in time and space and can be uniquely identified by assigned identification numbers, names and/or location addresses. Once these things are embedded with technologies, they become smart objects that, as pointed out by (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012, p.2) [46], may possess means to sense physical phenomena (e.g. temperature, light, electromagnetic radiation level) or to trigger actions, having an effect on the physical reality (actuators). Moreover, objects include not only electronic devices, but according to (Rouse, 2019) [58], they can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an IP address and is able to transfer data over a network.

In summary, as defined by (Borgia, 2014, p.4) [9] and (Evans, 2011) [22], IoT represents the next evolution of the Internet. It refers to a dynamic global network infrastructure with self capabilities based on standard and interoperable communication protocols where physical and virtual ‘‘things’’ have identities, physical attributes, virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network. In addition, IoT enable people and things to be connected not only ‘‘Anytime’’ ‘‘Anywhere’’ with ‘‘Anyone’’ and ‘‘Anything’’, but also use any type of location or network and any available service (See Figure 1).

Furthermore, as mentioned by (PIEMR, 2017) [55], leading Market Research firm IHS forecasts that the IoT market will grow from an installed base of 30.7 billion devices in 2020 to 75.4 billion in 2025 (See Figure 2).

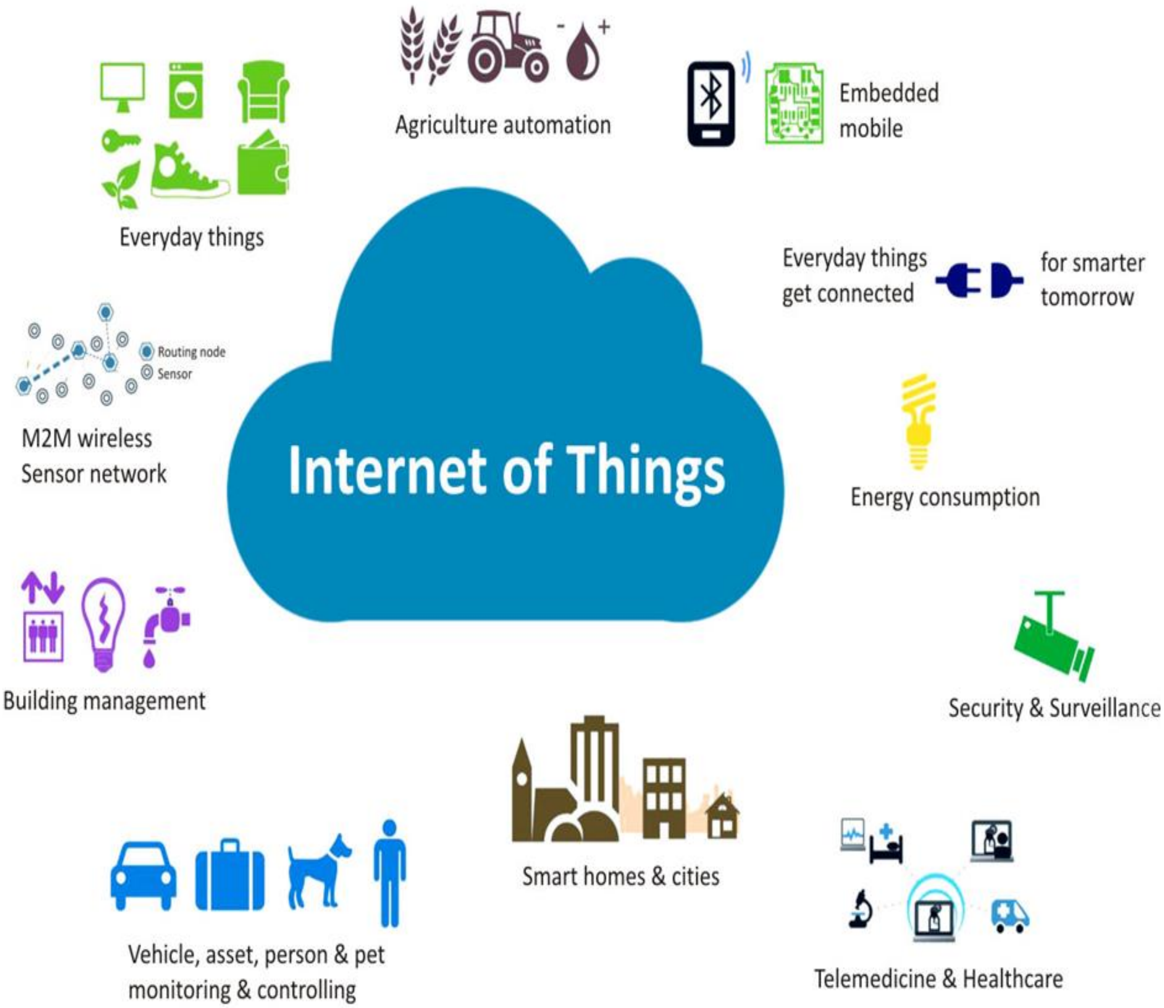

Figure 1: A depiction of an IoT environment in which objects, animals, businesses, and people can be connected and controlled over any network [1].

[1] Scientech IoT Builder. (2019). Retrieved from https://www.scientechworld.com/internet-of-things/iot-solutions/iot-builder.

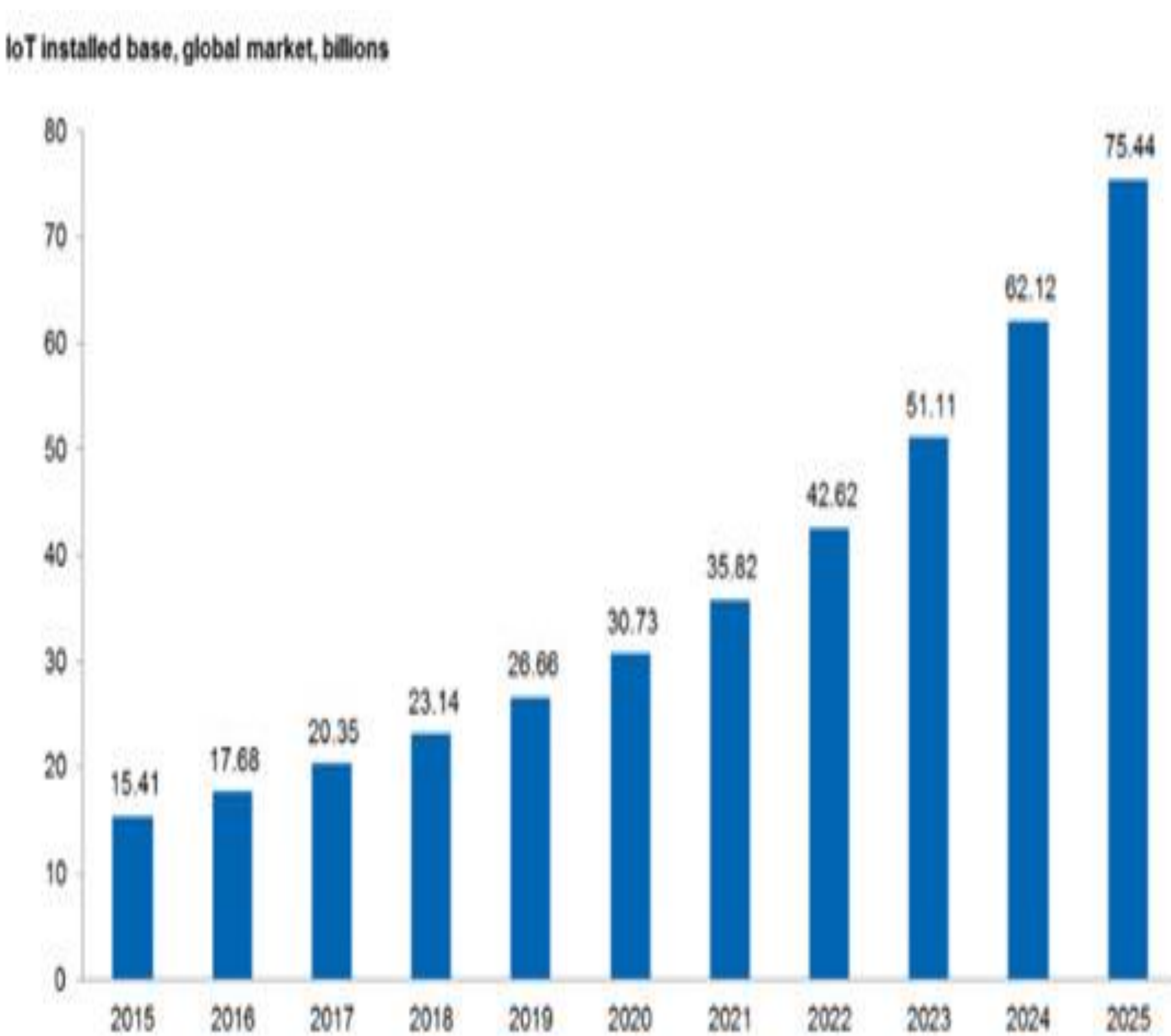

Figure 2: It shows the expected rise of billions of "IoT" devices in a span of years between 2015 and 2025[2].

[2] PIEMR. (2017, 07 12). Why should you be interested in the Internet of Things (IOT)? Retrieved from https://www.linkedin.com/pulse/why-should-you-interested-internet-things-iot-training-and

1.3 Architecture of IoT

According to (Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash, 2015, p.3) [2], the ever-increasing number of proposed architectures has not yet converged to a reference model. Currently, from the pool of proposed models, the architecture of IoT consists of five common layers that enable the collection, storage and processing of data. Basically, it explains how IoT system works. Figure 3 below introduces the global structure of IoT.

Overview of the architecture of IoT

1. Objects Layer

Embedded smart objects collect and process real-time information into data for analysis.

2. Object Abstraction Layer

Collected data are being transferred to the service management layer through secure channels or networks (1.3.2).

3. Service Management Layer

Receives data and stores in the relevant information to be analyzed, to be processed to make worthwhile decisions and to deliver the required services as per the user requirements.

4. Application Layer

Requested services by the end users are being provided to the best of its ability at this stage.

5. Business Layer

Manages overall IoT system activities, services, and supports decision making processes based on Big Data analysis to enhance services and maintain users' privacy.

Figure 3: This is a summary of how IoT system works from collecting data to delivering the requested services to the end users.

1.3.1 Objects Layer or Perception Layer

This first layer, as mentioned by (IMDA, n.d., p.14) [74], is made up of smart objects integrated with sensors. The sensors enable the interconnection of the physical and the digital worlds, allowing real-time information to be collected and processed. Sensors are grouped according to their unique purpose such as environmental sensors, body sensors, home appliance sensors and vehicle telematics sensors, etc. Furthermore, as asserted by (Al-Fuqaha et al., 2015, p.3) [2], this layer is not only made up of sensors, but also actuators to perform different functionalities such as querying location, temperature, weight, motion, vibration, acceleration, humidity, etc. Here, standardized plug-and-play mechanisms need to be used by the perception layer to configure heterogeneous objects. Then, the perception layer digitizes and transfers the data to the Object Abstraction Layer through secured channels. The big data created by the IoT are initiated at this layer.

1.3.2 Object Abstraction Layer or Transport Layer

(IMDA, n.d., p.15) [74] stated that massive volume of data is produced by these tiny sensors and this requires a robust and high performance wired or wireless network infrastructure as a transport medium. As indicated by (Al-Fuqaha et al., 2015, p.3) [2], Object Abstraction Layer transfers data produced by the Objects layer to the Service Management Layer through secure channels. These data can be transferred through various technologies such as RFID, 3G, GSM, UMTS, LAN, Wi-Fi, Bluetooth Low Energy, Infrared, Zigbee, etc. Furthermore, other functions like cloud computing and data management processes are being handled at this layer.

1.3.3 Service Management Layer

According to (IMDA, n.d., p.15) [74], the Management service renders the processing of information through analytics, security controls, process modeling and management of devices. Moreover, as noted by (Al-Fuqaha et al., 2015, p.3) [2], Service Management or Middleware (pairing) layer pairs a service with its requester based on addresses and names. This layer enables the IoT application programmers to work with heterogeneous objects without consideration to a specific hardware platform. Also, this layer processes received data, makes decisions, and delivers the required services over the network wire protocols.

1.3.4 Application Layer

As per (Al-Fuqaha et al., 2015, p.3) [2], the Application Layer provides the services requested by customers. For instance, the layer can provide temperature and air humidity measurements, etc. to the customer who asks for that information. The importance of this layer for the IoT is that it has the ability to provide high-quality smart services to satisfy customers' needs. The application layer covers numerous vertical markets such as smart home, smart building, transportation, industrial automation, smart healthcare, and more.

1.3.5 Business Layer

Lastly, (Al-Fuqaha et al., 2015, p.3) [2] stated that the Business (management) Layer manages the overall IoT system activities and services. The responsibility of this layer is to build a business model, graphs, flowcharts, etc. based on the received data from the Application Layer. It is also supposed to design, analyze, implement, evaluate, monitor, and develop IoT system related elements. The Business Layer makes it possible to support decision-making processes based on Big Data analysis. In addition, monitoring and management of the underlying four layers is achieved at this layer. Moreover, this layer compares the output of each layer with the expected output to enhance services and maintain users' privacy.

1.4 IoT Platform

As said by (Khan, 2019) [34], an IoT platform is an end-to-end software framework. It's the glue that pulls together information from sensors, devices, networks, and software that work together to unlock valuable, actionable data. Similarly, as stated by (AVSYSTEM, 2019) [77], an Internet of Things platform is the main place where the actual IoT magic happens. It is at the heart of every IoT deployment, bringing together the hardware, connectivity, software and application layers to offer an efficient solution for device management and configuration, data collection and analysis, enablement of applications as well as connection with the cloud or on-site server.

There are two parts that will be discussed in this section. The first part will talk about the eight criteria of an IoT platform and the second part will give some examples of IoT platforms.

I. The eight criteria of an IoT platform

According to (Padraig, 2016) [52], there are eight general components to a true end-to-end IoT platform and summarized in Table 1 below.

Table 1: The eight characteristics of an IoT Application Enablement Platform or IoT Platform[3].

<table>
<tr><td colspan="2">Connectivity & Normalization
Agents and libraries that ensure constant object connectivity and harmonized data formats</td></tr>
<tr><td colspan="2">Device management
Backend tool for the management of device status, remote software deployment and updates</td></tr>
<tr><td colspan="2">Database
Repository that stores the important data sets</td></tr>
<tr><td colspan="2">Processing & action management
Rule engine that allows for (real-time) actions based on incoming sensor & device data</td></tr>
<tr><td colspan="2">Analytics
Algorithms for advanced calculations and machine learning</td></tr>
<tr><td colspan="2">Data visualization
Graphical depiction of (real-time) sensor data</td></tr>
<tr><td>Additional tools
Further development tools (e.g. app prototyping, access management, reporting)</td><td>External Interfaces
API, SDKs and gateways that act as interfaces for 3rd party systems (e.g., ERP, CRM)</td></tr>
</table>

[3] Padraig, S. (2016, 01 26). 5 things to know about the IoT Platform ecosystem. Retrieved from https://iot-analytics.com/5-things-know-about-iot-platform/

1. Connectivity & Normalization

It brings different protocols and different data formats into one "software" interface, ensuring accurate data streaming and interaction with all devices.

2. Device management

It ensures the connected "things" are working properly, seamlessly running patches and updates for software and applications running on the device or edge gateways.

3. Database

Scalable storage of device data brings the requirements for hybrid cloud-based databases to a new level in terms of data volume, variety, velocity, veracity and value which are related to big data. From (Shanawaz. S., 2019) [67], Big data refers to a relatively modern field of data science that explores how large data sets can be broken down and analyzed in order to systematically glean insights and information from them. In terms of volume, Big data defines the 'amount' of data that is produced. In terms of variety, Big data entails processing diverse data types collected from varied data sources. Velocity refers to the speed at which the data is generated, collected and analyzed. The Veracity of big data is the assurance of quality or credibility of the collected data. And finally, in the context of big data, value amounts to how worthy the data is of positively impacting a company's business. As it is, (Nayyar D. A., 2018) [49] mentioned that the IoT platform should also be scalable enough to accommodate growing needs without any hiccups.

4. Processing & action management

It brings big data to life with rule-based event-action-triggers enabling execution of "smart" actions based on specific sensor data.

5. Analytics

It performs a range of complex analysis from basic data clustering and machine learning to predictive analytics extracting the most value out of the IoT data-stream. In fact, machine learning is an application of artificial intelligence (AI) that allows computer to think and learn independently.

6. Data visualization

It enables humans to see patterns and observe trends from visualization dashboards where data is vividly portrayed through line-, stacked-, or pie charts, 2D- or even 3D-models. As pointed out by

(Nayyar D. A., 2018) [49], the IoT platform's operations should not be hidden; rather the end user should be greeted with a centralized interface which gives all the details with regard to system statistics, hardware information and the modules or services.

7. Additional tools

They could be development tools which allow IoT developers prototype, test and market the IoT use case creating platform ecosystem apps for visualizing, managing and controlling connected devices.

8. External interfaces

They integrate with 3rd-party systems and the rest of the wider IT-ecosystem via built-in application programming interfaces (API), software development kits (SDK) which, from (Lionel Valdellon, 2019) [41], is a set of software tools and programs used by developers to create applications for specific platforms, and gateways. According to (Nayyar D. A., 2018) [49], the most important and foremost protocol to facilitate IoT is the message queue telemetry transport (MQTT). The IoT platform should support the MQTT protocol to provide all sorts of communication from sensors to the cloud. Almost all cloud service providers use MQTT. These include Microsoft Azure, Amazon AWS, Google Cloud, etc. Moreover, the IoT platform should support the API over WebSockets, REST and CoAP. As stated by (Pearlman, 2019) [53], API is a software intermediary that allows two applications to talk to each other. In other words, an API is the messenger that delivers your request to the provider that you're requesting it from and then delivers the response back to you.

Altogether, as noted by (Padraig, 2016) [52], these IoT platforms' building blocks mentioned above have to be solidly secured and the platform architecture has to be holistically designed so that the threat of cyber attacks is minimized at every level. This necessitates the protection and encryption of data, device access management, user authentication, and much more.

II. Some IoT platforms

(McClelland, 2019) [42] wrote that IoT platforms provide a head start in building IoT systems by providing built-in tools and capabilities to make IoT easier and cheaper for businesses, developers, and users. According to (DA14, 2018) [82], the criteria for choosing a platform may be based on price and pricing model (pay-as-you-go model, where you are charged for the resources you actually consume or the subscription model, where you are billed a flat fee per month). Moreover, the criteria could be based on the availability of a free tier (when you need to test your idea and need an opportunity to run a simple project with a minimum investment) or it could be based on the development team experience (by asking the development team about their experience and knowledge of available options and making your selection by balancing the project requirements and the team expertise).

The following pages compare some IoT cloud platforms (IoT vendors) that can provide the most optimal environment for running IoT applications [78][4].

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4 10 Best Iot Platforms In 2018. Iot Technology Forecast (Updated). (2018, 05 09). Retrieved from https://da-14.com/blog/10-best-iot-platforms-iot-technology-forecast/

Table 2: Below is a comparison of different IoT platforms [83][5].

IOT CLOUD PLATFORMS COMPARISON				
	Price & Pricing Model	**Availability of free tier**	**Services**	**Device Management Platform**
Amazon Web Services (AWS)	Pay as you go model (1) / Pricing is based on the connectivity, messaging, rules engine, and device shadow usage [83]	Yes; 12 months free trial period is available [83]	Supports all kind of cloud-based project (1). Provides support for HTTP, lightweight communication protocol, and MQTT [83]	Yes
Google Cloud IoT Suite	Pricing is based on the data volume. Price starts at $1758 per month [83]	Yes, it provides free data up to 250 MB per month [83]	Supports IoT solutions (2). Provides predictive maintenance for equipment, solutions for smart cities & buildings, and real-time asset tracking [83]	Yes
Microsoft Azure IoT Suite	Pricing is based on the number of messages per day [83]	Yes	Offers both preconfigured solutions & the possibility to customize them and create new ones according to the project requirements (3)	Yes
ThingWorx IoT Platform	Contact them for pricing details [83]	Yes	Designed for building industrial IoT solutions (4)	Yes
IBM Watson Internet of Things	Pricing is based on the data exchanged, data analyzed, and data analyzed at the edge. Cost starts at $500 per instance/month [83]	Yes	Supports effective remote device control, secure data transmission and storage in cloud, real-time data exchange, as well as machine learning options (5)	Yes

[5] 10 Best IoT Platforms to Watch Out In 2019. (2019, 08 21). Retrieved from https://www.softwaretestinghelp.com/best-iot-platforms/

1. Amazon Web Services

This platform uses the pay-as-you-go model and offers a free tier option with certain restrictions. No matter what kind of cloud-based project someone may have in mind, with an almost 100% probability, AWS will support it. The cloud services provided by Amazon include an IoT suite that supports all aspects of Internet-of-Things applications through:

* **AWS IoT Core**—is the base on which any IoT application can be built. Via AWS IoT Core, devices can connect to the Internet and to each other and exchange data. Billions of messages can be sent between the devices and cloud storage over a secure connection. The platform supports various communication protocols, including custom ones, thus enabling communication between devices from different manufacturers.

* **AWS IoT Device Management**—allows easy addition and organization of devices. The service ensures secure and scalable performance with the possibilities of monitoring, troubleshooting and updating the device functionality.

* **AWS IoT Analytics**—provides a service for automated analytics of large amounts of various IoT data, including unstructured data from different types of devices. The data gathered and processed by the service is ready for use in machine learning.

* **AWS IoT Device Defender**—supports the configuration of security mechanisms for the IoT systems. AWS IoT Device Defender enables the setup and management of security policies controlling device authentication and authorization, as well as providing encryption mechanisms.

2. Google Cloud IoT

Google Cloud Platform is another global cloud provider that supports IoT solutions. Its Google Cloud IoT package allows someone to build and manage IoT systems of any size and complexity. The Google Cloud IoT solution includes a number of services that enable the creation of IoT networks through:

* **Cloud IoT Core**, the heart of the Google Cloud IoT suite, which allows the connection of various devices and the gathering of their data.

* **Cloud Pub/Sub**, the service which processes event data and provides real-time stream analytics.

* **Cloud Machine Learning Engine**, which allows the building of ML models and use of the data received from IoT devices.

3. Microsoft Azure IoT Suite

The IoT platform comparison would not be complete without the solution by Microsoft Azure, a cloud service giant in the same league with AWS and Google Cloud Platform. Microsoft Azure IoT Suite offers both preconfigured solutions and the possibility to customize them and create new ones according to the project requirements.

With Microsoft Azure IoT Suite, someone gets the strongest security mechanisms, superb scalability, and easy integration with any existing or future systems. The platform allows end users to connect hundreds of devices by various manufacturers, gather data analytics and use the IoT data for machine learning purposes.

4. ThingWorx IoT Platform

ThingWorx by Parametric Technology Corporation (PTC) is designed for building industrial IoT solutions. It is considered one of the most complete toolsets for creating IoT applications of varying complexity and scale.

The platform has excellent sharing and collaboration possibilities, which makes it a great solution for large development teams. Its native capabilities are sufficient to build various IoT applications without the need to apply third-party components or libraries.

The IoT applications created on the basis of the ThingWorx platform have all the features of an advanced enterprise solution—great scalability options, and integration with cutting-edge technologies, such as augmented reality, and extensive analytics. This powerful functionality is implemented with a simple and intuitive user interface, thus combining great performance with high usability.

5. IBM Watson Internet of Things

According to their own description, with IBM Watson "the Internet of Things becomes the Internet that thinks". This bold statement means that IBM experiments with integration IoT with artificial intelligence creating unique experiences and solutions. Essentially, from (Frankenfield, 2020) [23], artificial intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions.

The IBM Watson IoT platform supports effective remote device control, secure data transmission and storage in cloud, real-time data exchange, as well as machine learning options thanks to their integration in AI.

The development platform offered by IBM includes a number of convenient tools and services, making IoT software creation easier and more efficient.

Part II: Advantages & Disadvantages of IoT and its Application Domains/Services

2. Advantages and Disadvantages of IoT

2.1 Advantages of IoT

IoT offers many opportunities that individuals and organizations cannot ignore. It represents a significant shift in technology that can both improve the living standards of people and businesses. Figure 4 below shows an overview of a few advantages of IoT.

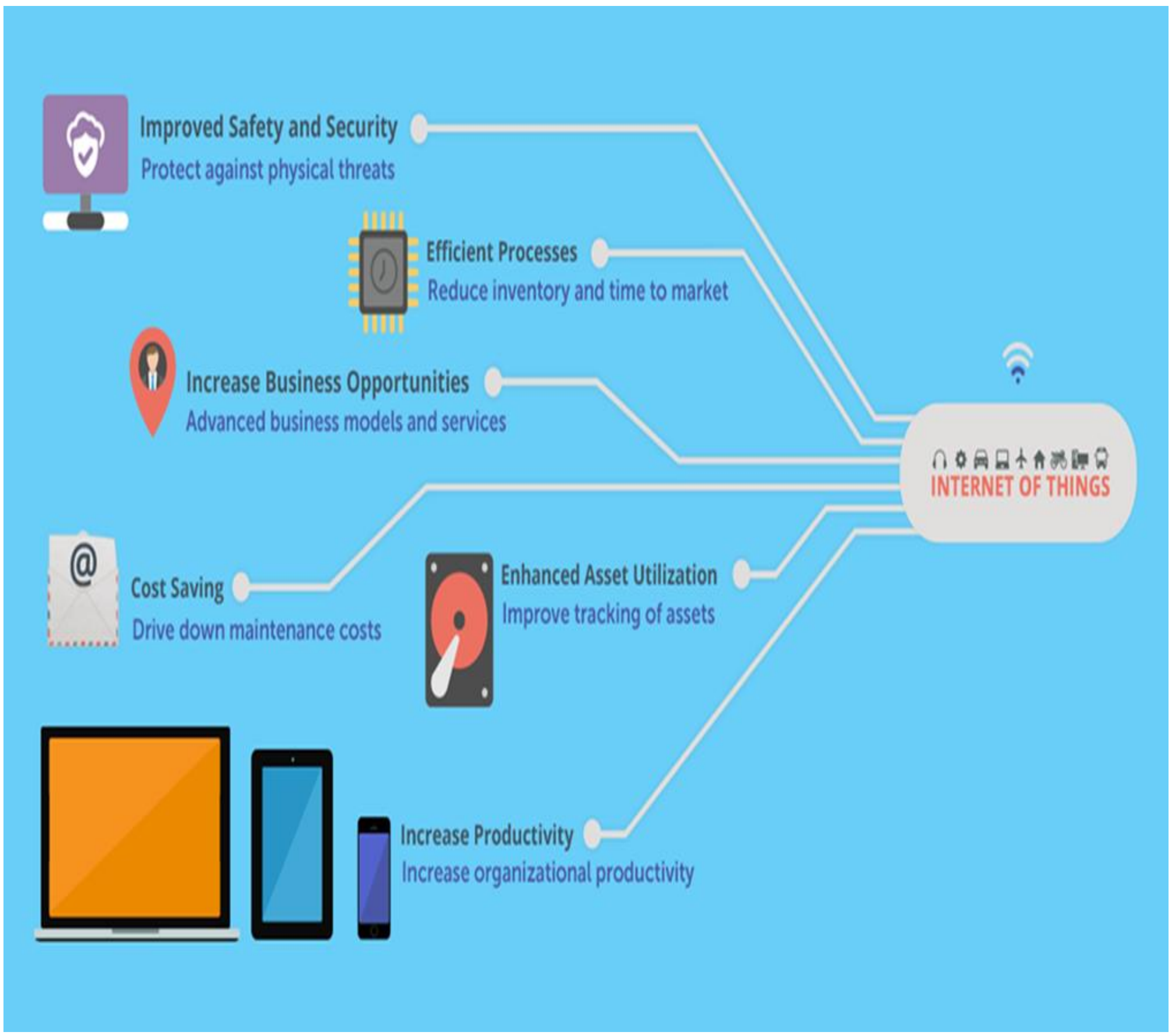

Figure 4: Some advantages of IoT [6]

Though the benefits of IoT are not limited, here is a comprehensive list of some its advantages.

[6] Herry, P. (n.d.). 6 Ways Businesses Can Take Advantage of IoT. Retrieved from https://vmokshagroup.com/blog/6-ways-businesses-can-take-advantage-of-IoT/

2.1.1 Efficient processes

(Cognizant, 2014, p.4) [14] said that organizations can use real-time operational insights to make smarter business decisions and reduce operating costs. They can use real-time data from sensors and actuators to monitor and improve process efficiency, reduce energy costs and minimize human intervention.

2.1.2 Improved Productivity

As stated by (Cognizant, 2014, p.4) [14], productivity is a critical parameter that affects the profitability of any organization. As it is, IoT improves organizational productivity by offering employees just-in-time training, reducing the mismatch of required vs. available skills and improving labor efficiency.

An instance of how an IoT device can improve productivity is provided by (New Era Technology, 2017) [50] in the case of changing the daily commute. Being stuck in traffic or on the subway can lead to lost time and productivity. However, since we have so many devices always connected to the Internet, employees can use this time to get work done instead of it going to waste. This can significantly increase overall productivity, especially as more employees use different forms of transportation other than a personal vehicle.

2.1.3 Improved Asset Utilization

According to (New Era Technology, 2017) [50] viewpoint, with the right connected devices and strategically located sensors, someone can better manage their assets and significantly boost their bottom line at the same time.

Additionally, as per (Cognizant, 2014, p.3-4) [14], with improved tracking of assets (machinery, equipment, tools, etc.) using sensors and connectivity, businesses can benefit from real-time insights and visibility into their assets and supply chains. For instance, they could more easily locate assets and run preventive maintenance on critical pieces of infrastructure and machinery to improve throughput and utilization.

2.1.4 Cost-Savings

One of the biggest advantages of IoT is that it saves money. (Cognizant, 2014, p.3) [14] stated that costs can be reduced through improved asset utilization, process efficiencies and productivity. Customers and organizations can benefit from improved asset utilization (e.g., smart meters that eliminate manual meter readings) and service improvements (e.g., remote monitoring of patients in clinical settings) to save or cut costs. General Electric has estimated that if intelligent machines and analytics caused even a tiny reduction in fuel, capital expenditures and inefficiencies, it would result in billions of dollars in cost savings.

2.1.5 Tracking Individual

As discussed by (Suny Cortland, 2012) [72], IoT can track individual consumers and target these consumers based on the information supplied by the devices. In a way, it provides a more "personalized" system that could potentially increase business sales and increase their demographic. It helps organizations better respond to customers' demands and improve on their business's strategies.

Furthermore, another way IoT can track individuals is in a medical setting, where a chip could be implemented into each individual, allowing for hospitals to track the vital signs of the patient. By tracking their vital signs, it could help indicate whether or not serious assessment is necessary.

2.1.6 Energy Conservation

(Suny Cortland, 2012) [72] mentioned that, with the increased number of devices connected to the Internet, the IoT device (Smart Grid) expands, conserving more energy. Devices will be able to make decisions and adapt without human guidance to reduce their energy usage. According to (Mehta, 2014) [43], high-energy consumption household appliances will also adjust based on dynamic price signals to lower the electric bill. Thermostats and lighting will learn one's habits to create the optimal setting based on one's daily life, such as turning to their ideal temperature just before the person arrives home. These gadgets will also sense when no one is in the house and turn off automatically to reduce wastes and costs.

2.1.7 Increase Business Opportunities

According to (Herry, 02 12) [27], IoT opens the door for new business opportunities and helps firms benefit from new revenue streams developed by advanced business models and services. IoT-driven innovations build strong business cases, reduce time to market and increase return on investments. IoT has the potential to transform the way consumers and businesses approach the world by leveraging the scope of the IoT beyond connectivity.

2.1.8 Improved Safety and Security

(Herry, 02 12) [27] also noted that IoT services integrated with sensors and video cameras help monitor workplace to ensure equipment safety and protect against physical threats. The IoT connectivity coordinates multiple teams to resolve issues promptly.

2.2 Disadvantages of IoT

IoT has many benefits but as with any technology, it's no surprise it comes with its disadvantages. These disadvantages can be largely destructive to society, individuals and businesses. To master IoT, the disadvantages listed below by (Sannapureddy, 2015) [60] need to be addressed.

2.2.1 Complexity

As with all complex systems, there are more possibilities of failure. With the Internet of Things, failures could skyrocket. Any failure or bugs in the software or hardware will have serious consequences. Even power outage can cause a lot of inconvenience. For example, a bug in the software could end up automatically ordering a new ink cartridge for your printer each and every hour for a few days, or at least after each power failure, when you only need a single replacement. Or a couple may receive messages that the milk has expired, and both end up buying twice the amount they need.

2.2.2 Loss of Privacy/Security

Privacy is an important issue in areas related to IoT. With all of this IoT data being transmitted, the negative consequences of losing privacy increases. As all the household appliances, industrial machinery, public sector services like water supply and transport, and many other devices are connected to the Internet; therefore, a lot of information is available on it. This information is prone to attack by hackers and it would be very disastrous if private and confidential information is accessed by unauthorized intruders. Furthermore, as (Cognizant, 2014, p.6) [14] mentioned, with many devices used for personal activities, many users might not even be aware of the types of personally identifiable data being collected, raising serious privacy concerns.

2.2.3 Safety

There is a chance that the software can be hacked, and someone's personal information get misused. The possibilities are endless. Imagine if a notorious hacker changes one's prescription, it could put the person at risk. Or if a store automatically ships you an equivalent product that you are allergic to, or a flavor that you do not like, or a product that is already expired. As a result, safety is ultimately in the hands of the consumer to verify any and all automation. Safety can also be described as an aspect of security against unwanted attacks.

2.2.4 Over-Reliance on Technology

People's lives will be increasingly controlled by technology and will be dependent on it. The younger generation is already addicted to technology for every little thing. People will have to decide how much of their daily lives they are willing to mechanize and be controlled by technology. Moreover, (Suny Cortland, 2012) [72] reminded that there are glitches that occur constantly in technology, specifically involving the Internet. Depending on the amount that an individual relies on the information supplied could be detrimental if the system collapses.

2.2.5 Lesser Employment

As per (Suny Cortland, 2012) [72], the connecting of more and more devices to the Internet will result in the loss of jobs. The automation of IoT "will have a devastating impact on the employment prospects of less-educated workers". For example, people who evaluate inventory will lose their jobs because devices can not only communicate between each other, but they can also transmit that information to the owner. Already, there have being jobs lost to automated machines, such as the checkout line in supermarkets and even ATM's.

2.2.6 Compatibility

Currently, there is no international standard for the tagging and monitoring equipment. However, this disadvantage is the easiest to overcome as the manufacturers just need to agree to a common standard, such as Bluetooth, USB, etc. This is nothing new or innovative needed.

Today, there are Bluetooth-enabled devices and compatibility problems exist even in this technology! Compatibility issues may result in people buying appliances from a certain manufacturer, leading to its monopoly in the market.

2.2.7 Data and Information Management issues

(Cognizant, 2014, p.6) [14] explained that routing, capturing, analyzing and using the insights generated by huge volumes of IoT data in timely and relevant ways is a huge challenge with traditional infrastructures. The sheer magnitude of the data collected will require sophisticated algorithms that can sift, analyze and deliver value from data. As more devices enter the market, more data silos will be formed, creating a complex network of connections between isolated data sources. The lack of universal standards and protocols will make it even tougher for organizations to eliminate data silos.

3. Other Applications and Services of IoT

From (Al-Fuqaha et al., 2015, p.5) [2], the ultimate goal of all IoT applications is to reach the level of ubiquitous services. IoT can impact many industrial areas while enhancing the quality of life, economy, society, etc. Its list of applications is not exhaustive.

3.1 Agriculture

According to (Ge, Bangui, & Buhnova, 2018) [24], agriculture is a vital domain of our society that takes advantage of the benefits from IoT technologies to assure the quality of the products and the satisfaction of end-customers. For example, monitoring from IoT devices plays an important role to protect the agricultural products from attacks by rodents or insects. To effectively manage all the agricultural activities and find the optimal environmental conditions, cloud platforms are used to store and analyze the sensed information and in turn improve the agricultural productivity as well as save energy. Likewise, as noted by (Borgia, 2014, p.9) [9], monitoring and controlling agricultural production and feed (e.g., presence of OMGs, additives, melanin) by using advanced sensor systems are further applications of IoT that will help ensure the health of plant origin products intended both for human and animal consumption. Figure 5 shows the application of IoT in agriculture (farming).

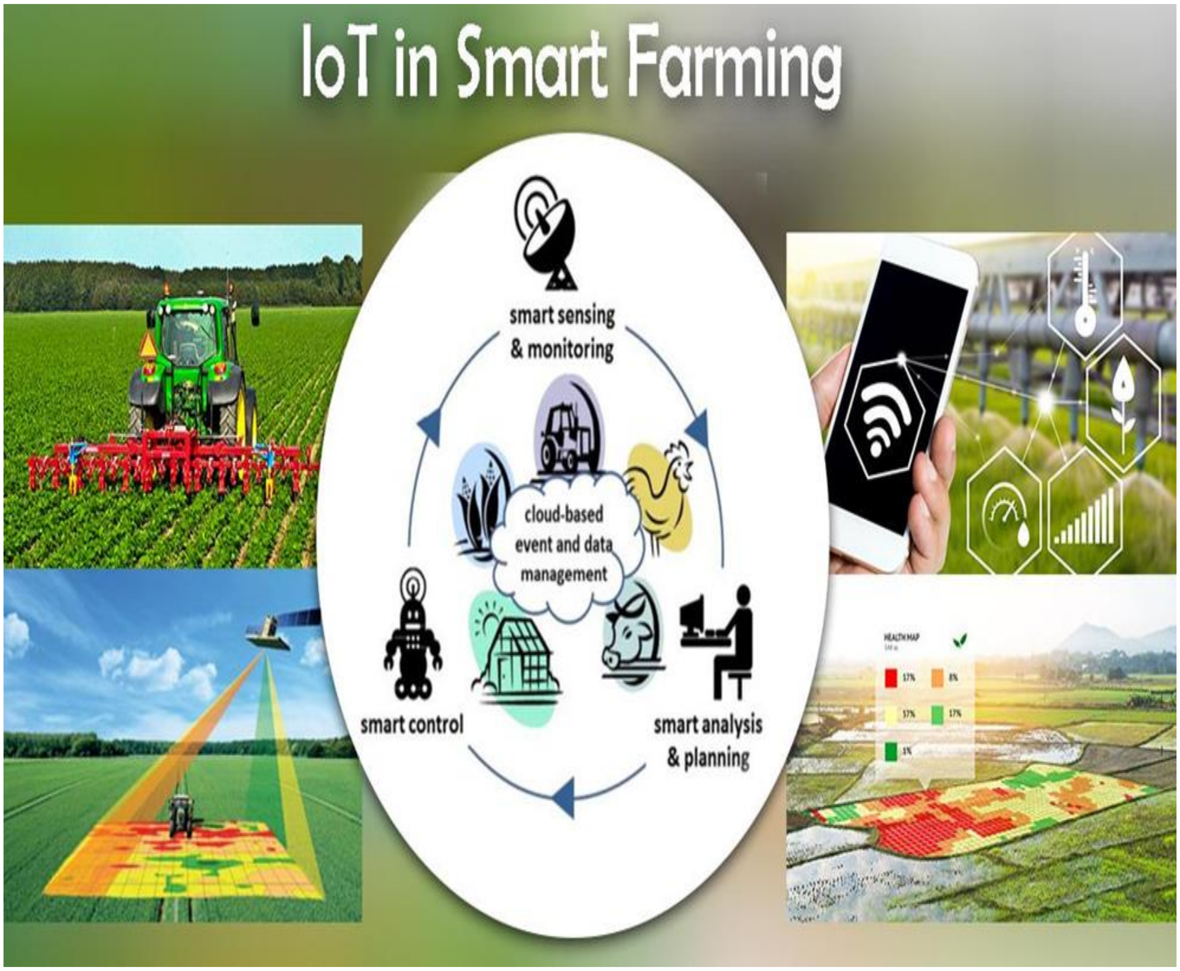

Figure 5: This shows how IoT can change the way farmers work by assuring the quality of products through monitoring, analyzing, and controlling the operations remotely on their device [7].

3.2 Breeding

As stated by (Borgia, 2014, p.8) [9], the regulations for traceability of animals require a continuous monitoring of animals and of their movements in order to report promptly to the appropriate authorities any relevant events, e.g., diseases. The use of IoT identification systems (e.g. RFID, sensors) allows to identify and monitor animals, and to isolate any infected animals from the healthy ones, thus avoiding the spread of contagious disease. Advanced microchips may store information about the status of the animal (e.g., demographic information, veterinary checks, contracted diseases, vaccines performed) or transmit information about the animal's body health (e.g., temperature) to streamline animal health

[7] DataFlair Team. (2018, 09 15). IoT Applications: Top 10 Uses of Internet of Things. Retrieved from https://data-flair.training/blogs/iot-applications/

certification, to control trade and imports, and to avoid possible frauds. More, by analyzing collected data, authorities may verify the actual number of livestock reported by local breeders and provide subsidies, accordingly.

3.3 Logistic and Product Lifetime Management

As mentioned by (Borgia, 2014, p.8) [9], the first relevant example of an industrial IoT application is the logistics and supply chain management. RFIDs can be attached to objects and used to identify materials and goods such as garments, furniture, equipment, food, and liquids. Their use help to manage efficiently warehouses and retails, and to simplify the inventory by providing accurate knowledge of current inventory, while reducing inventory inaccuracies.

Advanced IoT systems, composed of RFID-equipped items and smart shelves tracking items in real-time, may help to reduce material waste, thus lowering costs and improving profit margins for both retailers and manufacturers. Underproduction and overproduction may reduce drastically by having a correct estimate of needed items, which can be inferred by analyzing data collected by smart shelves. In addition, the real-time analysis by sensors allows to identify product deterioration events, which is of vital importance for food and liquids. For example, to ensure the freshness of perishables (e.g., fruits, vegetables, frozen food), sensors may monitor continuously temperature and humidity inside storages or cold storages, and actuators may modify them to make optimal the conservation of contained food.

Furthermore, the entire lifecycle of objects can be tracked too. For example, RFID readers installed along the production plant allow to monitor the production process, while the label can be traced throughout the entire supply chain (e.g., packaging, transportation, warehousing, sale to the customer, disposal).

3.4 Industrial Automation (Manufacturing)

As highlighted by (Al-Fuqaha et al., 2015, p.6) [2], Industrial Automation is computerizing robotic devices to complete manufacturing tasks with a minimal human involvement. It allows a group of machines to produce products quickly and more accurately based on four elements: transportation, processing, sensing and communication. The IoT is utilized in industrial automation to control and monitor production machines' operations, functionalities, and productivity rates through the Internet. For instance, if a particular production machine encounters a sudden issue, an IoT system sends a maintenance request immediately to the maintenance department to handle the fix. Furthermore, the IoT increases productivity by analyzing production data, timing and causes of production issues.

Moreover, from (Sannapureddy, 2015) [60], by using this IoT technology, manufacturing processes can be automated remotely. It can be helpful to monitor the emission of toxic gases to avoid damage to workers' health and the environment.

3.5 Smart Home

Smart Home is a very powerful application of IoT. Smart home products are promised to save time, energy and money. According to (Al-Fuqaha et al., 2015, p.5) [2], smart homes are required to have regular interaction with their internal and external environments. The internal environment may include all the home appliances and devices that are Internet-connected while the external environment may consist of entities that are not in control of the smart home such as smart grid entities. As it is, IoT services contribute to enhancing the personal lifestyle by making it easier and more convenient to monitor and operate home appliances and systems (e.g. air conditioner, heating systems, energy consumption meters, video surveillance, etc.) remotely. For example, a smart home can automatically close the windows and lower the blinds of upstairs windows based on the weather forecast. Also, as per (Sannapureddy, 2015) [60], it can be useful in detecting and avoiding thefts (See Figure 6).

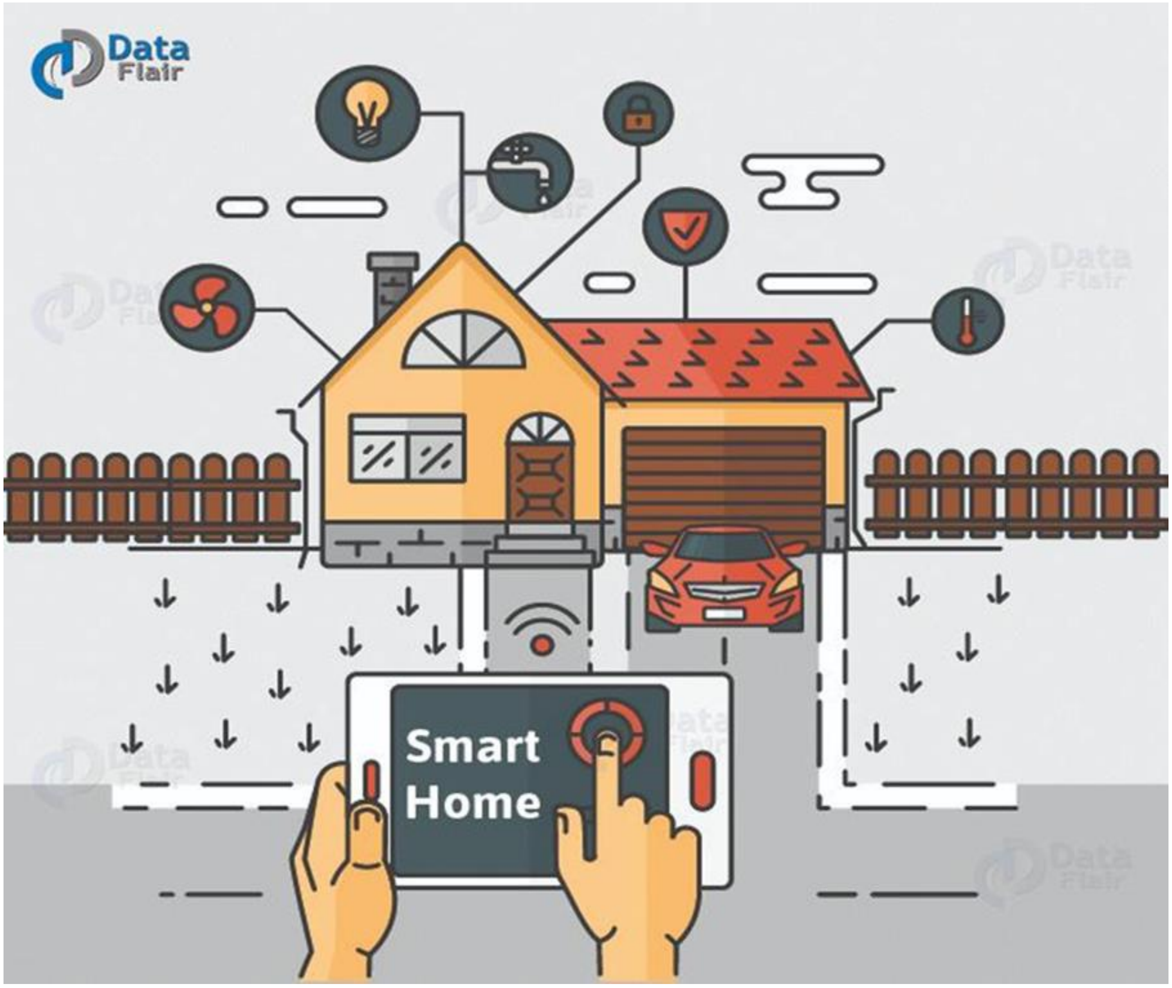

Figure 6: This shows how from a device whether be a smartphone or a tablet, IoT can be used to remotely monitor and program the appliances in a home[8].

3.6 Smart Building

(Miorandi et al., 2012, p.13-14) [46] stated that, instrumenting buildings with advanced IoT technologies may help in both reducing the consumption of resources associated to buildings (electricity, water) as well as in improving the satisfaction level of humans populating it, be it workers for office buildings or tenants for private houses. Impact is both in economic terms (reduced operational expenditures) as well as societal ones (reducing the carbon footprint associated to buildings, which are key contributors to the global greenhouse gas emissions). In this application, a key role is played by sensors, which are used to both monitor resource consumption as well as to proactively detect current users' needs.

[8] DataFlair Team. (2018, 09 15). IoT Applications: Top 10 Uses of Internet of Things. Retrieved from https://data-flair.training/blogs/iot-applications/

3.7 Smart Grid

As mentioned by (Borgia, 2014, p.10) [9], energy management is a requirement towards a sustainable environment and the smart grid represents a building block for its realization. The smart grid is defined as an intelligent electrical distribution system that delivers energy flows from producers to consumers in a bidirectional way. Unlike the traditional power grids, where the energy is generated only by a few central power plants and it is ‘‘broadcasted’’ to the final customers, via a large network of cables/transformers/substations, in the smart grid the producers may also be the final customers. The energy produced by the customers’ micro-grids (e.g., through solar panels, wind turbines) is sent to the grid, which, in turn, manages it appropriately through smart energy control services and stores it in specific energy storages. Monitoring and exchanging information about energy flows are additional applications of the smart grid. Using smart meters, automatic control devices, smart switches, smart appliances, the grid is able to know in advance the expected demands and to adapt the production and consumption of electricity, consequently avoiding peak loads, eliminating possible blackouts and acting promptly in case of failures/leaks. Information concerning consumed electricity is delivered to customers in order to increase their personal awareness about energy consumption habits and to lead them to a more rational energy usage. Figure 7 shows different areas IoT can be applied with the help of smart grid.

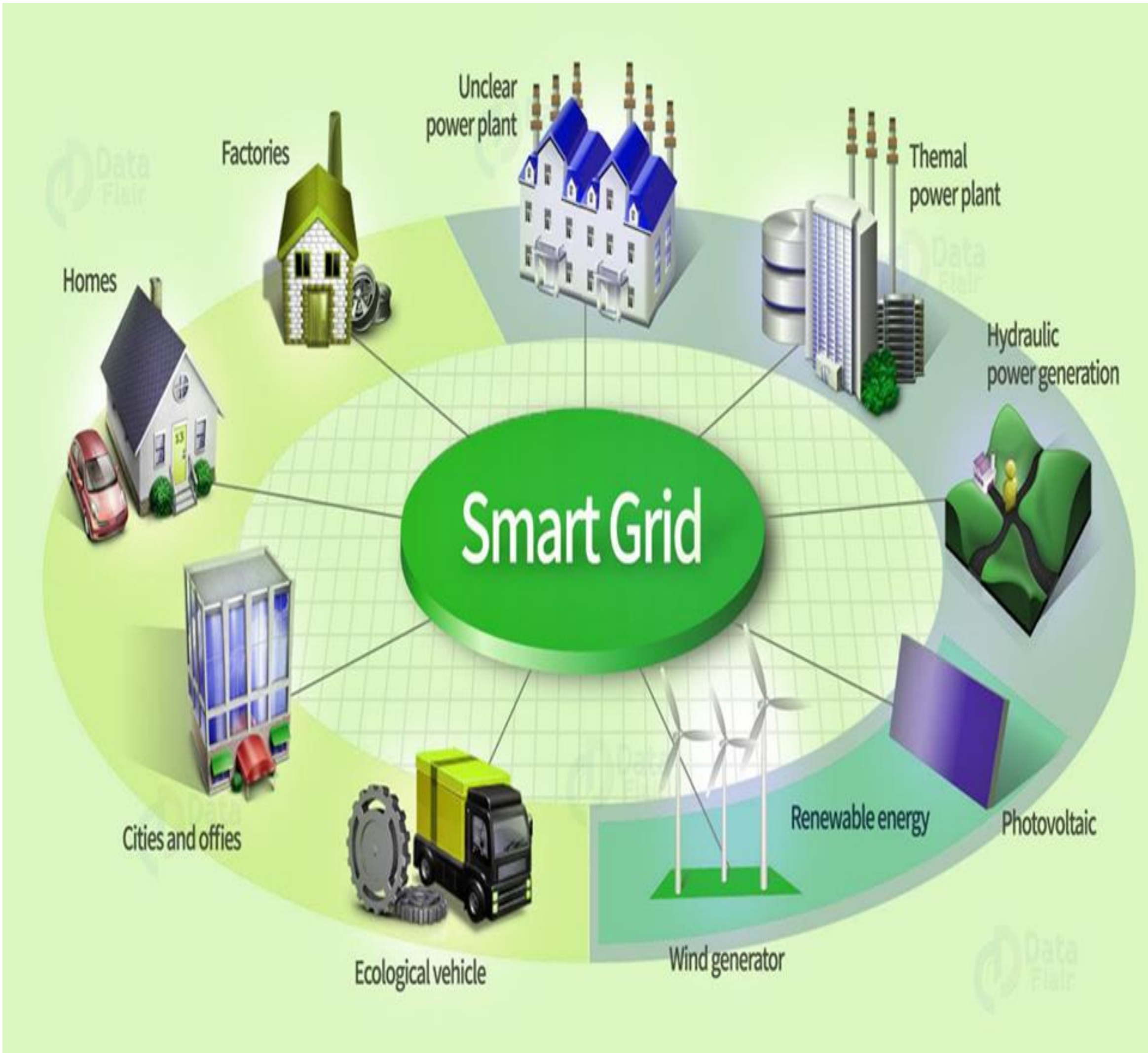

Figure 7: Different areas IoT can be applied by smart grid [9].

3.8 Public Safety Monitoring

As discussed by (Borgia, 2014, p.10) [9], local and national governments aim at creating secure society, by guaranteeing public safety and by planning emergency management accurately. The public security services include the maintenance of public order, the prevention and protection of citizens, and the safeguard of public and private properties. Emergency management assists the society in preparing for and coping with natural or man-made disasters such as chemical leaks, floods, fire, earthquakes, tornadoes, epidemics, and electrical outages. IoT offers solutions for monitoring and tackling these

[9] DataFlair Team. (2018, 09 15). IoT Applications: Top 10 Uses of Internet of Things. Retrieved from https://data-flair.training/blogs/iot-applications/

emergency scenarios. Data collected by fixed cameras located within the city and on personal citizens' devices allow advanced video surveillance and territorial monitoring services while helping the police to control public order in case of sport events, musical performances, political meetings. Safety of private and public buildings (e.g., banks, shops) can be reinforced by using sensor technology that will trigger alarms. Emergency management operations such as pre-emergency[10], lifesaving[11] and post-emergency[12] operations, can also be improved and strengthened through the use of IoT technologies. Currently, the emergency system lacks precise information about the emergency site. Dedicated sensors and intelligent cameras, as well as GPS and wireless technologies providing real-time localization and tracking, can be used to form a complete map of the event, to forecast its trends (e.g., direction and/ or speed of fire spread, major risk areas), and thus to establish a dynamic emergency plan to coordinate the rescue operations.

3.9 Environmental Monitoring

(Miorandi et al., 2012, p.14) [46] mentioned that IoT technology can be suitably applied to environmental monitoring applications. In this case, a key role is played by the ability of sensing, in a distributed and self-managing fashion, natural phenomena and processes (e.g., temperature, wind, rainfall, river height), as well as to seamlessly integrate such heterogeneous data into global applications. Real-time information processing, coupled with the ability of a large number of devices to communicate among them, provide a solid platform to detect and monitor anomalies that can lead to endangering human and animal life. Moreover, the vast deployment of miniaturized devices may enable access to critical areas whereby the presence of human operators might not represent a viable option (e.g., volcanic areas, oceanic abysses, remote areas), from where sensed information can be communicated to a decision point in order to detect anomalous conditions. In this perspective, IoT technologies can enable the development of a new generation of monitoring and decision support systems, providing enhanced granularity and real-time capabilities over current solutions. Another case in which the sensing ability of IoT devices supports the environmental safety is represented by fire detection. When a suite of sensors detects the possible presence of fire (by means, e.g., of temperature sensors), an alarm is sent directly to the fire department in a short time (exploiting the advanced

[10] This type of operations is based on the premise that sufficient warning allows the mobilization of resources.

[11] This operation deals with the rescue of the injured, provision of medical care, evacuation of homeless, firefighting, route clearance, salvage, etc. in and around the damaged area immediately after impact.

[12] This type of operation leads to full recovery and a return to a state of normality.
A concept of operations for emergency site management. (n.d.). Retrieved from https://www2.gnb.ca/content/dam/gnb/Departments/ps-sp/pdf/emo/sitemanag-e.pdf

communication features of IoT platform), along with other parameters that are useful in decision making and support, such as the description of the area subject to the fire, the possible presence of people, of inflammable materials, etc. Clearly, rapid response has the consequence of saving human lives, mitigating the damage to the property or vegetation and in general reducing the level of disaster.

3.10 Healthcare

(Al-Fuqaha et al., 2015, p.6) [2] stated that, smart healthcare plays a significant role in healthcare applications through embedding sensors and actuators in patients and their medication for monitoring and tracking purposes. The IoT is used by clinical care to monitor physiological statuses of patients through sensors by collecting and analyzing their information and then sending analyzed patient's data remotely to processing centers to make suitable actions. For example, Masimo Radical-7 monitors the patient's status remotely and reports that to a clinical staff. Recently, IBM utilized RFID technology at one of OhioHealth's hospitals to track hand washing after checking each patient. They realized that this operation could be used to avoid infections that cause about 90 000 deaths and lose about $30 billion annually. Also, according to (Rouse, 2019) [58], IoT systems can be used in hospitals to complete tasks such as inventory management, for both pharmaceuticals and medical instruments. Figure 8 shows how through connected devices a patient's health can be monitored.

Figure 8: Monitoring of a patient's health through connected devices[13].

3.11 Mobile Gadgets

According to (Ebersold & Glass, 2015, p.3) [19], mobile gadgets that are capable of acting as a sensor and provide real-time data transmission are being developed in increasing numbers. These devices are being used in applications that support individual users as well as providing social value such as aggregating the data to identify commuting patterns or traffic patterns that could be better understood, and even shaped in real-time. Individuals may use real-time data to actively manage their time more flexibly by receiving traffic updates, viewing the whereabouts of friends and colleagues through geo-tagging devices, changing meeting times and locations based on real-time information or to monitor air quality, weather and other urban environmental concerns.

Moreover, individuals are now using IoT gadgets to inform themselves, particularly in the area of monitoring one's physical indicators for personal health. This Quantified Self movement is not solely supported by mobile devices such as smartphones and is increasingly likely to be enabled through a variety of wearable technology, such as smart watches, bracelets, and necklaces. These are among a wider variety of new mobile technologies that are rapidly being developed. Wearables continue 24/7

[13] Hacking Medicine Institute's New App Review Program Helps Patients, Providers Cut through the Noise. (2016, 04 30). Retrieved from https://medtechboston.medstro.com/blog/2016/04/30/hacking-medicine-institute-digital-health-app-review-helps-patients-providers-cut-through-the-noise/

updates of a person or status—what they are up to, or what they are thinking'. So far, according to (Analytics Vidhya, 2016) [4], companies like Google, Samsung have invested heavily in building such devices. These devices broadly cover fitness, health and entertainment requirements. The pre-requisite from the IoT technology or wearable applications is to be highly energy efficient or ultra-low power and small sized.

3.12 Military

Based on (Ge et al., 2015) [21], the application of IoT is extended to the military domain and brings a significant and valuable source of information that could improve the intelligence of various military applications such as military logistics, surveillance and military robots. Furthermore, the integration of IoT in military domain is expected to save lives of citizens by detecting harmful chemicals or biological weapons. For these reasons, the management and analysis of the shared information is necessary to make the right protective decisions, provide guidelines to perform the tasks as well as understand, in real-time, the implications of these decisions. For example, the Internet of Battle Things (IoBT) is one of the IoT applications that introduces future smart battlefields. In this smart environment, the intelligent things are communicating, acting, and collaborating with one another without neither the presence nor the coordination of human war fighters. Unfortunately, according to (GlobalData Thematic Research, 2019) [26], there are many ethical dilemmas that arise from this IoT application, which involves firing against targets, especially when it comes to operations in civilian areas, where human identification and clearance for firing will always be necessary. This necessity is expected to act as barriers to the rapid expansion of IoBT in the field of armed unmanned systems. Therefore, for this reason, it is important for a user to invest in the quality and quantity of its sensors, so as to be able to recognize and identify targets.

3.13 Education

(DataFlair Team, 2018) [18] pointed out, one of the very smart components of present-day colleges and classrooms is that the IoT improves schooling itself and brings advanced benefit to the physical surroundings and systems. A smart college has facilities that function easily and provide a better step of getting to know each other personally. The smart gadgets that are used within the campus employ Wi-Fi community to send data and acquire commands. A computational Internet of Things gadget for faculties and studying facilities enables to create smarter lesson plans, maintain a tune of critical resources, improves admission records, design safer campuses and much more.

For instance, IoT can bring interactive gaining of knowledge in an educational setting. Getting to know these days is not restrained to the mixture of texts and pictures but beyond that. Most of the textbooks are paired with net-primarily based websites that consist of extra substances, films, exams, animations and different substances to support the mastering. This gives a broader outlook to the students to analyze new things with a better understanding and interplay with instructors and their friends. The instructional professionals can bring the actual world troubles inside the study room and permit college students to find their very own answers.

Part III: Enabling Technologies and Protocols of the Internet of Things

From (Santiago & Salazar, 2017, p.19) [61], successful application of the IoT concept into the real world is possible thanks to advancements in the underlying technologies and protocols cited below.

4. IoT Enabling (Drivers) Technologies

IoT is pushed forward by intelligence built into objects. Here are some of the most relevant enabling technologies that enable IoT systems to spread in the world. Each illustrates their function in IoT. Below, Figure 9 summarizes these enabling technologies.

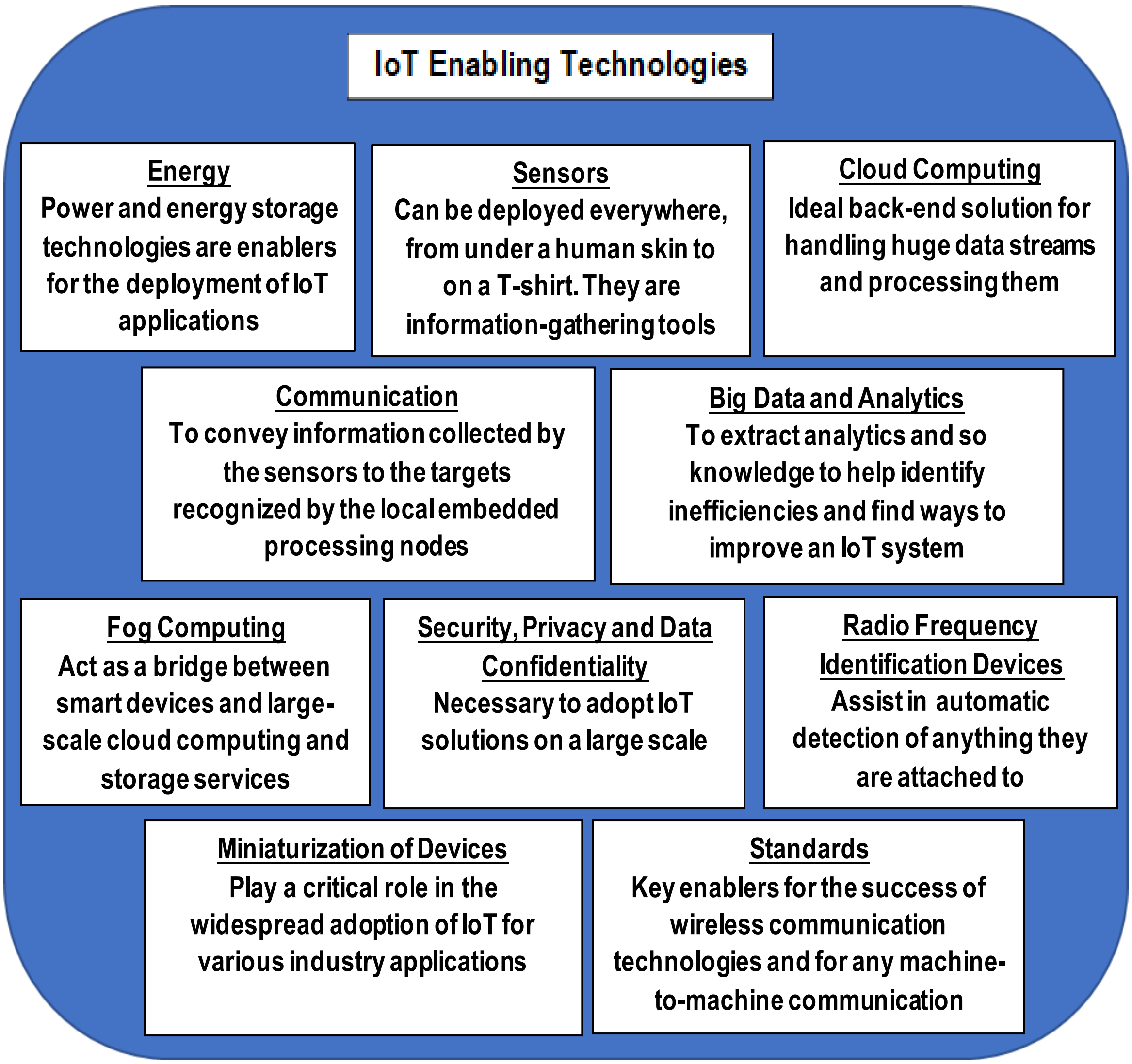

Figure 9: An overview of IoT enabling technologies

4.1 Energy

As referred by (Santiago & Salazar, 2017, p.20) [61], power and energy storage technologies are enablers for the deployment of IoT applications. Energy issues, in all its phases, from harvesting to conservation and usage, are central to the development of the IoT. These technologies have to provide high power-density energy generation and harvesting solutions which, when used with today's low power nanoelectronics, will enable to design self-powered intelligent sensor-based wireless identifiable device.

4.2 Sensors

According to (Abraham C, 2016, p.5) [1], sensors are information gathering tools that are responsible for collecting the specified information in a specific environment and then carrying the information with specific electrical signals from the collected information. As per (Santiago & Salazar, 2017, p.21) [61], they are one of the key building blocks of the Internet of Things. As ubiquitous systems, they can be deployed everywhere. They can also be implanted under human skin, in a purse or on a T-shirt. Some can be as small as four millimetres in size, but the data they collect can be received hundreds of miles away. They complement human senses and have become indispensable in a large number of industries, from health care to construction. Sensors have the key advantage that they can anticipate human needs based on information collected about their context. Their intelligence multiplied by numerous networks allows them not only to report about external environment, but also take action without human intervention.

4.3 Cloud Computing

From (IMDA, n.d., p.11) [74], Cloud computing is one of the enabling platforms to support IoT. As set out by (Santiago & Salazar, 2017, p.22) [61], Cloud computing is a model for on-demand access to a shared pool of configurable resources (e.g., computers, networks, servers, storage, applications, services, software) that can be provisioned as Infrastructure as a Service (IaaS) or Software as a Service (SaaS). One of the most important outcomes of the IoT is an enormous amount of data generated from devices connected to the Internet. Many IoT applications require massive data storage, huge processing speed to enable real-time decision making, and high-speed broadband networks to stream data, audio, or video. Cloud computing provides an ideal back-end solution for handling huge data streams and processing them for the unprecedented number of IoT devices and humans in real-time.

4.4 Communication

(Abraham C, 2016, p.5) [1] said, the main responsibility of the communication node is to convey information collected by the sensors to the targets recognized by the local embedded processing nodes. The IoT will cover every phase of one's daily life, therefore there is no boundary to the distance for which control and command communication can be used.

As noted by (Santiago & Salazar, 2017, p.23) [61], new, smart multi-frequency band antennas, integrated on-chip and made of new materials are the communication means that will enable the devices to communicate. On-chip antennas must be optimized for size, cost and efficiency, and could come in various forms like coil on chip, printed antennas, embedded antennas, and multiple antenna using different substrates and 3D structures. Modulation schemes and transmission speed are important issues to be tackled allowing multi-frequency energy efficient communication protocols and transmission rates. The communication protocols will be designed for Web oriented architectures of the IoT platform where all objects, wireless devices, cameras, PCs etc. are combined to analyze location, intent and even emotions over a network. New methods of effectively managing power consumption at different levels of the network design are needed, from network routing down to the architecture of individual devices.

4.5 Big Data and Analytics

Big data and IoT work closely together. (Al-Fuqaha et al., 2015, p.18) [2] stipulated that, what makes big data an important asset to businesses is that it makes it possible to extract analytics and consequently knowledge, by which a business can achieve competitive advantage. There are some platforms for big data analytics like Apache Hadoop and SciDB. However, these tools are hardly strong enough for big data needs of IoT. The amount of IoT data generally is too huge to be fed and processed by the available tools. In support of the IoT, these platforms should work in real-time to serve the users efficiently. For example, Facebook has used an improved version of Hadoop to analyze billions of messages per day and offer real-time statistics of user actions. In addition, instead of providing application specific analytics, IoT needs a common big data analytic platform which can be delivered as a service to IoT applications. Such analytic service should not impose a considerable overhead on the overall IoT ecosystem.

4.6 Fog Computing

As stated by (Al-Fuqaha et al., 2015, p.19-20) [2], fog computing (also known as cloudlets or edge computing) can act as a bridge between smart devices and large-scale cloud computing and storage services. Through fog computing, it is possible to extend cloud computing services to the edge devices of the network. Because of their proximity to the end users compared to the cloud data centers, fog computing has the potential to offer services that deliver better delay performance. Further, fog computing can serve as an optimal choice for the IoT designers. For instance, Fog allows IoT systems to be more scalable such that as the number of end-users increase, the number of deployed "micro" fog centers can increase to cope with the increasing load. Such an increase cannot be achieved by the cloud because the deployment of new datacenters is cost prohibitive. In general, fog computing has the potential to increase the overall performance of IoT applications as it tries to perform part of high-level services which are offered by cloud inside the local resources.

4.7 Security – Privacy and Data confidentiality

According to (Miorandi et al., 2012, p.9,11) [46], security represents a critical component for enabling the widespread adoption of IoT technologies and applications. Privacy and Data confidentiality are essential parts of security. Privacy is defined as the rules under which data referring to individual users may be accessed. The main reasons that makes privacy a fundamental IoT requirement lies in the envisioned IoT application domains and in the technologies used. As for Data confidentiality, it represents a fundamental issue in IoT scenarios, indicating the guarantee that only authorized entities can access and modify data. That said, without guarantees in terms of system-level confidentiality, authenticity and privacy, the relevant stakeholders are unlikely to adopt IoT solutions on a large scale. Overall, as mentioned by (IMDA, n.d., p.13) [74], with the IoT-distributed nature of embedded devices in public areas, threats coming from networks trying to spoof data access, collection and privacy controls to allow the sharing of real-time information, IoT security has to be implemented on a strong foundation built on a holistic view of security for all IoT elements at various interacting layers.

4.8 Radio Frequency Identification Devices (RFID)

As per (IMDA, n.d., p.8) [74], RFID technology is of particular importance to IoT as one of the first industrial realizations is in the use of RFID technology to track and monitor goods in the logistics and supply chain sector. In addition, (Abraham C, 2016, p.5) [1] mentioned that, they assist in the automatic detection of anything they are attached to, acting as an electronic barcode. With objects tagged with RFID and paired with the Internet of Things applications, consumers can improve their everyday wellbeing and even save time and money in the long run. Overall, as noted by (Miorandi et al., 2012, p.4), [46], RFID is expected to play a key role as an enabling identification technology in IoT.

4.9 Miniaturization of Devices

As mentioned by (IMDA, n.d., p.5) [74], IoT uses technologies to connect physical objects to the Internet. The size (and cost) of electronic components that are needed to support capabilities such as sensing, tracking and control mechanisms, play a critical role in the widespread adoption of IoT for various industry applications. Many applications such as remote healthcare and environmental monitoring require these integrated chipsets not only to be small, but also concealable and to act as "tiny" computers to sense the physical subjects. As it is, according to (Joe B., 2019) [33], in the world of Internet of Things (IoT), miniaturization is enabling new applications in the form of wearables, vehicles and transportation, disposable tracking tech for pharmaceuticals and produce, and more uses than we can count for smart city and smart home use.

4.10 Standards

(Santiago & Salazar, 2017, p.25) [61] noted that IoT devices are quite diverse and measure different parameters and with different conventions and units of measure. Though competing proprietary protocols keep getting proposed, it is likely that open source standards will be one of the ways to get this data to interoperate.

Clearly, open standards are key enablers for the success of wireless communication technologies and, in general, for any kind of Machine-to-Machine (M2M) communication. However, the need for faster setting of interoperable standards has been recognized an important element for IoT applications deployment. Clarification on the requirements for a unique global identification, naming and resolver is needed.

5. IoT Protocols

There are different protocols that fit together to provide the required IoT services. (Al-Fuqaha et al., 2015, p.2) [2] indicated that IoT protocols are needed for communication compatibility between heterogeneous things (living things, vehicles, phones, appliances, goods, etc.). Below is a list of some of the popular protocols shared by (Al-Fuqaha et al., 2015) [2] that helps power IoT devices and applications. Table 3 and Figure 10 gives the abbreviations and summarizes these IoT protocols respectively.

Table 3 : These are the abbreviations of the following detailed IoT protocols

Abbreviations of IoT Protocols	
CoAP	Constrained Application Protocols
MQTT	Message Queue Telemetry Transport
AMQP	Advanced Message Queuing Protocol
XMPP	Extensible Messaging and Presence Protocol
IPv6	Internet Protocol version 6
EPC	Electronic Product Code
mDNS	Multicast DNS
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
IEEE 802.15.4	For Low-rate wireless private area networks

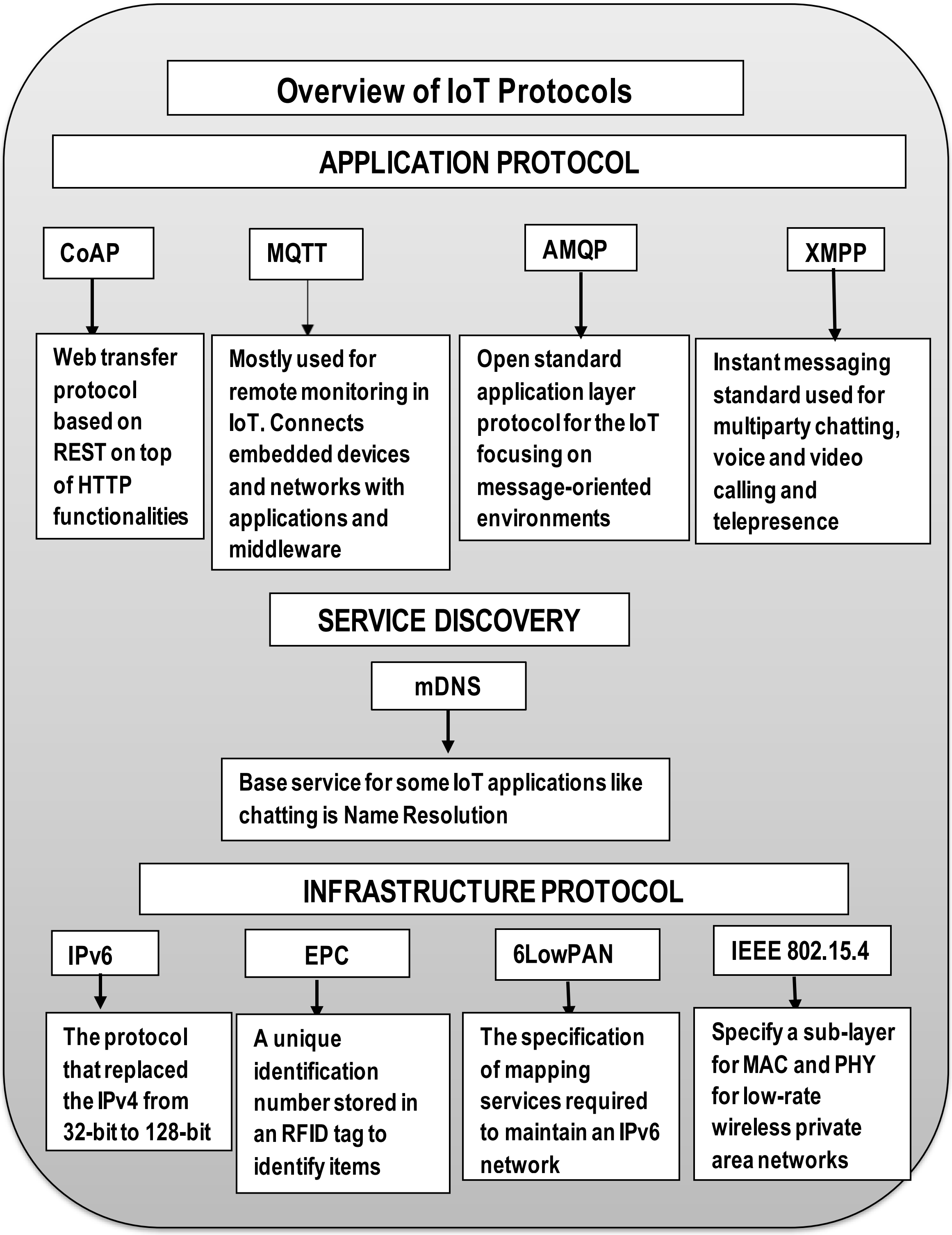

Figure 10: This is a summary of different IoT protocols that can deliver required IoT services[14].

[14] Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. *IEEE Communications Surveys & Tutorials, 17*(4), 2349. doi:10.1109/comst.2015.2444095

5.1 Constrained Application Protocols (CoAP)

The CoAP is an application layer protocol for IoT applications. It is mainly developed for constrained devices. The CoAP defines a web transfer protocol based on Representational State Transfer (REST) on top of HTTP functionalities. REST represents a simpler way to exchange data between clients and servers over HTTP. It is used within mobile and social network applications and it eliminates ambiguity by using HTTP get, post, put, and delete methods. For example, the GET method can be used by a server to inquire the client's temperature using the piggybacked response mode. The client sends back the temperature if it exists; otherwise, it replies with a status code to indicate that the requested data is not found. Furthermore, CoAP modifies some HTTP functionalities to meet the IoT requirements such as low power consumption and operation in the presence of lossy and noisy links.

5.2 Message Queue Telemetry Transport (MQTT)

MQTT is a messaging protocol that is mostly used for remote monitoring in IoT. MQTT aims at connecting embedded devices and networks with applications and middleware. The connection operation uses a routing mechanism (one-to-one, one-to-many, many-to-many) and enables MQTT as an optimal connection protocol for the IoT and M2M. More, MQTT simply consists of three components: subscriber, publisher, and broker. An interested device would register as a subscriber for specific topics in order for it to be informed by the broker when publishers publish topics of interest. The publisher acts as a generator of interesting data. After that, the publisher transmits the information to the interested entities (subscribers) through the broker. Furthermore, the broker achieves security by checking authorization of the publishers and the subscribers. Numerous applications utilize the MQTT such as healthcare, monitoring, energy meter, and Facebook notification. In all, the MQTT protocol represents an ideal messaging protocol for the IoT and M2M communications and is able to provide routing for small, cheap, low power and low memory devices in vulnerable and low bandwidth networks.

5.3 Advanced Message Queuing Protocol (AMQP)

AMQP is an open standard application layer protocol for the IoT focusing on message-oriented environments. It supports reliable communication via message delivery guarantee primitives including at-most-once, at-least-once and exactly once delivery. AMQP requires a reliable transport protocol like TCP to exchange messages.

By defining a wire-level protocol, AMQP implementations are able to interoperate with each other. Communications are handled by two main components: exchanges and message queues. Exchanges are used to route the messages to appropriate queues. Routing between exchanges and message queues is based on some predefined rules and conditions. Messages can be stored in message queues and then be sent to receivers. Beyond this type of point-to-point communication, AMQP also supports the publish/subscribe communications model.

5.4 Extensible Messaging and Presence Protocol (XMPP)

XMPP is an IETF (Internet Engineering Task Force) instant messaging (IM) standard that is used for multiparty chatting, voice and video calling and telepresence. XMPP was developed by the Jabber open source community to support an open, secure, spam free and decentralized messaging protocol. XMPP allows users to communicate with each other by sending instant messages on the Internet no matter which operating system they are using. XMPP allows IM applications to achieve authentication, access control, privacy measurement, hop-by-hop and end-to-end encryption, and compatibility with other protocols. Also, many XMPP features make it a preferred protocol by most IM applications and relevant within the scope of the IoT. It runs over a variety of Internet-based platforms in a decentralized fashion. XMPP is secure and allows for the addition of new applications on top of the core protocols.

5.5 Internet Protocol version 6 (IPv6)

According to (Santiago & Salazar, 2017, p.8) [61], in order to connect any device to the Internet, it's necessary to provide an IP address to the device. IPv6 is the most recent version of the IP, the communications protocol that provides an identification and location system for computers on networks and routes traffic across the Internet. The IPv6 is the successor protocol that replaced the IPv4 (Internet protocol version 4) as it was limited to a number of 32-bit address format, approximately 4.3 billion addresses for devices connected to internet around the world. But now, IPv6 uses a 128-bit address format, allowing 2^{128}, or approximately 3.4×10^{38} addresses, approximately 8×10^{28} times as many as IPv4. While increasing the pool of addresses is one of the most important benefits of IPv6, there are other important technological changes in IPv6 that improve the IP protocol: easier administration, better multicast routing, a simpler header format and more efficient routing, built-in authentication and privacy support among others.

5.6 Electronic Product Code (EPC)

The Electronic Product Code (EPC), an infrastructure protocol, is a unique identification number which is stored on an RFID tag and is used basically in the supply chain management to identify items. EPC global as the original organization responsible for the development of EPC, manages EPC and RFID technology and standards. The underlying architecture uses Internet based RFID technologies along with cheap RFID tags and readers to share product information. This architecture is recognized as a promising technique for the future of the IoT because of its openness, scalability, interoperability and reliability beyond its support to the primary IoT requirements such as objects IDs and service discovery.

5.7 Multicast DNS (mDNS)

Multicast DNS is a service discovery protocol. It is a base service for some IoT applications like chatting is Name Resolution. mDNS is such a service that can perform the task of unicast DNS server. mDNS is flexible due to the fact that the DNS namespace is used locally without extra expenses or configuration. mDNS is an appropriate choice for embedded Internet-based devices due to the facts that a) There is no need for manual reconfiguration or extra administration to manage devices; b) It is able to run without infrastructure; and c) It is able to continue working if failure of infrastructure happens. mDNS inquires names by sending an IP multicast message to all the nodes in the local domain. By this query, the client asks devices that have the given name to respond back. When the target machine receives its name, it multicasts a response message which contains its IP address. All devices in the network that obtain the response message update their local cache using the given name and IP address.

5.8 IPv6 over Low power Wireless Personal Area Networks (6LowPAN)

6LowPAN (WPANs), which many IoT communications may rely on, have some special characteristics different from former link layer technologies like limited packet size (e.g., maximum 127 bytes for IEEE 802.15.4), various address lengths, and low bandwidth. So, there was a need to make an adaptation layer that fits IPv6 packets to the IEEE 802.15.4 specifications. The IETF 6LoWPAN working group developed such a standard in 2007. 6LoWPAN is the specification of mapping services required by the IPv6 over Low power WPANs to maintain an IPv6 network. The standard provides header compression to reduce the transmission overhead, fragmentation to meet the IPv6 Maximum Transmission Unit (MTU) requirement and forwarding to link-layer to support multi-hop delivery. Also, 6LoWPAN removes a lot of IPv6 overheads in such a way that a small IPv6 datagram can be sent over a single IEEE 802.15.4 hop in the best case. It can compress IPv6 headers to two bytes.

5.9 IEEE 802.15.4

The IEEE 802.15.4 is a protocol that was created to specify a sub-layer for Medium Access Control (MAC) and a physical layer (PHY) for low-rate wireless private area networks (LR-WPAN). Due to its specifications such as low power consumption, low data rate, low cost, and high message throughput, it is also utilized by the IoT, M2M, and WSNs. It provides a reliable communication, operability on different platforms, and can handle a large number of nodes (about 65 k). It also provides a high level of security, encryption and authentication services. However, it does not provide QoS guarantees. This protocol is the base for the ZigBee protocol as they both focus on offering low data rate services on power constrained devices and they build a complete network protocol stack for WSNs.

Part IV: The Internet of Things (IoT) in Healthcare

6. Healthcare and IoT

According to (Wikipedia, 2019) [80], healthcare is the maintenance of a person's well-being (mentally and physically), via the prevention, diagnosis and treatment of different diseases, injuries, and other impairments or is the act of taking necessary medical procedures to maintain, improve or restore an individual's health. As mentioned by (LaPlante, Kassab, Laplante, & Voas, 2018, p.2) [39], healthcare can be delivered in three broad-based setting types: acute care, community-based care and long-term care. Acute care refers to a hospital setting where the caregivers are paid healthcare professionals. Community-based care is delivered in a home setting, where the patient is living in his or her own or another's home and where caregivers are either paid professionals or unpaid family members or friends. Long-term care refers to nursing homes, or other skilled nursing facilities where patients reside for weeks, months, years or for the remainder of their lives and where caregivers are paid professionals.

As noted by (Sola, Couturier, Scarso Borioli, & Raiciu, 2012, p.1,3) [69], healthcare systems have faced several challenges starting from an aging population to a growing demand for more advanced and better healthcare outcomes. This led to an increase of healthcare costs as well as a need for change in healthcare systems in terms of better and more efficient outcomes. Besides, the healthcare system can be hindered by a lack of systemic management in which there is no proper network where every node in the health system can have visibility on the whole medical information of patients to better meet their needs. However, with the implementation of IoT, it will give an opportunity for patients to remotely monitor their own health from anywhere through collected data from smart devices and as well alarm any nearby hospital in case of critical conditions or emergencies. Also, according to (Carnaz & Nogueira, 2019, p.3) [11], IoT will help prevent or combat in the most effective way in a weak health management system. It will help solve challenges such as medical consultation and communication links of medical images and video data, etc.

The applications, benefits, challenges with solutions, and the enabling technologies of IoT in Healthcare, and lastly, the IoT Healthcare services and example cases will be discussed comprehensively below.

6.1 Applications of IoT in Healthcare

As referred by (DataFlair Team, 2018) [18], the current technology in healthcare and a general practice of medicine gets enhanced with the IoT system. Professionals reach is expanding within a facility. The diverse data collected from large sets of real-world cases increases both the accuracy and size of medical data. The precision of medical care delivery is also improved by incorporating more sophisticated technologies in the healthcare system. Without a doubt, IoT can lead to many advances in healthcare.

6.1.1 Remote Health Patient Monitoring

(Sharma & Dr. Sunanda, 2017, p.2) [68] stated that this application is deployed for remotely monitoring the patient's essential parameters through the use of sensors, devices and objects surrounding them. In this, the real-time critical data of the patient is transmitted and shared between the patient and the caregivers. Its main relevance is for chronic disease management such as diabetes, cardiac disease monitoring, asthma, etc. Figure 11 shows how a remote health monitoring application works.

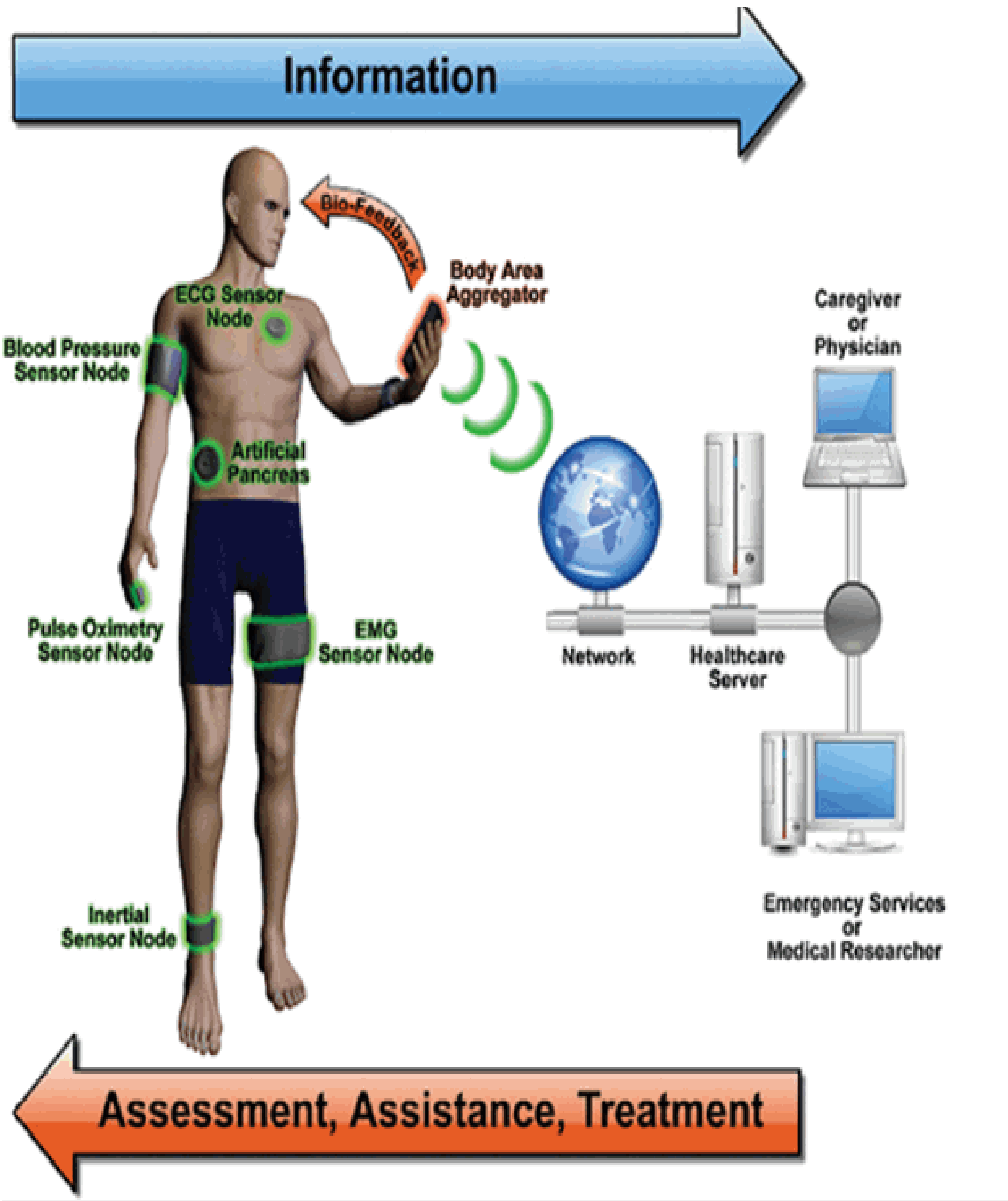

Figure 11: It shows how data can be easily shared between a patient and a caregiver remotely through sensors embedded in the patient over a network and thus care can be provided to the patient whenever an issue arises[15].

[15] Sharma, C., & Dr. Sunanda. (2017). Survey on Smart Healthcare: An Application of IoT. Retrieved from An Application of IoT: https://www.researchtrend.net/ijet/pdf/78-S-866.pdf

6.1.2 Devices

As per (Brucher & Moujahid, p.6) [10], the driver behind all the development of devices and sensors is the data that is generated. According to (DataFlair Team, 2018) [18], current devices are improving in their power, precision, and availability; however, they offer fewer benefits and qualities that an IoT system offers. IoT has the potential to unlock existing technology and lead us towards better healthcare and medical device solutions. It tries and fills gaps between the way healthcare and the equipment are being delivered by creating a system rather than just tools. Then, it detects flaws and reveals patterns and missing elements in healthcare and suggests improvements.

Besides, as stated by (Sharma & Dr. Sunanda, 2017, p.2) [68], smart devices in healthcare are used to store and manage key care parameters and to manage the captured clinical and non-clinical data which may lead to increased workflow efficiency. They are mainly deployed for providing fitness solutions by tracking target activities and diagnostic devices used for storing data from devices. Mainly, they are used as fitness solutions for tracking patient activities and smart diagnostic devices such as blood pressure devices, pedometers, Google glass, etc. used for capturing the data from the sensors for further analysis by doctors. Figure 12 illustrates a connected medical device.

Figure 12: It shows how a patient's health data can be readily available to them on their smart device[16].

[16] DataFlair Team. (2018, 09 15). IoT Applications: Top 10 Uses of Internet of Things. Retrieved from https://data-flair.training/blogs/iot-applications-in-healthcare/

6.1.3 Medical Information Distribution

As mentioned by (DataFlair Team, 2018) [18], this is the most prominent innovation of IoT applications in healthcare. The distribution of accurate and current information to patients remains one of the most challenging concerns of medical care. IoT devices not only improve health in the daily lives of individuals, but also facilities and professional practice.

IoT systems take healthcare out of facilities like hospitals and allow intrusive care into the office, home or social space. They empower and enable individuals to cater to their own health and allow healthcare providers to deliver better care to patients.

6.1.4 Telemedicine

Another way IoT can be applied to healthcare is through telemedicine. As pointed out by (Sharma & Dr. Sunanda, 2017, p.2) [68], this application provides virtual assistance through remote connectivity and efficient solutions enabling virtual care consultation, medicine delivery, education, etc. The diagnosis of providing remote medicinal assistance such as tele-consultations, mobile video solutions has become very common in few countries and markets.

6.1.5 Mobile Personal Assistance

As noted by (Sharma & Dr. Sunanda, 2017, p.2) [68], this application makes use of the mobile technologies to enable remote access to current clinical systems or care giving institutions. The smart mobile apps, portals, websites, etc. easily available to all have made the automation of e-health systems easy. From (James B., 2019) [32], e-health has helped to eliminate travel and the difficulties inherent for the less-than-mobile patient. It has also helped to improve access to care by significantly reducing clinical wait times. It is also effective for extending care to poor and rural populations and more. In fact, it is clear that e-health can improve patient quality outcomes as one report suggested that enrolling just 20% of Mississippi's diabetic population in this remote monitoring e-health pilot could save Medicaid $180 million annually.

6.1.6 Smartphones Apps—an effective solution

Based on (Sharma & Dr. Sunanda, 2017, p.2) [68], smartphone apps can be used as an interface to provide care giving to the needful. Various open source apps for providing healthcare solutions are developed to provide efficient healthcare facilities. Few of them are diagnosis apps (Diagnose, 5MCC, Prognosis, 5-minute infectious disease consult), drug reference apps (Medical doctor: reference tool, Epocrates, FDA drugs, Lab values), calculator apps (MedCalc, caddy medical calculator, uBurn lite), clinical communication apps (Voalte one, mVisum, Vocera), etc.

6.2 Benefits of IoT in Healthcare

IoT offers ample opportunities to the healthcare field. There are undeniable ways IoT can improve the patients' quality of life as well as the efficacy of treatments administered to them and more. Listed below are the benefits of IoT in the healthcare industry in which both the patients and caregivers can profit from. Figure 13 depicts some of the advantages of IoT in the medical field.

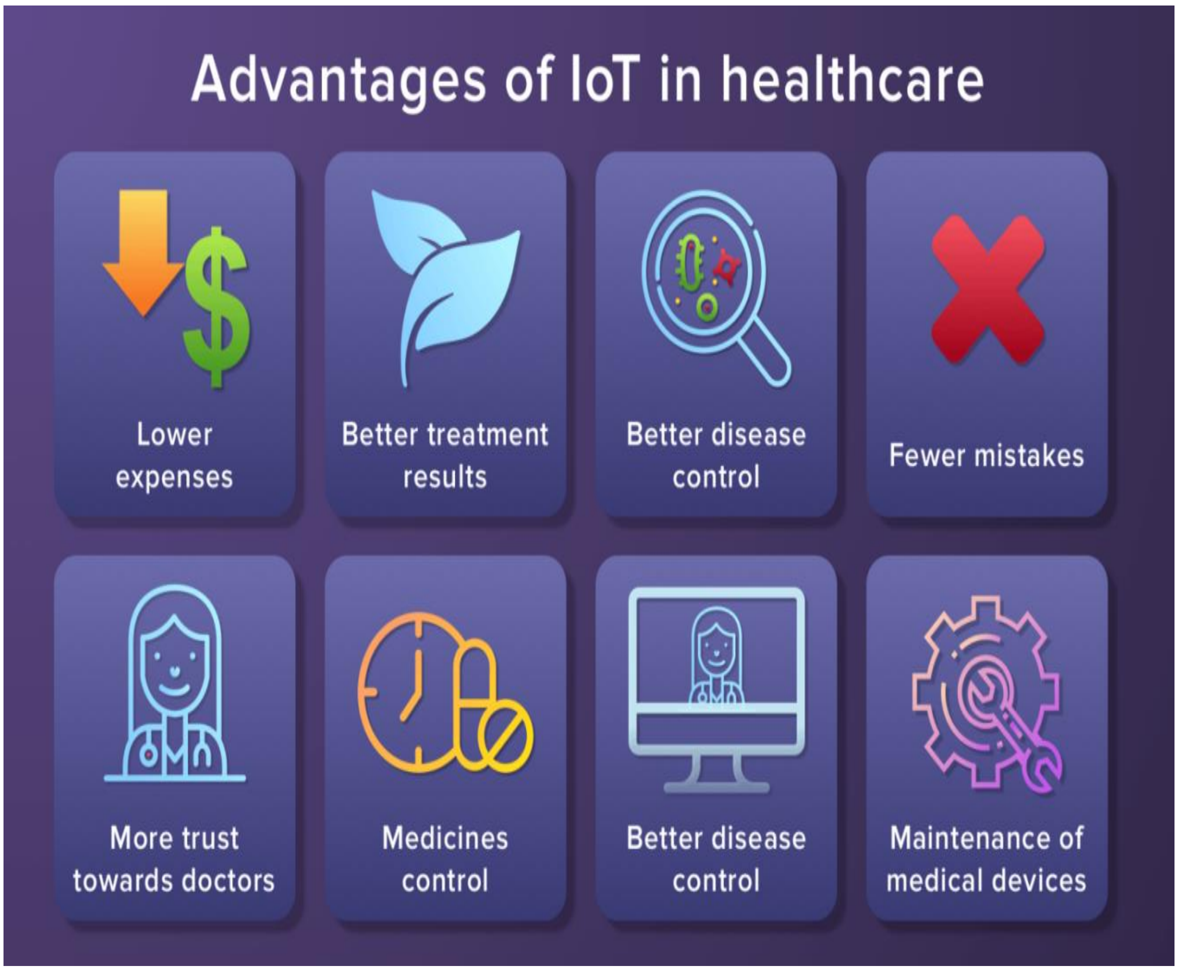

Figure 13: Advantages of IoT in Healthcare[17]

[17] Sergey L. (2017, 12 14). IoT in healthcare: how it gives a second wind to your medical software. Retrieved from https://www.cleveroad.com/blog/iot-in-healthcare-industry--see-why-it-has-a-promising-future

6.2.1 Decreased costs

According to (Brucher & Moujahid, n.d., p.6) [10], taking advantage of development in the connectivity of healthcare solutions allows healthcare providers to monitor patients in real-time based on the collection, the recording, and the analysis of comprehensive information using sensors. In particular, hospitalized patients whose psychological status requires close attention can be constantly monitored using IoT-driven, non-invasive monitoring. In this way, the IoT simultaneously improves the quality of care through constant attention and cuts down costs by eliminating the need for a caregiver to actively engage in data collection by checking the patient's vital signs at regular intervals. Furthermore, as per (Sola et al., 2012, p.2) [69], due to constant monitoring, the patient can be relieved from the hassle of routine checks when he feels better, replacing costly travel, unnecessary visits to the doctor and reducing patient stress. From (Castro, et al., 2017) [12], a study was done to show that one of the main benefits of a telehealth service is the reduction of associated travel expenses. During the 2005 and 2013-time frame, Veterans Affairs (VA) offices performed a study to analyze the travel expenses. The study measured the distance travelled and time saved by telemedicine, which resulted in an average travel savings of 145 miles and 142 min per visit, and also resulted in an average travel cost savings of $18,555 per institution per year.

6.2.2 Improved Disease Management

As noted by (Brucher & Moujahid, n.d., p.6) [10], when patients are continuously monitored and caregivers are able to access real-time data, diseases can be treated before serious complications occur. It enables preventive care, allows early diagnosis and gives insight into the efficiency of the prescribed therapy for the patient's health. For instance, based on (Susmit P., 2016) [73], IoT shows great promise in helping to improve the health of patients with chronic conditions. Combinations of remote monitoring, analytics and mobile platforms have repeatedly cut re-admissions of high-risk patients with congestive heart failure (CHF) by more than half. In fact, some researchers estimate that the value of improved health in patients with chronic disease using remote monitoring could amount to $1.1 trillion per year by 2025.

6.2.3 Improved Outcomes of Treatment

As stated by (Alqahtani, 2018, p.2) [3], the medical IoT is a system that comprises mainly of health-monitoring devices. Patients' health parameters are remotely recorded by a back-end system that analyzes the recorded data and provides appropriate feedback to the clinical staff. The feedback helps specialists determine the current health situation of patients and immediately react to critical cases. Essentially, according to (Brucher & Moujahid, n.d., p.6) [10], the IoT provides healthcare professionals with access to real-time information that enables them to make informed decisions and provide treatment that is efficient, and evidence based.

6.2.4 Remote Health Monitoring

As mentioned by (Brucher & Moujahid, n.d., p.6) [10], access to healthcare infrastructure and effective treatments can be complicated for populations living in remote regions. Small and powerful wireless solutions connected through the IoT now make it possible for these patients to have access to health monitoring. These solutions can be used to securely capture patient health data using a variety of sensors, analyze it, and then share it through wireless connectivity with medical professionals who can make appropriate health recommendations. For example, (Veilumuthu, 2017) [75] shared that Singapore has already implemented a sensor-based Elderly Monitoring System that helps office working family members to receive alerts when the health condition of their home living elderly parents or dependents deteriorates or exhibits abnormal behaviors. Currently, no reports on the outcomes of elderly.

6.2.5 Enhanced Patient Experience

(Mohan & Raja, 2016, p.2) [48] noted that, in future, the healthcare systems will not have enough facilities to accommodate all patients in hospitals or clinics. There is a directed push towards decreasing the length of stay within hospital and technology has been indicated as a possible influence with regards to assisting this. From (Brucher & Moujahid, n.d., p.6) [10] viewpoint, the connectivity of the healthcare system through the IoT places emphasis on the patients and on their needs. Patients will now be able to take control of their own health, to self-monitor, and to communicate whenever necessary with the healthcare providers. This will lead to a new type of physician-patient relationship in which the patient becomes a partner to set up appropriate (or even proactive) treatments, improve the accuracy of the diagnosis, and facilitate a timely intervention by physicians.

6.2.6 Improved Drug Management

According to (Brucher & Moujahid, n.d., p.6) [10], the creation and management of drugs is a major expense in the healthcare industry. Forbes reported the average cost to develop an approved drug at US $4 billion. IoT devices and processes may prove helpful in better managing these costs especially those related to drug supply chain management. RFID tags are already being added to medication containers to ensure producers, consumers, and regulators have greater confidence in the drug supply chain. The next step is to implant the RFID technology into the medication itself to be able to confirm its authenticity and reveal provenance information such as manufacturing location, dosage, packaging images, expiration date, supply chain data, and lot or batch number. Similarly, as (Sola et al., 2012, p.2) [69] explained, adding smart labels on the drugs or smart biodegradable dust inside pills will not only inform consumers on dosage and expiration date, but also, in combination with a smart device that reads information transmitted by the drug labels, patients will be reminded to take their medicine at appropriate intervals, leading to higher compliance rates. For example, from (Mhealth tallinn, 2019) [44], Proteus Discover offers sensor-aided drugs and a special patch attached to the body. The patch uses sensors to collect the data about the patient while a smart pill informs about the organism's state from the inside. Both a patient and his/her attending doctor may look through processed and analyzed data.

6.2.7 Emergency care

(DataFlair Team, 2018) [18] elucidated that, the emergency support services have always had the problem of suffering from limited resources and getting disconnected with the base facility. The advanced automation and analytics of IoT cater to this problem in the healthcare sector. An emergency can be analyzed from a far distance or rather miles away. The healthcare providers get access to the patient profiles way before their arrival which will aid in delivering essential care to the patients on time.

6.2.8 Decreased medical errors

Managing huge loads of information is not only time consuming, but records can be full of mistakes. Now, as mentioned by (Mohan & Raja, 2016, p.2) [48], electronic prescriptions can be stored directly on the card, eliminating paper transactions and the potential errors associated with them, as well as the potential for fraudulent prescriptions. The digital storage of information and automation of paper-based processes result in cost savings and reduce the errors associated with manual data entry and handwritten documents. Overall, according to (Archer, n.d.) [81], using IoT for data collection and workflow automation is an excellent way to cut down on waste (such as unnecessary tests and expensive imaging), reduce system costs and minimize errors (especially the ones related to human factor).

6.2.9 Maintain Medical Equipment

As referred by (Veilumuthu, 2017) [75], medical equipment cost a ton and they are hard to replace too. More seriously, it is difficult to predict when they might have a malfunction which can cost lives. However, IoT with its embedded systems technology and sensors can predict when equipment might be nearing a stage of breakdown. They analyze past behavior of the equipment, their recent performance and draw predictive conclusions that help calculate downtimes well in advance. These kinds of IoT healthcare benefits ensure that a hospital is able to plan for arranging alternative equipment to provide continuous care for the patient while the equipment is scheduled for maintenance.

6.3 Challenges and solutions of IoT in Healthcare

Based on (Brucher & Moujahid, n.d., p.6) [10], IoT certainly opens doors to many opportunities but also gives way to many challenges that must be tackled in order to allow the entire community to take advantage of the services offered by the IoT in the healthcare sector. Below are some areas that need to be addressed or suppressed to fully implement the IoT healthcare system.

6.3.1 Data Privacy and Security Issues

(Sharma & Dr. Sunanda, 2017, p.3) [68] noted that, since IoT is an open network, hence security requirements like confidentiality, integrity, and availability of patient's data should be ensured so that threats related to security and privacy can be dealt with. An active participation of the government bodies towards building regulations for safety and security of objects, devices and people associated should also be considered.

According to (Brucher & Moujahid, n.d., p.7) [10], healthcare devices and applications are expected to deal with vital private information such as personal healthcare data, including genetics. The area of IoT healthcare, which is connected to global information networks that are accessible anytime, anywhere, may be targeted by hacking in a world where data is the new gold. Protecting captured data from illicit access is crucial. For instance, information security, privacy, and data protection should systematically be addressed at the design stage when creating sensors and devices. Also, IoT devices do not always have enough computing power to implement all the relevant security layers. Therefore, the adoption of the IoT in the healthcare industry requires stringent policies, and technical security measures should be introduced to share health data with authorized users, organizations, and applications.

As suggested by (Alqahtani, 2018, p.4) [3], the IoT-based healthcare systems should as well be equipped with foolproof mechanisms that utilize minimum resources with maximum security performance. Moreover, as mentioned by (LaPlante & LaPlante, 2016, p.2) [38], as many researchers are working on the problem of securing IoT systems completely, yet, because no system can be 100 percent secure, ethicists and medical, legal, security, and financial professionals must define and quantify acceptable risk.

6.3.2 Scalability

According to (Sharma & Dr. Sunanda, 2017, p.3) [68], with the rapid advancement of IoT, billions of smart devices and objects get connected to the internet. These smart devices collect huge amount of data that need to be processed, analyzed and even stored for future use. Hence, scalability of IoT network and devices tend to be a major concern. (Lee, 2015) [40] stated that, the absence of standards slowed the adoption of health information exchanges (HIE) early on. Similarly, lack of standardization and common platforms are barriers to healthcare IoT. For this reason, experts agree standardization will need to be achieved to make healthcare IoT scalable and affordable.

6.3.3 Patient Data Issues

(Brucher & Moujahid, n.d., p.7) [10] pointed out that, IoT technology can create new safety risks if it is not designed appropriately, implemented carefully, and used thoughtfully. Data integrity errors as a result of incorrect or missing data in electronic health records (EHRs) and other health IT systems are a crucial issue in the healthcare sector that can dramatically affect patient health. Data integrity issues occurred with the use of paper medical records as well, but now, as EHRs become more interoperable and hackable, incorrect information is more readily available, more easily shared, and harder to eliminate. One patient's data appearing in another's patient record, missing data or delayed data delivery, and clock synchronization errors between medical devices and systems are examples of data integrity failures, as listed in the Top 10 Health Technology Hazards for 2015 report.

According to (Hindawi, 2019) [28], patient safety can be improved through technologies that enable patient identification, tracking, and monitoring, alongside platforms that increase privacy, security, and drug compliance.

6.3.4 Mobility

(Wifi Alliance, 2020) [79] defined mobility as a continuous network connectivity, providing the user with anytime, anywhere access to social media, clinical, or business application data. Mobility can be a major threat to the medical IoT system. As expressed by (Alqahtani, 2018, p.4) [3], It is a basic requirement for an IoT-based healthcare system to permit mobility of patients and devices so that the system is always functional, irrespective of the location. This feature makes it possible to connect heterogeneous patient environments. From (Borad, 2017) [8], the scope of mobility solutions has grown with the faster adoption of smartphones. It has opened many doors to serve the healthcare industry better. Here are some interesting facts about the usage of mobility in healthcare by the International Data Corporation (IDC): 66% of doctors use iPads or other tablets for medical purpose; 70% of physicians use smartphones to research medications; 93% of physicians think mobile health apps improve patient health; 81% of providers stores health data on mobile devices. Considering the above stats, it seems that IoT and mobility are the most promising technologies for patient care and hospital operations. Both IoT and mobility empower healthcare industry with connected devices and smart apps that are changing the landscape of healthcare industry. By implementing real-time monitoring, connected devices can collect medical and other required health data and use connectivity protocols to transfer collected data to doctors and other concerns. IoT and mobility can improve patient care operations as well as provide entirely new possibilities to serve patients anytime, anywhere.

6.3.5 Trust and ethical aspects of using IoT in healthcare

According to (LaPlante & LaPlante, 2016, p.2) [38], information that is being delivered from sensors might appear to be correct but could be corrupted somehow at the origin or during transmission, or deliberately altered by malware that can gain unwanted access to the IoT via the Internet. This corrupted information might then be used to make life and death decisions. How then, can we trust the information delivered to us in an IoT healthcare system? This problem has yet to be resolved.

Caring is about a relationship, one that is forged between the patient, their family and community, and nurses and other healthcare professionals. Compassionate care for the sick is an expectation for all healthcare providers, but compassion is based on trust. For example, for the 14th straight year, nursing has been rated as the most honest, ethical profession. This high rating has been built on a relationship that begins with trust and a personal connection with patients and the public. Nurses often struggle with balancing technology and patient contact, because technology can at times remove the nurse from the bedside. Conversely, technology has helped improve patient care by allowing for better assessment, surveillance, and treatment. With the advent of the IoT in healthcare, nurses and other healthcare professionals must incorporate technologies on many levels and determine the best use for their practice and how to use technology to achieve desired patient outcomes.

From (Mittelstadt, 2017) [47], Health-related internet of things (H-IoT) raises a host of ethical problems stemming from the inherent risks of Internet enabled devices, the sensitivity of health-related data, and their impact on the delivery of healthcare. A primary challenge of H-IoT is to ensure that devices and protocols for sharing the data that they create are technologically robust and scientifically reliable, while also remaining ethically responsible, trustworthy, and respectful of user rights and interests.

6.4 Enabling Technologies of IoT in Healthcare

As discussed by (Carnaz & Nogueira, 2019, p.3) [11], the many uses of the systems and products that connect to the Internet of Things (IoT) are changing the healthcare field. Patients and healthcare providers both stand to benefit from IoT carving out a bigger presence in healthcare. Hospitals use IoT to keep tabs on the location of medical devices, personnel and patients. The successful use of the IoT-based healthcare systems is driven by the following enabling technologies. As per (Niewolny, 2013, p.6) [51], without these technologies, it would be impossible to achieve the usability, connectivity and capabilities required for applications in areas such as health monitoring.

6.4.1 Smart sensors

According to (Niewolny, 2013, p.6) [51], smart sensors, which combine a sensor and a microcontroller, make it possible to harness the power of the IoT for healthcare by accurately measuring, monitoring and analyzing a variety of health status indicators. These can include basic vital signs such as heart rate and blood pressure, as well as levels of glucose or oxygen saturation in the blood. Smart sensors can even be incorporated into pill bottles and connected to the network to indicate whether a patient has taken a scheduled dose of medication. For smart sensors to work effectively, the microcontroller components must incorporate several essential capabilities:

* **Low-power operation** is essential to keeping device footprint small and extending battery life, characteristics that help make IoT devices as usable as possible. Freescale, which has long offered low-power processing, is working now to enable completely battery-free devices that utilize energy harvesting techniques through the use of ultra-low-power DC-DC converters.

* **Integrated precision-analog capabilities** make it possible for sensors to achieve high accuracy at a low cost. Freescale offers this enabling technology within microcontrollers which contain analog components, such as high-resolution analog-to-digital converters (ADCs) and low-power op-amps.

* **Graphical user interfaces (GUIs)** improve usability by enabling display devices to deliver a great deal of information in vivid detail and by making it easy to access that information. Freescale's i.MX applications processors with high graphics-processing performance support advanced GUI development.

Likewise, (Alqahtani, 2018, p.2) [3] stressed that it is possible to transform all the received data from the sensors into a digital form and immediately transmit it over a network. The prevalence of wireless sensors has made it possible for people to wear portable sensors capable of automated data collection and transfer.

6.4.2 Gateways

As stated by (Niewolny, 2013) [51], gateways are the information hubs that collect sensor data, analyze it and then communicate it to the cloud via wide area network (WAN) technologies. Gateways can be designed for clinical or home settings; in the latter, they may be part of larger connectivity resource that also manages energy, entertainment and other systems in the home. The Freescale Home Health Hub reference platform for instance, includes a gateway component. Medical device designers can also use the platform to create remote-access devices for remote monitoring and improve healthcare management.

6.4.3 Communication Technologies and Wireless Networking

As mentioned by (Alqahtani, 2018, p.2) [3], while considering an IoT-based system, the communication technologies enable the network infrastructure. IoT networks are based on heterogeneous frequencies, standards and transmission rates for transferring data. These networks can further be classified as long-distance and short-distance technologies. Long-distance technologies are intended to deal with regular means of communication, such as the Internet or mobile phones. Short-distance communication mostly utilizes wireless technologies, such as Bluetooth, Infrared Data Association (IrDA), Wi-Fi, ultra-wideband (UWB), RFID and so on. All these technologies enable data transmission over a short distance.

Furthermore, as referred by (Niewolny, 2013, p.7) [51], wireless networking removes the physical limitations on networking imposed by traditional wired solutions like Ethernet and USB. Freescale offers microcontrollers that support wireless connectivity for devices based on popular wireless standards such as Bluetooth and Bluetooth Low Energy (BLE) for personal area networks (PAN) used with personal devices and Wi-Fi and Bluetooth for local area networks (LAN) in clinics or hospitals.

6.4.4 Cloud Computing

Based on (Carnaz & Nogueira, 2019, p.3) [11], the integration of cloud computing into IoT-based healthcare technologies should provide facilities with ubiquitous access to shared resources, offering services upon request over the network and executing operations to meet various needs.

(Alqahtani, 2018, p.2-3) [3] pointed out that, during its operations, an IoT system generates a huge amount of data that has to be stored, processed and shared. Cloud computing forms the building block of the IoT architecture as it can support the storage and the processing of the immense data generated by individual sensors and devices. The cloud data centers collect data from the individual devices in an IoT system to analyze and share it with other sensor devices on the network. It is possible for the cloud data centers to enhance or decrease the computing capacity, depending on the demand.

Furthermore, research proves the huge potential of cloud computing for the next-generation smart systems for people with disabilities. All the future IoT systems are supposed to be based on the cloud. The associated devices from the computers can be decoupled by cloud computing by avoiding individual installation. An additional benefit of IoT devices is that they can be reconfigured without much user effort and time. Since cloud computing is reliable and platform independent, the setup of cloud centers in hospitals and medical centers facilitates resource sharing and leads to the development of highly reliable medical monitoring and management systems.

6.4.5 Augmented Reality

In accordance to (White, Cabrera, Palade, & Siobhan, n.d., p.1) [78], IoT is a combination of physical objects with virtual representations and services. Augmented reality provides an ideal interface to IoT applications by superimposing virtual information about smart objects and services on a user's view of the real world. This allows a user to interact with the physical object as well as receiving additional context aware information about the object e.g., size, speed and temperature, as well as information about nearby objects.

(Carnaz & Nogueira, 2019, p.4) [11] stated that augmented reality has brought about a significant change in the healthcare industry. There are different applications of this technology in the medical sector. For example, from providing assistance during surgeries to improving medical training, and more. Moreover, apart from saving patients' lives, existing processes in healthcare organizations can be made more efficient and precise with augmented reality.

6.5 Example Cases and Services of IoT in Healthcare

IoT is viewed as a means to improve healthcare delivery. It can address a broad set of health issues. The ability to track, collect, store and accurately analyze health data without human intervention is a key aspect of IoT. Below are few important health cases and services that are impacted by IoT.

6.5.1 Bulimia

According to (LaPlante & LaPlante, 2015, p.3) [37], Bulimia is an eating disorder. Symptoms of an eating disorder include a patient's displeasure with her appearance; abnormal attitude towards food which causes a change in eating habits; and self-perception as being overweight even when the patient is not. A patient with bulimia is characterized by bouts of overeating, to the point where the person can be in pain. The person will attempt to get rid of the calories consumed by taking laxatives and/or vomiting.

Treatment of a patient with bulimia includes addressing physical conditions and psychological counseling that is, treatment on achieving normal eating patterns, weight gain if the patient is underweight, and providing family support. Monitoring of these patients using an IoT helps to achieve these treatment goals.

For example, a patient with bulimia is carefully monitored regarding intake of food and output, including instances of vomiting. Monitoring of instances of bathroom use via an IoT can assist the staff in determining if bulimic behavior of vomiting is detected, as well as food binging in the kitchen area.

Patients with bulimia often use the bathroom after every meal. An IoT could be used to monitor bathroom use. Suppose the average person uses a bathroom to move his/her bowels once per day, then location sensors placed in the bathroom could detect if their usage exceeds some established limits.

Furthermore, in the patient's room, sensors could detect changes in certain physiologic measures, such as increased body temperature or blood pressure. Also, a sensor that can detect the odor of vomit could provide additional cues in the diagnosis and management of the bulimic patient in any care setting.

6.5.2 Alzheimer's disease

As described by (LaPlante & LaPlante, 2015, p.3-4) [37], Alzheimer's disease is the most common form of dementia accounting for 60-80% of all cases. Alzheimer's.org reports that 1 in 9 people age of 65 years and older has Alzheimer's disease. It is important to note too that 81% of people with Alzheimer's disease are age 75 or older. Safety is a key factor in the care of patients with dementia. Also, the average lifespan in general for all people continues to rise, with many surviving into their 80s and 90s. The costs associated with care of a patient with Alzheimer's disease are staggering. All of these statistics highlight the need for technologies to assist in monitoring and support of these patients, their families/caregivers, and health care providers.

Caregiver burden is a real concern because of the stress and level of care often needed, with most of this responsibility falling to family/caregivers. As the disease progresses, the patient can have difficulty walking and swallowing that will require additional monitoring and intervention to keep the patient safe. As the disease progresses, cognitive and functional abilities decline.

Clearly, this disease takes a toll on the patient, and it is easy to see the need for technologies to assist caregivers at different stages of the disease. Allowing the patient with Alzheimer's disease the best quality of life is a focus of care. Monitoring through sensors with IoT can be a means to do this. The sensors could be strategically placed to capture important data, but not be intrusive. For instance, as mentioned by (LaPlante & LaPlante, 2016, p.1) [38], an IoT could employ geolocation to prevent wandering or other unwanted mobility behaviors. Often, patients with Alzheimer's disease suffer from comorbidities with other diseases, such as hypertension (high blood pressure), macular degeneration, or diabetes. Therefore, appropriate interconnected devices could capture data for monitoring the unique signs and symptoms of these conditions.

6.5.3 Diabetes

Based on (Sola et al., 2012, p.8) [69], Diabetes is a chronic disease that affects how the body uses the glucose, the amount of sugar in the body, its source of energy. This amount of sugar is controlled by the insulin, a hormone produced by the pancreas. This hormone is the one responsible with transforming the glucose into energy. If there are problems in achieving this process, it is a sign of diabetes.

There are two types of diabetes: type 1 diabetes is a chronic condition in which the pancreas produces little or no insulin, a hormone needed to allow sugar (glucose) to enter cells to produce energy. Type 2 diabetes, which is far more common, occurs when the body becomes resistant to the effects of insulin or doesn't make enough insulin. For type 1 diabetes, but also in most cases of type 2 diabetes, the treatment involves taking insulin injections for life.

When managed effectively, diabetes is a disease which people can live normal lives with. Among the self-care behaviors recommended by physicians, self-monitoring of blood glucose is a key component of the treatment regimen. In these conditions, compliance becomes an issue, since it relies upon user lifestyle changes, upon regular sampling and measuring of blood glucose levels. Many people find that it is difficult to make blood glucose monitoring a routine part of their lives.

An IoT solution for diabetes management is a monitoring device which uses a blood pressure and glucose monitor to give accurate test results and better manage diabetes. The monitor communicates via Bluetooth to a smart screen, PC or cellular/or land-line phone, transmitting the data to a web-enabled server. Here, the data is stored, reviewed and interpreted by the patient's doctor, helping in providing a proper treatment.

According to (Sola et al., 2012, p.8) [69], this solution facilitates the improvement of patients' lives and of their clinical outcomes due to better monitoring. The solution is easy to implement and facilitates the transmission of the data regardless of the location, enabling the immediate contact with the medical staff. Furthermore, it has an immediate impact on the patient's behaviour since it will not only help them constantly monitor their blood sugar, but it will also enhance the consistent maintenance of glucose control.

Besides, (Sola et al., 2012, p.9) [69] underlined that the benefits for health providers are also considerable. Using the IoT solution strengthens their relationship with the patient, provides immediate access to data, which improves treatment and allows them to focus more on the patient and less on collecting information. Furthermore, the health system will have a direct feedback on the efficacy of the treatment based on the data provided by the devices. This can be then used to improve the efficacy of the overall clinical pathway.

6.5.4 Heart failure

As discussed by (Sola et al., 2012, p.7-8) [69], heart failure is a condition in which the heart can no longer pump enough blood to the rest of the body. When this happens, blood may back up in other areas of the body. Fluid builds up in the lungs, liver, gastrointestinal tract, and the arms and legs. This is called congestive heart failure.

For most people, the treatment of heart failure involves a balance of right medication, and in some cases, right devices that help the heart beats and contracts properly. Traditional methods of patient assessment have a low sensitivity for detecting pulmonary congestion and heart failure decompensation. Therefore, fluid volume overload (congestion) is a major complication for patients, many of them ending up frequently hospitalized for fluid overload.

An IoT solution to this condition is a fluid status monitoring device that is implanted in the patient's heart, helping him and his physician to detect any fluid build-up in the thoracic cavity. The device is connected to the patient's physician through the company's network system, facilitating the interpretation of the heart monitor. Therefore, patients at greater risk of worsening heart failure can be identified quickly and the doctor can recommend diet adjustments or alter medications in real-time.

The fluid status monitoring device helps doctors identify patients at greater risk of worsening heart failure, so they can better manage the disease. When a patient crosses the (fluid) threshold, diet and medication are immediately adjusted to get him back on track. Furthermore, the device helps patients comply with their treatment management routine, which often includes diet adjustments and evolved medication. This is made possible as a result of establishing a link between the fluid increase and a specific event in their routine, e.g. forgetting to take their pills.

6.5.5 Obesity

(Sola et al., 2012, p.10-11) [69] defined that, obesity refers to excessive body fat that a person is carrying for their height and gender. It is considered that an obese person has a body mass index (BMI) of 30 or greater.

The problems that obesity may cause are numerous and can have a negative aspect over the course of a person's life: high cholesterol and triglycerides, type 2 diabetes, high blood pressure, metabolic syndrome, heart diseases, stroke, cancer, sleep apnea, gynaecologic problems, such as infertility and irregular periods, erectile dysfunction and sexual health issues, osteoarthritis and skin problems, such as poor wound healing. Obesity can be treated by reaching and staying at a healthy weight. A diet and exercising plans need to be formulated together with health professionals in order to accomplish the necessary changes in the lifestyle. Medication and surgical treatment could also be prescribed by a specialised doctor, if the other methods are not successful.

An IoT solution for this disease is a wireless-enabled wearable fitness tracker, containing a 3D motion sensor that accurately tracks calories burned, steps taken, distances travelled and sleep quality. All the data collected by the device will be automatically uploaded on Internet every time the tracker is within about 15 feet of a base station. The data can be analyzed by the patient or if necessary, by the personal doctor who, in return, can prescribe a diet, medication or other advice that can improve the patient's life. The fitness tracker helps people monitor their lifestyle and understand in real-time what they should change/continue in their everyday lives to prevent the appearing of obesity, that may lead to chronic issues such as diabetes or heart diseases. By providing a large amount of information on people's activity levels, the device has a great potential to change their lifestyle.

6.5.6 Wheelchair Management

As noted by (Carnaz & Nogueira, 2019, p.10) [11], smart wheelchairs with full automation for disabled people is a response from IoT, like the acceleration in pace of work.

Furthermore, as per (Alqahtani, 2018, p.3) [3], several studies have already been conducted to develop smart wheelchairs which use the IoT application for people with disabilities. For example, Yang proposed an IoT-based healthcare system for persons with disabilities. The system utilizes Wireless Body Area Networks (WBANs) technology to control and coordinate different sensors. The vibrations in the wheelchair are controlled by the system. It also keeps track of the status of the person using the wheelchair by monitoring his or her sitting position, as well as giving information about the surroundings.

Despite all of these IoT proposed solutions, there might still be quite a few challenges to face for their implementation.

Part V: Internet of Things in Manufacturing—Maintenance (Industry 4.0 and Predictive Maintenance Impact)

7. Introduction

From (Cooper, 2019) [15], IoT innovation is not one size fits all. What it means for a healthcare company is necessarily different from what it will mean for a process manufacturing firm.

As defined by (Bayoumi & McCaslin, 2016, p.2) [5], the IoT is a network of interconnected objects or things. These objects are able to communicate and interact with each other regardless of physical location. In the maintenance world, these objects are embedded with sensors that monitor the condition of the object. Over the years, the IoT has increased in popularity in maintenance. It provides a framework for users to connect and collect data from all the components and systems that they are monitoring. This data is collected and analyzed in real-time to identify and extract meaningful relationships in the data. The collected data can also be compared to previous trends that were calculated with historical data. In the IoT framework, not only are the physical components and systems connected, but also every user in the maintenance process is connected. This means that a user does not need to be physically with the asset to know its condition. The information a user would need is presented to them with real-time dashboards and alerts.

According to (Perumal, 2019) [54], research advances in the last decades have allowed the introduction of Internet of Things (IoT) concepts in several industrial application scenarios, leading to the so-called Industry 4.0 or Industrial IoT (IIoT). The Industry 4.0 has the ambition to revolutionize industry management and business processes, enhancing the productivity of manufacturing technologies through field data collection and analysis, thus creating real-time digital twins of industrial scenarios. Moreover, it is vital for companies to be as “smart” as possible and to adapt to the varying nature of the digital supply chains. This is possible by leveraging IoT in Industry 4.0 scenarios. From (Starhub, 2017) [71], in short, Industry 4.0 is essentially the Internet of Things amplified to an Industrial scale, used to boost manufacturing efficiency, productivity and return on investment.

Additionally, based on (VROC, 2019) [76], Industry 4.0 is all about data—how it's collected, analyzed, synthesized, interpreted and applied. And that's why predictive maintenance and analytics is such a huge part of the Industry 4.0—because it's all about using data to predict outcomes and improve performance.

In the following pages, maintenance will be defined and its importance in an industry will be identified. In addition, different types of maintenance that can be adopted in a manufacturing setting will be discussed. Then, Industry 4.0 in maintenance will be addressed. Firstly, the three Industrial Revolutions that led to the Industry 4.0 will be presented. Secondly, Industry 4.0 will be explained in which distinct sub-topics will arise from. The main characteristics of Industry 4.0 will be examined. After, the main pillars (or enabling technologies) of Industry 4.0 in maintenance and the optimizing benefits of Industry 4.0 in total productive maintenance will be explored. Later, the Industry 4.0 use case, that is predictive maintenance will be discussed in depth: how it fits into the Fourth Industrial Revolution, how it actually works and its future in Industry 4.0. Lastly, some real-world examples of Industry 4.0 with predictive maintenance solutions in a manufacture will be given.

8. Maintenance

8.1 Definition and Importance

Before moving into understanding the Industry 4.0 in depth and its effects on maintenance management, lets first comprehend maintenance and its importance. According to (Bayoumi & McCaslin, 2016, p.2) [5], maintenance is a large part of any industry and depending on the industry, it can represent between 15 to 60 percent of total costs. In the United States, industries spend more than $200 billion each year on maintenance. Recent surveys have shown that there is a need for better maintenance implementation.

As it is, machinery is becoming more sophisticated and the maintenance team must keep up with the pace. As stated by (Krar, n.d., p.1) [36], as in personal health care insurance, maintenance may be considered as the healthcare of manufacturing machines and equipment. It is required to effectively reduce waste and run an efficient, continuous manufacturing operation, business, or service operation. The cost of regular maintenance is very small when it is compared to the cost of a major breakdown at which time there is no production. Therefore, regular checkups and maintenance of the manufactures' equipment to keep production running at its best, do really matters.

Additionally, based on (Jain, 2016) [31], maintenance management helps to keep the machines/equipment in their optimum operating conditions. It contributes towards revenue by decreasing the operating cost and improving the quality and quantity of the product being manufactured. In the absence of plant maintenance, frequent machine breakdown, poor quality of production, failure to meet delivery dates of product supply, industrial accidents endangering the life of workers/operators and allied costs etc. may occur. That said, maintenance is important to keep an industry functioning smoothly, efficiently and to ensure the safety of the personnel.

8.2 Types of Maintenance

There are various ways maintenance can be implemented in an industrial sector depending on its structure, to sustain the flow of operations. Figure 14 shows four basic types of maintenance.

Figure 14: These are different types of maintenance programs[18]

[18] Mike. (2018, 05). Types of Maintenance Programs in Industries. Retrieved from https://instrumentationforum.com/t/types-of-maintenance-programs-in-industries/4185

8.2.1 Corrective maintenance

(Soldatos, Gusmeroli, Pedro, & Orio, 2016, p.24) [70] stated that corrective maintenance, also called run-to-failure reactive maintenance, is the oldest policy and envisions the repair of a failure whenever it happens. It implies that a plant using run-to-failure management does not spend any money on maintenance until a machine or system fails to operate. As per (Bayoumi & McCaslin, 2016, p.1-2) [5], it can save money in the short-term, but long-term can lead to higher repair costs and longer downtimes.

8.2.2 Preventive/Preventative maintenance

(Bayoumi & McCaslin, 2016, p.1-2) [5] mentioned that preventive maintenance is a time-based or usage-based strategy where maintenance actions are performed after a set amount of time. It results in higher reliability but can be more costly if maintenance is performed before it is actually needed. According to (Soldatos et al., 2016, p.24) [70], in preventive maintenance management, machine repairs or rebuilds are scheduled based on the mean time to failure (MTTF) statistic—an average time an equipment will function before it fails.

8.2.3 Proactive maintenance

As noted by (Soldatos et al., 2016, p.24) [70], proactive maintenance is a totally policy that is not “failure” oriented like the others. As a matter of fact, proactive maintenance envisions not the minimization of the equipment downtime but the continuous monitoring of the machine and equipment conditions with the main objective of identifying the root causes of a possible failure and/or machine breakdown and proactively schedule maintenance intervention to correct the abnormal values of the root causes. Thus, in proactive maintenance policy, the minimization of the downtime is only the consequence of a strategy that is aimed to improve the machine/equipment health during its lifecycle and to assure overall high production system productivity, reliability, robustness while paradoxically reducing the number of maintenance intervention. That said, proactive maintenance is a necessary state in the main path to effective maintenance. It has not been thought as an alternative to predictive maintenance but as a complementary approach to predictive maintenance in the direction of effective maintenance.

8.2.4 Predictive maintenance

According to (Bayoumi & McCaslin, 2016, p.2) [5], predictive maintenance allows for predictions to be made on when a component will fail which allows maintainers to be prepared for that failure before it happens. Implementing predictive maintenance can provide a company with an optimal maintenance strategy at a low cost with the highest reliability.

Furthermore, based on (Soldatos et al., 2016, p.24) [70], predictive maintenance, also called condition-based maintenance, is a policy that envisions the regular monitoring of machine and equipment conditions to understand their operating condition and schedule maintenance interventions only when they are really needed. In predictive maintenance management, machine repairs and/or rebuilds—i.e. maintenance interventions—are programmed in real-time avoiding unforeseen downtimes and their related implications. Predictive maintenance is a philosophy or attitude that uses the actual operating condition of plant equipment and systems to optimize total plant operation.

9. Industry 4.0 in Maintenance

As stated by (Seebo, n.d., p.3) [65], one third of all maintenance activities are carried out too frequently. For machine operators and factory managers, preventative maintenance and asset repairs consume unnecessary resources, eat deeply into operational costs, and present a serious impediment to efficient operations. For product manufacturers, this means higher field service costs, higher customer service center costs, lower customer satisfaction, and a distinct disadvantage facing the competition. Manufacturers and asset managers are now turning to Industry 4.0, also known as the Industrial Internet of Things, for a superior approach. This involves continually generating and transmitting product behavior data, capturing the data in a central repository, and applying advanced big data analytics techniques to sort through massive amounts of data and identify important patterns.

9.1 Background – The first three Industrial Revolutions

To be able to understand the Industry 4.0, lets first take a look back at the three notable industrial revolutions that shaped it. According to (Ben-Daya, Hassini, & Bahroun, 2017) [7], Industry 4.0 refers to the Fourth Industrial Revolution where the first three industrial revolutions are related to mechanical power (Industry 1.0), mass production (Industry 2.0) and digital revolution (Industry 3.0). Below, (Epicor, 2019) [21] described the manner in which these industrial revolutions evolved. Figure 15 shows the three phases of industrialization leading to this Industry 4.0.

1. **The First Industrial Revolution (Industry 1.0)**

The first industrial revolution happened between the late 1700s and early 1800s. During this period of time, manufacturing evolved from focusing on manual labor performed by people and aided by work animals to a more optimized form of labor performed by people through the use of water and steam-powered engines and other types of machine tools.

2. **The Second Industrial Revolution (Industry 2.0)**

In the early part of the 20th century, the world entered a second industrial revolution with the introduction of steel and use of electricity in factories. The introduction of electricity enabled manufacturers to increase efficiency and helped make factory machinery more mobile. It was during this phase that mass production concepts like the assembly line were introduced as a way to boost productivity.

3. **The Third Industrial Revolution (Industry 3.0)**

Starting in the late 1950s, a third industrial revolution slowly began to emerge, as manufacturers began incorporating more electronic—and eventually computer—technology into their factories. During this period, manufacturers began experiencing a shift that put less emphasis on analog and mechanical technology and more on digital technology and automation software.

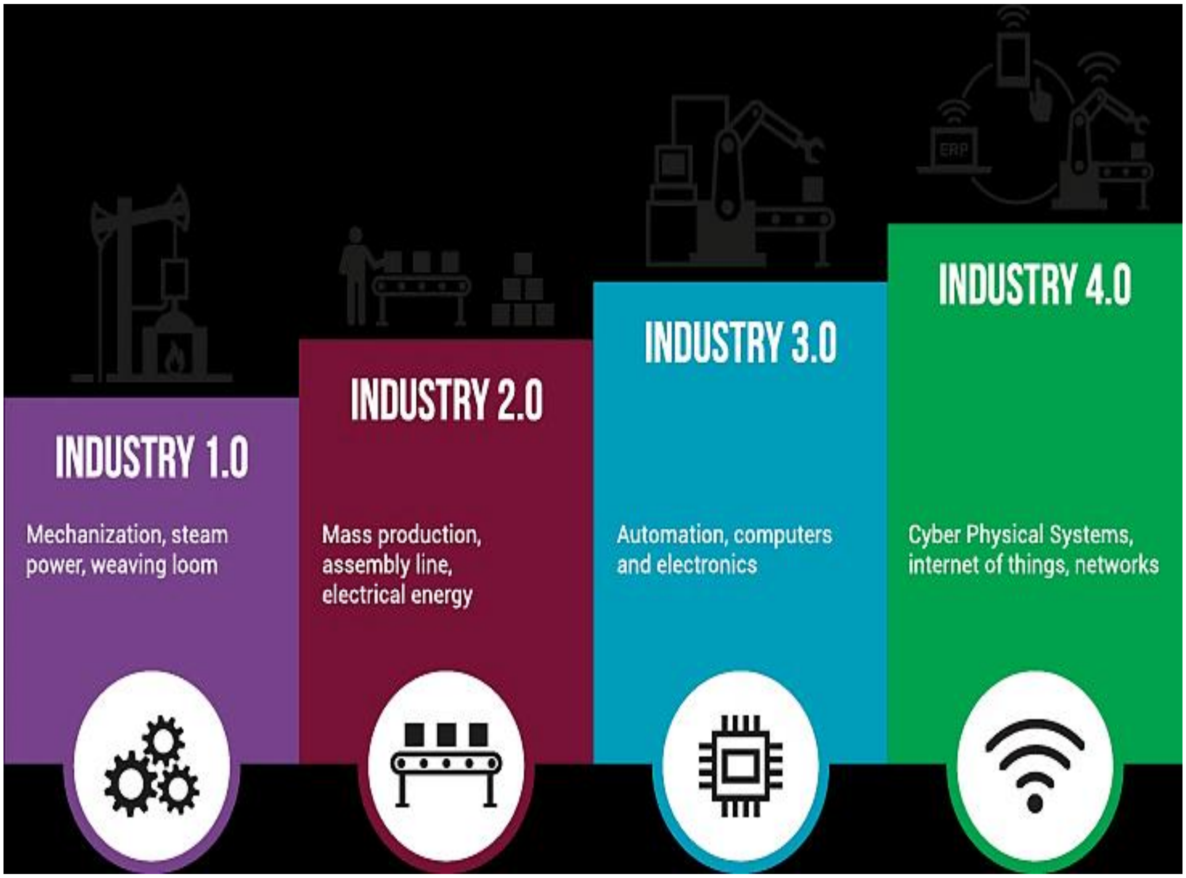

Figure 15: The first three Industrial Revolutions leading to Industry 4.0[19]

[19] Industry 4.0. (n.d.). Retrieved from https://www.simio.com/applications/industry-40/index.php

9.2 Industry 4.0

From (Epicor, 2019) [21], Industry 4.0 is referred to as a new phase in the Industrial Revolution that focuses heavily on interconnectivity, automation, machine learning, and real-time data. Industry 4.0, which encompasses IIoT and smart manufacturing, marries physical production and operations with smart digital technology, machine learning, and big data to create a more holistic and better-connected ecosystem for companies that focus on manufacturing and supply chain management. While every company and organization operating today is different, they all face a common challenge—the need for connectedness and access to real-time insights across processes, partners, products, and people. That's where Industry 4.0 comes into play.

From (bdc, 2019) [6], Industry 4.0 has received a lot of media attention in recent years, but the concept remains abstract for many entrepreneurs. Beyond the buzz, Industry 4.0 has the potential to significantly boost your productivity, reduce costs and improve the quality of your products. This is done by collecting real-time data, analyzing and using this information to improve operations through immediate feedback.

Basically, "the core application of Industry 4.0 is to monitor and control your machinery and equipment in real-time by putting sensors at every step of the production process," said Pierre Cléroux, Vice President, Research and Chief Economist at BDC.

Essentially, the technology allows you to check on your production at every step of the process, therefore improving quality. It also helps reduce and even eliminate downtime, because the data from your equipment tells you when your machine needs maintenance or when it's about to break down.

Furthermore, according to (Ben-Daya et al., 2017) [7], In Europe, and particularly in Germany, IoT is one of the founding technologies of Industry 4.0 in the manufacturing sector. Zhou, Liu, and Zhou from (Ben-Daya et al., 2017) [7], defined the concept of Industry 4.0 as the integration of Information and Communications Technologies with industrial technology. In addition to IoT technology, Industry 4.0 needs cyber-physical systems (CPS) and cloud manufacturing (CM). A CPS is composed of machines, storage systems and production facilities that could autonomously exchange information, trigger actions and monitor each other. According to Cheng et al., from (Ben-Daya et al., 2017) [7], a CPS links a manufacturing entity virtual (computing) and physical (machines) elements by integrating analogue/digital hardware. IoT provides the needed platform to connect the CPS using a network of sensors, actuators and devices. Also, IoT platforms use generally cloud computing capabilities in external data centers, which led to the concept of cloud manufacturing (CM) in the Industry 4.0 context. Figure 16 portrays a cyber-physical system.

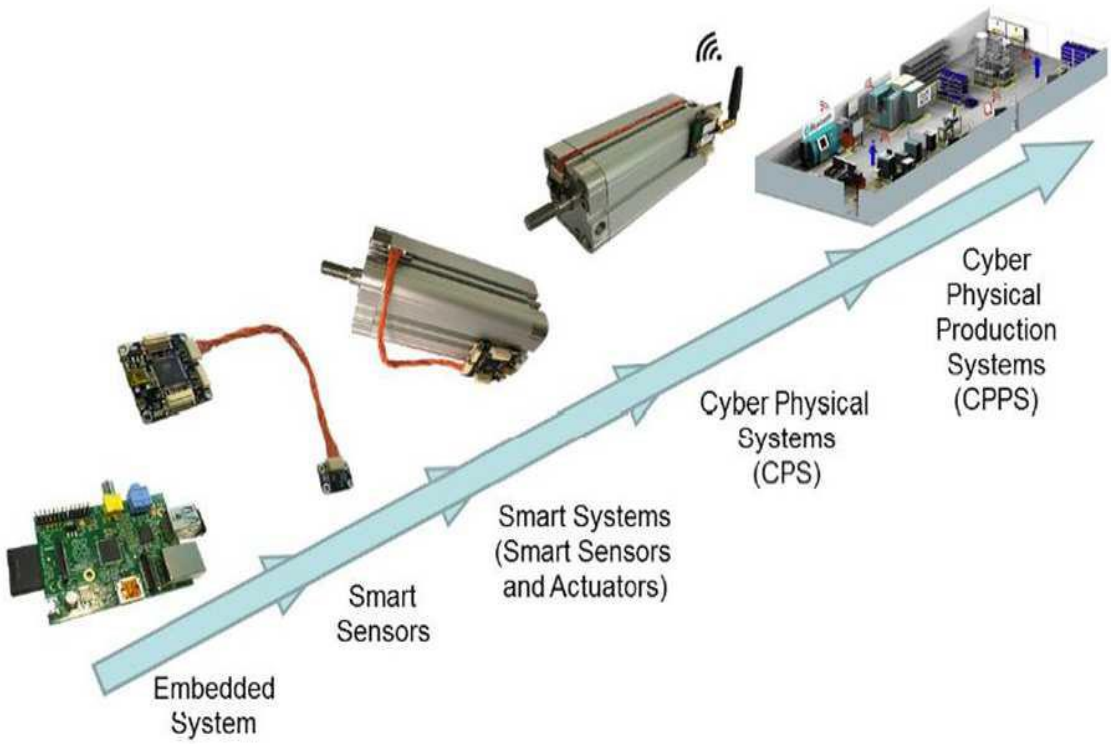

Figure 16: This is a representation of a cyber-physical system[20]

[20] Crnjac, M., Veza, I., & Banduka, N. (2017, 03 02). From Concept to the Introduction of Industry 4.0. Retrieved from https://www.researchgate.net/publication/319007861_From_concept_to_the_introduction_of_industry_40

9.2.1 Four Main Characteristics of Industry 4.0

According to (Crnjac, Veza, & Banduka, 2017) [16], Industry 4.0 is focused on creating intelligent products, processes and procedures. As per (Schlaepfer & Koch, 2015, p.8-10) [62], the following four main characteristics of Industry 4.0 demonstrate the huge capacity that industry and traditional manufacturing have for change. Figure 17 depicts an Industry 4.0 setting.

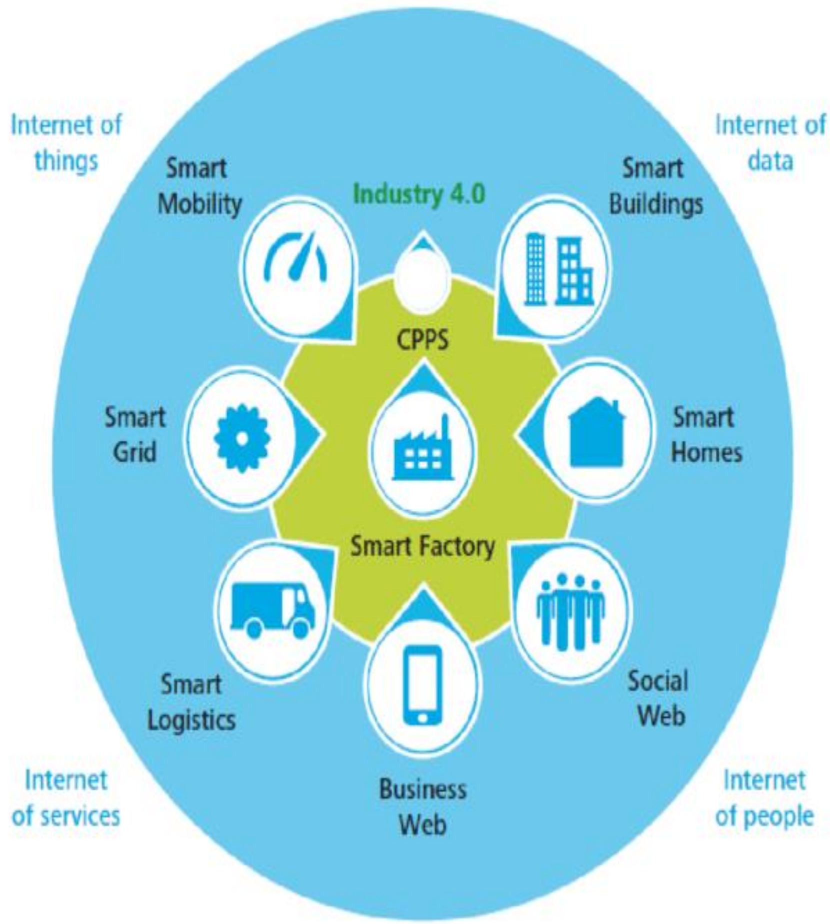

Figure 17: This is a depiction of an Industry 4.0 environment[21].

[21] Researchgate. (2019). Retrieved from https://www.researchgate.net/figure/Industry-40-environment-source-Deloitte-2015_fig2_325803630

1. **Vertical Networking of smart production systems**

Based on (Gilchrist, 2016, p.209-210) [25], smart factories, which are essentially the core of the Industry 4.0, cannot work on a standalone basis. There is a need for the networking of smart factories, smart products, and other smart production systems. The essence of vertical networking stems from the use of cyber-physical production systems (CPPSs), which lets factories and manufacturing plants react quickly and appropriately to variables, such as demand levels, stock levels, machine defects, and unforeseen delays. Similarly, networking and integration also involve the smart logistics and marketing services of an organization, as well as its smart services, since production is customized in such a way that it is individualized and targeted specifically to customers. Further, as noted by (Schlaepfer & Koch, 2015, p.8) [62], CPPSs enable not only autonomous organization of production management, but also maintenance management. Resources and products are networked, and materials and parts can be located anywhere and at any time. All processing stages in the production process are logged, with discrepancies registered automatically. Amendments to orders, fluctuations in quality or machinery breakdowns can be dealt with more rapidly. Such processes also enable wear and tear on materials to be monitored more effectively or pre-empted. All in all, waste is reduced.

2. **Horizontal integration through global value chain networks**

According to (Crnjac et al., 2017) [16], horizontal integration refers to the integration of different information systems that are used in the phases of production planning and business processes. Those systems include the exchange of materials, energy and information within the company (such as internal logistics, production, marketing) or among different companies. The aim of this integration is to deliver information across the whole network (from the supplier to the customer). Presented integration is especially very helpful to suppliers as they are always informed on time about the state of stock so they can better plan and organize future delivery. Today, customers can contact the manufacturer to find out current state of their products. Horizontal integration will enable the customer to monitor his product (computer will present completed tasks, but precondition is "smart product" that knows everything about itself). If a problem occurs, the customer will be able to immediately intervene and decide about a way of solving the problem.

Furthermore, as stated by (Gilchrist, 2016, p.210) [25], the integration will facilitate the establishment and maintenance of networks that create and add value. As per (Schlaepfer & Koch, 2015, p.9) [62], these new value-creation networks are real-time optimized networks that enables integrated transparency, offer a high level of flexibility to respond more rapidly to problems and faults, and facilitate better global optimization.

3. Through-engineering across the entire value chain

As laid out by (Gilchrist, 2016, p.209) [25], the whole value chain in industry is subjected to what is termed through-engineering, where the complete lifecycle of the product is traced from production to retirement. Under other manufacturing disciplines, for example, clothing, the focus would be on the manufacturing process alone, to make the product, sell the product, then ship it and forget about it. There is little concern for what happens to a poorly manufactured shirt for example, let alone what happens to its future sales trends, after the customer throws it in the trash. However, when dealing with industrial components, quality is king. Consequently, there must be focus on quality and customer satisfaction so the manufacturer must build products to meet the customer's expectations. For example, an owner of a Mercedes Benz will expect components manufactured to the highest quality and have after-service support. Industry 4.0 covers both the production process and the entire lifecycle of the product.

4. Acceleration of manufacturing through exponential technologies

As discussed by (Schlaepfer & Koch, 2015, p.10) [62], the fourth main characteristic of Industry 4.0 is the impact of exponential technologies as an accelerant or catalyst that allows individualized solutions, flexibility and cost savings in industrial processes.

Industry 4.0 already requires automation solutions to be highly cognitive and highly autonomous. Artificial intelligence (AI), advanced robotics and sensor technology have the potential to increase autonomy further still and to speed up individualization and flexibilization.

AI not only help to plan driverless vehicle routes in factories and warehouses more flexibly, save time and cost in Supply Chain Management (SCM), increase reliability in production or analyze big data, but also can help to find new construction and design solutions or enhance the cooperation between humans and machines to the point of services.

Flying maintenance robots in production halls and using drones to make inventories of warehouse stock levels and deliver spare parts, at any time of day or night and in any terrain and weather, are further applications that will simply become routines in the autonomous and smart factories of the future.

Functional nanomaterials and nanosensors can also be used in production control to make quality management more efficient or allow the production of next generation robots to work “hand in hand” and safely with humans.

A prime example of an exponential technology that is already accelerating Industry 4.0 and making it more flexible is the 3D printing (additive manufacturing). 3D printing allows new production solutions (e.g. functionality, higher complexity without additional cost) or new supply chain solutions (e.g. inventory reduction, faster delivery times), or a combination of both that lead to disruptive new business models (e.g. disintermediation of supply chain members, customer integration).

9.2.2 Main pillars (or enabling technologies) of Industry 4.0

According to (Senn, 2019) [66], as more smart technologies are implemented into manufacturing systems and processes, there is room for enormous potential. Connected machines will interact, visualize the production chain, and make decisions automatically and autonomously. There are nine main pillars of the Fourth Industrial Revolution, also referred to as Industry 4.0. These pillars outline the new technology manufacturers are using to improve all areas of production processes. Whether you work in the manufacturing industry or not, it is imperative to familiarize yourself with these pillars, as they are expected to have a widespread impact across all industries and society as a whole. (Rüßmann, et al., 2015, p.1-5) [59] explained the nine pillars or enabling technologies transforming industrial production below. Figure 18 depicts, and Figure 20 briefly describes these nine pillars of technological advancement.

Figure 18: These are the nine enabling technologies of Industry 4.0[22].

[22] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015, 04 09). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Retrieved from http://www.inovasyon.org/pdf/bcg.perspectives_industry.4.0_2015.pdf

1. Big Data and Analytics

Analytics based on large data sets has emerged only recently in the manufacturing world, where it optimizes production quality, saves energy, and improves equipment service. In an Industry 4.0 context, the collection and comprehensive evaluation of data from many different sources—production equipment and systems as well as enterprise and customer management systems—will become standard to support real-time decision making.

For instance, semiconductor manufacturer Infineon Technologies has decreased product failures by correlating single-chip data captured in the testing phase at the end of the production process with process data collected in the wafer status phase earlier in the process. In this way, Infineon can identify patterns that help discharge faulty chips early in the production process and improve production quality.

2. Autonomous Robots

Manufacturers in many industries have long used robots to tackle complex assignments, but robots are evolving for even greater utility. They are becoming more autonomous, flexible, and cooperative. Eventually, they will interact with one another and work safely side by side with humans and learn from them. These robots will cost less and have a greater range of capabilities than those used in manufacturing today. Figure 19 represents the impact of Industry 4.0 integration in any particular industry.

For example, Kuka, a European manufacturer of robotic equipment, offers autonomous robots that interact with one another. These robots are interconnected so that they can work together and automatically adjust their actions to fit the next unfinished product in line. High-end sensors and control units enable close collaboration with humans. Similarly, industrial-robot supplier ABB is launching a two-armed robot called YuMi that is specifically designed to assemble products (such as consumer electronics) alongside humans. Two padded arms and computer vision allow for safe interaction and parts recognition.

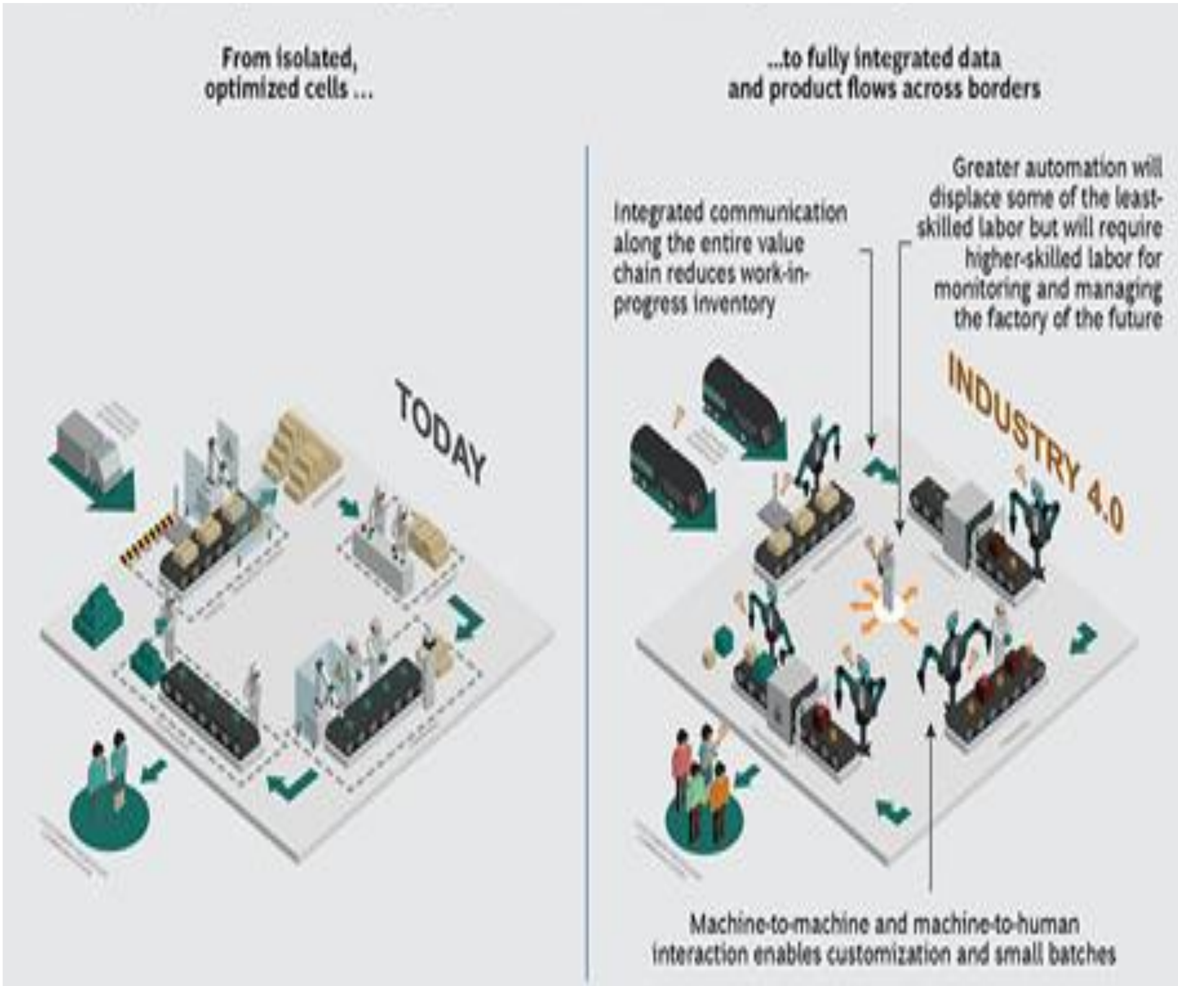

Figure 19: This represents the impact of Industry 4.0 in any industry if established[23].

[23] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015, 04 09). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Retrieved from http://www.inovasyon.org/pdf/bcg.perspectives_industry.4.0_2015.pdf

3. Simulation

In the engineering phase, 3D simulations of products, materials, and production processes are already used, but in the future, simulations will be used more extensively in plant operations as well. These simulations will leverage real-time data to mirror the physical world in a virtual model, which can include machines, products, and humans. This allows operators to test and optimize the machine settings for the next product in line in the virtual world before the physical changeover, thereby driving down machine setup times and increasing quality.

For example, Siemens and a German machine-tool vendor developed a virtual machine that can simulate the machining of parts using data from the physical machine. This lowers the setup time for the actual machining process by as much as 80 percent.

4. System Integration—Horizontal and Vertical System Integration

Most of today's IT systems are not fully integrated. Companies, suppliers, and customers are rarely closely linked. Nor are departments such as engineering, production, and service. Functions from the enterprise to the shop floor level are not fully integrated. Even engineering itself—from products to plants to automation—lacks complete integration. But with Industry 4.0, companies, departments, functions, and capabilities will become much more cohesive, as cross-company, universal data-integration networks evolve and enable truly automated value chains.

For instance, Dassault Systèmes and Boost AeroSpace launched a collaboration platform for the European aerospace and defense industry. The platform, AirDesign, serves as a common workspace for design and manufacturing collaboration and is available as a service on a private cloud. It manages the complex task of exchanging product and production data among multiple partners.

5. The Industrial Internet of Things

From (Senn, 2019) [66], the Internet of Things refers to the networking and connectivity of smart devices. When you think of IoT, devices such as smartphones, tablets, and laptops are usually top of mind. However, also think of wearables, cars, and any machine or device that allows the transmission of data, even our refrigerators. In the world of manufacturing, this IoT technology is often referred to as the Industrial Internet of Things (IIoT).

Based on (Rüßmann, et al., 2015, p.4) [57], with the Industrial Internet of Things, more devices—sometimes including even unfinished products—will be enriched with embedded computing and connected using standard technologies. This allows field devices to communicate and interact both with one another and with more centralized controllers, as necessary. It also decentralizes analytics and decision making, enabling real-time responses.

Bosch Rexroth, a drive-and-control-system vendor, outfitted a production facility for valves with a semi-automated, decentralized production process. Products are identified by radio frequency identification codes, and workstations “know” which manufacturing steps must be performed for each product and can adapt to perform the specific operation.

6. Cybersecurity

Many companies still rely on management and production systems that are unconnected or closed. With the increased connectivity and use of standard communications protocols that come with Industry 4.0, the need to protect critical industrial systems and manufacturing lines from cybersecurity threats increases dramatically. As a result, secure, reliable communications as well as sophisticated identity and access management of machines and users are essential.

During the past year, several industrial-equipment vendors such as Microsoft, HP, Cisco and more have joined forces with cybersecurity companies through partnerships or acquisitions. According to (Daniel D., 2019) [17], some of these companies have tried to form groups around goals related to the future of the internet and digital networks. Some of these groups (those he calls the operational alliances) are mainly practical, sharing intelligence or technical data. Others (the normative alliances) are explicitly aimed at changing the ways companies deal with cybersecurity vulnerabilities and renegotiating the social contract between states and their citizens.

7. Cloud Computing

Companies are already using cloud-based software for some enterprise and analytics applications, but with Industry 4.0, more production-related undertakings will require increased data sharing across sites and company boundaries. At the same time, the performance of cloud technologies will improve, achieving reaction times of just several milliseconds. As a result, machine data and functionality will increasingly be deployed to the cloud, enabling more data-driven services for production systems. Even systems that monitor and control processes may become cloud based.

8. Additive Manufacturing

Companies have just begun to adopt additive manufacturing, such as 3D printing, which they use mostly to prototype and produce individual components. With Industry 4.0, these additive-manufacturing methods will be widely used to produce small batches of customized products that offer construction advantages, such as complex, lightweight designs. High-performance, decentralized additive manufacturing systems will reduce transport distances and stock on hand.

For instance, aerospace companies are already using additive manufacturing to apply new designs that reduce aircraft weight, lowering their expenses for raw materials such as titanium.

9. Augmented reality

Augmented-reality-based systems support a variety of services, such as selecting parts in a warehouse and sending repair instructions over mobile devices. These systems are currently in their infancy, but in the future, companies will make much broader use of augmented reality to provide workers with real-time information to improve decision making and work procedures.

For example, workers may receive repair instructions on how to replace a particular part as they are looking at the actual system needing repair. This information may be displayed directly in workers' field of sight using devices such as augmented-reality glasses.

Another application is virtual training. Siemens has developed a virtual plant-operator training module for its Comos software that uses a realistic, data-based 3D environment with augmented-reality glasses to train plant personnel to handle emergencies. In this virtual world, operators can learn to interact with machines by clicking on a cyber-representation. They also can change parameters and retrieve operational data and maintenance instructions.

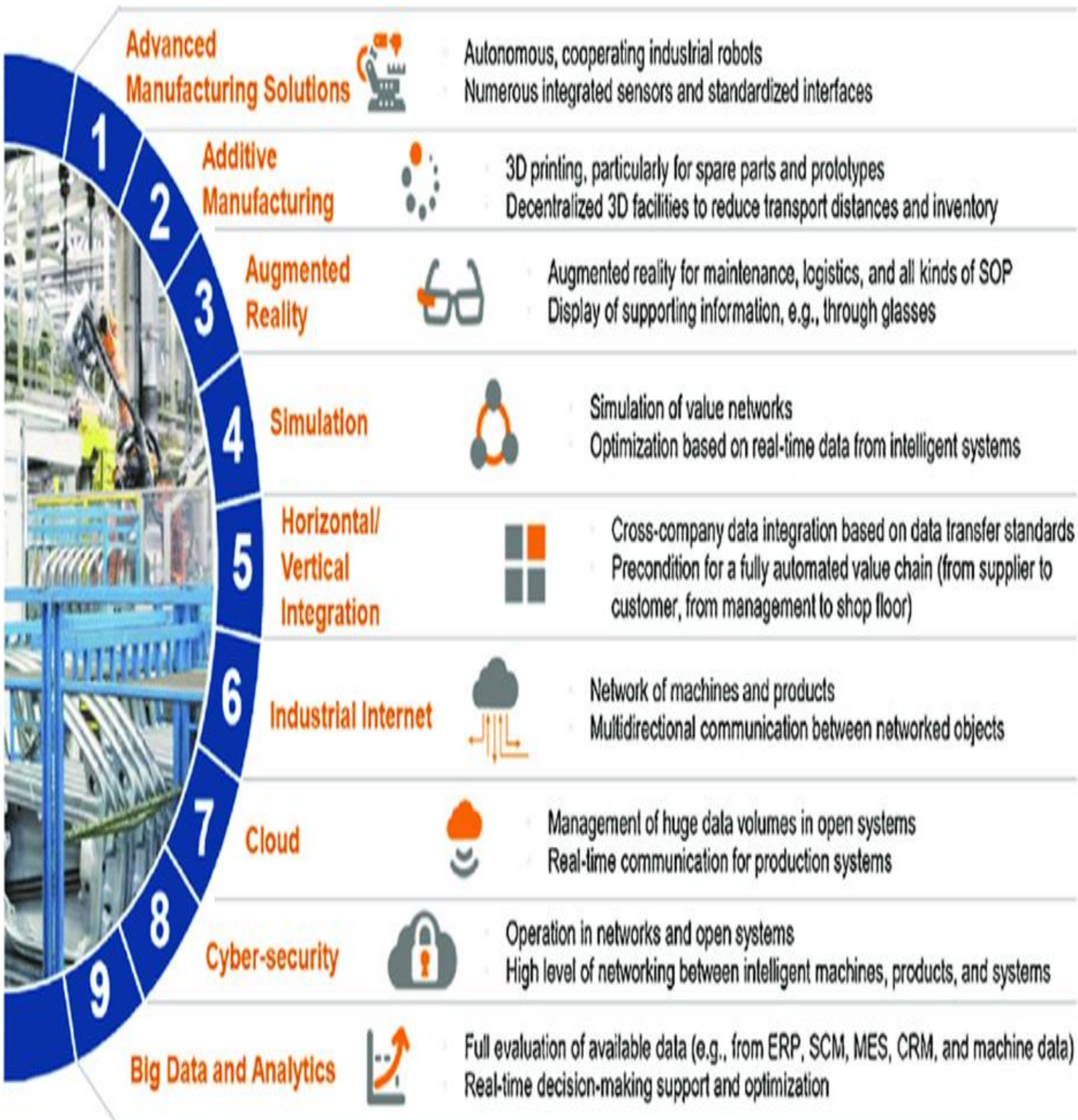

Figure 20: This is a review of the nine Industry 4.0 enabling technologies[24].

24 Researchgate. (2019). Retrieved from https://www.researchgate.net/figure/Industry-40-enabling-technologies-151-152_fig5_327931443

9.2.3 Industry 4.0 and the eight pillars of Total Productive Maintenance (TPM)

From (Richter, 2018) [56], while this wave of innovation (Industry 4.0) is being greeted with much enthusiasm by a traditionally conservative industry, a clear strategy for deployment and ongoing management is required to successfully adopt Industry 4.0 technologies.

In a nutshell, Total Productive Maintenance is a system for optimizing maintenance and reaching a state of perfect efficiency in production. TPM focuses on driving efficiencies by organic means e.g., by using existing company resources. The main goals of Total Productive Maintenance are no short stoppages or sub-optimal production rates, no defects, no unplanned downtime, no accidents. Below, (Richter, 2018) [56] gave an outline of the eight pillars along with how Industry 4.0 can take this approach (TPM) even further. Figure 21 shows the eight pillars of TPM that can be improved by Industry 4.0 technologies.

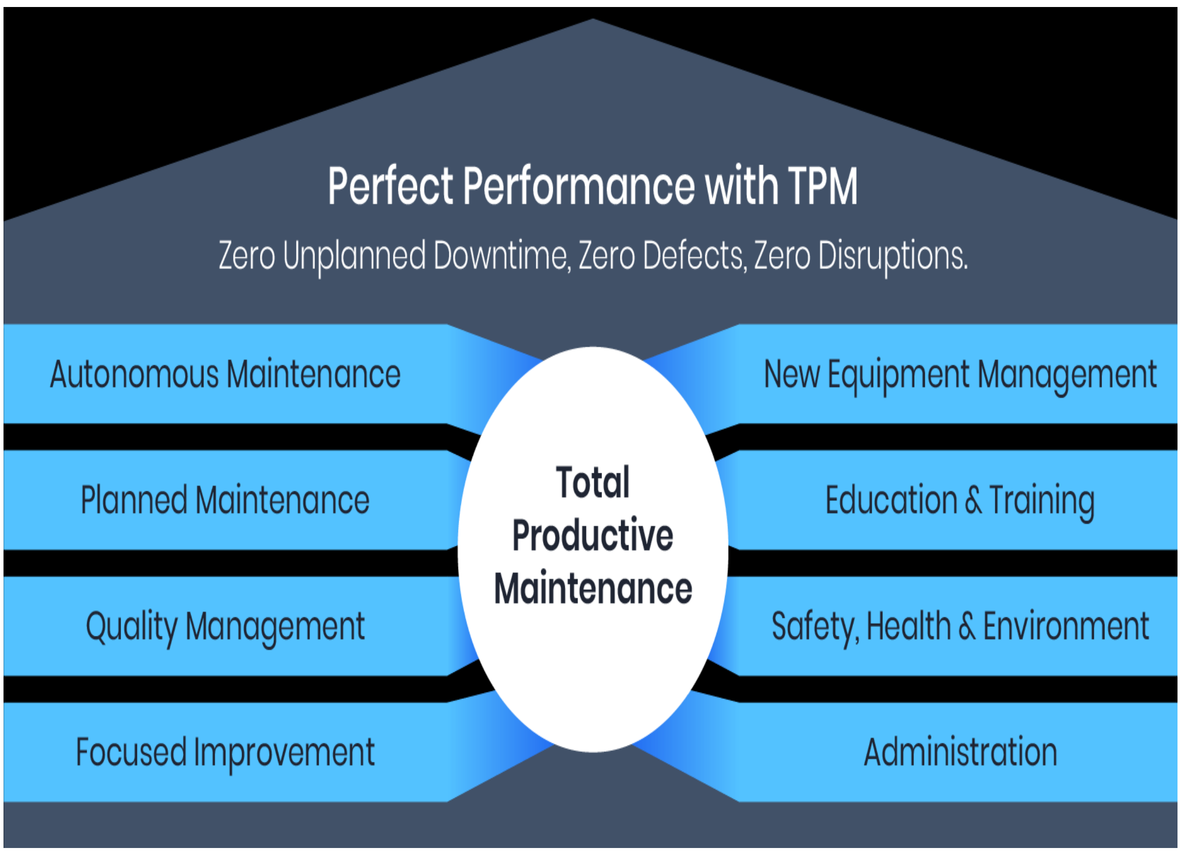

Figure 21: The eight pillars of TPM[25].

[25] Richter, I. (2018, 12 30). How Industry 4.0 Brings Total Productive Maintenance. Retrieved from https://blog.seebo.com/how-industry-4-0-brings-total-productive-maintenanceinto-the-digital-age/?source=post_page-----18de485aec8d----------------------

1. Autonomous Maintenance

Probably the unique characteristic of TPM—the idea here is that the people working with a machine on a day-to-day basis are the most "in-tune" with its behavior and performance.

Operators are trained to claim "ownership" over their machines, taking care of routine maintenance activities such as cleanliness, lubrication, and inspection, and should be the first to attempt handling issues within the realm of their training, before calling upon expert technicians.

With Industry 4.0: As machines become more automated, monitoring improved, and dashboards easier to read, operation will become less complex making the "ownership" suggested by TPM much simpler and therefore more accessible to workers.

2. Planned Maintenance

Maintenance pre-empts malfunction while interventions by high-level technicians are carefully planned so that minimal downtime is required for any software updates or part replacements.

With Industry 4.0: Using predictive maintenance by means of machine learning, maintenance activities are only performed when necessary and can be timed to avoid downtime completely.

3. Quality Management

Workers are trained and encouraged to identify issues in production that ultimately lead to defects and quality issues.

With Industry 4.0: Enter "predictive quality"—sensor data and machine learning help identify anomalies in machine behavior, alerting operators, who can then perform focused root cause analysis. Problems can be corrected much earlier than what was previously possible, reducing the financial damage of quality deterioration and defects.

4. Focused Improvement

Cross-functional teams are formed, and proactive involvement is encouraged. Problems affecting production are tackled by workers who start with the major hindrances/showstoppers, moving down to more minor inefficiencies.

With Industry 4.0: Through organized data collection and the application of artificial intelligence algorithms (e.g. neural networks), less obvious correlations between defects and root causes can be exposed. Inspection information and hypotheses can be shared company-wide, allowing for better synchronized and more successful collaboration.

5. New Equipment Management

The design and installation processes of new equipment should be planned based upon previous experiences to ensure that performance targets are reached quickly with minimal start-up issues and for improved safety.

With Industry 4.0: Production data in historian systems can be analyzed to identify best practices from previous installations/designs while taking into account current plant/factory conditions.

6. Education & Training

Operators receive training giving them the necessary skills to maintain machinery and identify problems. In turn, maintenance technicians learn approaches to more proactive work while managers are encouraged to improve leadership skills.

With Industry 4.0: Digital Twin visualization provides an excellent opportunity to learn about the complexities of manufacturing on all levels: from components and machines to production lines and overall facility management.

7. Safety, Health & Environment

A safer work environment is created by identifying health risks and potential hazards and working to eliminate them. Uncomfortable conditions harm productivity and employees should not be expected to be productive while at risk.

With Industry 4.0: Sensors can measure air quality, radiation, temperature and other environmental conditions which may affect health and performance while the early detection of harmful gases, electrical surges and fire can save lives and prevent damage to equipment.

8. Administration

The TPM approach can be applied to systems that aren't directly involved in manufacturing, including office administration. The significance of including administrative functions as one of the eight pillars is that this level of management—order processing, scheduling, workforce management, accounting—should be in sync with the other facets of the facility through effective communication, transparency and tried and tested protocols.

With Industry 4.0: Artificial Intelligence algorithms are very well suited to analysis and decision-making processes making this technology extremely advantageous to office automation. Office automation is destined to develop and will include demand forecasting, intelligent pricing, and smart purchasing and outsourcing.

According to the Total Productive Maintenance approach, achieving excellence in each of the 8 pillars mentioned above is verification that a manufacturing facility is producing “World Class” results.

9.3 Industry 4.0 use case—Predictive Maintenance in depth (How Predictive Maintenance fits into Industry 4.0)

As stated by (Roubaud, 2017) [57], in the manufacturing space, IoT technology is a crucial enabler for predictive maintenance. Through the use of IoT sensors, smart factories are coming to life, with connected machines that can communicate with each other and with humans, who can take action when necessary. This technology can catch changes and faults that are unseen by the human eye. Instead of solving a problem after it happens, predictive maintenance will alert the system ahead of time, so humans (or machines) can take the necessary action to ensure no problem occurs at all.

According to (Seebo, 2019) [64], until now, factory managers and machine operators carried out scheduled maintenance and regularly repaired machine parts to prevent downtime. In addition to consuming unnecessary resources and driving productivity losses, half of all preventive maintenance activities are ineffective. As an illustration, based on (Epicor, 2019) [21], without IoT systems in place at a factory, preventive maintenance happens based on routine or time. In other words, it's a manual task. But with IoT systems in place, preventive maintenance is much more automated and streamlined. Systems can sense when problems are arising, or machinery needs to be fixed and can empower to solve potential issues before they become bigger problems. Predictive maintenance/analytics allow companies to not just ask reactive questions like, "what has happened? "or "why did it happen?" but also proactive questions like, "what is going to happen," and, "what can we do to prevent it from happening?" These types of analytics can enable manufacturers to pivot from preventive maintenance to predictive maintenance.

Therefore, from (Seebo, 2019) [64], It is not a surprise that predictive maintenance has quickly emerged as a leading Industry 4.0 use case for manufacturers and asset managers. Implementing industrial IoT technologies to monitor asset health, optimize maintenance schedules, and gaining real-time alerts to operational risks, allows manufacturers to lower service costs, maximize uptime, and improve production throughput.

Overall, from (VROC, 2019) [76], Industry 4.0 encompasses the pervasive trend towards automation and data exchange, Internet of Things (IoT), cloud computing, artificial intelligence and of course, predictive analytics. Through the lens of Industry 4.0, predictive maintenance—which is in essence an extension and improvement of condition-based monitoring—is one of its many positive outputs. By proactively and pre-emptively managing asset maintenance around predicted failures, uptime is significantly increased, and productivity is majorly optimized.

The toolkit for making it possible comes in the form of artificial intelligence (AI)-enabled analysis of big data. Using machine learning (a specific subset of artificial intelligence), it becomes a method of preventing asset failure by analyzing industrial production data to identify patterns and subsequently predict issues, breakages and failures before they happen. Figure 22 shows the process of predictive maintenance analysis in an industry.

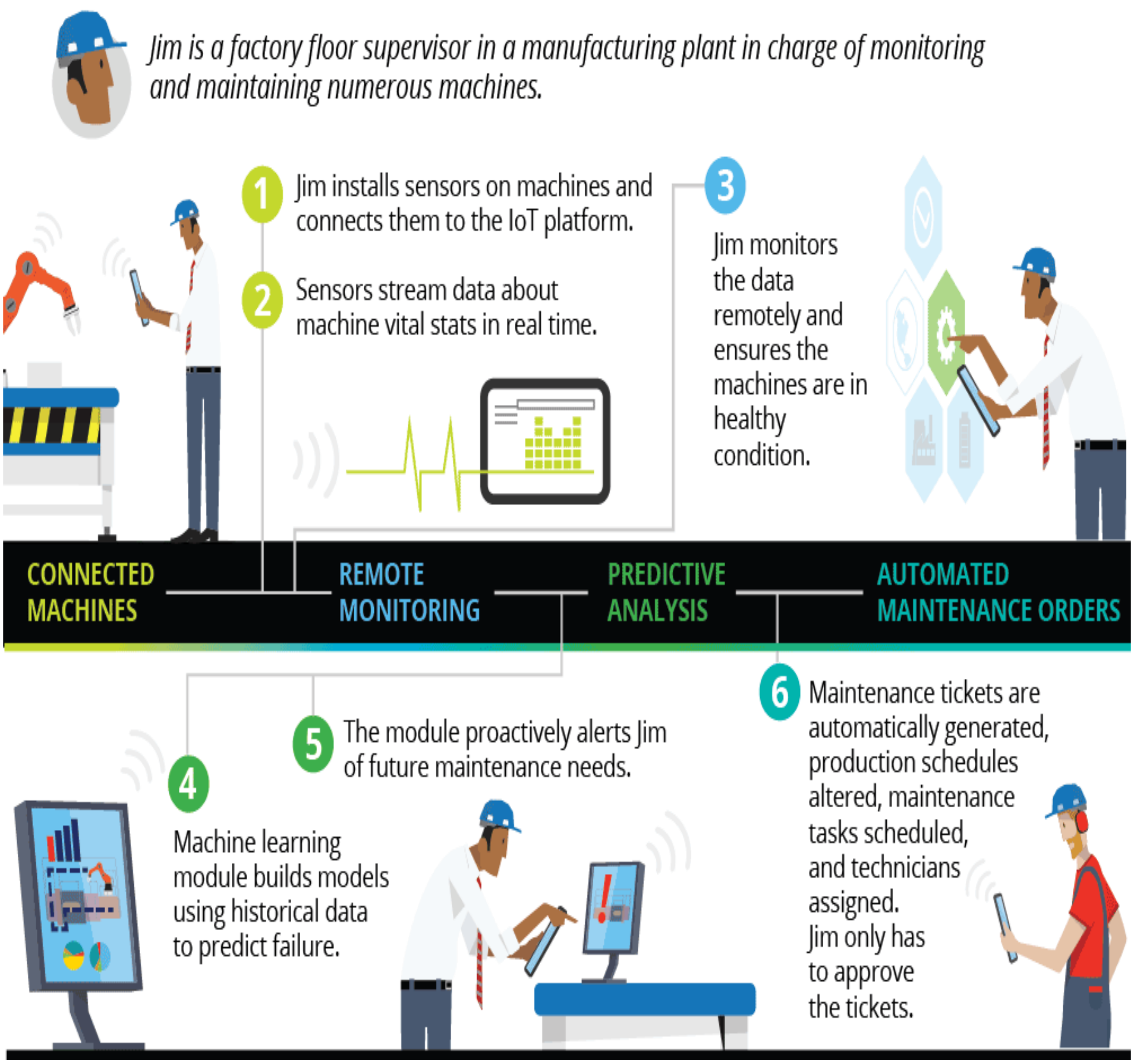

Figure 22: An illustration of the predictive maintenance process[26].

[26] Sylvie Rioux. (2019, 02 21). Discover Jim's new predictive maintenance process! Retrieve from https://www.andromediatech.com/en/discover-jims-new-predictive-maintenance-process/

9.3.1 How IoT predictive maintenance works

According to (Schreiner, 2019) [63], predictive maintenance is one of the most tangible applications within Industry 4.0. It allows status data to be obtained from machines and proactive maintenance to be carried out on systems.

Predictive maintenance refers to a maintenance process that is based on the evaluation of process and machine data. It is used primarily in the context of Industry 4.0. The real-time processing of underlying data makes it possible to make forecasts that form the basis for needs-based maintenance and consequently the reduction of downtimes.

As mentioned by (VROC, 2019) [76], there are several components that must exist for an industrial asset to be predictively maintained and therefore considered Industry 4.0 as listed below. Figure 23 portrays the architecture of predictive maintenance.

1. **Sensors**

The first step in any IoT enabled process is having high quality sensors that are streaming live data. Sensors will ideally be collecting a wide variety of metrics, without bias.

2. **Data Communication**

The next critical component is a secure system by which data can flow between assets and the central data lake.

3. **Central Data Lake**

Creating a data lake that can act as a secure home for all source data is the next important step. It's irrelevant if this is on premise or cloud based, just that it's accessible by the programs that need it—including your predictive analysis software.

4. **Predictive Analytics**

Powered by artificial intelligence for profound insight, machine learning algorithms will ingest, aggregate and synthesize data, with the ability to recognize complex patterns and generating detailed insights.

5. **Time to Failure and Root Cause Analysis Predictions**

Predictions are ideally in the form of a user-friendly dashboard that provides time-to-failure and root cause analysis alerts and insights. Operational staff can quickly and easily identify and action preventative maintenance as and when required.

6. Increased Uptime

Every company wants to remove the word "downtime" from their vocabulary and their operations. With predictive maintenance, you can eliminate unscheduled maintenance and instead plan for it with optimal material and staff resourcing, increasing productivity and profits.

In summary, assets data are streamed from the sensors to a central data lake using communication gateways. Creating a data lake can act as a secure home for all source data. Then, predictive analytics algorithms are applied to recognize complex patterns and generate detailed insights for reducing downtime, which are examined using root cause analysis software.

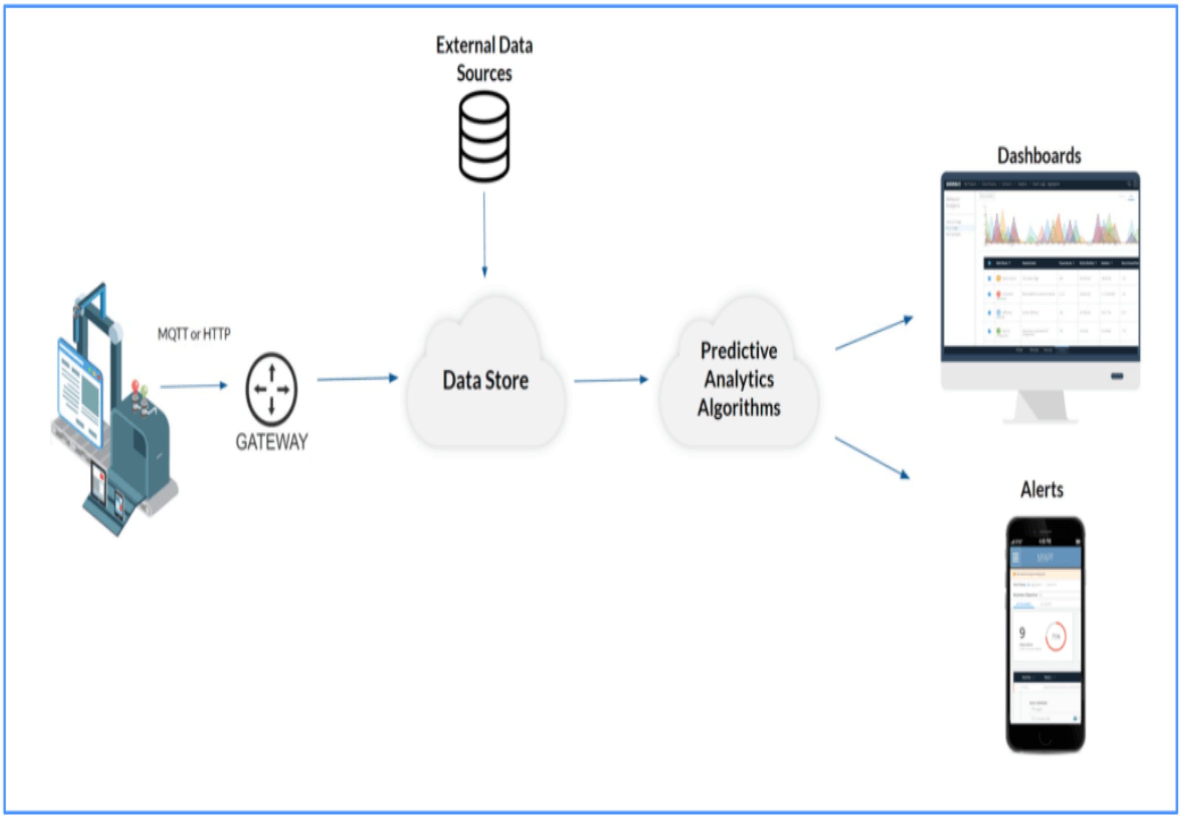

Figure 23: The architecture of predictive maintenance[27].

[27] Seebo. (2018, 07 11). What is predictive maintenance? Retrieved from https://medium.com/@carina.k/what-is-predictive-maintenance-ed98eb9f13d9

9.3.2 How to effectively implement predictive maintenance

As reported by (Seebo, 2019) [64], to implement a predictive maintenance system effectively, manufacturers need to map the parameters of failure for machines and create a blueprint for their connected system—the manufacturing assets and sensors, business systems, communication protocols, gateways, cloud, predictive analytics, and visualization.

Using a visual IoT modeler, engineering teams can graphically capture the production processes in the shop floor, including data flows, dashboards, and the logic of the system—with rules that monitor and alert to maintenance issues. The modeler generates a system blueprint, which is critic al for accurate predictive analytics.

Predictive analytics are applied to the machine data—and the system blueprint data—in order to predict conditions of upcoming failure. A dashboard for predictive analytics synthesizes operational data, allowing process and maintenance engineers to address actionable insights in the form of corrective action.

9.3.3 The Future of Predictive Maintenance in Industry 4.0

According to (VROC, 2019) [76], Predictive maintenance is already playing a key role in Industry 4.0. As machines get smarter and AI technology and platforms get more advanced, maintenance decisions will be increasingly left up to them to reduce the risk of human error and increase the chances of optimal performance. Data—the currency of our age—is already and will continue to usher in a new era of industrial operations, smart factories and revolutionized ways of working.

As more and more companies recognize the value of implementing asset management software, we will only see a faster gallop towards the end of Industry 4.0 and the start of whatever comes next.

9.4 Real world examples of Industry 4.0 with Predictive Maintenance solutions

Manufacturers are now focusing their attention on the Industry 4.0 as it holds potential benefit. From (Electronic Products, 2018) [20], according to the U.S. National Response Center, it costs approximately 50% more to repair a failed asset than if the problem had been addressed before failure. In addition, if an asset such as a motor fails in an unpredictable way in a factory environment, it could hurt an operator working with it, possibly resulting in a lost-time incident, fines, or audits. Finally, an unavailable asset can slow down or even stop production, causing the loss of millions of dollars and, in some cases, even customers. Cost, safety, availability, and reliability are the main reasons why predictive maintenance is fundamental in Industry 4.0, a trend whose goal is to make factories more productive, efficient, and flexible.

Below are examples of companies where Industry 4.0 made a difference as well as few predictive maintenance solutions by sector.

1. **BOSCH'S Factory in Hamburg**

From (Minturn, 2019) [45], Bosch's factory in Hamburg in southern Germany achieved a 10 per cent output increase and 30 per cent stock reduction within a year through the deployment of Industry 4.0. The plant, which manufactures hydraulic valves for mobile machinery such as tractors, had a manual production line that was manufacturing six main valve product types with 250 variants and 2,000 individual parts. Bosch needed to improve cost and delivery times for a line that also needed to remain highly flexible, working with small batch sizes and requiring assembly experts for each product family.

Solution

Bosch set up nine autonomous intelligent workstations that could quickly switch between products as required. To facilitate the quick learning of manual work steps, they employed their ActiveAssist assembly technology. The system used pick-to-light technology to guide assembly steps, eliminate errors and check all assemblies via a 3D camera. By combining this technology with radio-frequency identification (RFID) of each single product, they ensured that workers could pick only the necessary components for the new run. Each workstation recognized employees via a Bluetooth tag and every step of the process was recorded and relayed to production operatives in real-time using RFID chips to monitor the position of individual components. ActiveAssist also made a difference by ensuring that all workers received exact instruction tailored to their qualification level and preferred language.

Results

Smart technology allowed the Hamburg staff to reduce logistical and set-up time from 450 seconds to zero within the space of a year. Inventory days were halved, and cycle times were cut by eight per cent. The result for the plant was a saving of €500,000 (or 752,430.49 CAD) in the first year alone. They are now implementing Industry 4.0 solutions to the next steps in their value stream. Having started with valve assembly, Bosch is looking forward to the machining area and will follow up with the valve test area. They are certain there are huge potential benefits from connecting the worker, machine and material in industrial production in this way.

2. **Industry 4.0: Predictive maintenance for milling machines**

As stated by (Kohler, 2015) [35], spindles in milling machines are prone to breaking during the production process. What's more, repairing spindles can be very expensive. Therefore, being able to predict damage and precisely when the spindle will break can greatly reduce costs.

To overcome this challenge, special sensors (e.g. ultrasonic or vibration sensors) identify the patterns of a fragile spindle. Relevant alert settings for the current state of the machine can then be created.

The sensors generate data which is then compared to the information from the machine and the specific workpiece being processed. By analyzing the data, it is possible to identify patterns of behavior that more accurately predict when the spindle is about to break. This enables maintenance schedules to be planned accordingly. The benefits in detail are higher process transparency, lower maintenance costs and reduced machine downtime.

3. **Industry 4.0: Predictive maintenance for heat exchangers**

According to (Kohler, 2015) [35], deposits in the conduits can cause heat exchangers to clog. A further complicating factor is the fact that it is impossible to measure the flow rate of a heat exchanger directly. A complete blockage can cause serious problems, resulting in manufacturing errors and hours of downtime.

One solution to this issue is to measure the temperature differential upstream and downstream of the heat exchanger. After gathering and visualizing the measured values, it is possible to define threshold values. These values can then be input into an alert system to notify employees as soon as the first signs of clogging appear. The benefits in detail are early warning of anomalies indicating potential blockages, reduced machine downtime and less wastage of materials.

4. Texas Instruments (TI)

As noted by (Electronic Products, 2018) [20], Texas Instruments (TI) implemented predictive maintenance in one of its factories by equipping several vacuum pumps with a sensor node, a reference design developed by TI, which measures and collects data from the pump, such as temperature, motor current, nitrogen flow, and water flow, transmitting the data to the internet through a gateway as depicted in Figure 24.

TI can easily access the data through the internet for continuous monitoring and analysis, giving operators of the pumps insight into operating conditions. For example, independent of the usual maintenance schedule, operators can identify defective equipment that might cause a system shutdown and replace it before any damage occurs.

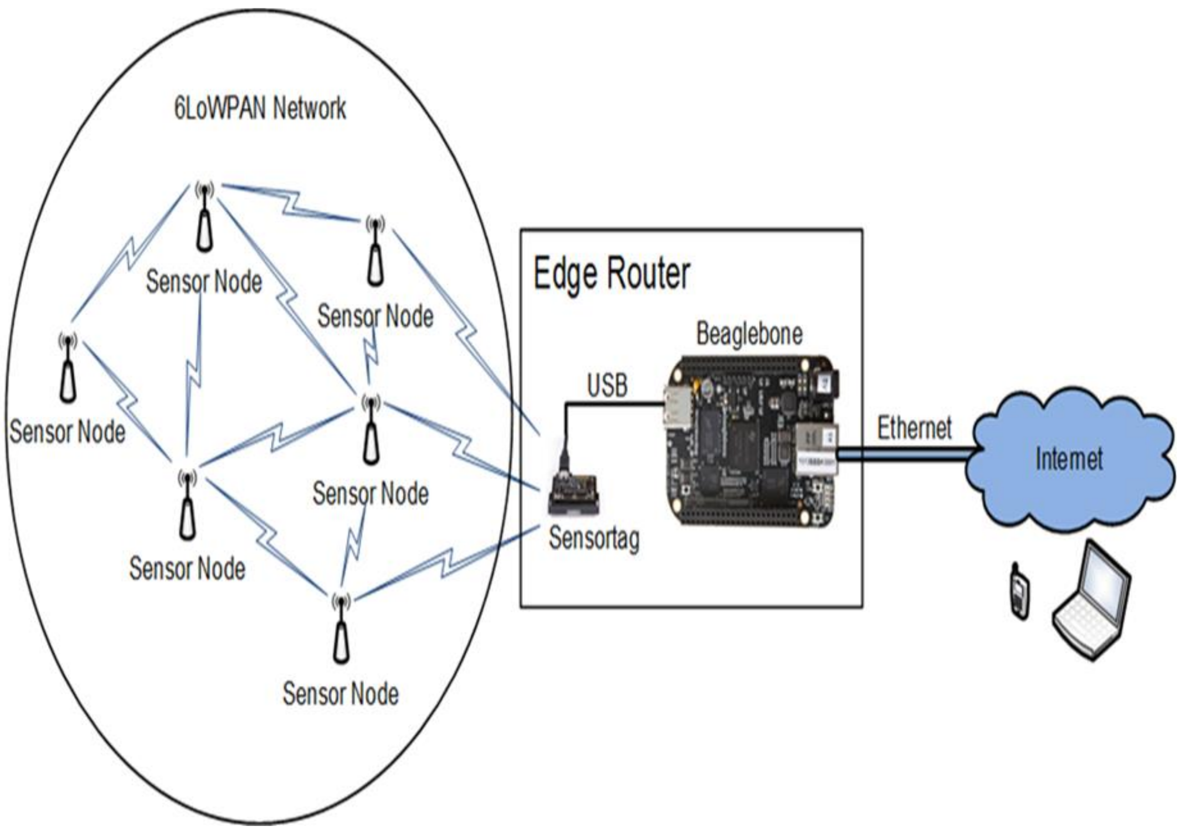

Figure 24: Example of a wireless mesh network for predictive maintenance[28].

With this practical example, TI has been able to upgrade its own factory to a smart factory enabling predictive maintenance by monitoring the condition of in-service equipment.

5. Industry 4.0 in the Automotive sector

According to (Infineon, 2019) [29], the automotive sector is also already using Industry 4.0 successfully. Daimler, for instance, evaluates machine data to improve the quality of cylinder head production. The persons in charge can thus detect deviations and irregularities at an early stage in the manufacturing process and take action quickly. As a result, they reduce the error rate and make the production process more cost-effective.

Volkswagen is pursuing another exciting approach. In an Industry 4.0 project, it uses RFID (radio frequency identification) technology to capture data from components in test vehicles faster. The components are already fitted with RFID chips by the suppliers. When the vehicles are tested,

[28] Electronic Products. (2018, 05 09). Why predictive maintenance is fundamental in Industry 4.0. Retrieved from https://www.electronicproducts.com/Internet_of_Things/Why_predictive_maintenance_is_fundamental_in_Industry_4_0.aspx

engineers can identify the installed prototype parts effortlessly and display detailed information they need for development. They thus have the right information at the right place and at the right time.

6. Industry 4.0 in logistics

Based on (Infineon, 2019) [29], in logistics, Industry 4.0 technologies help optimize transport routes, utilize storage capacities perfectly and plan ahead. The Port of Hamburg is one such example. 140 million tons of goods are transshipped there every year, a figure that will likely double by 2030. However, there’s not enough space at the port. The Hamburg Port Authority therefore faced the challenge of shifting the containers faster.

People, trucks, containers, ships, cranes and traffic management systems were connected with each other in an Industry 4.0 project. They all communicate with each other and supply business-related data. The upshot: Trucks reached their destination faster, and the drivers knew where they can unload their consignment more quickly. Shipmasters can plan their trips in advance. All that has simplified the processes, allowing the Port of Hamburg to transship goods more swiftly.

Conclusion

The Internet of Things (IoT) is an advanced technology embedded with sensors and actuators that enable autonomous communication among heterogeneous devices. Though IoT present some set of challenges, its advantages extend to almost every area of lifestyle and businesses. For instance, IoT has applications across all kinds of industries such as in manufacturing, agriculture, healthcare and among other domains. Without the right technologies, platforms and protocols to facilitate networking, IoT expansion would have been limited. Similarly, relevant data for analysis to meet customer needs would have been inaccessible.

My research was based on the application of IoT in healthcare and in manufacturing, precisely the maintenance area where Industry 4.0 and predictive maintenance were the focus. IoT systems applied to healthcare enhance existing technology and the performance of healthcare. Through the collection of data from large sets of real-world cases, IoT can help to improve the healthcare and patients and clinicians experience and give precise treatment solutions. For instance, patients can be remotely monitored and cared for without the need to be physically at the hospital. Another advantage is that disease and treatments can be easily managed through IoT technologies to improve the patient's experience and more.

In regard to IoT in manufacturing, IoT opens the world to a whole new way to respond to industrial requirements and to efficiently meet market demands. It leads way to the Industry 4.0 which is at the center of the digital transformation of any industry with connected robots that can communicate with each other and humans. Likewise, it is an enabler for predictive maintenance which plays a key role in the Industry 4.0 (or the fourth Industrial Revolution).

As it stands, predictive maintenance leads to new approaches of work as in manufacturers will now be alerted in time to fix any potential problems before they arise. Some of the observed benefits from implementing the Industry 4.0 with predictive maintenance solutions in a manufacturing setting are: increased productivity, profits and safety, reduced human's error and waste, cuts in maintenance costs, reduced or elimination of unplanned downtime and unscheduled maintenance, etc.

All things considered, IoT help smart devices interact among each other without even human intervention. Though there might be some challenges to face with this network of internet-connected objects, most principally in the areas of security and privacy of data, there are multiple of solutions under way to remedy the situation. Aside from that, IoT has the power to change the world for the best.

That said, I will recommend future studies focus on how to establish better IoT standardization to ensure the secure spread of IoT devices. In addition, I will suggest that future studies focus on how IoT technologies can be properly integrated into healthcare or manufacturing facilities while maintaining their current processes.

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Annex A: Characteristics of IoT

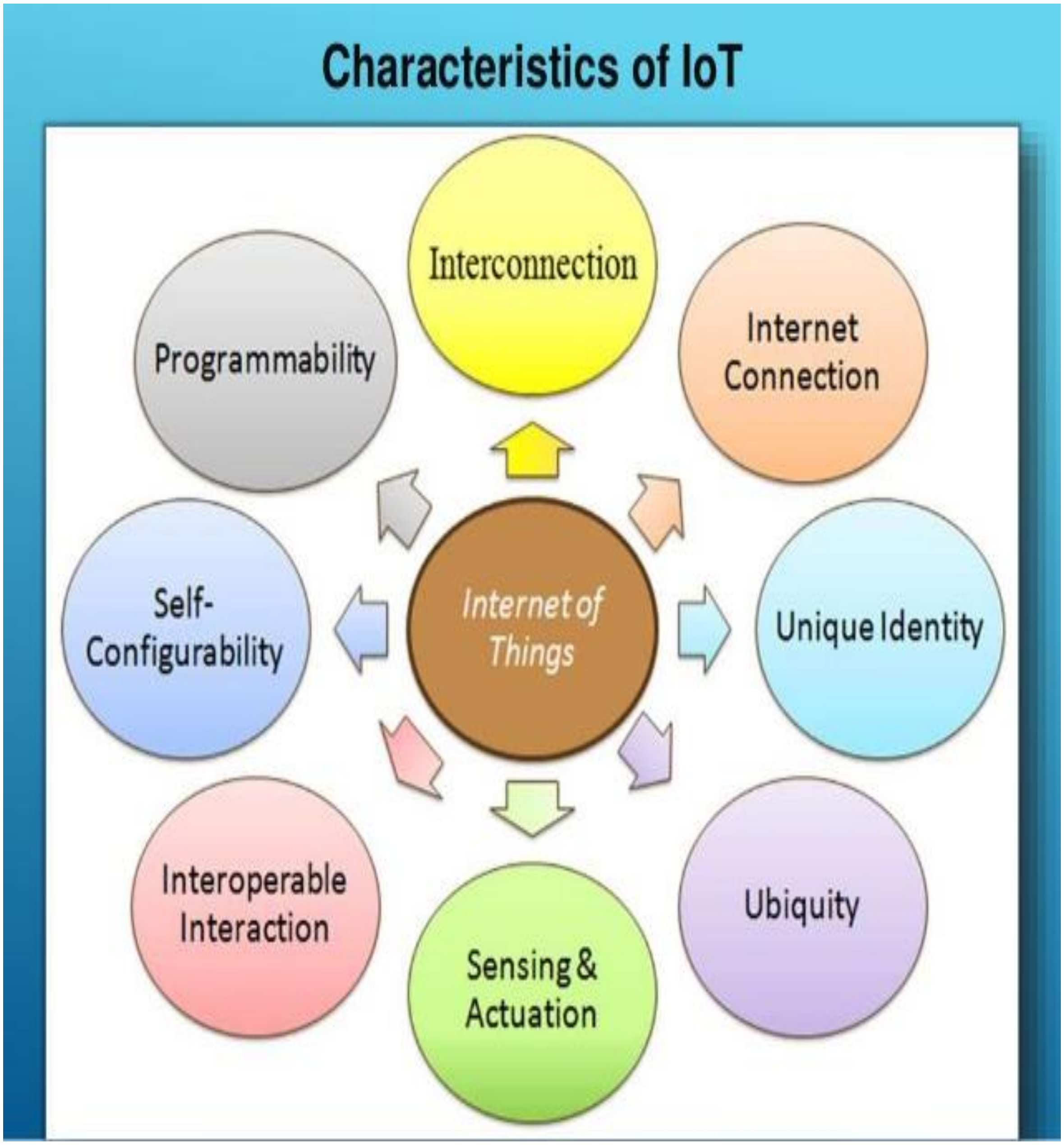

Figure 1: The characteristics of IoT[29]

[29] LinkedIn. (2019). Emerging Applications Perspective for Internet of Things. Retrieved from https://www.slideshare.net/Blessingdon7/emerging-applications-perspective-for-internet-of-things

Annex B: Meaning of IoT

Figure 2: How IoT works[30]

30 Quora. (n.d.). What exactly is Internet of Things (IoT)? Retrieved from https://www.quora.com/What-exactly-is-Internet-of-Things-IoT

Annex C: Different fields of impact of IoT

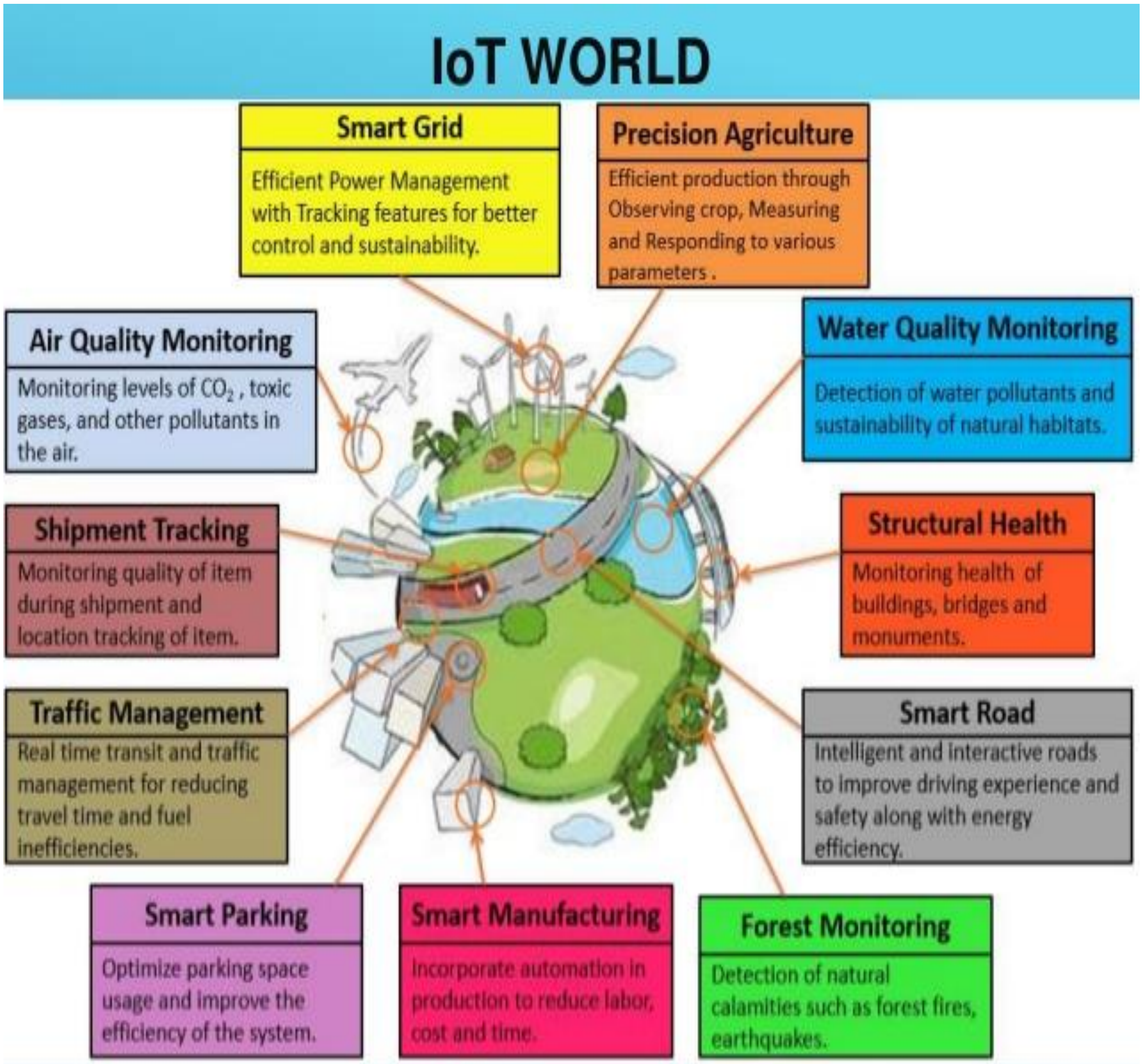

Figure 3: Different applications of IoT[31]

[31] LinkedIn. (2019). Emerging Applications Perspective for Internet of Things. Retrieved from https://www.slideshare.net/Blessingdon7/emerging-applications-perspective-for-internet-of-things