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The Use of Sensors in Complement to Industry 4.0 Technologies to Optimize Production Operations

An analysis of the industry technologies and model for their relations with optimized production

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Abstract:
Industry 4.0 is the revolution of the industry where all machines and their systems are combined together through complex networks in order to achieve higher degree of machine autonomy. Now there are 9 major technological advancements that marks i4.0's advent. Out of these, 3 (Sensor, AI, AR/VR) have been taken as the most easily industry assimilable and thus their influence on the efficiency of manufacturing industry has been studied in the paper and an Informal model has been presented showing how they positively effect lean production in a modern industry and how their complexity cost and Advancements have a moderating impact on the industry and lean production.

Keywords:

Industry 4.0, AR and VR, AI, Sensors, Lean Automation, Lean Optimization, Cyber-Physical systems

Introduction
Industry 4.0, often referred to as the 4th Industrial Revolution, emerged in 2011 during a German industrial convention, representing a significant technological shift across various industries. This transformation is driven by the convergence of advanced technologies like Big Data, Cloud Computing, the Internet of Things (IoT), and Artificial Intelligence (AI) and machine learning. The primary objective of Industry 4.0 is to amalgamate technology and digitization to attain greater autonomy in machines. It enjoys extensive support from German industry representatives like BITKOM, VDMA,and ZVEI, as well as global initiatives like IIC and Industries.

At the core of Industry 4.0 lies the Reference Architecture Model Industries 4.0 (RAMI 4.0), developed by the German manufacturer association ZVEI. RAMI 4.0 offers a comprehensive framework that outlines the relationships between life cycle value, products, facilities, and functional business layers in a 3-dimensional graph. Key principles of Industry

4.0 encompass service orientation, intelligent systems, interoperability, adaptability, optimization for effectiveness, data integration, reliable communications, and information security.

Industry 4.0 technologies are categorized into five central research themes: horizontal integration, end-to-end value chain engineering, vertical integration, cyber-physical system technology, and new social infrastructures. Although Industry 4.0 is technology-driven, resource-efficient, and sustainable, it has raised concerns about reduced human interaction in industries and its potential impact on worker rights and well-being.

In response to these concerns, Industry 5.0 emerged in 2021, with a strong emphasis on human values and environmental sustainability in smart factories. It complements Industry 4.0 by advocating for a more human- and eco-centric application of technology. Industry 5.0 emphasizes three core values: human centricity, sustainability, and resilience, with a focus on re-skilling human workers, environmental friendliness, and system robustness against global or local disruptions.

Industry 5.0 technologies include bio-inspired production, energy efficiency, personalized human and machine interactions, data system interoperability, simulations, and AI for addressing problems. These technologies work in tandem with Industry 4.0, addressing different aspects of the industry's needs.

The text also explores the intersection of Industry 4.0 technologies and sustainability, introducing a novel framework based on the United Nations Sustainable Development Goals (SDGs). This framework highlights the need for thoroughevaluation before adopting Industry 4.0 technologies, considering their economic, environmental, and social impacts.

The researchers discussed Industry 4.0, driven by AI, Big Data, IoT, and Cloud Computing, enabling data-driven decisions and automation across sectors. It emphasizes the universal adoption of AI, reshaping manufacturing, finance, and more. Human-machine collaboration and a "robot coordinator" play a pivotal role. The "new sand cone model" highlights human quality and the need for workforce training. In summary, Industry 4.0 combines advanced tech and human expertise for enhanced efficiency and productivity.

Additionally, the research discusses the compatibility of Lean Production with Industry 4.0. Lean Production focuses on efficiency, waste reduction, and continuous improvement, and when integrated with automation and cyber-physical systems, it facilitates the development of smart factories.

The structure of Industry 4.0 is built on three components: horizontal integration, end-to-end engineering, and vertical integration, all controlled through Cyber Physical Systems (CPS) and interconnected via a cloud system. This setup enables efficient resource allocation, promoting sustainability across economic, social, and environmental dimensions.

To elaborate further on Lean Production, it revolves around principles that emphasize waste reduction, continuous improvement, respect for people, just-in-time production, standardization, and error reduction. Lean Production's ability to minimize waste and enhance efficiency aligns with the resource-efficient goals of Industry 4.0. Automation and cyber-physical systems enhance the impact of Lean Production by enabling real-time data collection, analysis, and decision-making. This synergy contributes to both economic and environmental sustainability.

Lean Production principles are integral to Industry 4.0, enhancing efficiency, reducing waste, and promoting a culture of continuous improvement. When applied in conjunction with advanced technologies, Lean Production becomes a powerful tool for achieving sustainable and human-centric manufacturing processes within the fourth revolution of industry.

Sensors are the unassuming yet essential components of Industry 4.0. They serve as the eyes and ears of the digital factory, continuously capturing data on various parameters, such as temperature, humidity, pressure, and motion. This real-time data collection empowers manufacturers to monitor and analyze processes with unprecedented accuracy.

Sensors enable proactive maintenance, reducing downtime and improving overall operational efficiency. As a result, data-driven decisions are made, leading to the optimization of manufacturing processes.

Artificial Intelligence (AI) has found its way into machines, transforming them into smart, autonomous entities. AI algorithms are designed to learn and adapt to changing conditions, making machines more efficient and responsive. These AI-driven machines have a wide range of applications, from predictive maintenance to quality control. They can diagnose issues, detect anomalies, and even optimize their own performance. The outcome is increased productivity,minimized errors, and a substantial contribution to the core goals of Industry 4.0.

Digital cloning involves creating virtual replicas of physical machines or processes. These digital twins faithfully mimicthe behavior of their real-world counterparts, serving as a sandbox for experimentation. Manufacturers can test various scenarios and optimizations in this risk-free digital environment, reducing the costs and risks associated with making physical changes. Digital cloning is pivotal in enabling manufacturers to innovate and improve without disrupting their physical operations.

Digital twins extend their influence into the realms of Augmented Reality (AR) and Virtual Reality (VR). AR technologyoverlays real-time data on the physical world, offering workers valuable insights for maintenance tasks and quality control. AR glasses worn by workers facilitate improved visualization and collaboration. VR, on the other hand, immerses users in a virtual environment, enabling training, design reviews, and simulations. Both AR and VR bridge the gap between the physical and digital worlds, enhancing efficiency and safety in Industry 4.0.

The integration of AI in examination techniques has revolutionized quality control and assurance. AI-driven inspectionsystems excel at analyzing vast datasets in real-time, ensuring consistent product quality. These techniques are crucial in identifying defects in manufacturing processes, verifying product specifications, and ensuring compliance with industry standards. Industries such as automotive, electronics, and pharmaceuticals benefit from the precision and speed offered by AI examination techniques, raising the bar for quality assurance in Industry 4.0.

This Model provided below shows how Sensors shall be integrated along with machine system so as to work perfectly. Firstly, the Sensors shall collect live data from the working machine, thus after collection the data will be transferred to an AI computer system through an Internet of things (IOT) network, with that the AI will configure the data by making it into a CAD (Computer Aided Design Model) and finally the CAD model shall be worked by a digital twin cloning system to be viewed by the workers and supervisors in order to examine for operational wastages or ***Muda*** in lean terms. All of this can also be remotely viewed by the managers so as to oversee their smart manufacturing units. The model though basic and barebones, has never been worked on before.

In conclusion, Industry 4.0, represents a major technological transformation driven by advanced technologies like Big Data, Cloud Computing, IoT, and AI. It's aimed at achieving greater autonomy in machines and enjoys global support. The fundamental framework, RAMI 4.0, underscores service orientation and data integration. Complementing this, Industry 5.0 places a strong emphasis on human-centric values and sustainability, advocating for workforce re-skilling and eco-conscious technology utilization. Both revolutions contribute to sustainability and quality assurance. The concepts of digital twins, AR, VR, and AI-driven machines enhance efficiency and decision-making. Meanwhile, AI examination techniques elevate quality control, particularly in industries like automotive and electronics. Sensors andAI play crucial roles in real-time data collection and analysis, enabling proactive maintenance and data-driven decisions,thus driving the industry toward greater efficiency and innovation. This combined effort represents a pivotal phase inthe evolution of modern manufacturing and industry.

Research Introduction:

Research Background:

The idea of i4.0 is about 13 years old at the time of the writing of this article but still no substantial research regarding manufacturing systems and smart factories has been made. Thus, untapped potential of the 4th industrial revolution i.e. How can it be achieved and how can it change the industry SOPs and norms are still unclear and will be if not worked upon. Along with that the vagueness and complexity of its major technologies also have not created a good impact on the existing mindset of the industry professional.

Research Problem:

The major problem faced by this research topic are the lack of research on its technologies from a commercial and management point of view. This can be seen as the majority of articles about industry 4.0 are about research on technologies but from an engineer and computer technician's perspective which helpful to the industry person but is clearly not solving their problems.

Research Purpose:

The purpose of this research is to work onto the I4.0 topic but from a commercial perspective. Also providing a viable theory as to how the various I4.0 technologies will influence the manufacturing industry in creating a fully-fledged smart factory. Hopefully this paper will set a trend as the standard framework of research or in the least provide a pathway for interested researchers as to what their course of action should be.

Literature Review

There were over 125 articles studied during the course of the research all with the following keywords:

Industry 4.0
AR and VR
AI
Sensors
Lean Automation
Lean Optimization

Cyber-Physical systems

Out of the 125 articles studied nearly 40 were deemed to be not useful for the research while the rest were citated according to the presence of reference.

The bulk of the articles were in technological and Medical in pretext but the data they gave was useful nonetheless.

Key Terms Explanation:

The key terms used in the articles are explained as follows

Industry 4.0:

Industry 4.0 refers to the 4th Industrial revolution marked by the Amalgamation of technology with digitization coupled with Ultimate goal of achieving higher degree of autonomy in machines. Its idea was first given in a German industrial convention in 2011. Over a Decade has passed but much work has been done on this revolution thanks to different countries adapting the 4th revolution into their industries. These include German Industry representatives BITKOM, VDMA, ZVEI along with global initiatives like IIC, Industria etc (**15**).

As the advent of various communication systems reaches its peak, new ways of analysis and optimisation emerge. This leads to a follow of questions about implementation of industry 4.0 technology in complement to new communication tech. To answer those question the I4.0 technology is divided into two classes based on production ends.

These are **Front-End Technologies** *(The first layer)* and **Back-End Technologies** *(The second Layer)*, now these Front-end and back-end technologies are consistent of few technological functions. These are for Front-End: *Smart*

Working, Smart Manufacturing, Smart Supply Chain and Smart Products and as for Back-End these are: *Base Technologies and their Derivatives*. Now in a Smart factory there are some aspects of CPS present but in order to further automize the factory different technologies can be used.

Now the working of the technologies is as the Front-End Technologies shall be at the forefront of the industry while the Back-end Technologies make the base of the Industry, The Front End signifies the value chain while the Back End provides the intelligence of the front-end technologies. Firstly, we have the ***Smart Manufacturing***, it uses various I4.0 tech to efficiently process products, the technologies used are Vertical Integration, Virtualization, Automation, Traceability, Flexibility and Energy Management. Vertical Integration can help in decision making process by linking the shop to the Top or Middle level management by means of PLCs, SCADAs, MES, ERPs and M2M comms. Virtualization by virtue of AR and VR technologies can help in pre-planning possible disruption management. Automation helps through provision of fatigue-less and precise robots that are either Collaborative or Operational. A.I will aid in problem identification and optimization solutions. Sensors also help in traceability of inventory which can be optimized to a larger extent. Additive Manufacturing (3D Printing) is helpful in sustainability since it has a very small carbon footprint. And Energy efficiency can be achieved by Efficiency Monitoring of resources, Their Synergistic relation with IOT and Digital systems can give birth to CP systems (**51**).

Sensors:

A Sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor (**60**).

They are of a range of types and have different uses in a variety of scenarios. They play a key role in the creation of a workable environment by collecting data of various types (**61**). The sensors are of 2 major types in the market today. These are **Active** and **Passive** Sensors. They are sensors which rely on external and internal power of the system respectively. Examples include Accelerometers and Mercury in Thermometer (**62**).

A simple working of a sensor is as follows; Stimulus is created in the environment-The stimulus reaches the sensor-The sensor reacts to the stimulus in an appropriate way (**62**).

Sensors are a cornerstone of modern interconnected ecosystems and are responsible for the base model presented in the below discussion (**61**). Sensors as form standard component of the Human Computer Interaction as well (**63**). Thus, in light of their versatility and cheapness they are fit to be used in the industry as a workable Lean optimization provider as well.

AI:

Ai or Artificial intelligence is relatively new form of technology that gained popularity in the public in 2020 when OpenAI launched its Chat-Gpt and showcased the power of machine learning. But at an Accessible cost. Before that Ai was available in a much simpler form for the public. But now it has evolved to such a grade that it can be used in the industry (**66**).

AI is a branch of engineering which is concerned with the mechanization of tasks that are believed to require intelligence when performed by humans (**64**). In simple terms AI is the making of the machine to be autonomous in its tasks and give adequate reasoning for its actions, *to think like a human*.

AI works on the simple method of input processing and output. All we need is to train the memory systems of the computer so that they can perform the tasks we require them to perform. A good advantage of AI is that it removes the variable of human error from the equation as it is in it-self a bunch of code that can never be wrong. The use of AI in the below mentioned system is of the DT (Data Technology) variety. The AI used is to analyse data in large volumes and form data sets that can be used by external software as digital twin maker so as to form a final system that can be implemented in an industry (**65**).

AR/VR:

AR or Augmented Reality and VR or Virtual reality are fundamentally two very different concepts but here for the sake of simplicity are taken as one due to both of their use are same.

AR is defined as a real-time direct or indirect view of a physical real-world environment that has been enhanced or augmented by adding virtual computer-generated information to it. AR has been present since the 1950s as a way to enhance cinematographic experience (**67**), we can judge from this that the main use of AR has been in entertainment industry since it requires the creation a real virtual space for the user that provides extra-real stimulus to the senses (**68**). It works by imposing 3D objects onto the real-world using tracking sensors which can be manipulated in from gestures and marks. The users can also view 3D objects in a real environment removing difficulty of production and transport (**69**).

VR is defined as a term used for 3D environments that allow a user to enter and interact in alternate realities, the users are able to immerse themselves to varying degrees in a computer-generated artificial world. It was first coin by John Lanier of VPL Technologies (**70**). VR works as a projector on our eyes creating an artificial sense of depth perception for our eyes resulting in a creation of a super imposed image that can be immersive to a higher degree, along with tracking and motion sensors VR can also provide the ability to interact with the environment as well. Now a days haptic feed back is also a viable option for advanced sensory feedback (**71**).

The both above mentioned technologies though different are often overlapping each other in terms of work, the model shown below also uses the both technologies as a viewing output method and this is due to high in detail model formation.

Cyber-Physical System:

Cyber-Physical Systems also referred to as CPS is an innovation of modern era technology where a human brain or any human part can be paired up with a machine or sensor in order to perform a physical or mental task with the more accuracy and efficient that too with saving a lot of time. CPS has already been launched in many industrial sectors and our daily in use gadgets are also becoming more of a CPS. Now moving forward into the era of Industry 4.0, the manufacturers are facing various challenges and complexities regarding the hardware and software of the CPS based machines due to more and more advancements in silicon chips, many new researches are being conducted to coupe with new challenges in implementation of modern CPS in industries.

CPS is now being widely used Biological field such as detection of cancer cells in human body via x-rays, sensors to read the electrical pulse coming out of human brain, interoperable and open medical systems; certification methods for medical device software and systems and networked patient monitoring and assistance; model-based frameworks that support component-based modelling, design, testing, and certification using patient-specific models including MRI And CT Scan which are the best applications of CPS in modern days. It is also being implemented in Aviation sector to monitor the speed of jets, their current location in geographical network spread all around the globe and the structural status of airplanes in order to avoid the unplanned downtime. Smart grid and renewable energy research and development has been in the forefront of public interest and is therefore a high priority for policy makers. The goal is to improve energy efficiency by investing in modernization of the energy infrastructure. Advances in optimization of multiscale stochastic dynamic systems as well as in distributed control are necessary to improve smart grid performance with respect to security, efficiency, reliability, and economics. These issues have been identified by the research community in several workshops dealing with information technology and smart grids.

Conclusionary, Cyber-physical systems are expected to play a major role in the design and development of future engineering systems with new capabilities that far exceed today's levels of autonomy, functionality, usability, reliability, and cyber security. Advances in CPS research can be accelerated by close collaborations between academic disciplines in computation, communication, control, and other engineering and computer science disciplines, coupled with grand challenge applications **(72).**

Internet of Things:

With the new dawn of technology, Internet of thing (IoT) is getting more and more advanced and complex implications that help *the industries to integrate the machines in such a manner that the all the operating machines are interconnected via cloud* and the communication of various smart factories setup is made easy with cloud computing. In what's called the Internet of Things, sensors and actuators embedded in physical objects—from roadways to pacemakers—are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet. These networks churn out huge volumes of data that flow to computers for analysis. When objects can both sense the environment and communicate, they become tools for understanding complexity and responding to it swiftly. What's revolutionary in all this is that these physical information systems are now beginning to be deployed, and some of them even work largely without human intervention.

The introduction of dispensable technology of Radio Frequency Identification (RFID), with that the information of any individual about any particular thing can be stored in wrist-band device and can be used for the betterment of operations **(73).** Security remains one of the most important issues that baffles the development and applications of IoT. To address this issue, a trust model is proposed in which the billing or trust operator works as an agent to provide trust authentication for all service providers **(74).** The emerging standard 6LoWPAN allows a vast number of smart objects to be deployed using the huge address space of IPv6 for data and information harvesting through the Internet. The potential security threats in 6LoWPAN and the intrusion detection system (IDS) based solutions for countering insider/internal threats are dealt in way where a three novel QoS-related security threats and a new two-layer IDS concept is used as a countermeasure method for securing the routing protocol for low-power and lossy network-built network topology from the internal QoS attacks. Another important aspect to be noted is use of interconnected sensors via network at security systems to detect any harmful objects using supersonic waves.

Lean Optimization:

Taking into account that both lean and simulation hold an important role in the future of Lean manufacturing, in the industry 4.0 context, it seems important to analyse how their combination can support the companies. Some limitations of the lean optimization approach in relation to the new changes in the market demands are identified including: 1) strong deviation in market demands versus required levelled capacity utilization; 2) lean was originally designed for mass production, not for mass customization; 3) lean does not take into account the new capabilities that modern IT offers. Additionally, the trial-and-error approach inherent to lean to continuously improve the processes is time consuming to achieve the required improvement status which does not match the future requirements for shorter product life cycles and therefore the needed quick changes **(75).** Furthermore, the future production characteristics related to complexity, to have capacity for innovation and flexibility can be easily tackled by simulation and optimization techniques. This is not the case of lean tools such as VSM that have limitations to handle variation and the stochastic behaviour of complex systems. However, when building those simulation models, lean principles still need to be taken into account, so the combination of both of them will be crucial. Simulation and optimization techniques can support quicker and more effective production systems' design and improvements by providing the decision makers with better alternative scenarios **(76)**. As simulation is not an optimization tool by itself, the mash up of simulation and optimization, the so-called Simulation-based Optimization (SBO) or Simulation-based Multi-objective Optimization (SMO), in the case of having multiple objectives, is a better approach SMO will offer the decision makers with trade-off solutions between several conflicting objectives **(77).** To be able to take quality decisions, the more knowledge and understanding on how the system performs, the better will be the decision taken and this is what SMO can offer the best to the decision makers. The quality of the decisions made according to this approach will impact in the performance of the processes, and therefore, in the overall organizational performance **(78).**

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Discussion:

Explanation of the Model:

The model as we see is based on findings of previous works by researchers, while the relations drawn are entirely original works by the authors. The model as we can see is extremely straight forward as it draws relations between the major technologies of Industry 4.0, the sought after lean optimization and the industry structure as of whole.

What the model aims to accomplish is to provide a framework for future industry professionals to judge the optimized structure of an industry just by working with one or more variables. A sort of scale to base industry efficiency and effectiveness on but from an industry formations perspective.

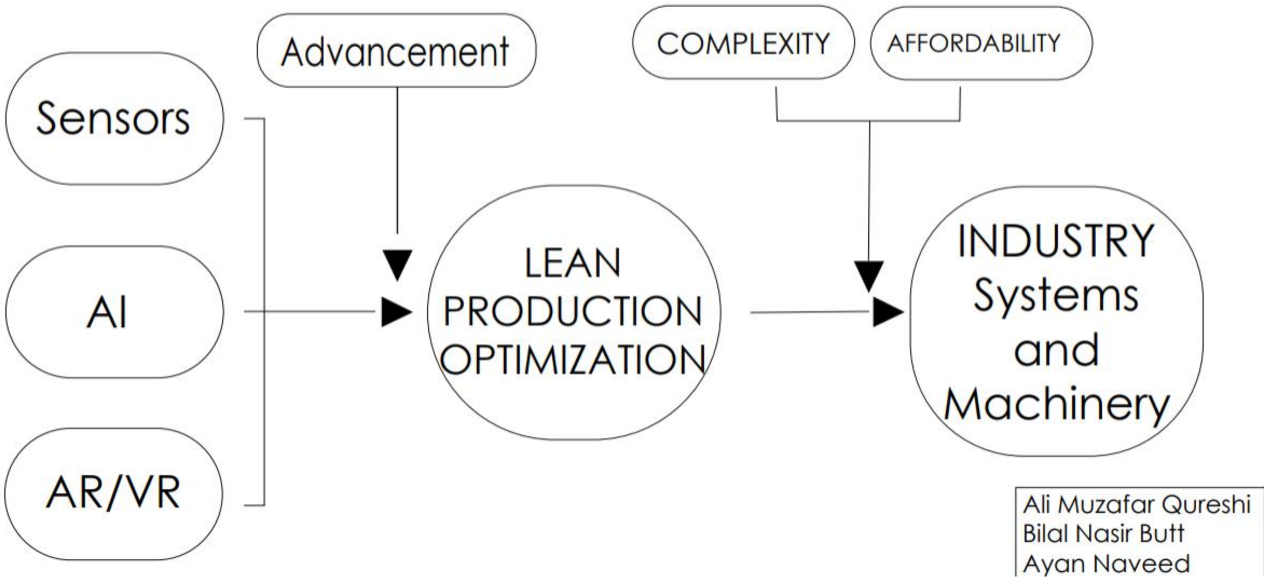

FIGURE 1

The full model showing the relations between industry 4.0 technology and the industry itself

The model states that there is a direct relation between industry 4.0 technologies most notably the sensors, AI data processors and AR/VR units with Lean Optimization which in turn will affect the industry systems and Structure, accordingly the exponentially expanding works in this field (**0**) will also affect the way the optimization occurs as the changing technology will provide new and better ways to optimize a production task thus the moderating effect is imminent, at the same time lean optimization is also effected by the complexity and cost of the technology, since the tech is new is the market and not well assimilated thus it is difficult to implement and costly as well, all of these prove to be a hindrance to lean optimization of industry and therefore are moderating the relation.

We saw that in an industry manufacturing perspective the 3 technologies the most impactful since they are being implemented at a small scale and out of the 9 technologies highlighted (**21**) these 3 are the most manufacturing centric and helpful in making a Smart factory.

Speaking of which, a Smart factory is also an extension of the 4th industrial revolution that uses autonomic machinery to streamline production process. It is a hypothetical factory and is in the works of being implemented as of now. What It advocates is the fact that factories can be created that are totally machine-centric and thus require no human assistance to operate (**80**) and since in the future with advent of industry 4.0 there will be an abundance of these smart factories (**56**), therefore models such as the Figure 1 are useful in the formation and finding out the efficiency of such smart factories.

Justifications for usage of variables as in such way

Independent variables:

The selection of independent variables was done by following a reference of a smart factory whose idea was presented in an article **Digital Twin in smart manufacturing: remote control and virtual machining using VR and AR technologies** Uroxin Geng, Mian Li, Zongyang Hu, Zixi Han, Rui Xiang Zheng. According to which an intelligent monitoring system implementing I4.0 technologies can be created using some of the all-present industry 4.0 technologies. Now in our

case the independent variables chosen are Sensors, AI and AR/VR, these devices are used to make a Cyber-Physical-System as shown in the **Figure 2.** These systems are a high-tech generation of systems with *integrated computational and physical capabilities that can interact with humans through many new modalities. The ability to interact with, and expand*

the capabilities of, the physical world through computation, communication, and control is a key enabler for future technology developments.

Now in case of the following model we have ignored the digital twin constructor on the grounds that it is only a software and has no effect of the industry or lean production whatsoever. Digital twin is an Industry 4.0 concept but its creation is not since it requires only CAD and Cameras. Similarly, the remote display units are a novel concept of LED or LCD display units and can be ignored. Our major interest is of the three variables that provide remote monitoring and correction facilities. Now there are 9 such technologies of industry 4.0 as identified by BCG consultants (**59**) that are

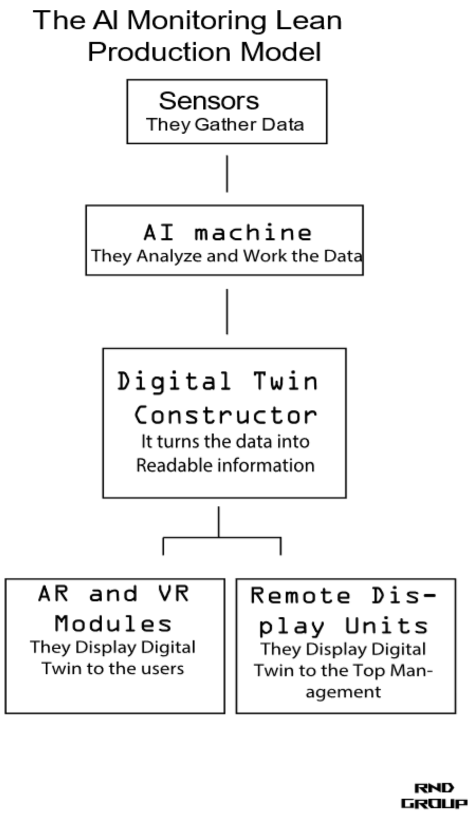

FIGURE 2

- Big data and analytics
- Autonomous robots
- Simulation
- Horizontal and vertical system integration
- Industrial Internet of Things
- Cybersecurity
- Additive Manufacturing
- Augmented Reality
- Cloud

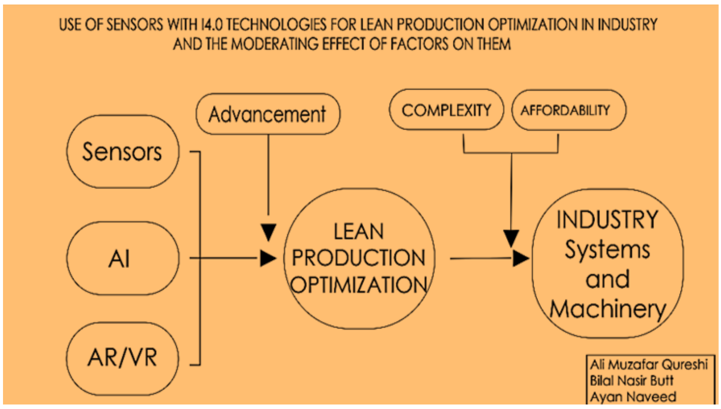

FIGURE 3

and the given variables coincide with the 2 of those technologies that **being Augmented reality and Simulation**. Now the reason why we are not focusing our interest on the other 7 technologies is simple, they are not responsible in any form for manufacturing monitoring and control, Technologies like Robots can be used for monitoring but the line where robots end and simplified sensors with additional capabilities start is very blurry. In the given hypothetical model by us **Figure 3** we can see that the three independent variables used are in a vertical relation**.**

So how can they be in a horizontal formation in the hypothetical model?

Simply because of the fact that in the reference model each variable is dependent on each other and with that explanation they all become an integral part of a CPS in order to make it function properly, more over the vertical relation of the model only follows a traditional architecture of a computing device that being of Output, Processing, and Input. These variables all represent one of the three workings.

Relations with Sensors, AI, and AR/VR

1. Sensors:

A Sensor is a device that through transduction of electric Signals detects input signals of various degree. They can be Electric, Chemical, Physical or Photo-Sensitive

In I4.0 the sensors being used are for process and condition monitoring as shown in (**1**), Where Stretchable sensors are used for monitoring of Bio Chemicals from Deformed cells. And In (**2)** where mechano-sensors in a smart watch is being used to monitor dyskinesia in patients. While in Factory POV various sensors are being used to monitor a range of different production scenarios e.g. In tough Working environments at a narrow range (**3**) and by radio-sense technology in order to measure employee efficiency and human robot interactions (**4**)

These are some of their applications but in a Production optimization sense their use is not dissimilar they can be used to monitor production control in real time as in (**5**), and we can also monitor mobile manipulators of machinery so that their work can be further optimized (**6**). All of these uses can help in further making precise production monitoring.

They can also be used in quality management as in (**7**) where they are used for air quality monitoring as previously difficult to detect gases are now easier to detect. They are valuable for fault detection in machinery during production as in (**8-9**). Finally they are used for product optimization as well in temperature, weight and other specification monitoring of the products in the line, Like the acute monitoring of humidity in production sites (**10**) and their use in production control of pasta manufacturing (**0**) .This all this gives ample evidence of impact of Sensors on Production optimization.

2. AI:

Artificial Intelligence can be defined as the use of Machine learning algorithms to mimic and supersede human intelligence. It is the *simulation or approximation of human intelligence in machines* (**30**), thus can provide adequate reasoning for its decisions like humans.

In manufacturing only theories are provided till date for its use since it is a relatively complex category of I4.0 tech and therefore is not used widely. But In production optimization its use can be limitless since it has shown to exceed human intelligence (**12**). Thus, this capability alone is useful in production efficiency. They can be used to detect machinery faults of physical nature like rolling bear through the help of Convolutional Neural Networks (**13**) Neural Networks themselves of the capability to be used in medical fields (**14**).

They can be used to simplify production costs in larger projects as in (**15**) along with their use in improving work efficiency by predicting work system disruptions (**16**).

Further use can be shown as in Quality control where AI can be used to detect blister defects in batteries using Optical Sensors (**17**)

AI in production optimization is being used as means to monitor and control laser welding machinery through NN and Predictive modelling (**18**), Finally it can be used in additive manufacturing as a Monitoring and Data analysis tool as well (**19**).

3. AR and VR:

AR means Augmented Reality and VR means Virtual Reality, and they both are relatively new concepts in field of entertainment and output devices. An AR device aims to show 3D objects in real life by juxtaposing them into the surroundings through a camera and Sensors, *combines the real world and computer-generated content. The content can span multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory* (**28**), while in a VR headpiece an artificial environment is created using CAD and the user can view those environments without moving an inch basically *real-time interactive graphics with 3D models, combined with a display technology that gives the user the immersion in the model world and direct manipulation* (**29**). They both aim to provide an in depth and Immersive experience to the user.

In production there are many ways by which AR and VR tech can be used to monitor and view machines remotely and in depth (**20**). Digital twin often comes into the discussion which is the result of one of I4.0s prime tasks that being creation of a Cyber-Physical System or CPS (**21**). For production optimization AR can be used to predict and improve the structural life of an object through creation of a Digital twin (**20**). A concept of how AR tech can be used to visualize monitoring data of a ship was presented with a case study as well (**23).** AR based support systems for decisioning are also a useful application of the work that provide a useful insight on how AR tech can be used in decision making and simulating a manufacturing environment (**24**). Similarly, VR equipment can also be used to simulate work environments in order to gather data and optimize work remotely in Real time (**0**), the given Reference gives a conceptual model of how VR and Digital twins can be used to simulate and re-simulate a work environment in real time so that problems can be handled and viewed.

Now the Lean Optimization can also be taken care of specifically using VR modelling and Implementation. The concept (**26**) provides an overview of how a virtual workspace can be used to optimize any manufacturing unit. Similarly, an AR based application of Augmented stats and graphs to be showed in real time, which shows any problems with when viewed as well as production stats (**27**)

Lean production optimization's effect on the industry

The concept of lean production started in 1950s introduced by Taiichi Ohno of Toyota motors as Toyota Production Systems, it was further given research importance by *The Machine That Changed the World* by Womack and Jones in the year 1990 (**31**). The concept of Lean Production is simple in nature it advocates *use less of everything – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering working hours to develop a new product in half the time. Also, it requires keeping far less than half the inventory on site, results in fewer defects, and produces a greater and ever-growing quality of products* (**32**)

In the production industry Lean production has a big increase due being the trend of the modern industry and the increased competitiveness and customer demand (**33).** The effect of lean systems in increasing efficiency of the industry has been positive throughout (**34**) and therefore much work is being done in its research, we are talking about a term that was unheard of in 1990s now has over 500 papers published over its methodology and theories in 2019 (**33**). Lean Provides ample methods to optimize industry tasks and remove wastes or *Muda* they most popularly include Kanban, Just in Time and ABC (**35**). Use of lean in production industry is mainly for the removal of wastes and introduce *leanness* throughout that is Less resource use with ample customer satisfaction (**36**).

We know with ample proof that Lean has a positive effect on the industry but the methods require extreme diligence and hard work and the size of the organization is an obstacle in lean Implementation (**37**). Thus, lean automation is talked about and due to emergence of i4.0 technologies it can be achieved as well, this results in the creation of a new field of study for researchers as well as Managers looking to use Lean Automation (**0**).

Moderating factors in any industry 4.0 technological implementations:

1. Advancements
As 4.0 technologies get more advanced, they can be used to optimize lean production in industries,

Nations worldwide are becoming more and more aware of industry 4.0 technology's potential and are willing to invest great capitals into its advancement.

A project undertaken by PricewaterhouseCoopers (PwC), estimated that "artificial intelligence technologies could increase global GDP by $15.7 trillion, a full 14%, by 2030." [**40**] That includes advances of $7 trillion in China, $3.7 trillion in North America, $1.8 trillion in Northern Europe, $1.2 trillion for Africa and Oceania, $0.9 trillion in the rest of Asia outside of China, $0.7 trillion in Southern Europe, and $0.5 trillion in Latin America. China is making rapid strides because it has set a national goal of investing $150 billion in AI and becoming the global leader in this area by 2030.

Meanwhile, a McKinsey Global Institute study of China found that "AI-led automation can give the Chinese economy a productivity injection that would add 0.8 to 1.4 percentage points to GDP growth annually, depending on the speed of adoption." [**41**]

[**42**] Recent advancements of sensor technologies have been powered by high-speed and low-cost electronic circuits, novel signal processing methods and innovative advances in manufacturing technologies. The synergetic interaction of new developments in these fields allow completely novel approaches increasing the performance of technical products. Innovative sensor structures have been designed permitting self-monitoring or self-calibration. The rapid progress of sensor manufacturing technologies allows the production of systems and components with a low cost-to-performance ratio.

[**43**] According to industry reports, the VR and AR market is expected to reach a value of 15.5 billion euros by 2022. The Asia-Pacific region is expected to lead the expansion in the VR and AR market. The healthcare and retail industries are among the key drivers of the adoption of VR and AR technologies.

2. Affordability
Such technologies are not yet affordable for most businesses as they can cost pretty much depending on the need of the business. Custom AI solutions can cost up to hundreds of thousands of dollars (6000-300000$) [**44**], sensors can cost somewhere between a few dollars to tens of thousands of dollars per day (2-12000$/ day) [**45**] and AR/VR technologies can also cost hundreds of thousands of dollars depending on their quality and features (5000-250000$<) [**46**].

According to Geiss Bauer Et Al. (2014) [**47**], firms who are intending to implement Industry 4.0 initiatives would have to increase their annual capital investments by 50% for the next 5 years. Firms would not only will have to invest to re-engineer their existing strategies but also to implement industry 4.0 technologies, a considerable amount of capital would be required. Kache and Searing (2017) [**48**] support this statement by mentioning that high investment regarding people, processes and technology is required both at the corporate level and the supply chain level.

By involving Industry 4.0 technologies [AR/VR, AI & Sensors] in business activities, such involvement will increase the complexity of the technologies involved and along with that affordability will also become a concern.

2. Complexity
Industry 4.0 technologies are yet to be advanced and to be led into industries for optimizing lean productions. What makes them complex is that very few experts exist because of such technologies being relatively newer and expensive. Among the non-technical challenges faced by Industry 4.0 technologies, employees don't have required technical knowledge and skills required, is amongst that list. (Hung, 2016)

Breunig Et Al (2016) discusses that many firms don't have the necessary expertise to realize the full potential of industry 4.0 technologies applications. Underqualified employees exist in firms and they could not know the complexities involved in implementing such procedures, Geiss Bauer Et Al (2014) [**47**] support such claim, and as businesses will become more data driven and complexity will increase, firms would require more qualified experts.

Conclusion:

Finally, we can conclude by addressing the fact that the model is very simplistic and only serves a way forward step in the direction of industry 4.0. The authors did not have the time or the funds to fully test the model and they leave it up to further studies and researches to either reject or accept the model. The concept of Industry 4.0 is to create an ecosystem of industry and consumers where normal supply and manufacturing chains are obsolete and there is a need for newer models to explain and gauge those relations.

Models such as Figure 1 serve to do just that and further exemplify how can one create a newer form of efficient industry.

The relations of AR, AI and Sensor technologies are very simply of a data processing unit and what that unit does is optimize manufacturing with the most effective and efficient way possible, with the autonomic nature of these devices the manufacturing unit will also learn to adapt to problems along the thus the older the unit gets the better it will be at manufacturing. In the end with the fast-changing landscape and changing values we can easily assume that more models of this degree will emerge and eventually we can get a single model that is helpful in implementing a fully functional smart factory unit.

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