A Study on Reliable IoT Adoption to Handle Future Pandemics

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ABSTRACT
The Covid-19 pandemic has given a new visibility to IoT enabled services in the various fields of the world especially in healthcare. The objective of this study is to provide possible solutions that can be delivered rapidly via connected AI enabled IoT devices. This study analyzed current pandemic preventions techniques used in different areas namely agriculture, education, health care, city management, industrial, transport, construction and other commercial activities. Big data management concerns, reliable connectivity issues, cost, security and privacy, etc., are the major challenges in adopting IoT paradigm in handling pandemics. More sophisticated AI enabled software requirements are essential for the proper handling of the data. This paper points out the potential ways in which IoT can help in managing and controlling the spread of future pandemic situations including security and privacy. Proposed different techniques and future directions to collaborate IoT to control the widespread of the virus that causes the pandemic situation.

General Terms
IoT adoption for pandemic situations.

Keywords
IoT, Pandemics, COVID-19, intelligent applications

1. INTRODUCTION
The idea of embedding sensors and intelligence to basic objects and communicating these devices over internet is the fundamental technology involved in the Internet of Things (IoT). The IoT enabled systems become dramatically more responsive in industries as well as in commercial world due to comprehensive real time data collection and analysis. Successful implementations of IoT are now available in the field of production, supply chain management, and automobile industry. The negligible cost of smart objects helped in adopting widespread use of IoT devices even in household purposes.

The COVID-19 is one among the world wide health crises in our time and the greatest challenges facing since world war II[1]. The countries are still trying to hamper the spreading of viruses by taking different methods like vaccination, testing, social distancing, lockdown, case detection, isolation, contact tracing and quarantine. It can kill healthy adults additionally to elderly people with existing health problems. A typical infected person spread the corona virus to two or three others results in an exponential rate of increase [2]. The governments are worried about the spreading of this pandemic that affects all the fields of economy, business and daily life of citizens even though now it is controlled by vaccination. The main matter is, whether technology can aid in overcoming the difficulties in different areas of mankind and how to stop the epidemic conditions using the available technology.

The severe pandemic like COVID-19 demands reduction in people to people interactions technically termed as social distancing and reduction in social crowding to reduce the spread of these diseases. Governments of most of the countries have declared lockdowns and have taken similar measures to implement social distancing and crowd reduction. Almost all the fields like industry, transportation, agriculture, education etc., are severely affected due to these remedial measures taken by the Governments and authorities. Currently the IoT adoptions in different areas are carried out in a piecemeal manner, which require massive change in future to increase automation. So, new methodologies need to be designed in the affected fields to continue its operations even though some vaccines are developed to fight against Corona virus and its variants like Omicron. Adoption of an appropriate automation technology is the best solution for the same. The adopted technology should be in such a way that it must be interactive to the machine as well as to the human world. In this sense the best choice of technology is IoT as it can connect any real world entities. Through embedded sensors, it can collect appropriate data for the analysis and integration of best decision making technology like Artificial Intelligence (AI) can do wonders[3]. This will help to reduce huge crowds in various fields and customer services can be delivered to the people with minimum interaction respecting the social distancing and crowd reduction policies. Now, limited implementations are fighting against COVID-19 by different countries.

The technological solutions are essential for the proper handling of the current pandemic situations. How this technological innovations affects the different aspects of the life such as health care, education, agriculture, transportation, construction, city management, industrial and commercial activities. IoT devices continuously produce variety of data. This wide range of data handling is one of the major issues in

adopting IoT paradigm. A lot of sophisticated software requirements along with AI algorithms are essential for the proper handling of the data. AI methods are also to be used for predicting the dominant variants of the virus and its future impacts on the world. In this scenario, this paper points out the potential ways in which IoT can help in managing and controlling the spread of future pandemic situations including security and privacy. The proposed different techniques and future directions to collaborate IoT to control the widespread of the virus that causes the pandemic situation.

1.1 Taxonomy Adopted

This study considered recent articles published about COVID-19 pandemics and other similar situations handled by the mankind. This paper describes how IoT as a tool to be won't to curb the spread of future pandemic viruses. This article analyzed current pandemic preventions techniques used in different sections like agriculture, education, health care, city management, industrial, transport, construction and other commercial activities. The Figure 1 shows the coverage of areas in this study in pandemic situations.

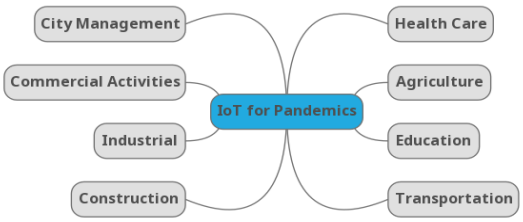

Fig 1: Organization of this study

1.2 Organization of the Study

The remaining part of this paper is arranged as follows. Section 2 describes current IoT installations in the various fields of business. Section 3 is to explain how IoT are often utilized in different areas to prevent future pandemics and this section is further divided into several sub sections. Security and privacy concerns are described in section 4. Section 5 describes issues in adoption IoT and provides recommendations to further enhancement during this field. Finally concluding remarks are given section 6. The general organization of this document is given in Figure 1.

2. CURRENT SCENARIO

The current pandemic situation COVID-19 triggered many ideas and solutions to integrate IoT in many fields to limit direct human interactions. This includes usage of remote personal monitoring, prediction, preventing and controlling of infectious diseases. There are several individual studies available for IoT implementation in agriculture [4], education [5], health care [6], city management [7][8], industrial [9][10], transport [11][12], construction [13][14] and other commercial activities[15].

Certain smartphone apps are getting used to trace infected people, issue self-quarantine guidelines, provide latest communication to the citizens and ease the burden on healthcare staff [16]. If an individual tests positive for COVID-19, people that were near that person for a particular period of time are often alerted via their phones using Bluetooth technology. Some people in Singapore and India say they're willing to use such an app, even at some cost to their privacy [17][18]. Vodafone has launched a heat-detection camera designed to screen people coming into buildings for signs they'll be running a fever and potentially be infected with Covid-19. If elevated temperatures are detected, alerts are sent to the operator of the camera to assist them to identify the infected person [19].

From the COVID-19 experiences, the containment measures and aggressive contract tracing are mandatory to stay the infection until an approved treatment or a vaccine is out to the world wide community [20]. Unlike Ebola, HIV and Influenza, COVID-19 has only a one strand ribonucleic acid (RNA), so it is able to rapidly mutate. Algorithms are used to predict the structure of viruses (Lineatrfold)[21]. The paper [22] focuses on the system for early prediction of epidemic.

The educational field can support teachers, parents/caregivers, innovators, communications experts and other persons in this field through radio programmes, home-schooling, online learning and other innovative approaches [23]. It also impacts on transport organizations. Transport organizations can continue to operate throughout the lockdown while planning ahead for when measures are lifted. The availability of skilled personnel during the lockdown and potential financial shortfalls are other concerns [11]. The literature[24] proposes recommendations for farm workers, owners and to the government on employment, social, and economic factors have the potential to affect the magnitude of an influenza pandemic among farm workers and in related fields. The COVID-19 pandemic can generate a relevant transformation within the business field, the pandemic forced the workplace operations to travel virtual and lots of businesses have made such transition successfully during a short period of time [25].These changes in this field could also be long lasting even after the things eases. Pandemic created lack of transparency about employees' whereabouts and their well being since most of them are locked at home. Transparency is also a crucial issue in manufacturing and construction fields, since physical site visits are restricted due to regulations. The same issue also big problem in transportation of goods [26].

IoT gives us the pliability of video conferencing and also virtually meeting of our loved ones with an easy voice command [15]. Also, IoT technology can be helpful in monitoring patients who are high-risk and hence are often a source of data to healthcare staff to require adequate action [27]. More research must be administered for the event of automated and effective alert systems to supply early and timely detection of outbreaks of such diseases so as to scale back morbidity mortality and to stop global spread [28].

The paper [29] proposed a point-of-care (POC) diagnostic device. The fast and user friendly system uses miniaturized polymerase chain reaction (PCR) device specifically concentrates on the dengue fever virus (DENV). The sample containing the DENV is collected and first processed at the POC. The diagnostic results along with the GPS coordinates of the POC are then transferred to the central control point through the user's IOT enabled phone. The huge data collected in this way from various locations are stored in cloud databases for further large scale analysis to continue the monitoring. The authors are claiming that the system can be extended to use for other diseases and the data collected can be used to monitor and prevent any pandemic outbreaks.

The connected medical devices through IoT technology could help in controlling the spreading of pandemic diseases[30]. Now, the available wearable devices like fitness bands have many medical related data sensing capabilities which will help to collect health related data and are then communicated to cloud storages. The analysis of such data will really helps in the pandemic spreading prediction.

AI plays an important role in the detection of cluster of cases. It can be used for predicting where the COVID-19 virus will affect in future. The paper[31] found 7 applications of AI in COVID-19 pandemic scenario starting with early detection and diagnosis of the infection till prevention of the disease. The AI technology can help in developing virus prevention strategies and vaccine development too. The technology enabled approach will overcome the challenge of effectiveness of infection prevention methods due to the lack of readily available and relevant data.

The COVID -19 outbreaks made the technologist to understand that there are a several potential IoT based solutions are needed in future. Higher level of Government funding and support are necessary for such innovations and making sure that people respond quickly in pandemic situations. Mathew et al. [32] have developed a framework named IoT for Smart Disease Surveillance. A smart device located at hospitals will collect patient data, process it and send the results to the backbone network. The backbone network will process the given information and the relevant results will be communicated to the health ministry. Then the ministry can understand the trends and act accordingly. The necessity of such a system is described with three pandemic cases in India viz. Cholera outbreak in 1988, Plague outbreak in 1994 and Dengue cases between 2006 and 2012.A few applications with limited facilities are used in IoT enabled remote asset access and supply chain management are currently used in some smart city initiatives[33].

In transportation industry, an IoT enabled truck will help not only for tracking the movement of the truck but also to assess the level of shock that results in damage of the products and thereby better protect the products during its transit. An IoT network with remote temperature sensors deployed in restaurants will helps in the automatic temperature control and prevents the food waste due to it. An Italian company AME developed a product to maintain safe distance between people during infectious situations [34]. A web based product named EGOpro social distancing can help people inside malls, public offices or companies to maintain social distancing by providing an active TAG to each person entering the area. It produces an alarm if social distancing is violated. The article [35] proposed a framework for real time monitoring of persons and report abnormal health conditions of them and will be notified to concerned people, relatives or to a nearby doctor directly. The current Corona virus outbreak shown that humans are not infallible and communities need to be prepared against such pandemics.

There are certain studies already conducted like architecture for social distancing[37], internet of medical things[38], smart management in hospital building[41], open IoT Platform for infective pandemic diseases[42] etc. In article[39] analyzed internet search behaviour of people in Philippine during pandemics. The article[40] presented a report on the impact on IoT adoption in different areas like smart homes, smart cities including healthcare and industry. This paper proposes different techniques and future directions to collaborate IoT to control the widespread of the virus that causes the pandemic situation.

3. APPLICATIONS OF IOT IN PANDEMIC SITUATIONS

Currently IoT had done a little in the fight against current pandemics, but new innovations will make it do wonders in future pandemic situations. In this section we have described about how IoT may be helpful in prevention and control of future situations in the different areas.

3.1 Healthcare

The demand in healthcare systems around world to adopt the latest remote monitoring tools, devices and technologies that enable more efficient disease tracking, early diagnosis and treatment. IoT is the technology adopted for the automated disease diagnosis, tracking and remote monitoring. The pandemic situations demand this adoption on a great scale to reduce the human interactions, especially the remote monitoring of disease affected people. The self suspected patients residing at home can even sense and send their health information to the healthcare personnel's residing in healthcare institutions.

Early Detection: It is used to say that prevention is better than cure. Early detection of a pandemic is one of the key prevention of diseases like COVID-19. So IoT along with AI is already being used to predict the future outbreak areas. Further enhancement can be done using deployed AI sensors to help the targeted quarantines and quick treatment to mitigate the spread of the corona like virus. So there is a need to develop an early detection system to uncover these infectious diseases before they become global emergencies.

Quarantine compliance: Once the potentially infected persons enter into quarantine, it is necessary to guarantee patient observance. A public health official can monitor the movements of patients' in quarantine using IoT enabled devices. The collected movement data will also help them to track down who else may be exposed due to the breach.

Patient care: Patient management with care is the most important thing in pandemics like COVID-19. IoT devices are used to monitor such patients during treatment and quarantine, which enables them to undergo a medical examination without direct contact. Remote temperature, pressure and ECG monitoring devices are needed to take patients regularly and pass this information to the doctors for the analysis of applications. Portable small devices are also helpful to the general public for their use in homes and offices.

IoT Enabled Bed Management System: Bed management systems are needed to seamlessly identify the availability of beds across a cluster of hospitals in an area to allocate patients.

More sophisticated smart thermometers, remote glucose monitors, telemedicine facilities are the other methods that may be invented in future. Numerous airports all over the world now installed thermal cameras to screen the people with elevated body temperature, as fever is the main symptom of COVID-19. Connected thermometers can be used by hospitals (and at other public locations) to screen patients and staff. To collect data from these devices data points to be made available wherever needed and this could serve as an early warning sign of new clusters of the spreading diseases.

Drones are being used to deliver medical samples and supplies to and from pandemic hotspots. Drones can also be used to spray disinfecting chemicals in some public spaces and on vehicles travelling between impacted areas. Some of the IoT adoption needed in the future are shown in Figure 2.

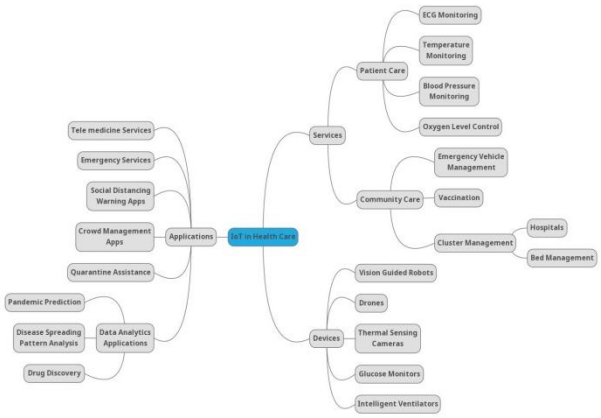

Fig 2: A Future View IoT Adoption in Healthcare

The programme Electronic Vaccine Intelligence Network (eVIN) carried out in India is one of the largest IoT enabled health care services in the world. It is a mobile based technology which tracks real time vaccine temperature with location. Real time epidemic prevention and control health code enabled Apps are required for large scale monitoring to stop the spread of pandemics. It is important that technology is playing a growing role in helping authorities to prevent the spread of pandemics like COVID-19, while also treating those that are unfortunately infected. When, IoT combined with transformative technologies like Cloud and AI, can be used in a wide range of applications during the crisis management in epidemics and pandemics.

Crowd Management: Machine vision and imaging along with IoT can play an important role in controlling and managing people. The people flow intelligence cameras can be used for people counting traffic and people flow metrics for crowd management. This can be used for improving sales and operations in retail, transportation hubs, and smart buildings. Drones can be used for this purpose.

Applications for maintaining social distancing and trace: Covid-19 contacts applications like ArogyaSetu (India), TraceTogether (Singapore), CovidWatch (Stanford University) are now available. People always demands privacy preserved powerful patient tracking applications.

Applications using connected wearables, vision guided robots etc., are to be employed in future to control and manage pandemic situations. Robots can be used to minimize the infection rate by performing diagnostic functions, contactless delivery, medical sample transport and spraying disinfectants. In this regard, companies from all parts of the IoT ecosystem should consider how their current solutions can be tactically repurposed to aid organizations and governments in fighting the future pandemics.

3.2 Transportation

Transportation of goods, medicines, vegetables across the countries is essential. During pandemics, the demand for medicines and medical equipment will rise highly. There will be strict regulations for the transportation of the essential items during this period. Most of the medicines and vegetables should be transported with strict temperature restrictions. Medical equipment also requires transporting without vibrations. IoT can help to track these conditions with real time sensors. Also GPS to track location and measure the exact travel time to the desired destination. Also it will provide a way to supply the items considering the real time demand. More sophisticated user driven IoT applications are to be developed to get products into the hands of those who need them is most effective when the products arrive in peak condition. The future IoT in Transportation is shown in Figure 3.

Automated vehicles (AVs): The current pandemic might be a catalyst for the AV industry. In lockdown conditions, the empty roads seem like an ideal scenario for driverless delivery of medicines, grocery and other essential items with autonomous vehicles. But in the conventional scenario, it may possess different challenges. It is inevitable that alternative systems will come into play with the awareness created by the current pandemic. Autonomy was very interesting because there's a lot of integration work to be done across multiple disciplines.

Vehicle manufacturers will need to adapt the changes in the consumer's attitude and behaviour due to current pandemic. Upcoming development will certainly be informed and likely to be enhanced by considering the current and future needs created by this Covid-19. Now, Specific scenarios will be identified and implemented to overcome the situations created by the pandemic. Certainly, delivery systems will be emphasized and the opportunities that can be met with AVs. There likely will be efforts to determine the most effective cleaning protocols and making health and safety procedures transparent to riders and other consumers.

In the pandemic fight, AVs represent another tool that could provide effective, safe mobility to people for essential activities and beyond once we are no longer sheltering in place. For example, people who suspect that they might be sick; AVs could serve as a transport option for the person to a hospital or doctor's appointment. Upcoming AVs may be designed with unique passenger compartments, allowing for additional space between individuals in furtherance of social distancing guidelines. It may be used for contactless delivery of medicine and food. Whether it's automated in-cabin cleaning or hands-free boarding, AV companies including Voyage, are thinking seriously about building a product that can operate safely when another pandemic strikes.

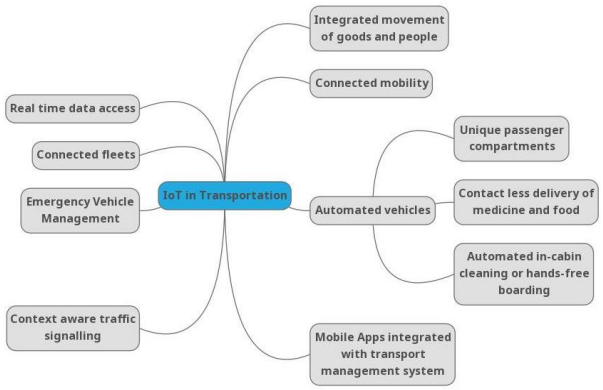

Fig 3: Future IoT in Transportation

In the view of pandemics, IoT enabled traffic signalling systems need revamping to assist emergency vehicles. Since transportation is the only source of movement for (includes water, rail and air transport) medicines, food items, people, etc., the industry should look on an integrated approach to control the pandemic situations. Logistic management IoT solutions with easy to track and trace features are needed in future to widespread adoption in transportation.

In future cloud assisted transportation will aid in handling pandemic situations with rapid arrangement of emergency vehicles for people, goods, medicines and other emergency needs including fire fighting vehicles.

Integrated movement of goods and people: During pandemics we need a more integrated mobility system, it will become more efficient. With integrated transit management and passenger information system, any service adjustments can be automatically updated to passenger journey planning apps and passenger information displays.

Mobile Apps: Mobile applications can also be used to control passenger flow, providing notifications or introducing measures to stagger ridership. Passenger counting devices and cameras installed in vehicles can be integrated with the transit management system and this mobile App.

Real time data access: Drivers can avoid unnecessary stops on their way for delivery or passenger stops. It is also a cost reduction due to wastage of fuel during stoppage of vehicle. From the IoT sensors installed in the vehicles, fleet owners can gather all these real-time data, which will help them to optimize vehicle schedules and increase efficiency and their business.

Connected mobility: In the post COVID-19 pandemic IoT will gain more pace in the fleet-based activities and it will become more advanced. Fleet stations will be able to manage incoming and outgoing vehicles more efficiently and easily according to demand and availability. IoT sensing solutions with proactive monitoring and analyzing ability is needed for smoother fleet handling. Data analyze tools are required to provide insights in this regard. This also results in low fuel consumption.

Connected fleets improve operational efficiency and less environmental impact: The Connected trucks enable a more efficient, productive enterprise while simultaneously reducing environmental impact due to less fuel consumption.

3.3 Industrial IoT

No one in the world anticipated that the COVID-19 pandemic would throw the global economy, and their own operations, into an unprecedented crisis. As the corona virus continues to spread all over the world, governments, healthcare authorities, and business leaders are focused on safeguard lives and control the pandemic. In parallel, they want to lessen the humanitarian toll by protecting the livelihoods of millions of workers who are now furloughed, unemployed, or in danger of losing their jobs.

Within industrials, shocks to both supply and demand have significantly decreased production volumes or stopped operations. For instance, all major automotive have shut down their production networks, resulting in the breakdown of entire value chains. Where business has continued, physical-distancing measures are dramatically altering operations, employee responsibilities, and staffing. In order to return to business in the pandemic conditions the industries should go for complete IoT adoption.

Industrial IoT (IIoT), a major element of Industry 4.0, can help companies as they proceed on this journey. It has demonstrated its value on many occasions over the past few years, but some skeptics still doubt it's worth and elected not to make bold investments in this area. What's more, few business leaders view IIoT as a critical improvement lever in times of crisis, especially if their organizations have not previously explored it. The concerns of IIoT are shown in Figure 4.

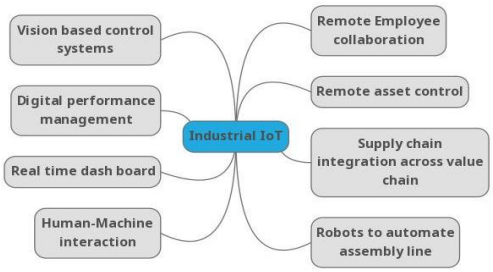

Fig 4: Industrial IoT concerns

IoT can be applied to secure business continuity in pandemics like situations. They can continue their operations using IoT implementations in the production line. This will increase safety and security of the employees, lowering production cost and improving liquidity. When working with less number of employees with social distancing conditions, industrial IoT tools can play a vital role in remote employee collaboration, workforce management and operations. Remote asset control and vision based controls systems ensure security of the employees. IoT enabled inventory management is good for managing supply chains and customer demand. Waste reduction is another area where IoT can perform well in future. Strong connectivity and cyber security enable better visibility across the supply chain, allowing industrials to respond more rapidly to disruptions. IIoT-based software solutions can provide a real-time dashboard of key performance indicators to support shop-floor performance dialogs, increasing transparency. These tools also allow the tracking of improvement actions and send alerts to operators via mobile devices. The software evaluates machine data, such as information on overall equipment effectiveness, part production, and quality through IIoT connectivity.

IIoT facilitates real-time data exchange between all supply-chain participants, creating an integrated view of production programs, scheduling, inventories, quality, and anticipated delivery times. In addition to building transparency and trust, such tools can also reduce supply-chain costs and risks—for instance, by receiving signals from connected machines when they are running out of raw materials, or by tracking the flow of materials along the supply chain using geo-location tags. With these insights, companies can optimize inventory levels, production planning, and transport utilization through a more holistic approach.

The current pandemic COVID-19 has focused the world's attention on how we're overcoming social isolation using technology, as well as how it's helping to reduce the scale of the tragedy and save lives. In future we need to replace humans with robots, so that we need a robust and centralized system in factories to automate the assembly lines.

3.4 Construction

The construction sector is a key enabler for other sectors and it contributes major investments taking place in most of the countries. Construction and engineering projects around the world are being impacted by the COVID-19 pandemic in numerous ways, and many projects have stopped. Even though the risk of transmission of infectious diseases in this area is lower than for those employed in the healthcare sector, but less number of labourers, delay and shortage in the supply of materials, etc affected this area.

In order to overcome the pandemic effects, this field needs

successful IoT implementations from labour control to the advanced structural health monitoring of buildings. The Figure 5 shows the areas in which IoT applications can be implemented to automate construction processes and to reduce the effects of pandemic and related lockdown conditions.

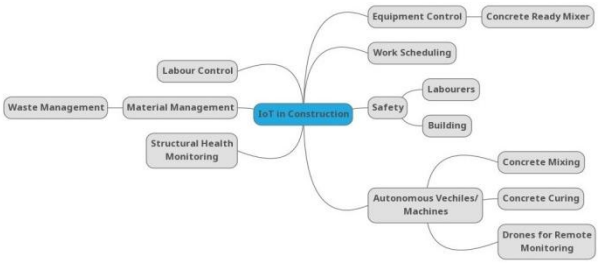

Fig 5: Construction Management – An IoT view

There are many high-tech solutions to address some of the issues shown in Figure 5. The need for reliable and timely data in construction and critical infrastructure management is crucial. But the data collection for structural health monitoring has been a tedious manual exercise [13]. Manual data gathering is slow, unreliable and highly inefficient. Also, in pandemics with a minimum work force, it is very difficult to perform these actions. IoT along with cloud platforms can be used to collect the structural data remotely for appropriate strength analysis.

IoT enabled concrete mixing can achieve high performance-concrete with minimum labour intervention. Such IoT systems are connected to the cloud so that all of the data collected from truck-mounted sensors is captured and analyzed in real time for actionable ready-mix business improvements. In the view of pandemics, for achieving precision automation of concrete curing, material and waste management in construction sites are needed for more reliable IoT technologies. Excellent safety measures can be used for the IoT enabled controlling of man, machine and monitoring of all the activities in this field.

3.5 Agriculture

In a recent study by United Nations revealed that the global population is going to hit 9.7 billion in 2050 [36]. So the agriculture sector must be strong and rich enough to feed such a big population. The farmers must be able to take appropriate decisions and the right time with the changes in weather conditions, climate and environment to increase the crop yields with minimum cost. The pandemic situation like COVID-19 which may occur in future times too demands that the involvement of more people in the farming duties cannot be entertained. These facts lead to a change in the traditional methods of farming.

The introduction of technology into the farming process will solve these issues to a great extent and here is the role of IoT comes into picture. The sensors will get appropriate data from the farm fields, send their information to the cloud computing environment and the data analysis results will be available to farmers which will help them to make appropriate decisions. The setting of an IoT environment will help the farmers to monitor the crop watering and the water tank levels in real time. It will help the farmers in every stage of the farming process of crops. This will eventually result in the increase of yields without the wastage of any agriculture resources and with minimum number of human interventions. Some of the sub areas in the agriculture field where IoT can be used are described in the following sections and these sub areas are shown in Figure 6.

Smart farming: Smart farming is the technology enabled way of farming with the application of monitoring devices and technologies that help the farmers to monitor their crops and fields remotely. Integration of IoT and associated technologies into agriculture thus help the farmers to do farming with less physical efforts yielding the best productivity. The IoT devices and associated technologies will help the farmers to monitor the filed in real time like (a) the water content in the soil to take a decision on watering the crops, (b) the pH level and other physical condition of the soil to monitor the soil nutrient level and to take decisions on applying fertilizers, and (c) the environment condition like temperature, humidity etc to take decision on appropriate countermeasures. This will help the farmers to get a clear observation of their crop fields and to take appropriate decisions to proceed with absolutely no wastage of time. The timely response will increase the productivity and efficiency of the farming system.

Precision farming is another connected area where different smart farming applications such as inventory monitoring, stock monitoring, vehicle tracking etc are used to make the farming process more precise and up-to-date.

Soil checking for watering and fertilization: The real time monitoring of the field soil has a great role in smart agriculture. Doing the irrigation at exact time will reduce over watering or under watering of soil and will improve the crop performance and production. In the traditional scenario these activities involve large human interventions which are not appreciable in pandemic situations. This can be mitigated using IoT technology. One of the simple applications of the IoT environment is to monitor the water level in the soil in real time. If the level goes below a threshold level, the system will automatically alert farmers and he can proceed with watering of the fields. The system can be made even more automated so that the watering system will get switched on automatically when the water level goes below the threshold. The electrochemical sensor technology is so advanced that the level of various chemicals or micro nutrients like nitrogen, phosphorus and potassium can be measured in real time. Knowing the micronutrient contents in the crop field will enable the farmers to apply an appropriate fertilization mechanism to improve the productivity.

Self sufficient Smart Greenhouses: The great pandemic threat in the world due to COVID-19 taught another great lesson of social distancing and crowd minimization. It taught the man kind that it is better to be independent and self sufficient. The idea of greenhouses in our home premises or even at our house roof top will help us to a great extent to achieve independence and self sufficiency with regards to vegetables farming and consumption. But the man kind in this century are so busy that they won't get enough time to spend much on looking after the green houses they build. The technology will help in this regard to a great extent. The IoT technology will help the people to monitor their greenhouses, in fact their smart green houses. The system can monitor the moisture level of the soil, the temperature and humidity inside the green house accordingly. A fully automated system even can water their greenhouses in appropriate time intervals; alert their boss if it needs special attention like fertilization.

A variation of this though is urban farming. In urban areas people live in a small crowded geographical area and need to go outside and to depend on others a lot to fulfill their living needs. Considering the self-sufficiency side of life, urban

farming will help to a certain extent. Since the people living in urban areas are less prone to farming and they depend on technology. The predictions and alert subsystems of the IoT enabled sensor infrastructure they establish in their farming area will give guidance to the people and help them in doing the farming in their respective living areas.

Remote administration of water bodies: Water bodies play a vital role in human's life in multiple dimensions. As far as agriculture is concerned, it is very much important to keep our public water bodies safe and free from contaminants. Fencing around the water bodies and fixing cameras nearby will make it safe from trespassing and physical damages. But the quality of water cannot be ensured with these physical mechanisms. IoT technologies will help the government authorities in this regard. The sensor based infrastructure deployed in and around the water bodies can remotely monitor the goodness of water and make sure that it is free from chemical impurities in real time. If any variation in the chemical content of the water is found, the IoT system will send alerts to the authorities to take appropriate actions. The periodic chemical content data collection from the water bodies can be analyzed using a machine learning based big data analysis system running in a distributed computing environment to deduce appropriate conclusions and predictions on the actions that need to be taken to resolve the issues. The adoption of technology will bring the human interventions to the minimum respecting the social distancing policy insisted by the authorities to protect the public from the pandemic spreading.

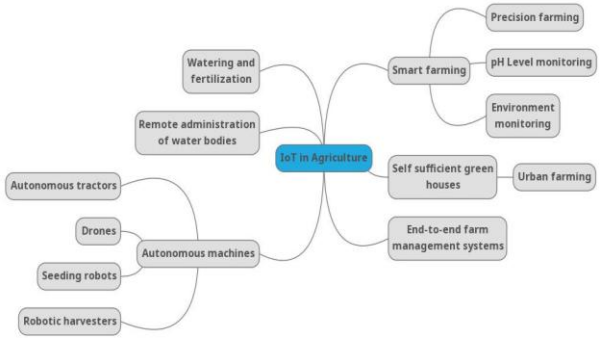

Fig 6: Future IoT in Agriculture

Keeping food and agricultural systems alive is the major problem during pandemics. Unlike other sectors, agriculture will be heavily affected during pandemics. If countries announced lock downs to restrict people movement as in the case of COVID-19 for long durations, it will affect cultivation of the majority of the crops because of the strict planting and harvesting calendar for most of the crops. Then, the countries should ensure that farmers have the harvest and market for their crops. A fully automated reliable IoT assisted system needs to be developed to cope with live agricultural activities.

To be sure, automation in the agriculture sector requires huge investment, and some jobs like harvesting fruits and vegetables are more difficult to automate than others. But we can employ technologies like drones, autonomous tractors, seeding robots, and robotic harvesters with IoT assistance, a reduction in farmers' reliance on more number of labourers. But, after the current pandemic, technological diffusion is also likely to accelerate in this field, not because of domestic demand-market conditions, but because of the need to compete in global markets and with advanced-country producers that do embrace automation.

Future end-to-end farm management systems can able to handle activities from cultivation to the final sale at markets according to customer demands are to be developed. It should handle any situation including pandemics with minimum human intervention. This should include several devices and sensors installed on the premises as well as a powerful dashboard with analytical capabilities and in-built accounting, reporting capabilities.

3.6 Education

The Covid-19 pandemic education threatened progress of all levels in the education system. The closing of schools and economic recession sparked by a pandemic control measure now changes the approaches to education. Currently IoT adoption in online learning facility is limited to interactive boards, automated attendance tracking systems, ID cards, etc. An expert believes that the technological innovations used by the teachers during the outbreak have a large impact on the nearby future. The technological advancement with IoT in educational sectors provides a better-connected and more collaborative future. It provides easy access to information from learning materials in real time. Since pandemics affects normal class rooms, potential learning platforms are needed for the different levels of learning from schools to higher education institutions that support online learning to evaluation of the progress of each individual student. Need more mobile Apps to enrich personalized learning experience and to support task based flipped classrooms.

Adoption of IoT in education sector is quiet difficult task. Since our current educational system is based on the class room teaching which need contact hours for teaching. First of all, for the successful IoT implementations in educational system a strong government policy decisions are indeed. The main reason behind this is that IoT enabled teaching-learning process needs huge IT-infrastructure investments. The challenges in IoT adoption in education sector is shown in the Figure 7.

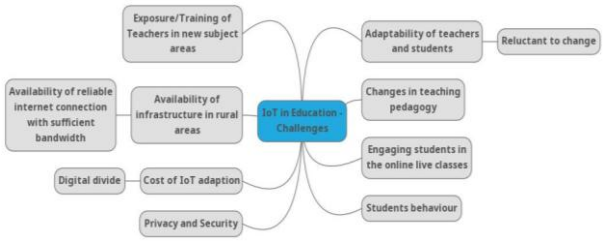

Fig 7: IoT in Education challenges

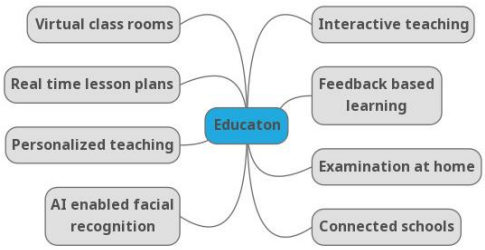

Fig 8: Future IoT implementation in Education

Interrupt free internet availability in each and every corner of a country is the backbone for a successful IoT implementation in this sector. Before moving towards this new paradigm shift there is a need of massive pedagogy training to the educators to how it can be used effectively to benefit student community. In order to overcome the barrier of distance in the online learning systems, IoT can be used in the following

ways in future in any situation including pandemics. Figure 8 shows how IoT implementations will benefit education sector.

Interactive teaching: The potential IoT solution may alter the basic teaching methodology of current education system. In this a teacher or an instructor no longer explains a topic, instead, she or he interacts with various components of a virtual classroom to convey and teach the concept.

Virtual class rooms: Students can experience more realistic technical side of a topic with virtual reality along with IoT integrated solutions. This will provide students some class room experience at home, even though the schools are closed. The group activities such as discussions, webinars and debates can be conducted over the internet.

Feedback based learning: Also, IoT can be effectively used for the activities that require constant feedbacks. For example coaching or academic trainings to boost an individual's specialized skills. IoT can be used to develop task based instruction where students learn-by-doing and teachers assist when needed in real time.

Real time lesson plans: Teachers can use smart-microphones to assign homework and update it to student's planners automatically. Smart pens can be used find or refer real-world situations when writing.

Examination at home: A secure and credible IoT based remote monitoring system where a student can write their examinations at home without any invigilator is yet to be developed. The use of real-time data will provide valuable insights to all the stakeholders in this sector for more realistic examination solutions in future to minimize human interactions.

Personalized teaching: IoT can be used to identify a weak student with learning disability. The problem with these categories of students is that in a weak or shy student often falls behind in class rooms. A student does not respond promptly may require one-on-one attention. In this circumstance, teachers can design IoT based interactive learning modules to match their pace. The personalized teaching modules are to be developed to teach and build a stronger subject base for them.

Connected Schools: With help of smart school bus system the concept of connected schools can be realized. In future connected schools may be useful to provide smart buses. They could inform parents when a child is dropped off at home or provide students with internet access, allowing them to consume content en route.

AI: With the help of AI enabled facial recognition system, teachers can monitor and recognize whether the students are attentive in a class or not. Based on this a teacher can intervene the confused or distracted students and clear their doubts. IoT and AI can be combined to help disabled students to get education.

3.7 City Management

It is estimated that by 2050, nearly 68% of the world's population will live in cities. So, the city planning against pandemics will become even more essential in the coming years. Smart city applications provide some relief to the strained healthcare system due to continued urbanization, industrialization, an aging population, climate change, and growing healthcare costs. When it comes into pandemic condition, the prevention, surveillance and rapid-response efforts can slowdown or stalling the outbreaks. Here after the smart city management should contain measures to prevent and to detect pandemic outbreaks before they reach massive scale.

The prospect city management system can provide a great relief to the society by deploying smart applications and devices all over the city for handling the pandemics. For example, mandated installation of connected thermometers with IoT applications should be installed in common places. Network of sensors that detect traces of pandemic is another future application. Upon detection, the location could be 'locked down' to control the spread and to ensure the necessary treatment for the infected ones. It's not too hard to imagine such systems being incorporated into future smart city deployments, which already include applications aimed at improving public safety such as gun fire detection and air quality sensors. The Figure 9 shows the future IoT enhancements need to be done in city management.

Remote administration of utilities: Management of power, water and cooking gas is one of the biggest worries during the time of pandemics. Finding ways to power cities and provide energy in the time of crisis will be the key for city management during future pandemics. In the future, energy can be controlled through the internet. Then the appliances will be designed with interconnectivity. That is, the appliance itself uses digital systems so that we have the entire control over how energy is stored and used in each appliance. Buildings will also become more power efficient. Novel IoT enabled solutions are needed for the essential services like water, cooking gas supply and other location based services.

Waste management: In the pandemic condition, the prevention of food waste and maintaining safe storage conditions are also challenges for both houses and for the restaurants. During this situation, thelock down is progressively imposed in different countries. This generates a tremendous impact on the public authorities and municipal waste operators for the disposal of waste.

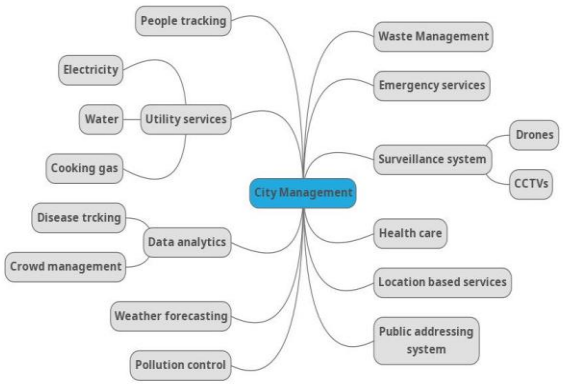

Fig 9: Future IoT in Smart city management

Restaurants are allowed with fewer employees per shift. However, manual temperature checks for coolers and freezers are a challenge to do on schedule even when a restaurant is functioning with fully staff. An IoT network with remote temperature sensors can report those readings to managers so they can quickly deal with problems like open cooler doors or malfunctioning equipment. This makes employees to give more focus on other tasks, and reduce the possibility of food borne illness, and prevent costly food waste.

There are a plethora of procedures that can be introduced to the potential city management from healthcare to utility management with security and privacy protection. The above

are some of the already available technologies and we have to think differently about city design in the future to handle infectious diseases outbreaks.

Surveillance systems to rapidly detect and report cases are to be deployed to collect data. Big data and related data analytics can be used to track and trace a virus in a city. This will help in early detection of influenza and can take preventive action against spreading.

3.8 Other Commercial Activities

The current pandemic crisis forced business organization to adapt new forms of dealing with customers and other business organizations. The new ways of working, and profound financial impacts, many businesses are seeking ways to stay afloat with fewer resources. Social distancing is one of the relevant methods to prevent pandemic like COVID 19 infections, the direct contact can be eliminated by various scenarios using IoT and continuing the commercial activities. Many such commercial activities include sales, marketing, customer support, trading etc. A few scenarios are described in the following subsections. The respective details are shown in the Figure 10.

Work from Home: Many business organizations now moved towards remote working technologies to support social distancing and maintain business continuity. In future it will be regular practice all over the world. There is a need for more infrastructure facilities to support this. New kinds of IoT devices are needed to support and manage remotely working people.

AI and Context enabled Video Conferences: Video conference has widely used in the field of medical, sales, marketing and customer support teams. Technologies with AI based platforms are one of the simplest ways for handling tedious tasks. AI advancement features such as machine learning, deep learning, neural networking and voice search are associated with video conferencing. This technique helps the organizers to maintain the communication and associations with others without losing the relevance, touch and personalization. Deployment of video conferences on hospitals and disease control departments enable epidemic prevention, online training and consultations. The AI assisted diagnostics and treatment system is already implemented in Thailand.

Smart Transferring of Data: The advancement in technology makes a secure transmission of data without any direct contact. As discussed in many sections of this article robot integration, driverless autonomous vehicles and other IoT enabled devices will change the nature of current business organizations in the post COVID 19 pandemics.

Smart Conference Rooms: in the digital world, conference calls, email, web chat and phone can lack the visual and personal impacts on persons. In the industrial field, it may affect the client or customer satisfaction .The latest smart video technology focuses on real-time collaboration and smooth meetings without any pain. There are certain applications now available to support smart conference rooms. The COVID-19 pandemic will change the nature of face to face business meetings and in future it may eventually result in the end of business travels and trips.

Online Shopping: The online shopping sites like Flipkart, Amazon, Snapdeal, Deb etc are the most commonly divided their supply based on shopping areas. There are several IoT enabled methods like Bluetooth Beacons, smart shelves based on RFID, Dash buttons from Amazon are now available for making the shopping more reliable. But all this method requires delivery of items using people. During pandemics this kind of door delivery method is impractical. Upcoming IoT enabled solutions must contain smart lockers like facilities for contactless delivery of items. It may support innovative pick, pack and delivery to ease the burden on e-commerce operations which are struggled to cope with the increased demand and to produce a 'zero-touch' approach. This will make organizations for an easier and safer business operation during lockdown situations.

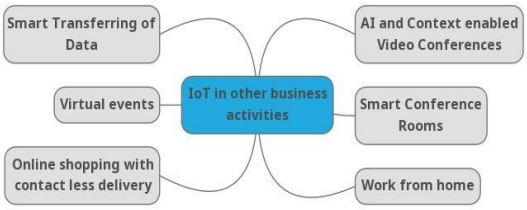

Fig 10: Other commercial activities

4. SECURITY AND PRIVACY CONCERNS

All are very concerned about the security of the information gathered from the IoT devices. Also, too much data and unwanted public profile causes privacy concerns for the individuals. Personal identification, authentication and device heterogeneity are the major security and privacy concerns in IoT.

4.1 Security Challenges

COVID 19 is tipping the world into a new phase. The situation may persistent for years and will influence the security of the business and cooperative world. So, critical steps are needed for the secure operations with thread detection. Because IoT security requirements are not ensured by traditional security techniques, novel countermeasures are needed to deal with the new challenges posed by the IoT.

Challenges for secure IoT services, includes limitations in computation, memory requirements, energy considerations of devices and network components. Another issue is the mobility of the wearable devices. Such devices are connected to the web through IoT service providers. For example, a wearable blood heat sensor or a cardiac monitor could also be connected to the web and notifies the concerned caregiver of the user's conditions. Such wearables are connected to the house network when the user is at reception, whereas they're connected to the office network when he or she is at office. Different networks have different security configurations and settings. Therefore, developing a mobility-compliant security algorithm may be a serious challenge.

Scalability of network as well as devices, limitations of communication media, variety of devices, topology of the network, communication protocols, different security softwares on the connected networks, etc., are serious concerns in security challenges adopting widespread adoption of IoT networks in critical areas like health care.

IoT integration in the educational environment is very difficult due to security and privacy challenges. The IoT devices gather and measure data from students and store it in a public network, and this makes student's security at hazard.

The physical protection of the remote administration and monitoring devices is also a challenge. As the sensor devices used in the monitoring devices are very sensitive and light, it may get damaged soon. So, protective measures must be taken

when deploying such devices in the monitoring premises. Another psychological impact is that many of the monitoring devices thus connected give a feeling in people that these devices restrict their movement and affect their freedom. So they may damage the monitoring devices.

Industrial Security: Connecting industrial machinery to IoT networks increases the potential risk of hackers discovering and attacking these devices. Industrial espionage or destructive attacks on critical infrastructure are both potential risks. That means businesses will need to make sure that these networks are isolated and protected with data encryption for security of sensors, gateways and other components a necessity. Even though ethical hacking allows documented willingness of hackers to tamper with industrial systems that are connected to the online for identifying security risks, but it is dangerous.

The hacking into critical devices can have dangerous real-world consequences. Hacking into the sensors controlling the temperature during an influence plant could trick the operators into making a catastrophic decision; taking control of a driverless car could also end in disaster.

4.2 Privacy Concerns

The network of sensors that gathers personal medical data could present civil liberty questions and concerns. Even in the midst of COVID-19 outbreak, WHO has expressed concerns about the protection and privacy regulations of data. Ultimately the pandemic situations will likely to change the level of restrictions and monitoring acceptable for the persons for the betterment of society. But, the economic, social and personal impact of current corona virus is obvious and likely to result in greater willingness from various governments and the public to implement systems where personal health information is monitored on a continuous basis.

Who will handle data: Data outsourcing is serious concern in IoT paradigm. The data need to be stored or archived only if it is necessary. Even though data appear to be the currency of the IoT, there is lack of transparency about, who gets access to data and how those data are used to develop products or services and sold to business organizations, advertisers and third parties is a big concern.

How long will handle data: The duration of data to be stored is also a major concern in maintaining individuals' privacy. Strict government policies are to be made in this regard.

Technology breaches: High potential for altering, erasing, losing, or unauthorized access of devices and data is high in IoT connected networks. Hence, high-end technological and lawful mechanisms are needed to protect privacy of the individuals.

5. ISSUES AND RECOMMENDATIONS

This paper summarizes the issues and makes specific recommendations to the successful prevention and monitoring mechanism for future pandemics using internet of things.

5.1 Issues

Big data management: IoT devices generate massive amounts of data. Management of this big data is the most serious issue. There is a need for more sophisticated software requirements for managing this data along with computation infrastructure. The big data management issues are shown in Figure 11.

AI algorithms can mine through news reports and online content for helping experts to recognize anomalies even before it reaches epidemic proportions. The corona outbreak itself may be a great example where researchers applied AI to the review flight traveller data to predict where the novel corona virus could pop up next. A National Geographic report demonstrates how the monitoring of the internet or social media can help to detect the early stages of a potential outbreak.

Predictive modelling could represent a serious breakthrough in the fight to rid the planet of a number of the foremost infectious diseases. Big data analytics can help decentralize the process and enable the timely analysis of widespread datasets generated through Internet of Things (IoT) and mobile devices in real-time.

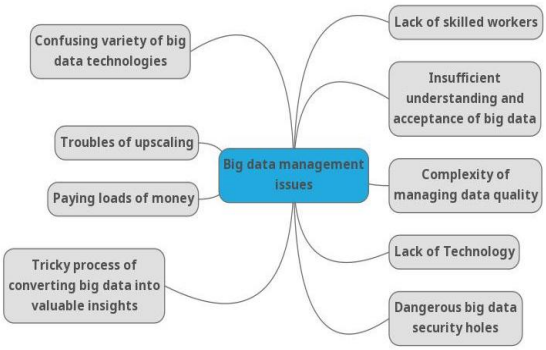

Fig 11: Big data management issues

Data Storage: During pandemics more office employees will be on work from home, data centers are crucial to the survival of businesses that rely on the internet and cloud services to operate. Remote data centre maintenance is a critical issue. To preserve equipment and maintain uptime as demand grows, data center technicians and managers need to be aware of the temperature, humidity, and dew point near critical equipment in their centers at all times. The most accurate picture comes from real-time data fed from condition sensors placed on or near key equipment, rather than counting on ambient air temperature and humidity for an entire room. For efficient and quick action localized data centres are needed to place local sensor data.

Reliability of Internet Connection: Persistent internet connectivity required for adopting IoT. In any sector to use modern technologies wireless networks with good bandwidth and speed is required for multimedia applications and real time monitoring. In a short period of time providing internet infrastructure is a cumbersome task.

Management challenge: For innovative implementation of IoT in an operational mode, all the sectors discussed above need to develop suitable sensor embedded devices. Especially educational institutions must ensure that these devices and methods of teaching in the classroom backing the utilization of IoT are efficiently used.

Cost: The most of the IoT applications use sensor devices with less cost. But in some sectors discussed above the implementation needs mass initiative by the Governments. For example in educational institutes implementation is costly. Also, it is not easy to implement IoT based education in a short period of time even when there is no pandemic situation. It is also a main factor that cost acquiring IoT enabled devices for students is not affordable in the majority of the countries. Another challenge is the cost of providing backbone internet facilities all over the country is huge. Finally, the most important concern is that widespread adoption of IoT will force reluctance to change. Since, already

there is a well functioning learning system with heavy physical infrastructure.

Immaturity of IoT standards: The basic drawback of IoT systems is lack of standards and protocols for implementations. This cause interoperability issues for authentication and authorization of IoT edge devices. Different product vendors come with their own versions of standards and protocols for their products, which create in chaos in interoperability.

Digital Divide: The IoT adoption will increase the chance of widening the digital divide especially in the education sector. Companies and end-users that are not digitally connected may need a retrofit solution that is easy to install and use. General purpose IoT solutions are needed against currently available customer specific solutions which are difficult to install, configure and use.

5.2 Recommendations

With the help of intelligent surveillance systems the outbreak of disease can be detected and reported. The AI can be used to track the spread of viruses and other infectious diseases. Thus it improves the speed and efficiency of fighting against epidemics or pandemics. The collected big data can be accessed by any government authorities, scientists, and researchers to make appropriate decisions and they can inform decisions in real time to the public. Laboratories and other virus testing stations can be automated to remove the need for person to person interaction. This contactless collection and recording of health information reduce the risk to healthcare workers. All the virology laboratories can be networked for coordinated effort to determine the pandemics. To operate this system successfully a well trained workforce is needed to identify, track, and contain future outbreaks. Common standard and protocols are necessary at least in the health sector IoT devices and implementations. Also an emergency management system is needed to coordinate the effective response of all the subsystems under this anti-pandemic system. The summary of these recommendations are shown in the Figure 12.

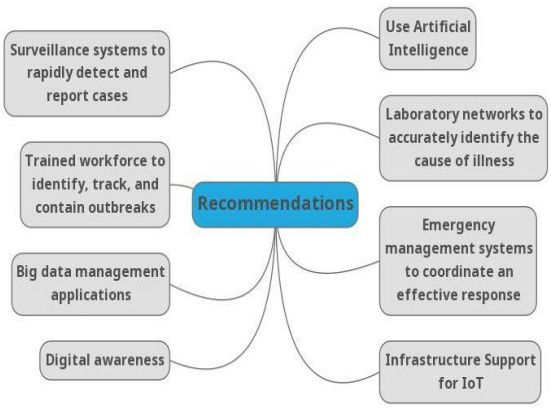

Fig 12: Recommendations of this study

6. CONCLUSIONS

During the beginning of every epidemic or pandemic conditions, the truth is that there will not be any specific antiviral medicine to prevent or treat it. But those affected should get care to relieve from the disease. In future adding context and intelligence to IoT applications may be required for more accurate and intelligent applications. Enterprises can leverage IoT in combination with different technologies to deal with disease outbreaks, but they are fragmented and still require more infrastructures to connect the components of data collection, processing, analysis, and storage. A total epidemic response program covers all systems, including healthcare, surveillance, epidemic tracking, and others in the same vein. IoT solutions form the technology backbone that can support all of these systems. Service providers should work on the integration and interoperability of IoT solutions to make them more sustainable and reliable.

COVID-19 has shown that we have been using IoT use cases in a piecemeal manner rather than combing them to create a proper response system. Each of the above discussed sectors can be interconnected to create a response system for the pandemic. An integrated approach is needed in achieving this aim. The real benefit of IoT may be availed only when the devices can connect seamlessly with other devices to provide benefit to the user using the interoperability feature. The devices that equip police officers with real-time information will help to improve awareness and make better decisions, and allows cars to communicate with other cars, transport infrastructure, and pedestrians, Data that anyone can access that contributes to the transparency of government and smart city initiatives, Solar powered, sensor-equipped smart bins allow waste collectors to track waste levels and optimize their fuel usage, Systems that collect data from different areas like pollution levels and traffic density to raised manage smart cities. These technologies could lead on to a wide-range of transformative effects for cities that are willing to embrace them.

In future with intuitive human to machine interactivity allow humans to interact in real time over great distances; both with each other and with machines – and have similar sensory experiences to those that they experience locally. This will enable new opportunities within remote learning, surgery and maintenance in pandemic or any other conditions. Immersive mixed reality applications have the potential to become the next platform after mobile – realized through 3D audio and haptic sensations and becoming our main interface to the real world. Bringing future IoT to life need close synergy between the IoT and network platforms that will enable us to fight against future pandemics.

7. REFERENCES

[1] United Nation Development Program; 2020 May 23; Covid19 Humanity needs leadership and solidarity to Defeat the Coronavirus; Available from: https://ama.com.au/media/junior-doctors-and-medical-students-call-urgent-solution-medical-training-crisis

[2] Bill Gates. Responding to Covid-19- A Once-in-a-Century Pandemic?. The New England Journal of Medicine. 2020: 1677-1679. https://www.nejm.org/doi/full/10.1056/nejmp2003762

[3] Julian Watson, Josh Builta; 2020 April; IoT set to play a growing role in COVID-19 response; Available from: https://technology.informa.com/622426/iot-set-to-play-a-growing-role-in-the-covid-19-response

[4] Catalin Vieru; 2020 May 17; AWS IoT-Driven Precision Agriculture - The Internet of Things on AWS – Official Blog; Available from: https://aws.amazon.com/blogs/iot/aws-iot-driven-precision-agriculture

[5] Mohamed Abdel Basset Gunasekaran Manogaran Mai

Mohamed Ehab Rushdy, Internet of things in smart education environment: Supportive framework in the decision making process, Concurrency Computat Pract Exper, 2019; https://doi.org/10.1002/cpe.4515.

[6] S M Riazul Islam, Daehan Kwak, M D Humaun Kabir, Kyung-Sup Kwak. The Internet of Things for Health Care: A Comprehensive Survey. IEEE Access. 2015. Vol. 3: 678-708; 10.1109/ACCESS.2015.2437951

[7] R. R. Harmon, E. G. Castro-Leon and S. Bhide. Smart cities and the Internet of Things. In: Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET), Portland,2015. DOI: 10.1109/PICMET.2015.7273174

[8] Michele Acuto. COVID-19: Lessons for an Urban(izing) World, One Earth, Volume 2, Issue 4; 2020. 317-319 p.

[9] Hugh Boyes, Bil Hallaq, Joe Cunningham, Tim Watson. The industrial internet of things (IIoT): An analysis framework. Computers in Industry. October 2018: Volume 101:1-12. https://doi.org/10.1016/j.compind.2018.04.015

[10] Jesús Martín Talavera, Luis Eduardo Tobón, Jairo Alejandro Gómez, María Alejandra Culman, Juan Manuel Aranda, Diana Teresa Parra, Luis Alfredo Quiroz, Adolfo Hoyos, Luis Ernesto Garreta. Review of IoT applications in agro-industrial and environmental fields. Computers and Electronics in Agriculture. Elsevier.2017. Volume 142: 283-297. https://doi.org/10.1016/j.compag.2017.09.015

[11] Simon Dixon [Internet]. Understanding COVID-19's impact on transport organizations; 2020March 26. Available from: https://www2.deloitte.com/global/en/pages/about-deloitte/articles/covid-19/understanding-the-sector-impact-of-covid-19---transport-organiza.html

[12] Ray Almgren. How IoT can help facilities quickly adapt to pandemic related disruption; 2020 April 27. Available from: https://www.newequipment.com/industry-trends/article/21129759/the-iot-can-help-facilities-quickly-adapt-to-pandemicrelated-disruption

[13] Luis Alonso, Javier Barbarán, Jaime Chen, Manuel Díaz, Luis Llopis, Bartolomé Rubio. Middleware and communication technologies for structural health monitoring of critical infrastructures: A survey, Computer Standards & Interfaces. Elsevier. 2018. Volume 56 : 83-100. 10.1016/j.csi.2017.09.007

[14] Ronald Chun Yu Lam, Alvin Junus, Winnie Man Ying Cheng, Xinyu Li, Louis Chi Hung Lam. IoT Application in Construction and Civil Engineering Works. In: Proceedings of the IEEE International Conference on Computational Science and Computational Intelligence (CSCI). 2017. 10.1109/CSCI.2017.230

[15] Sushree Mishra. The Growing Role Of IoT In COVID-19 Response. 2020 May. Available from: https://www.iotforall.com/the-growing-role-of-iot-in-covid-19-response

[16] Aditya Chaturvedi. Top 10 popular smartphone apps to track Covid-19. 2020 May. Available from: https://www.geospatialworld.net/blogs/popular-apps-covid-19

[17] Aradhana Aravindan, Sankalp Phartiyal. Bluetooth phone apps for tracking COVID-19 show modest early results. 2020 April 21. Available from: https://www.reuters.com/article/us-health-coronavirus-apps/bluetooth-phone-apps-for-tracking-covid-19-show-modest-early-results-idUSKCN2232A0

[18] Stacey Higginbotham. Pandemic vs. privacy. IEEE Spectrum, Volume: 57, Issue: 6; 2009. 20 p.

[19] Jack Loughran. Vodafone launches Heat detecting cameras to protect offices from covid-19. Engineering and Technology, 2020.

[20] Khanna RC, Cicinelli MV ,Gilbert SS, Honavar SG, Murthy GS. COVID-19 pandemic : Lessons learned and future directions. Indian J Ophthalmol, 2020.

[21] Aditya Chaturved. The China way: Use of technology to combat Covid-19, Geo spatial world, 2020 November.

[22] Jagdish Khubchandani,Timothy R. Jordan, Y. Tony Yang, Ebola, Zika. Corona What Is Next for Our World?, Int. J. Environ. Res. Public Health. 2020, 17 : 3171. 10.3390/ijerph17093171.

[23] Covid-19 and Education in Emergencies" Education cannot wait. 2020 May. Available from: https://www.educationcannotwait.org/covid-19.

[24] Steege AL, Baron S, Davis S, Torres-Kilgore J, Sweeney MH. Pandemic Influenza and Farmworkers: The Effects of Employment, Social, and Economic Factors. American Journal of Public Health Supplement. 2009, Vol 99, S308-S315. 10.2105/AJPH.2009.161091.

[25] Rae Yule Kim. The Impact of COVID-19 on Consumers: Preparing for Digital Sales. IEEE Engineering Management Review.2020. 1-1,23.

[26] Knud Lasse Lueth. The impact of Covid-19 on the Internet of Things. 2020 April. Available from: https://iot-analytics.com/the-impact-of-covid-19-on-the-internet-of-things.

[27] Mahashreveta Choudhary. How IoT can help fight COVID-19 battle. Geospatial World. 2020 January.

[28] Md. Siddikur Rahman, Noah C. Peeri, Nistha Shrestha, Rafdzah Zaki, Ubydul Haque, and Siti Hafizah Ab Hamid. Defending against the Novel Coronavirus (COVID-19) Outbreak: How Can the Internet of Things (IoT) help to save the World?, Elsevier Public Health Emergency Collection. 2020 April.

[29] Hanliang Zhu, Pavel Podesva, Xiaocheng Liu, Haoqing Zhang, Tomas Teply, Ying Xu, Honglong Chang, Airong Qian, Yingfeng Lei,YuLi, Andreea Niculescu, Ciprian Iliescu, Pavel Neuzil. IoT PCR for pandemic disease detection and its spread monitoring. Sensors and Actuators B: Chemical. Elsevier. 2019.

[30] Igor Tovberg, Connected devices have a key role to play in an era of pandemics, IoT Now. 2020 May 7. Available from : https://www.iot-now.com/2020/05/07/102686-connected-devices-have-a-key-role-to-play-in-an-era-of-pandemics

[31] Vaishya R, Javaid M, Khan I. H, Haleem A. Artificial Intelligence (AI) applications for COVID-19 pandemic. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2020. 14(4): 337–339.

[32] Ashly Mathew, Farha Amreen S.A, Pooja H.N, Aakriti

Verma. Smart Disease Surveillance Based on Internet of Things (IoT). International Journal of Advanced Research in Computer and Communication Engineering. 2015. Vol. 4, Issue 5: 180 -183.

[33] Knud Lasse Lueth. The impact of Covid-19 on the Internet of Things – now and beyond the Great Lockdown: Part 1. 2020 April 16. Available from : https://iot-analytics.com/the-impact-of-covid-19-on-the-internet-of-things

[34] Covid19 - AME's solution: EGOpro Social Distancing. 2020 April 1. Available from : https://www.ameol.it/en/covid19-la-soluzione-di-ame-egopro-social-distancing

[35] Ananth S, Sathya P and Madhan Mohan P. Smart Health Monitoring System through IOT. In: Proceedings of the IEEE International Conference on Communication and Signal Processing. 2019. 10.1109/ICCSP.2019.8697921

[36] World Population Prospects 2019: Data Booket. ST/ESA/SER.A/424, United Nations, Department of Economic and Social Affairs, Population Division (2019).

[37] Siddiqui Shama, Shakir Muhammad Zeeshan, Khan Anwar Ahmed, Dey Indrakshi. Internet of Things (IoT) Enabled Architecture for Social Distancing During Pandemic. Frontiers in Communications and Networks, VOLUME=2, YEAR=2021,PAGES=6; DOI=10.3389/frcmn.2021.614166

[38] Mehrdad Sarmad, Wang Yao, Atashzar S. Farokh. Perspective: Wearable Internet of Medical Things for Remote Tracking of Symptoms, Prediction of Health Anomalies, Implementation of Preventative Measures, and Control of Virus Spread During the Era of COVID-19. Frontiers in Robotics and AI. VOLUME=8, YEAR=2021, PAGES=84. DOI=10.3389/frobt.2021.610653

[39] Exploring online search behavior for COVID-19 preventive measures: The Philippine case. Galido A, Ecleo JJ, Husnayain A, Chia-Yu Su E (2021) Exploring online search behavior for COVID-19 preventive measures: The Philippine case. PLOS ONE 16(4): e0249810. https://doi.org/10.1371/journal.pone.0249810

[40] Umair, M.; Cheema, M.A.; Cheema, O.; Li, H.; Lu, H. Impact of COVID-19 on IoT Adoption in Healthcare, Smart Homes, Smart Buildings, Smart Cities, Transportation and Industrial IoT. Sensors 2021, 21, 3838. https://doi.org/10.3390/s21113838

[41] Omid Akbarzadeh, Mehrshid Baradaran, Mohammad R. Khosravi, "IoT-Based Smart Management of Healthcare Services in Hospital Buildings during COVID-19 and Future Pandemics", Wireless Communications and Mobile Computing, vol. 2021, Article ID 5533161, 14 pages, 2021. https://doi.org/10.1155/2021/5533161.

[42] Ramallo-González, A. P., González-Vidal, A., & Skarmeta, A. F. (2021). CIoTVID: Towards an Open IoT-Platform for Infective Pandemic Diseases such as COVID-19. Sensors (Basel, Switzerland), 21(2), 484. h ttps://doi.org/10.3390/s21020484.