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The Fourth Industrial Revolution in the Developing Nations: Challenges and Road Map

Sohail Asghar, Gulmina Rextina, Tanveer Ahmed
& Manzoor Illahi Tamimy

Commission on Science and Technology for Sustainable
Development in the South
(COMSATS)




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**Commission on Science and Technology for Sustainable Development in the South
(COMSATS)
Islamabad, Pakistan**

SOUTH CENTRE

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In August 1995 the South Centre was established as a permanent inter-governmental organization. It is composed of and accountable to developing country Member States. It conducts policy-oriented research on key policy development issues, and supports developing countries to effectively participate in international negotiating processes that are relevant to the achievement of the Sustainable Development Goals (SDGs). The Centre also provides technical assistance and capacity building in areas covered by its work program. On the understanding that achieving the SDGs, particularly poverty eradication, requires national policies and an international regime that supports and does not undermine development efforts, the Centre promotes the unity of the South while recognizing the diversity of national interests and priorities.

COMSATS

The idea of establishing a high-level Commission on Science and Technology (S&T) for countries of the South was conceived by Pakistani Nobel Laureate Prof. Dr. Abdus Salam, in recognition of the increasingly widening gap of scientific knowledge and economic development between the North and the South. It was realized that sustainable socio-economic development in the South cannot be achieved without building and sustaining indigenous capacities in science and technology and that the strengthening of South-South and North-South collaboration, and exchange of technical know-how, is imperative for the generation and sustenance of such capacities. Professor Salam's enthusiasm and personal contacts motivated a number of Heads of State/Government of developing nations to join hands for the establishment of the Commission on Science and Technology for Sustainable Development in the South (COMSATS).

In 1994, on the invitation from the Prime Minister of Pakistan, representatives from several developing countries met on 4th and 5th October in Islamabad and agreed to establish the Commission as a high-level forum, represented by Heads of State/Government, aiming at sustainable socio-economic uplift of the developing countries through appropriate applications of science and technology.

The General Meeting of the Commission is the highest forum of COMSATS, which is represented by the Heads of State/Government of COMSATS' twenty-seven Member States. COMSATS' membership is spread across three continents, i.e. Asia, Africa and Latin America. The first General Meeting of the Commission was held in 1994 that led to the establishment of COMSATS itself.

Focal Points are designated in each of the Member States to ensure that the cooperation avenues among Member States are explored with the support of their respective governments. These Focal Points in the Member States are mostly the ministries/government-bodies responsible for S&T resource-management and governance designated by the respective Governments. By virtue of their membership, COMSATS' Member States are entitled to certain Benefits and Obligations.

Mission Statement: To help create a world where all nations are at peace with one another and capable of providing a good quality of life to their populations in a sustainable way, using modern scientific and technological resources.

As derived from the Statutes of the Commission, the mission of COMSATS has been translated into broad objectives.

Member States: Bangladesh, China, Colombia, Egypt, Gambia, Ghana, Iran, Jamaica, Jordan, Kazakhstan, Democratic People's Republic of Korea, Morocco, Nigeria, Pakistan, Palestine, Philippines, Senegal, Somalia, Sri Lanka, Sudan, Syria, Tanzania, Tunisia, Turkey, Uganda, Yemen, Zimbabwe

A Memorandum of Understanding was signed between COMSATS and The South Centre on September 3, 2018.

For more information on COMSATS, please go to: http://comsats.org/?page_id=28

ABSTRACT

Technological advancements and the amalgamation of several fields, including Advanced Robotics, Artificial Intelligence (AI), Big Data Analytics, Cyber Security, Cloud Computing, and Internet of Things (IoT) have brought the world on the cusp of a Fourth Industrial Revolution (FIR). This industrial revolution has the potential to sky rocket economic growth or on the other hand, cause countries to lag behind in terms of economic development if the potential of FIR is not exploited. A number of developed countries such as Germany, the UK and USA have put in place public policies that focus on implementing FIR in their respective countries. It is critical that developing countries also take steps to adapt FIR in order to take advantage of it as well as not be adversely affected by these technologies if not adopted. There are a number of reasons why developing countries are not able to fully implement FIR technologies such as lack of commitment, infrastructure and lack of skilled workers. The objective of this study is to identify the challenges and issues faced by the developing countries in the implementation of the FIR. This study proposes a strategic framework: “Centre for the Fourth Industrial Revolution (CFIR)” for developing countries in order to face the challenges of FIR. Consequently, CFIR will work on establishing research labs for capacity building through collaboration and establishing technology-based incubation centers. CFIR will bring together an international network of governments, leading companies, civil society and experts to co-design and pilot innovative policy and governance frameworks.

Les progrès technologiques et la fusion de plusieurs domaines, dont la robotique avancée, l'intelligence artificielle (IA), l'analyse de données massives (Big data), la cybersécurité, l'informatique en nuage (cloud computing) et l'Internet des objets ont amené le monde à l'aube d'une Quatrième révolution industrielle qui peut tout autant contribuer à favoriser la croissance économique qu'elle peut, si son potentiel n'est pas exploité, ralentir le développement économique et laisser certains pays sur le bord de la route. Un certain nombre de pays développés tels que l'Allemagne, le Royaume-Uni et les États-Unis ont mis en place des politiques publiques visant à favoriser la mise en place de ces technologies sur leur territoire. Il est important que les pays en développement prennent également des mesures d'adaptation à ces technologies afin de pouvoir en tirer profit et de ne pas subir les conséquences qui pourraient résulter de l'absence de cadre opérationnel et réglementaire. Un certain nombre de raisons expliquent l'impossibilité pour les pays en développement de mettre pleinement en place ces technologies, notamment le manque d'engagement, d'infrastructures et de travailleurs qualifiés. L'objectif de cette étude est de mettre au jour les difficultés rencontrées par ces pays. Elle propose un cadre stratégique sous la forme d'un Centre pour la quatrième révolution industrielle qui s'adresse aux pays en développement, l'objectif étant de leur permettre de faire face aux défis liés à la Quatrième révolution industrielle. Le Centre œuvrera à la création de laboratoires de recherche dont le but sera de renforcer les capacités par la mise en place de collaborations et de centres d'incubation technologiques. Il rassemblera un réseau international composé de gouvernements, d'entreprises de premier plan, de membres de la société civile et d'experts chargés de concevoir ensemble et de piloter la mise en place de cadres réglementaires et de gouvernance innovants.

Los avances tecnológicos y la combinación de varios campos, entre ellos la Robótica Avanzada, la Inteligencia Artificial (AI), el Análisis de Datos a gran escala, la Ciberseguridad, la Computación en la Nube y el Internet de las Cosas (IC) ubicaron al mundo en la cima de la Cuarta Revolución Industrial (CRI). Esta revolución industrial tiene el potencial de impulsar el crecimiento económico o por el otro lado, de hacer que los países que no explotan dicho potencial se quedan atrás en términos de desarrollo económico. Varios países desarrollados tales como Alemania, el Reino Unido y los Estados Unidos han puesto en práctica políticas públicas enfocadas en la implementación de la CRI en sus respectivos países. Es fundamental que los países en desarrollo también avancen en la adaptación de

la CRI a fin de sacarle provecho a la misma y que no se vean afectados negativamente por estas tecnologías en caso de no adoptarlas. Existen muchas razones por las que los países en desarrollo no pueden implementar de manera completa las tecnologías de la CRI, entre ellas la falta de compromiso, de infraestructura y de trabajadores especializados. El objetivo del presente estudio es identificar los desafíos y los problemas que enfrentan los países en desarrollo en la implementación de la CRI. Este estudio propone un marco estratégico: "Centro para la Cuarta Revolución Industrial (CCRI)" para los países en desarrollo a fin de enfrentar los desafíos de la CRI. Por consiguiente, el CCRI trabajará en el establecimiento de laboratorios de investigación para el desarrollo de capacidades a través de la colaboración y el establecimiento de centros de incubación de base tecnológica. El CCRI reunirá una red internacional de gobiernos, empresas líderes, sociedad civil y expertos a fin de co-diseñar y poner a prueba políticas innovadoras y marcos de gobernanza.

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INTRODUCTION

The world is ready to set foot in a Fourth Industrial Revolution (FIR), due to technological advancements that are changing the way we work, live and interact with each another. This revolution is made possible by the previous industrial revolutions. The seeds of the first industrial revolution were sown in the 18th century, when the world uncovered the potential of steam power. This power of steam was harnessed to replace muscle power in manufacturing. This resulted in a tremendous increase in production with a profound socio-economic impact. The second industrial revolution was based on electricity, assembly lines and the replacement of iron with steel, to name a few. This had a dramatic impact on manufacturing resulting in increased production and decreased cost. The third industrial revolution can be defined in terms of automation and use of information technology in manufacturing. Each industrial revolution has propelled the human race forward, in terms of economic benefits and the quality of life. Figure 1 summarizes the four industrial revolutions that the world has witnessed so far.

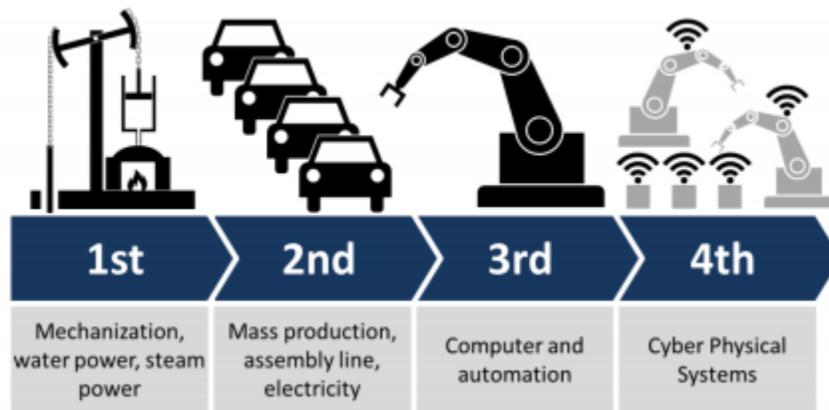


Figure 1: The Four Industrial Revolutions in a Nutshell (Stăncioiu, 2017)

The previous industrial revolutions pale in comparison to the fourth industrial revolution. The changes happening due to the fourth industrial revolution are unprecedented in terms of growth and new breakthroughs. This revolution has been made possible by technologies such as Cyber-Physical Systems (CPS), Cloud Computing, Internet of Things, Big Data, Robotics, Augmented Reality, Horizontal Vertical Integration, Additive Manufacturing and Cyber Security (Petrillo *et al.*, 2018). These enabling technologies for the fourth industrial revolution have been depicted in Figure 2.

This industrial revolution is changing the way products are designed and manufactured, by connecting different sensors and systems together. The increased access to information, artificial intelligence & machine learning as well as the presence of smaller and cheaper sensors mean that an intelligent network can oversee the entire manufacturing process autonomously. One of the defining characteristics of this industrial revolution is that it is merging the physical, cyber and biological systems together (M. Xu *et al.*, 2018). This has the potential of boosting economies and drastically improving standards of living.

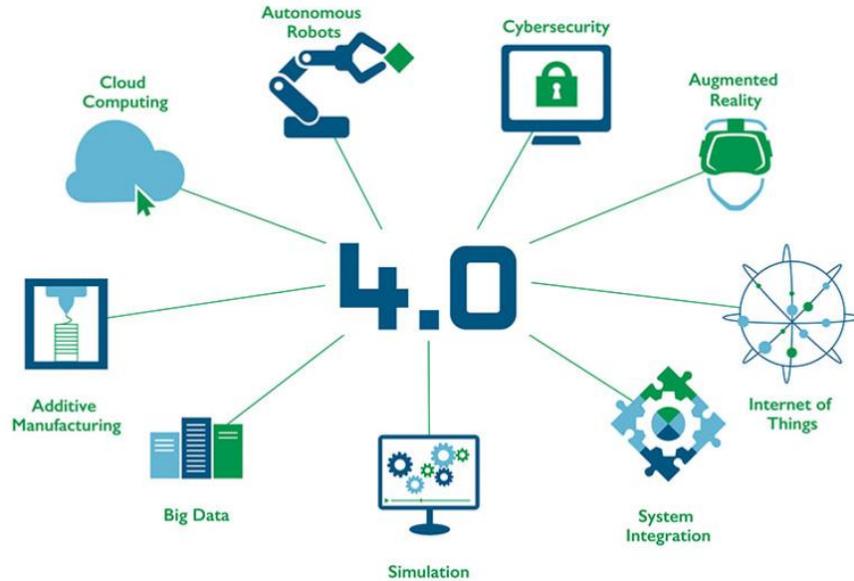


Figure 2: Enabling Technologies for Industry 4.0 (Domino Printech, 2017)

The FIR has the potential for greatly re-shaping the global economy. Keeping pace with this technological wave requires innovation and drastic restructuring of the manufacturing sector. Many developed countries are trying to achieve the vision of FIR due to its many advantages such as improved efficiency, use of fewer natural resources and increased productivity. Many developing countries rely on outsourcing and offshoring of jobs, due to reduced labor cost. However, this may change as many developing countries would bring back manufacturing to their own shores as products would be manufactured more cheaply and efficiently in the smart factories of the FIR. Countries which fail to adopt the new manufacturing paradigm would most likely lag behind in terms of economic growth and prosperity.

In view of the growing importance of taking advantage of the technologies used in FIR many developed countries have developed and started to implement public policies that chalk out strategies for implementing the FIR. A number of developing countries have also started to focus on adopting the FIR. There are however many challenges that these countries have to overcome before they can benefit from these technologies. The first challenge is the lack of awareness and a coherent strategy to adopt the FIR. Other challenges include lack of infrastructure and lack of specialists in the required areas, lack of collaboration between industry and academia and lack of collaboration among different countries. Some developing countries are taking steps to implement FIR. Ghana for example, is preparing to setup Artificial Intelligence (AI) research centers with the help of Google. Similarly, in Pakistan, the President launched the Presidential Initiative for Artificial Intelligence & Computing (PIAIC) that is aimed to be a center of education and research in AI. Many other countries, such as many countries in Africa would need to invest in infrastructure before they can take further steps for implementation of FIR.

It is imperative for the developing countries to try to keep up with the rapidly evolving manufacturing paradigm, by making a concentrated effort to adopt and further enhance the technologies which are considered to be the foundations of the fourth industrial revolution. Most developing countries lag significantly in terms of infrastructure and technology; therefore, it is critical to develop and implement public policies to tackle this challenge. The purpose of this paper is to identify the challenges faced by developing countries to unleash the potential of the fourth industrial revolution and to provide a

framework to overcome those challenges. In this paper we are proposing the establishment of the Center for the Fourth Industrial Revolution (CFIR) which would aim to address all the challenges faced by the developing countries through mutual partnership and collaboration among Commission on Science and Technology for Sustainable Development in the South (COMSATS) member countries.

The rest of the paper is organized as the following: the first section provides a brief overview of the technologies which are responsible for FIR. Section 2 discusses the challenges faced by developing countries in adopting the FIR. A few examples of some of the initiative already taken by some governments to tackle the challenges of the FIR are discussed in section 3. Section 4 attempts to provide a detailed strategic framework for adopting FIR.

1. OVERVIEW OF THE FOURTH INDUSTRIAL REVOLUTION—ENABLING TECHNOLOGIES

The fourth industrial revolution is grounded on the fusion of a broad diversity of engineering sciences and concepts. Some of the technologies that are considered to be an integral part of the FIR have been used in manufacturing before, such as robotics and additive manufacturing. However, with the advancement of fields such as machine learning, data science and the Internet of Things, it is now possible to amalgamate these and related technologies to revolutionize manufacturing. Figure 3 gives an overview of smart factory architecture.

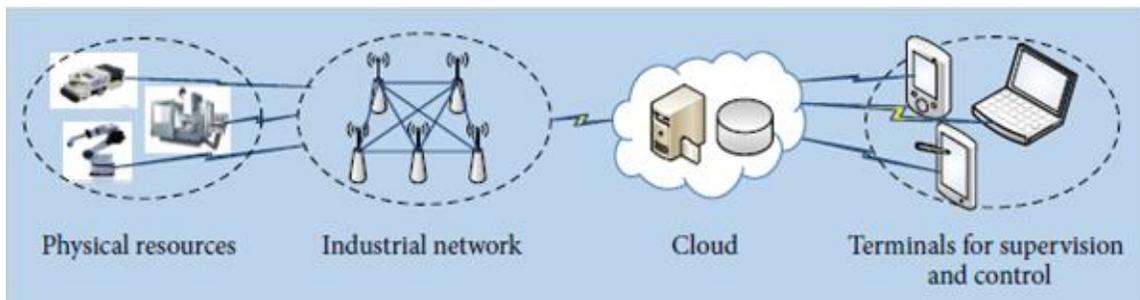


Figure 3: A Framework of the Smart Factory of FIR (Wang *et al.*, 2016)

A discussion of the key components is given below. The following, and some other related technologies are responsible for the dawn of a new industrial revolution.

1.1 Cyber Physical Systems

“Cyber-physical systems (CPS) are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core” (Rajkumar *et al.*, 2010). Cyber physical systems are at the core of FIR. They work by maintaining a digital copy of the physical and mechanical system in a factory. Cyber physical systems are complex systems that consist of sensors and other means to collect data; Big data (generated continuously); networks, through which the different components are connected to each other with the help of cloud; and an intelligent cyber core, that responds to the real time data to keep the factory working intelligently and autonomously (Lee *et al.*, 2015; Vaidya *et al.*, 2018; Zhong *et al.*, 2017).

CPS are what connects all the physical components, data and the cyber components connected to one another. They work by maintaining a cyber copy of the physical systems that helps in running the factories autonomously. Needless to say, CPS is the foundation stone for the FIR on which all the rest of the other components of the FIR depend.

1.2 Cloud Computing

The National Institute of Standards and Technology (NIST) defines cloud computing as “ a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly

provisioned and released with minimal management effort or service provider interaction"(Mell *et al.*, 2011).

In cloud computing, the role of service providers is of two types - the infrastructure providers and the service providers. The infrastructure providers are responsible for providing central processing unit (CPU) and storage etc. whereas the service providers rent or lease resources for the infrastructure providers and provide these services to the end users. Cloud computing has been made possible by the development of high-speed internet and cheaper resources. It provides many advantages such as no initial investment for infrastructure, lower operational cost, scalability and no maintenance expenses (Zhang *et al.*, 2010). The aforementioned advantages make cloud computing a lucrative option for businesses such as manufacturing.

The main idea of FIR is based on intelligent manufacturing, and to achieve this goal, there is a need for access to shared space for data storage, computation power, services and applications. Cloud computing is the solution for all the aforementioned needs (Ooi *et al.*, 2018).

1.3 Robotics

The use of robotics in manufacturing is not a novel concept. In the past robots were pre-programmed to carry out specialized tasks. Now with the latest advances in sensors, networking and cloud computing, robots can respond to changes in the environment and can access information from the cloud to carry out their tasks. In the modern digital age, robots become more autonomous, cooperative and flexible (Rüßmann *et al.*, 2015). Due to the aforementioned characteristics, autonomous robots are capable of accomplishing the required tasks in a much more efficient and precise manner (Bahrin *et al.*, 2016). Autonomous robots can also be utilized where human workers are restricted to work with a focus on safety. They will interact and work securely, alongside humans and learn from them (Vaidya *et al.*, 2018). Bionic Robots are biologically inspired robots that mimic biological structures such as a human arm or even biological creatures. Table 1 summarizes some autonomous robots that are utilized in various industries.

#	Company	Name of Robot	Purpose
1	Rethink Robotics	Baxter	Interactive production robot for packaging purpose
2	Kuka	Kuka LBR iiwa	Lightweight robot for sensitive industrial tasks
3	Gomtec	Roberta	6-Axis industrial robot used for flexible and efficient automation
4	Bionic Robotics	BioRob Arm	Use in close proximity with humans

Table 1: Some Autonomous Robots utilized in various industries (Vaidya *et al.*, 2018)

1.4 Internet of Things

Many definitions exist for the Internet of Things (IoT), some of which only focus on a single or a few aspects of it. A more comprehensive definition is as follows: "An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in the face of situations and changes in the environment" (Madakam *et al.*, 2015).

The fourth industrial revolution is made possible by all the technologies being discussed here, but it is what connects the physical and digital systems to one another. Thus, making it possible for different

people, sensors and devices to communicate with one another intelligently (Madakam *et al.*, 2015). Figure 4 depicts the key technological developments in the context of IoT application (Gubbi *et al.*, 2013).

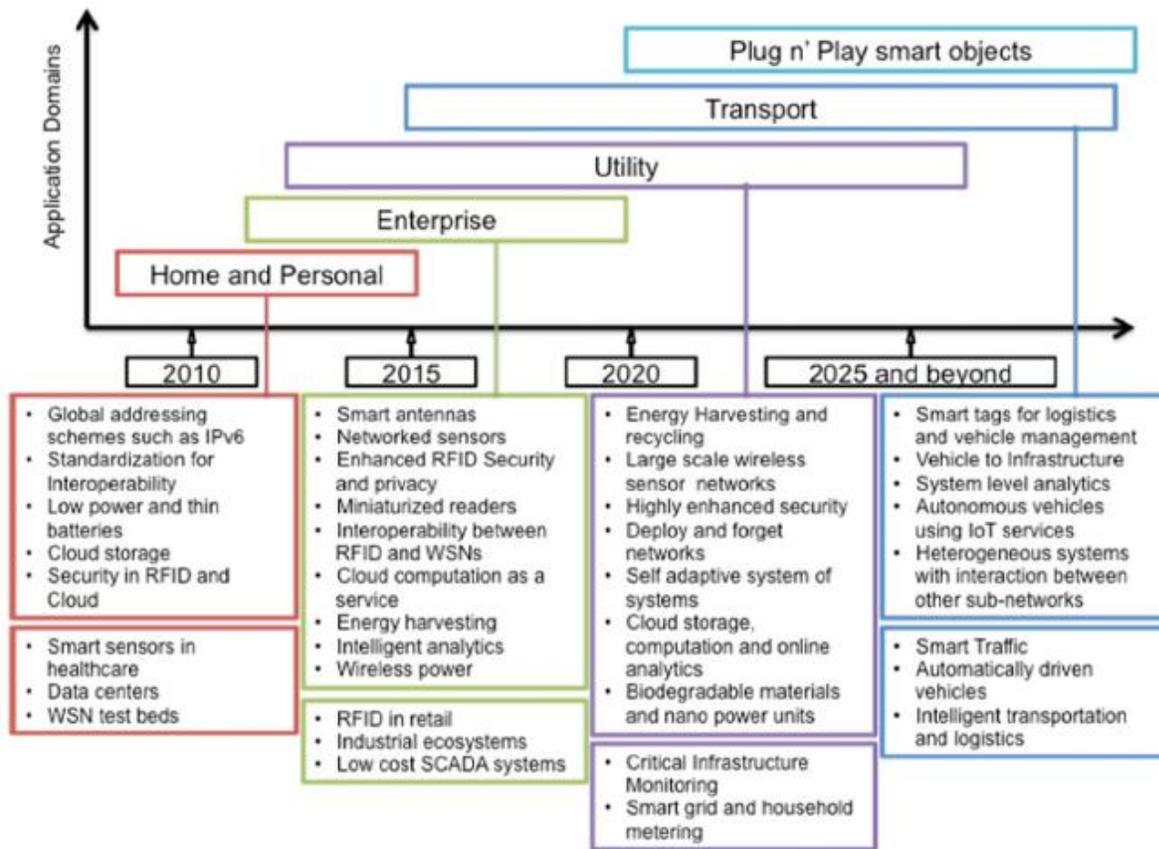


Figure 4: Predicted advancements in IoT Applications (Gubbi *et al.*, 2013)

1.5 Big Data

Big Data has been defined in many different ways, for example “High volume, velocity and variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making” (Beyer *et al.*, 2012) and “*Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value*” (Ward *et al.*, 2013), are two out of many definitions found in literature.

The use of sensors and IoT has resulted in the generation of large amounts of data. This data is essential for the whole concept of FIR. However, it is critical that this data is utilized efficiently so the information it generates can be used for decision making on the factory floor. Traditional analytical software cannot handle the volume of data generated in this environment. Advanced analytical techniques are needed to uncover patterns and make decisions based on the abundance of data being generated in a manufacturing environment (Zhong *et al.*, 2017).

Traditionally, decisions were made on the basis of experience. This is now rapidly changing as more and more industries are turning towards big data analytics to uncover hidden patterns and make decisions on the basis of those patterns and data (Qi *et al.*, 2018). Generally, manufacturing uses three types of data: (i) Data collected from smart factories through IoT; (ii) Management data such as order dispatch, material distribution, production, planning, marketing, sales and other related data; (iii) User data that is gathered from sources such as e-commerce sites, social networks etc. (Qi *et al.*, 2018).

Data collected in real time from the factory floor is used to make day to day decisions and to allow the smart factory to work intelligently and efficiently. It is therefore essential that the data gathered in real time is quickly processed and utilized. This is achieved with the help of IoT, cloud and Artificial Intelligence.

The management data is used to plan the production at the start based on available resources, constraints and material data. This helps to make planning faster and more efficient (Qi *et al.*, 2018). Data analysis of the user data and market trends are used to optimize the design of the products itself by translating customer demands and needs to product features (Qi *et al.*, 2018).

1.6 Augmented Reality

Augmented Reality (AR) augments the user's perception of a real-world entity into the real environment by introducing relevant digital information. AR technology influences all the industries and is impacting the business. Augmented reality can have many interesting applications in manufacturing, such as providing spatial information to workers where required, such as performing an unfamiliar task as well as other applications such as cyber training (Paelke, 2014; Rübmann *et al.*, 2015). Figure 5 shows some statistics about the market share of Augmented Reality in various industries.

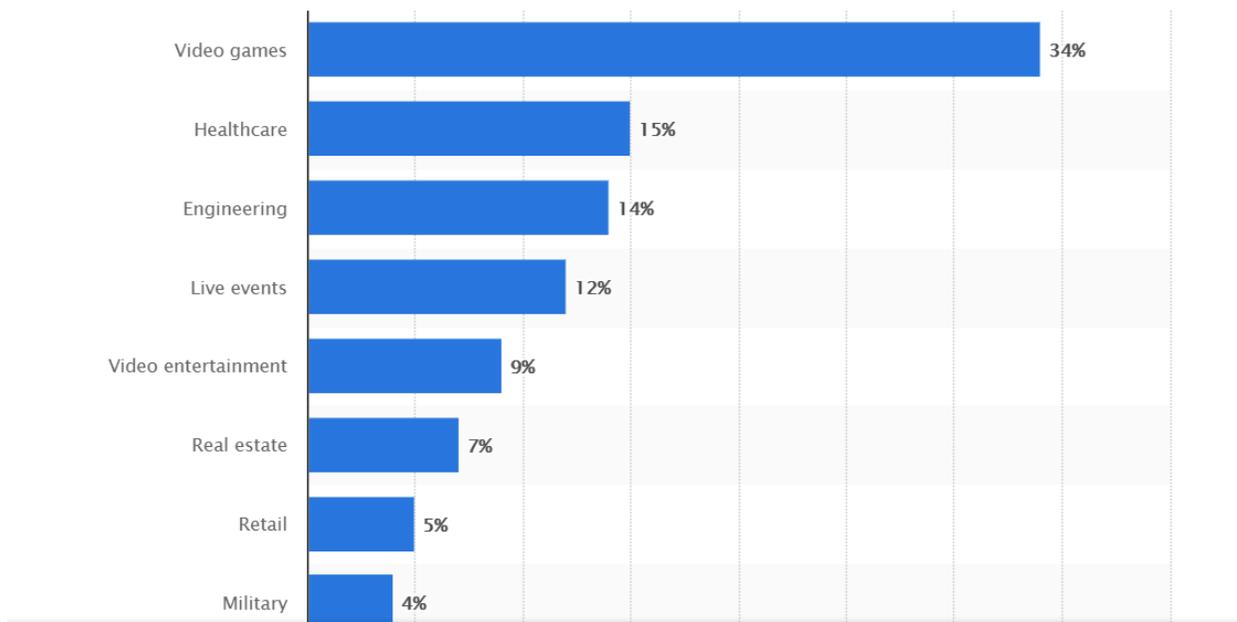


Figure 5: Market share of Augmented Reality in various industries (Statista, 2018)

1.7 Additive Manufacturing (3 D printing)

Additive manufacturing has been around for some time now, but its use in mainstream manufacturing is now considered to be essential for the fourth industrial revolution. Additive manufacturing (AM) creates products based on digital information, layer by layer as opposed to the traditional method of carving products from blocks of materials (Ford *et al.*, 2016).

AM is suitable for the fourth industrial revolution due to its ability to produce mass customized products much faster as compared to traditional methods (Dilberoglu *et al.*, 2017; Thompson *et al.*, 2016). AM is already being used in various industries such as manufacturing of components in the fields of biomedical and aerospace (Thompson *et al.*, 2016). There is a fast growth in the field of AM, where the growth in market for AM parts increased by 66% in 2014 as compared to the previous year (Thompson *et al.*, 2016).

In the case of AM, the process starts with a computer model of the product/part to be manufactured, using any Computer-aided Design (CAD) software, and then this model is used to manufacture the actual product/part layer by layer (Thompson *et al.*, 2016). This technique has many advantages such as (i) less wasteful as compared to traditional methods, (ii) production can be decentralized, models can be developed in a different location from the manufacturing, resulting in products being built closer to consumers, thus reducing deliver time and cost, (iii) the products can be customized in different ways including using less or more material (Strange *et al.*, 2017).

1.8 Cyber Security

In an era of Industry 4.0, the organizations are hyper connected with their smart devices and smart networks. This presents a very lucrative target for the cyber criminals who find much easier and insecure entry points into networks and devices. Botnets have become the weapons of choice to carry out Distributed Denial of Service Attacks (DDoS) and crypto-jacking attacks. Cyber-attacks on critical infrastructure and strategic industrial sectors have become more frequent and sophisticated. Figure 6 describes the cyber risks faced by modern connected digital supply networks, smart factories, and connected objects.

With the increased need for connectivity that is an inherent part of the fourth industrial revolution, securing the different systems, data and components becomes even more critical and challenging. Stakes would be much higher in the case of any type of cyber threat. Therefore one of the most critical challenges for any smart factory would be ensuring the security of its data and applications.

Production life cycle stage	Secure, vigilant, resilient categorization	Cyber imperative	Objective
Digital supply network 	Secure, vigilant, resilient	Data sharing	Ensure integrity of systems so private, proprietary data cannot be accessed
	Secure, vigilant, resilient	Vendor processing	Maintain trust when processes cannot be validated
Smart factory 	Vigilant	Health and safety	Ensure safety for both employees and the environment
	Vigilant, resilient	Production and process resilience/efficiency	Ensure continuous production and recovery of critical systems
	Vigilant, resilient	Instrumentation and proactive problem resolution	Protect the brand and reputation of the organization
	Secure, resilient	Systems operability, reliability, and integrity	Support the use of multiple vendors and software versions
	Vigilant, resilient	Efficiency and cost avoidance	Reduce operating costs and increase flexibility with remote site diagnostics and engineering
	Secure	Regulatory and due diligence	Ensure process reliability
Connected object 	Secure	Product design	Employ secure software development life cycle to produce a functional and secure device
	Vigilant	Data protection	Maintain the safety of sensitive data throughout the data life cycle
	Resilient	Remediation of attack effects	Minimize the effects of an incident while quickly restoring operations and security

Figure 6: Smart Production Life Cycle and Cyber Attack (Waslo *et al.*, 2017)

1.9 Horizontal/Vertical Integration

Horizontal integration means that one corporation should collaborate and cooperate with other similar corporations, in terms of sharing resources and information (Wang *et al.*, 2016). Vertical integration refers to the different components and networks within an intelligent factory, that are flexible enough to readjust according to the requirements and in response to transfer of information among different components with the help of cloud (Zhou *et al.*, 2015).

2. FOURTH INDUSTRIAL REVOLUTION: CHALLENGES FOR DEVELOPING COUNTRIES

The first step towards providing a solution is to highlight the challenges. In this section, the key challenges faced by the developing countries have been outlined.

The idea of the fourth industrial revolution holds great potential for economic growth; however, adopting it is not a trivial task. This new industrial revolution is still in its infancy. It would take a significant amount of time and effort before Industry 4.0 can be fully implemented. Advanced countries which are on the path of the fourth industrial revolution have a long way to go before they can reach the full potential of the benefits that can be offered by the fourth industrial revolution. It is essential for developing countries to develop strategies to adopt the fourth industrial revolution. There are many challenges that need to be addressed in order to reap the benefits of the fourth industrial revolution or Industry 4.0.

Bangladesh is one of the leading manufacturing countries for producing apparel (Islam *et al.*, 2018). In the following **box** we examine the challenges faced by Bangladesh in following the road to the fourth industrial revolution.

Bangladesh - Challenges (Islam *et al.*, 2018)

According to a study carried out for Bangladesh, they have concluded that Bangladesh is lagging behind in adopting the fourth industrial revolution. They have considered the following multifaceted challenges to harness the opportunities of the FIR:

- *lack of government support*
- *lack of knowledge*
- *poor infrastructure*
- *availability of cheap labor*
- *expensive installation of technologies*

We have categorized the challenges faced by developing countries into four categories: (i) Infrastructure, (ii) Lack of trained and skilled work force, (iii) Scalability, and (iv) Funding.

2.1 Infrastructure

One of the biggest challenges would be developing the infrastructure which is required to adopt this new manufacturing paradigm. Some developing countries lack even basic infrastructure; hence they have a long way to go before they can be prepared for FIR. Electricity which is taken for granted in developed countries can also be an issue for developing countries. Pakistan, for example, has a supply demand gap of 7 gigawatts (Kazmi *et al.*, 2019). 46 million rural households lack electricity in India (Phadke *et al.*, 2019). Figure 7 shows the access to electricity by different countries. As can be seen many countries in Africa don't have access to electricity. This lack of access to electricity or shortage in electricity is one of the first hurdles that need to be overcome.

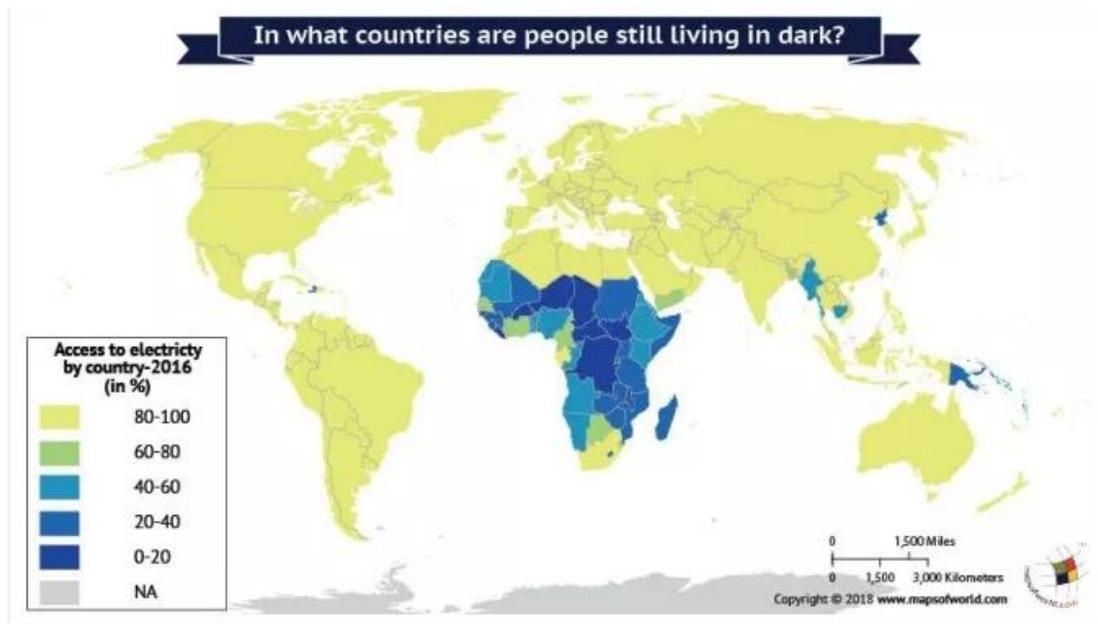


Figure 7: Access to Electricity across the World (Maps of the World, 2018)

The second basic requirement that may not be an issue in developed countries, but can prove to be a stumbling block on the path to FIR for many developing countries is the lack of internet access. Figure 8 shows the map of internet connectivity across the globe. All the devices in a smart factory would be connected to one another and need to communicate frequently across remote locations therefore a high-speed internet connection would be essential. As shown in Figure 8, the internet penetration in many developing countries, especially African countries is cause for concern. This issue must be addressed before such countries can move further in implementing the FIR.

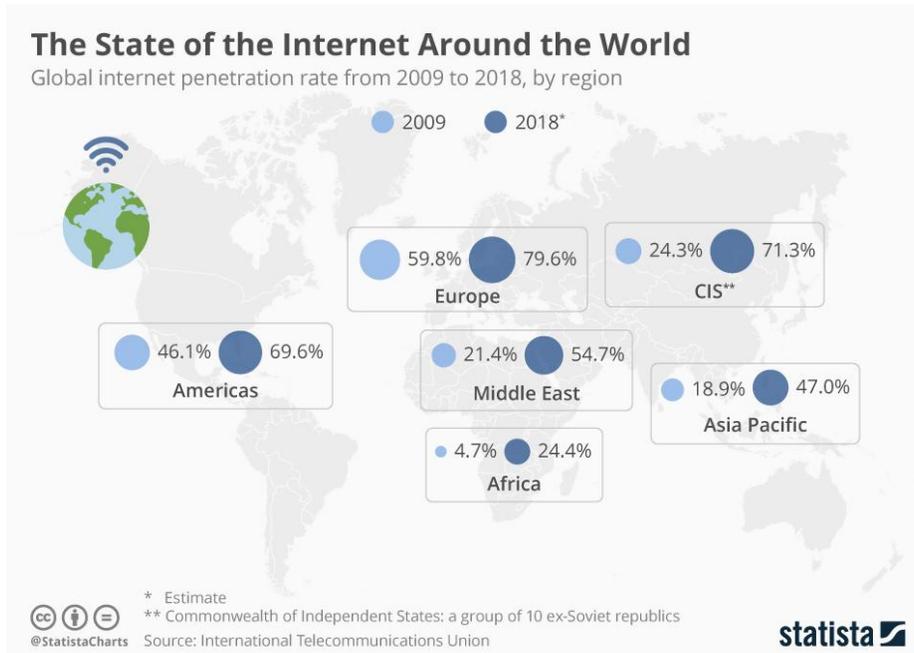


Figure 8: Internet Penetration by Region (Feldman, 2018)

Factories would be smarter than ever before, which implies that smart devices have to be developed (Zhou *et al.*, 2015). One of the defining attributes of Industry 4.0 is the interconnection of heterogeneous devices, including connection of physical objects with cloud etc. A reliable network needs to be established that can link all the components of a smart factory (Zhou *et al.*, 2015).

2.2 Lack of Trained and Skilled Workforce

The increased interconnectivity that is an essential part of the smart factory of the future brings with it the additional challenge of ensuring the security of different devices and data as well as privacy (L.D. Xu *et al.*, 2018). It would be critical to prevent hacking and other cyber-crimes to ensure the smooth functioning and prevent loss. This can prove to be a major challenge, since without ensuring the security, adoption of this new technology would suffer. Countries developing smart factories need to have security experts and research centers to keep pace with new security threats and their prevention.

Another key component would be the implementation of the Cyber Physical Systems that can autonomously oversee the entire production line. Data science and big data analytics would be needed to process an enormous volume of data, that would be produced constantly, and gain useful knowledge out of them. Developing systems that can process massive amounts of data from heterogeneous sources can prove to be difficult (L.D. Xu *et al.*, 2018). Developing countries lack the specialists in fields such as machine learning and data science to build systems that can be part of the FIR. This revolution is different from previous revolutions, as previously the manual work of people was automated, but in this technological wave, even the decision making and potentially design tasks can also be automated. The manpower required in this new age would have to be highly skilled. Therefore, human resources with the required skill set is a challenge faced by many developing countries.

One of the most important facets for responding to FIR is the adequate number of knowledgeable scientific and technical manpower in industry 4.0 technologies. Due to inadequate training opportunities and awareness building programs in industry 4.0 technologies, developing countries are still in its infancy. For instance, if we look at the demand for trained data engineers, data analysts, and data scientists for responding to FIR in the recent years in developing countries, it has gone nowhere but up. Data is considered as crude oil for the industry 4.0 business community. Data scientists utilize their skillset to convert all the information into actionable insights about everything from product development to customer retention to new business opportunities. In developing countries there are not enough trained data scientists who can make use of most of big data. This is really hampering the capability of their businesses and governments alike to produce quality data products for their customers and local communities alike. Due to inadequate training opportunities and awareness building programs, their professional expertise in mining this gold is not only limited but they are also unable to capitalize on flourishing opportunities of Data Sciences available across the globe.

2.3 Scalability

The issue of scalability arises in the developing countries due to lack of implementation of leading industry 4.0 systems. In order to resolve the scalability issues, we need to connect and combine technology, the market, and society in all industries based on Information Technology (IT). Thus, the combination of the new business model is core for company innovation or a start-up. However, IT itself is not the source of competitiveness for innovation and company business models in developing countries. Therefore they are facing the following two main issues as far as scalability is concerned:

- a) How to productively combine industry 4.0 technologies and the national and international market?
- b) How well such a combination meets the requirements and expectations of users or consumers?

2.4 Funding

It is widely accepted that new technology-based firms can play a vital role in job creation and the economic prosperity of a country. Establishing new technology-based firms requires capital. “Fluidity of capital” is a main issue for developing countries. Developing countries can resolve this issue by increasing “crowd funding”, and the activation of entrepreneurs coming from workers, created through major users or customer co-creation rather than capitalists, and reforming national taxation structure. This segregates capital from the capitalist. Moreover, this will strengthen the institutional system to secure the safety of FIR.

In Box 2, we look at the challenges and importance of FIR, from the point of view of Africa.

Africa and the Fourth Industrial Revolution?

Africa is a region with many countries with vast differences in terms of development and economies. Sub Saharan Africa is a region with a fast-growing economy. Many countries in Africa have made remarkable progress in adopting technology in the last two decades; nevertheless it still lags behind in comparison to the rest of the world.

According to the World Economic Forum, Sub Saharan Africa is home to 13% of the world’s working age population and this continues to grow (Leopold et al., 2017). It also has the world’s youngest population; therefore in terms of work force this region cannot be ignored. The future of jobs lies in high skilled jobs as compared to low skilled jobs due to automation. Some African countries such as South Africa, Mauritius and Botswana have a higher percentage of skilled workers compared to the rest of Africa (Leopold et al., 2017).

Challenges

As discussed earlier, Africa is a region with heterogeneous economies. However, the following are some of the challenges faced by a majority of the African countries.

- **Infrastructure**
As discussed above, most of the developing countries lack the infrastructure that is essential before their economies can rely on the fourth industrial revolution. Africa also must improve its infrastructure, including the availability of electricity, high speed internet connections and even roads.
- **High Skilled Man Power**
Africa lags behind in terms of highly trained people that would be a vital part of an economy relying on smart manufacturing. Governments in Africa as well as both public and private sector educational institutions have to improve the quality of their education and focus on Science and Technology education (Simbanegavi et al., 2018).
- **Informal Economy**
The economy of many countries in Africa specially countries like Ghana, Zimbabwe, Sierra Leone, Tanzania and many other countries relies on small businesses and trading

on a small scale. These small businesses have low growth rates and lack the culture of innovation, which is essential for FIR (Ayentimi et al., 2019).

African countries have a great potential for economic growth, if they adopt the technologies of the fourth industrial revolution. However, failing to do so will further increase the economic divide between Africa and the rest of the world. Most of the African countries are far from ready to tackle the challenges of FIR. It is therefore imperative to develop infrastructure and take other necessary steps such as improving required education, so that African countries can take advantage of this new industrial revolution.

It is important for developing countries not to lag behind and take steps to take advantage of this industrial revolution. Many developing countries are realizing the importance of investment in knowledge, science and innovation. This is an important step to ensure that these countries can also benefit from the advancements in manufacturing and production.

3. DEVELOPING COUNTRIES ON THE PATH OF THE FOURTH INDUSTRIAL REVOLUTION

The idea of the fourth industrial revolution (or Industry 4.0) started from Germany in 2013 and is rapidly gaining a lot of attention in other advanced countries due to its potential to accelerate economic growth (Petrillo *et al.*, 2018). In this section the steps taken by some of the developing countries to grapple with the challenges of this new technological wave are discussed. Pakistan has been taken as a case study to understand the opportunities and challenges it faces in adapting the technologies of FIR.

Many countries have taken the initiative to take advantage of the different technologies that constitute the fourth industrial revolution. Some countries have outlined plans that will help them create smart factories that take advantage of the technologies mentioned previously in this paper. Germany's public policy "Industry 4.0", the United States' "Advanced Manufacturing Partnership" and China's policy "Made in China 2025" are a few examples of the public policies that have attempted to outline strategies to embrace the fourth industrial revolution (Liao *et al.*, 2018).

Google AI in Ghana (Dean *et al.*, 2018)

Africa lags behind from the rest of the world in terms of education, technology and infrastructure to adopt the FIR. Google has taken a step in this direction by aiming to strengthen Africa's educational institutions by providing infrastructure and software.

Google has under taken many projects in Africa with the aforementioned goal in mind. One such initiative is the Google AI research center in Accra, Ghana. Their aim is to bring researchers of AI and machine learning to collaborate with other educational institutions, and to use AI to solve challenges in different areas, such as agriculture, healthcare and education.

There is a need to ensure that developing countries are not left behind in this new era of smart factories, shorter development life cycles and mass customization. Some of the developing countries have attempted to take steps towards embracing the fourth industrial revolution. It is vital for the developing countries not to lag behind as the economies of many developing countries depend on their manufacturing industry. A joint effort is needed by both private and public organizations. Government role should be to promote and support innovation by providing the infrastructure and seed money for startups working for innovation in the required areas as well as tax holidays.

Most of the countries still have a long way to go before they can embrace this new industrial revolution. In the next section we discuss some of the initiatives in Pakistan that could help propel Pakistan into the era of the fourth industrial revolution.

3.1 Fourth Industrial Revolution: A Case Study for Pakistan

Pakistan is traditionally an agriculture-based economy. However, like many other countries, Pakistan is realizing the importance of investing in Science and Technology (S&T). A significant effort is taking place at different levels to improve infrastructure, education and research in science and technology. One of the first steps that needs to be taken by any country aiming to take advantage of the FIR would be capacity building. Pakistan has taken an initiative towards capacity building by establishing research

centers and educational institutions. The following subsections contain details of different initiatives taken in Pakistan.

HEC Sponsored Research Centers

Pakistan's Higher Education Commission (HEC) is a governmental organization that is responsible for the quality of education in Pakistan and strategic decision making according to the needs of the future. Pakistan's Higher Education Commission is actively promoting the establishment of research centers in key emerging areas. HEC has successfully launched the following four centers of excellence in 2018:

- Artificial Intelligence
- Robotics and Automation
- Data Analytics and Cloud Computing
- Cyber Security

Each research center consists of a number of labs at different universities. These centers promote research, collaboration and capacity building.

Presidential Initiative for Artificial Intelligence & Computing (PIAIC)

In December 2018, PIAIC was launched. The aim of this center is to become the hub for education and research for fourth industrial revolution technologies namely: artificial intelligence (AI), data science, cloud computing, edge computing, block chain, and the internet of things (IoT) related fields. A number of programs have been launched that could play a vital part in capacity building for the future work force. The following one-year programs have been launched:

- Artificial Intelligence
- Cloud Native Computing and Amazon Web Services
- Block Chain

Ignite

Ignite is a national technology fund, which aims to promote startups to promote knowledge economy. The mission of Ignite is to prepare one million people for the future work force. Ignite funds startups that are aiming to work in fourth industrial revolution technologies. They aim to support innovation by providing seed funds, funding for Final Year Projects (FYPs) of students and providing funding to projects. As of July 2019, they have funded more than 2260 FYPs, 182 projects and 250+ incubatees (Ignite, 2018). They also aim to provide more than 1 million training in the future of work by 2020 (Ignite, 2018).

COM CERT

COM CERT is a cyber security initiative by COMSATS. The aim is to provide a focal point for any cyber security incident and to ensure that the users feel safe online. This initiative aims to provide the following services in the first phase:

- Alerts & Warning
- Incident Handling
- Incident Analysis
- Incident Response Support/Coordination

- Announcement
- Awareness & Capacity Building

In the second phase, Threat Intelligence Platform (TIP) will be developed which would work on “collecting”, “analyzing”, and “distributing” actionable intelligence on cyber-threats from around the world.

The initiatives mentioned above are helpful. However, even more steps are needed if Pakistan is to successfully step into the age of smart manufacturing, steps such as improving infrastructure, improving internet connectivity and electricity.

Developing countries each have their own set of challenges to tackle in implementing FIR. However, as can be seen from the above discussion a number of hurdles are common among all the developing countries. The next section outlines the strategy which can help developing countries cope with the emerging technological landscape through collaboration. Governments must make a concentrated effort to adapt to the FIR.

4. STRATEGIC FRAMEWORK FOR RESPONDING TO FIR: A ROAD MAP FOR DEVELOPING COUNTRIES

Some of the developing countries as discussed in Section III have attempted to take steps towards embracing the fourth industrial revolution. However, technologies that constitute the fourth industrial revolution entail highly specialized and multidisciplinary knowledge. It would be a herculean task for a single country to specialize in all the technologies and knowledge, as mentioned in Section I. Therefore, there is a need to establish links between developing countries that will enable them to take advantage of the diverse set of fourth industrial technologies collectively. Thus, this study suggests a platform (Centre for the Fourth Industrial Revolution (CFIR)) between developing countries in terms of a global center to address the challenges and opportunities presented by fourth industrial revolution technologies. The CFIR will work across COMSATS member countries.

The membership to CFIR shall initially be open to any developing country that expresses interest to respond to FIR through a networked approach and partnership. The COMSATS headquarters located in Pakistan will have the overall fiduciary and operational responsibility of CFIR. It is both an intergovernmental and intra-governmental linkage between developing countries. It will bring together diverse stakeholders including governments, academia, business organizations, dynamic start-ups, and civil society of the developing countries.

These stakeholders will identify the game-changing impact of emerging fourth industrial technologies. Hence CFIR will serve as a useful global platform between developing countries for collaboration. COMSATS will design the coordination and communication channel between CFIR participating members. Gradually, with their partners (participating member country and relevant stakeholder) CFIR will co-design innovative governance protocols and policy frameworks. Table 2 briefly describes the strategic plan of CFIR.

Mission	<i>To accomplish socioeconomic prosperity, national security, equitable & sustainable development of developing countries through Industry 4.0 technologies and innovation-driven cluster of research and development-oriented labs in the Industry 4.0 technologies.</i>		
Target Groups	<i>The target groups are the developing countries that want to enhance their capacity for (1) research and (2) technology transfer in technology 4.0.</i>		
Finance	<i>Primarily, financing to CFIR come from government and/or private money from participating members</i>		
Final Beneficiaries	<i>Final beneficiaries are the national scientific community, companies from participating countries, respective governments, and the society as a whole. The resulting economic growth and development of society in general represents a benefit for the whole society.</i>		
Executorial Plan			
Phase 1 Opportunity Mapping 3-6 months	Phase 2 Framework Development 6 months	Phase 3 Prototype, Test and Iterate 9+ months	Phase 4 Scaling and Adoption
Key activities <ul style="list-style-type: none"> • Landscape review of existing efforts • Specify government and industry needs 	Key activities <ul style="list-style-type: none"> • For each focus area selected in the scoping phase, identify the policy or governance changes most likely to achieve systemic change 	Key activities <ul style="list-style-type: none"> • Execute short pilot projects with government and industry partners to test governance 	Key activities <ul style="list-style-type: none"> • Globally disseminate the protocols and frameworks from successful pilots and support international

<ul style="list-style-type: none"> Identify project focus areas <p>Who?</p> <ul style="list-style-type: none"> Fellow (if applicable) supports initial research through interviews, workshops and desk research Senior expert joins 1-2 Working Group calls CEO attends 1 virtual Global Council meeting 	<ul style="list-style-type: none"> Co-design governance protocols and policy frameworks <p>Who?</p> <ul style="list-style-type: none"> Fellow (if applicable) contributes to policy and framework design Senior expert joins 2-3 Working Group calls to provide guidance and feedback CEO attends 1 in-person Global Council meeting 	<p>protocols and policy frameworks</p> <ul style="list-style-type: none"> Collect key learnings from pilot and improve protocols and frameworks <p>Who?</p> <ul style="list-style-type: none"> Fellow (if applicable) engages in pilot projects Senior expert reviews and contributes to final products 	<p>adoption</p> <p>Who?</p> <ul style="list-style-type: none"> Fellow (if applicable) supports policy and protocol implementation within partner company CEO and senior experts serve as ambassadors for policies and protocols
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Table 2: Strategic plan of CFIR

Since each participating developing member country of CFIR has its own expertise and infrastructure in FIR technologies, the proposed CFIR will establish various clusters of research and development-oriented labs in the industry 4.0 technologies. These labs will work in collaboration at the national and international levels with the help of the CFIR headquarters, as shown in Figure 9. These clusters of labs located in different locations across a member country/member countries will promote the strategic objectives of CFIR.

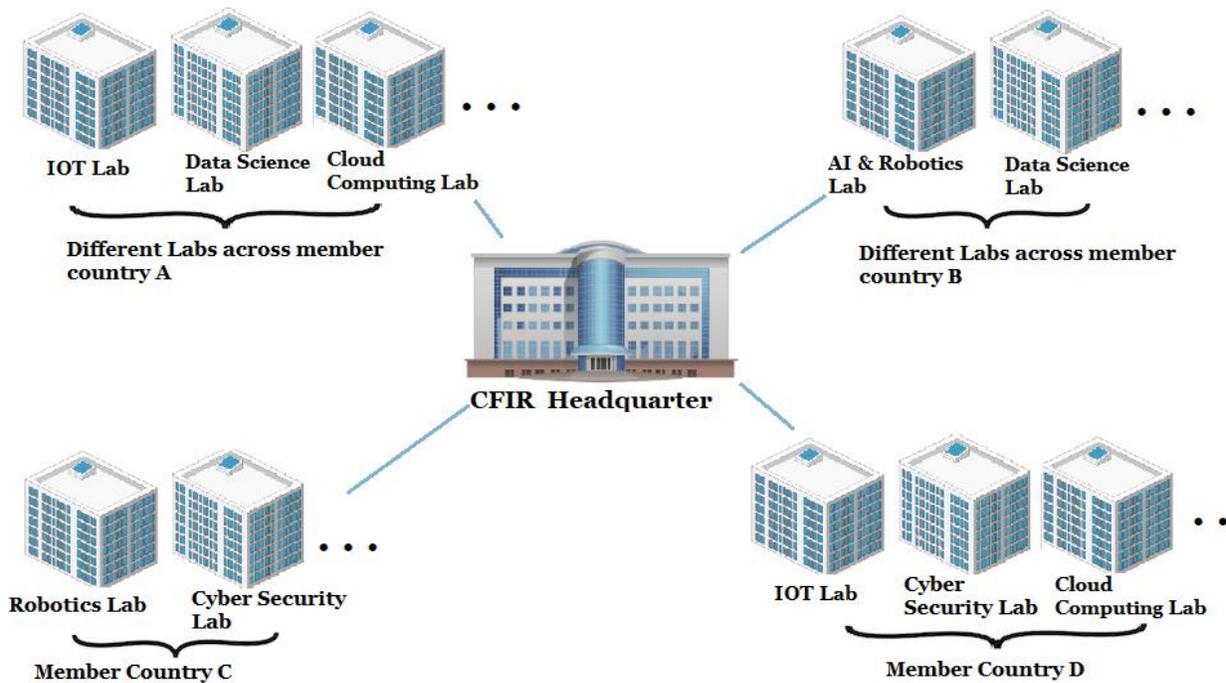


Figure 9: Suggested Structure for CFIR

Initially CFIR will incorporate the strategic framework in four directions as shown in Figure 10, to address the above-mentioned challenges.

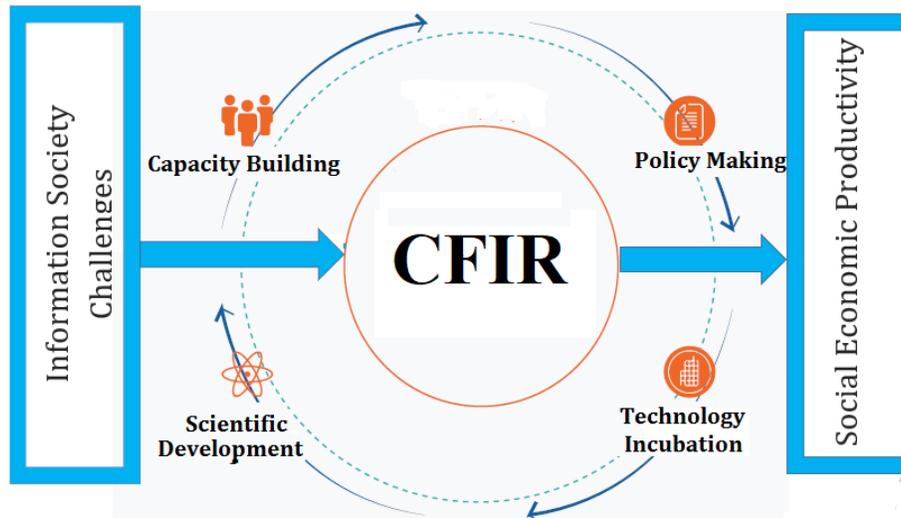


Figure 10: Strategic goals of CFIR for responding to FIR for developing countries

Strategic Plan 1: Capacity Building

Evolution of human resource is one of the most important facets for responding to FIR, as without an adequate number of knowledgeable scientific and technical manpower at all strata (i.e. researchers and technicians), any investment in buildings and equipment would be counterproductive. Therefore, as the first step in responding to FIR, CFIR will prepare a well qualified, knowledgeable, motivated, dynamic and adaptive work force depending upon the needs of each developing country. CFIR will have the following targeted action plans for promoting industry 4.0 technology capacity building.

Action 1:

Educate developing countries' human resources with industry 4.0 technologies by offering technical and professional hands on workshops and seminars.

Action 2:

Re-organize professional education system (technical and vocational) that can accommodate the FIR technologies.

Action 3:

Prepare collaboration plan with industry (private sector) of relevant member country to organize work-based learning for technical and vocational students.

Action 4:

Promote careers through public campaigns, vocational tracks in education, and investment in technical and vocational training systems.

Action 5:

CFIR will bring together policy makers, researchers, entrepreneurs and business managers to ensure knowledge and equipment sharing among the participating developing countries.

Action 6:

CFIR will also ensure the availability of trained professional workforce to the participating countries by designing education policies that respond rapidly on developments in the knowledge space.

To support these actions, CFIR will design comprehensive and tailor-made training programs according to individual needs of a member country. The focus of these training programs will be on imparting practical knowledge in their respective fields to prepare a task force that would be ready to tackle the challenges of the fourth industrial revolution. Figure 11 describes the capacity building framework for CFIR.

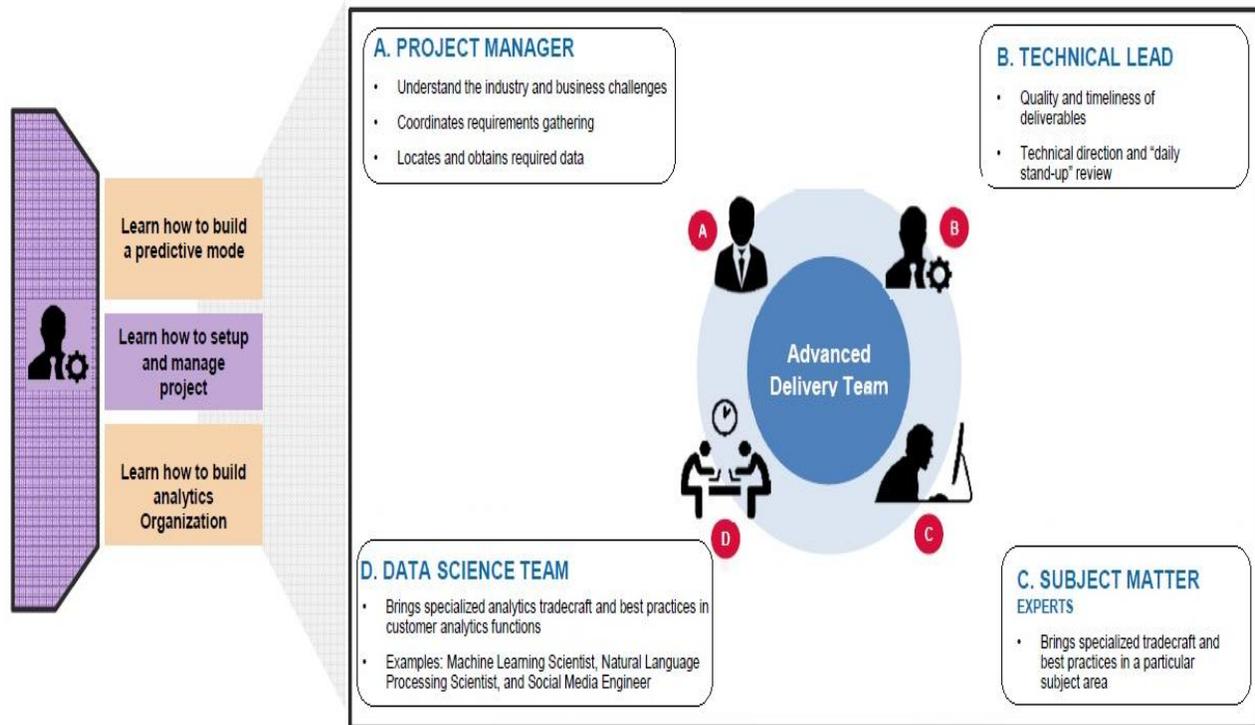


Figure 11: Capacity Building framework for Technology 4.0 for CFIR

Strategic Plan 2: Technology Incubations

Strategic Plan 2 will promote all enabling technologies of FIR in terms of technological incubations. Technological incubators are responsible for providing technical, business and infrastructure support to ensure that new businesses develop linkages and survive and grow as organizations (Bergek *et al.*, 2008). It is widely accepted that new technology-based firms can play a vital role in job creation and the economic prosperity of a country (Colombo *et al.*, 2002). In the era of the fourth industrial revolution, it is even more critical to support research and innovation as this revolution is based on knowledge and innovation. CFIR team and stockholders will make policies regarding capital generated from technology incubation. Initially CFIR will focus on the following actions to implement the strategic plan 2.

Action 1:

Establish beneficial cooperation between large companies and Small and Medium-sized Enterprises (SMEs) or start-ups as collaboration between mature and new start-ups play a vital role in fast and dynamic implementation of the FIR.

Action 2:

Design a new combination Business Model to promote technical innovation of companies that meets social demands to create social values and market values through a rapid dynamic process.

Action 3:

Activate entrepreneurs (coming from workers, created through major users or customer co-creation rather than capitalists) using crowd funding. This action will segregate capital from capitalists, which improves the economy of the country.

Action 4:

Strengthen the entrepreneurial role of the governments of developing countries; for instance, the installation and reinforcement of national investment banks.

Strategic Plan 3: Scientific Development

The industry 4.0 technologies are among the driving forces of globalization. These technologies have played a significant role in bringing people together and bringing decision makers new tools for development. The proposed CFIR will establish an application-oriented basic research network among developing countries to develop prototypes and patentable solutions for the countries. Initially CFIR will provide an IT solution to local problems using these technologies and take solutions to the market through technology commercialization and licensing. CFIR may set the following action plans for implementing strategic plan 3.

Action 1:

Create an environment conducive for innovation and technology development.

Action 2:

Develop product functions, prototypes and patentable solutions in the field of data science, block chain, 3 D printing, cyber threat intelligence and Internet of Things.

Action 3:

Act as a think-tank specializing in providing high-quality consultative services on industry 4.0 technologies to its member countries.

Strategic Plan 4: Policy Making for responding to FIR and adopting industry 4.0 technologies

The vibrant policies such as economic, innovation, educational, structural and public policies play a vital role in the promotion of FIR in the developing countries. These policies not only increase economic growth but also mobilize resources and links between participating member developing countries. Therefore, there is a dire need to develop sustainable policies for developing countries that will facilitate government (of participating country) and their national and international organizations' response to FIR. From the implementation perspective of industry 4.0, diverse policies are required that would help developing countries to plan and implement FIR activities. There exists a need to develop lucid and pertinent policies across the developing countries that can set the foundation for the growth of science and technology. CFIR would focus on achieving the following targets:

Action 1:

Develop collaborative linkages between well-established Science, Technology, and Innovation (STI) policy makers and institutions.

Action 2:

Design educational, fiscal, structural and public policies that will be necessary for responding to FIR for developing countries.

Action 3:

Evaluate existing Innovation Policy and renew them on a regular basis.

CONCLUSION

The fourth industrial revolution is greatly re-shaping the global economy. It is based on the fusion of a wide variety of technologies such as robotics, machine learning, data science, Internet of Things, cloud computing, Augmented Reality, Additive Manufacturing (3 D printing) and cyber security. Many developed countries are trying to achieve the vision of FIR. However, developing countries are facing various technical and societal challenges for responding to FIR. The technical challenges that these developing countries are facing include lack of infrastructure for adopting the new manufacturing paradigm, shortage of trained and skilled work force, lack of self-organization and self-actualization, lack of collaboration between government and civil society, and lack of massive technology–market–society projects.

The proposed CFIR will bring together governments, academia, business organizations, dynamic startups, and civil society of the developing countries to identify the game-changing impact of emerging fourth industrial technologies. It will be a network of capacity building, technology incubation, scientific development and policy decisions in the aforesaid domains. It makes strong connections between symbolic and non-symbolic computation, conjointly between applied and theoretical areas to resolve the challenges faced by developing countries for responding to FIR. The focus of the CFIR will be to bridge the gap in academia and industry and allow researchers, domain experts and developers to work on real-world problems while giving their industry partners a substantial leap forward. Besides, it will offer a wide variety of activities that include trend flashes, lecture series from international luminaries, workshops, guest lectures from industry. A high degree of collaboration between various national and international research groups and organizations will be the communication channel with other forums such as the United Nations. In this regard, the CFIR will, perhaps, be unique in terms of its commitments to respond to the fourth industrial revolution.

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