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Towards Sustainable Water Supply: Schematic Development of Big Data Collection Using Internet of Things (IoT)

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Abstract

Water supply systems in the United States connect raw water sources to hundreds of millions of water consumers through humongous infrastructure that include approximately one million miles of buried water mains and service connections and thousands of treatment facilities and appurtenances. This enormous set-up is currently operated by more than 170,000 public water systems. Sustainability of the water supply system faces several imminent challenges such as: 1) increasing water main breaks, 2) decreasing fresh water resources, 3) untraceable non-revenue water use, and 4) increasing water demands. However, current water supply management practices are not capable of providing fundamental solutions to the issues identified above. Big Data is a new technical concept to collect massive amounts of relevant data from sensors installed to monitor structural condition, usage, and system performance. This Big Data concept can be realized by deploying Internet of Things (IoT) technology throughout the water supply infrastructure and consumers' usage. This paper presents a schematic development of IoT application for Big Data collection through a myriad of water clients. The scheme consists of downstream and upstream data collection using Wireless Sensor Network (WSN) technologies connecting to IoT. Downstream data shall provide water usage and performance data to clients and upstream data is similar to traditional SCADA and Automated Meter Reading (AMR) systems. Ultimately, all data will be converged to build a Big Data collection system where data mining identifies 1) local and system performances including pressure and flow, 2) non-revenue and illegitimate water consumption, and 3) locations and quantity of water breaks and water losses. The goal of this development is to enable both utilities and consumers to proactively manage their water usage and achieve higher levels of sustainability in water supply.

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1. Introduction

Water distribution infrastructure is crucial to economic, political and societal prosperity along with basic survival of the human race. Major challenges that threaten water supply are the depleting freshwater resources in several regions of the US and the deteriorating supply infrastructure. There is an increasing awareness among the water supply stakeholders regarding the imminent water scarcity issue. While we strive to make our water resources sustainable, existing water infrastructure systems are in need of huge capital investment to tackle aging and the resulting deterioration issues. Focusing on water supply systems, the industry has been challenged with devising a functional database, which can be used to justify the development of efficient asset management tools that control further deterioration of infrastructure and lead to future water sustainability by saving billions of gallons of water that is currently lost in the leaky distribution systems. Current asset management system mainly focuses on inventory database and is particularly inadequate to capture data such as: water loss, leak location, and detailed consumption. As an emerging information technology concept, Big Data is now considered to be a technological solution for infrastructure condition monitoring, assessment and rapid intervention prior to failure. Furthermore, Big Data analysis can lead to improved algorithms for solving problems such as deterioration modeling, pressure and flow modeling, and leak and loss detection modeling. Big Data analyses provide an in-depth insight into several other infrastructure related issues for effective decision making. The Big Data concept is realized by deploying Internet of Things (IoT) technology throughout the infrastructure system. IoT consists of three main components: 1) sensing hardware; 2) data transmission network; and 3) data process capability. Conceptually, IoT is similar to nerve cells (neurons) connected by synapses to the brain. The main database system is a brain and a network system works like synapses. In other words, a combination of Big Data and IoT is similar to creating an organic nerve system from an artificially man-made water supply system to a brain. After fully implementing IoT and Big Data, the water supply system acts like a smart living creature wherein problems are instantly detected and diagnosed without continuous third party monitoring. Approximately one million miles of buried water mains and service connections, thousands of treatment facilities and appurtenances operated by more than 170,000 public water systems need to be smarter, and more controllable, and eventually become more sustainable. Aspects of sustainability from fully implementing IoT and Big Data concepts can be summarized in twofold: 1) improving mechanical system performance by minimizing water main breaks, leaks, and identifying structurally vulnerable locations; 2) optimizing system performance including pressure, flow, and usage.

This paper proposes conceptual applications utilizing the proposed Big Data plan for the water industry. The objectives of introducing new technologies are to enable both utilities and consumers to proactively manage their water usage and achieve higher levels of sustainability in water supply. This paper introduces an example of advanced technology implementation which is called Automated Meter Reading. More than 40 percent of total U.S. households is now equipped with AMR. Conceptual development of IoT is presented and its implementation in water supply system is proposed. The paper also describes benefits acquired from IoT and Big Data technology implementation.

2. Automated Meter Reading (AMR) Application

Meter reading is a key business process to maintaining utility's business revenue collection. Historically, meter reading has been labor intensive and subsequently an expensive process. Several major advancements have been attempted to automate meter reading process. Automated Meter Reading (AMR) is the technology of automatically collecting consumption, diagnostic, and status data from water meter or energy metering devices and transferring that data to central database for billing, troubleshooting, and analyzing. AMR is a good example of recent technology development and successful implementation in the water industry. By 2013, AMR system was reported to be installed in over 40 percent of total U.S. households [1], highlighting the industry's transition from manual meter reading to AMR. AMR uses data sensing for flow metering and transmit through a network system, handheld device, or drive-by data collection. Most significantly AMR eliminates field operators who manually read. The utility owner is able to handle billing more effectively and accurately, not based on estimated rate per significant period of billing process cycle, and most significantly to reduce overall costs of service. Other benefits include

improving accuracy and standardizing meter inventory. Improving accuracy of meter reading provides an insight of potential water leaks and enables to determine water distribution pipelines that need to be replaced. AMR has focused on providing benefits to utility owners with fewer benefits on offer for the consumers.

AMR technology has followed steps of IT development in networking technology. In the beginning of AMR development, the network system was not free of wired connection, short-range network such as radio frequency (RF), drive-by data collection, and connection of power source. Recent development of AMR uses advanced network technologies such as Wi-Fi, GSM modem, and power line communication. Figure 1 illustrates an existing AMR system using GSM modem system

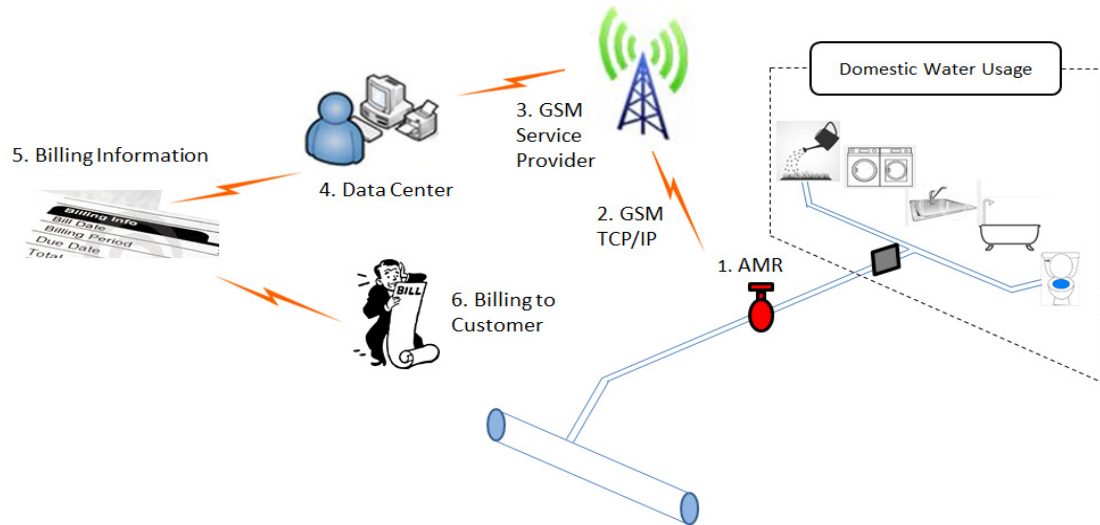


Figure 1. AMR system using GSM modem system

3.0 Internet-of-Things (IoT) Development

Big Data as a new technical paradigm is emerging with different definitions. Few common definitions include: 1) massive amount of data collection, 2) extract insightful information which has been previously inaccessible, and 3) developing technologies for Big Data collection [2]. Big Data is necessary to capture huge data through all possible sources. For example, sensors placed on infrastructure components could retrieve specific data such as strain, temperature, pressure, flow, and corrosion. All the collected data is integrated through a process called “data fusion.” The most accepted definition of data fusion is provided by JDL [3]: “A multi-level process dealing with the association, correlation, combination of data and information from single and multiple sources to achieve refined position, identify estimates and complete and timely assessments of situations, threats and their significance.” The data fusion process builds a platform for Big Data.

Internet of Things (IoT) is the next wave in the era of computing. It is a new paradigm wherein many objects (Things) are inter-connected and the objects communicate with or without human interaction. A fundamental difference of IoT comparing to existing technologies such as AMR or condition monitoring system is that IoT extends its data utilization beyond independently operating utility billing system or water leak detection warning. Big Data integrates the data and seeks mutual benefits for multiple stakeholders including water utility owner and customers through easy access facilitated by Internet operated via individual’s smart phone or computer. Figure 2 illustrates a schematic and holistic view of IoT application development.

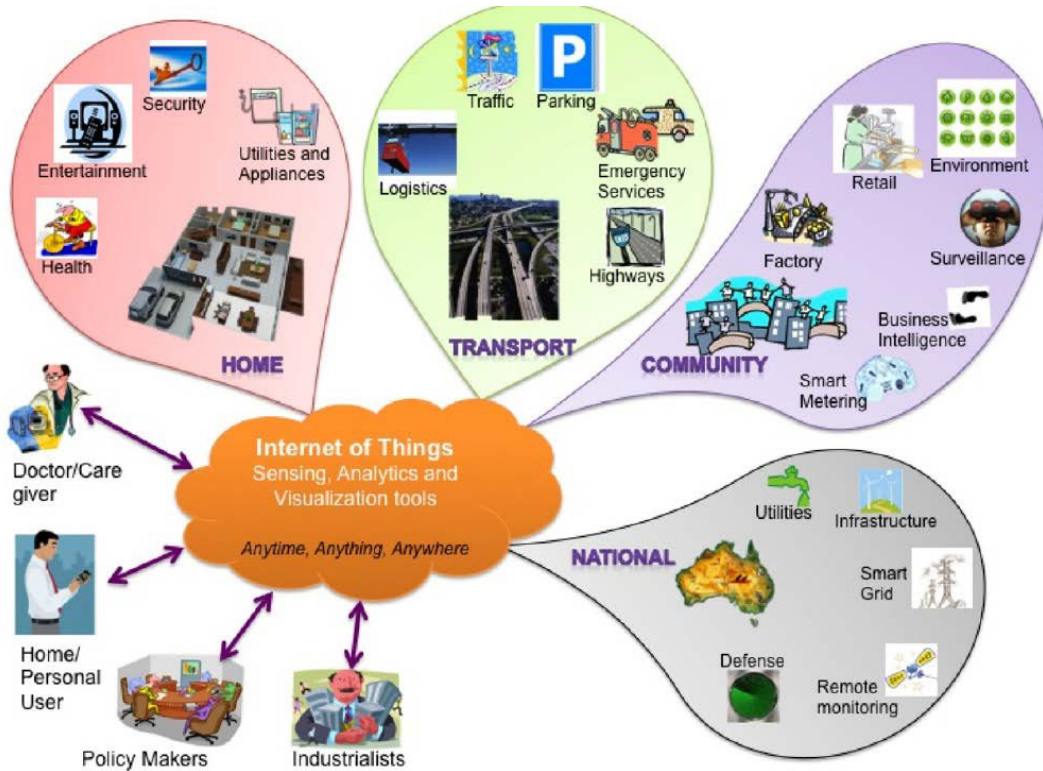


Figure 2. Internet of Things Schematic Showing the End Users and Application Areas Based on Data [4]

IoT consists of several key elements: 1) Hardware system is made up of sensors, sensor actuators, and embedded communications board; 2) Middleware system is made up of data storage such as data cloud in network system or embedded data storage in IoT device; 3) visualization system is comprised of user interface display, user interaction, data interpretation, and event determination [4].

Future IoT development is a momentous technical advancement implementing artificial intelligence and controls various things to assist well-being of human. Human involvement shall be minimized and most procedural decisions in a normal process will be made by algorithms obtained from Big Data analyses. Early development of network connections of things was already utilized in many areas. For example, pressure monitoring sensors were installed in petroleum pipeline to prevent theft, vandalism, leak and rupture. Pore-water pressure sensors were installed to set an automatic alarm prior to land sliding. This early development of above sensors and its application are limited only to collect specific data. Figure 3 shows co-relationship between expected service levels as IoT technology develops. IoT must have an intelligent function that automates decision making without human interference. Figure 4

demonstrates main functions of IoT. Combination of these functions provides an opportunity to extend sensory and decision functions which only human beings possess.

A developing concept for smart home is commercially viable and getting public popularity. Three main areas of a smart home concept are home appliances, energy and utility management, and home security. However, a smart city concept has a larger scale and requires significant upfront public infrastructure investment such as networked sensor installations. Development and implementation of IoT technology in urban environment and infrastructure system seems to be right direction to make the smarter city that improves efficiency and effectiveness of using limited resources and becoming more sustainable in long-term perspective. However, significant upfront capital investment is required to implement the concept of IoT technology and its infrastructure. Planning including feasibility and economic benefits analysis of the smart city will be perplexing task comparing to a conventional project.

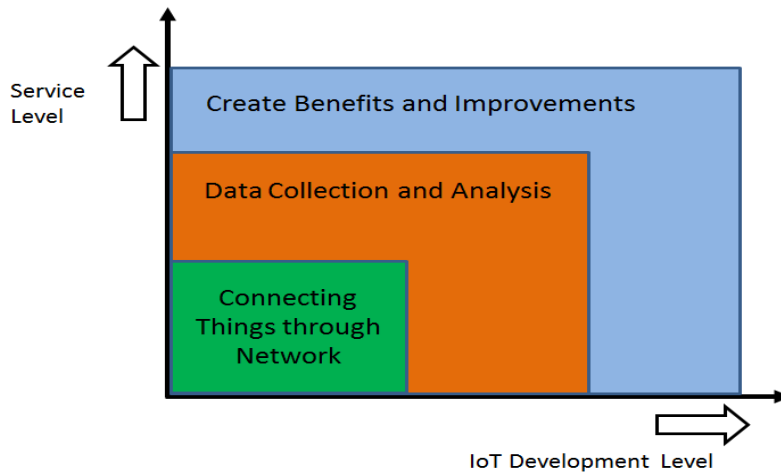


Figure 3. Service Level vs. Development Level of IoT Application

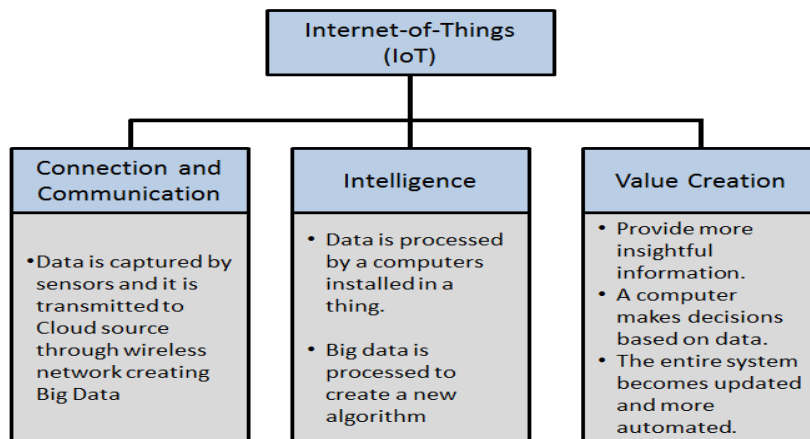


Figure 4. Main Functions of IoT

4.0 Application toward Sustainable Water Supply

Water as an essential natural resource is not substitutable. Extracting, pumping and distribution of water require approximately 3-4 percent of the total electricity in the United States [5]. A typical American household uses approximately 260 gallons of treated water per day. Many attempts were made to reduce water consumption and improve efficiency, such as 1) using water-efficient appliances, 2) fixing running toilet, 3) fixing faucets and showerheads, and 4) controlled landscaping and irrigation. Real water losses occur before the treated water reaches the user. Average water loss in public water systems is approximately 17 per cent [6] which translates to approximately 6 -7 billion gallons per day. It is not just the water that is lost but also the energy that is spent in extraction, treatment and distribution of it. Minimizing distribution losses will reduce freshwater withdrawals, save energy and reduce the carbon footprint of water, and eventually make water supply more sustainable.

Asset management intrinsically pursues to manage existing assets being more sustainable in terms of environmental, societal, and economical aspects. Some asset management focuses on achieving lowest life cycle cost, which is economic aspect of sustainability. Many previous studies developed asset management frameworks, data collection, and failure prediction models. Pipe condition assessment is typically the second step of asset management followed by asset inventory. Pipeline condition assessment becomes baseline for various decisions made towards enhancement of sustainability. However, the industry severely experiences lack of adequate data collection and sensor technologies which is fundamental for an effective pipe condition assessment. Vairavamoorthy et al. proposes various indicators for the pipe condition assessment as shown in Figure 5. Other studies also proposed similar set of indicators. Limited access to this kind of data is one of the major challenges that warrant installing sensors to capture condition data from the buried pipes.

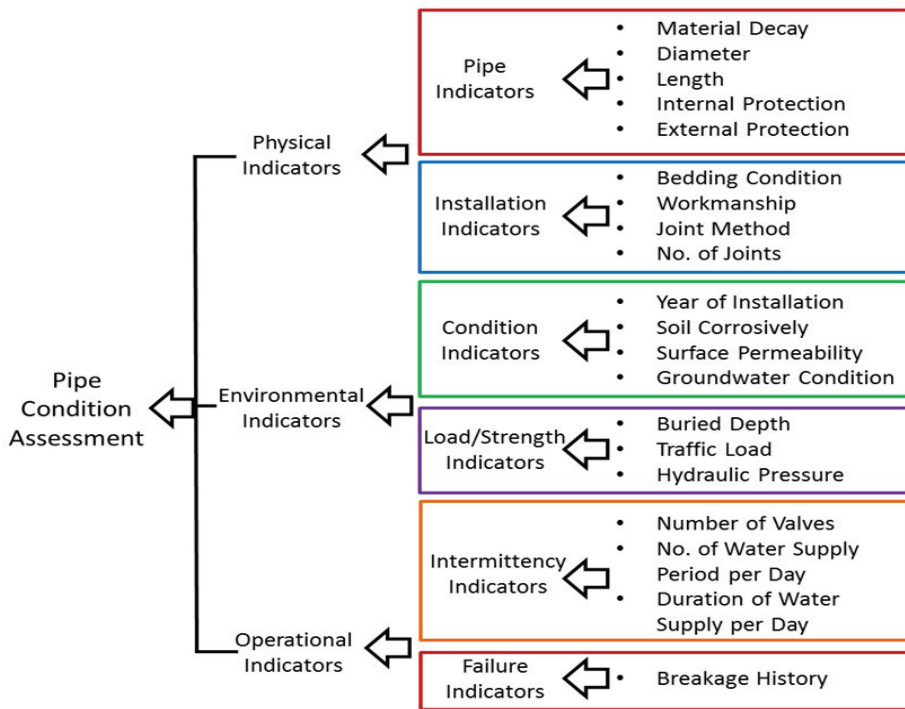


Figure 5. Indicators for Pipe Condition Assessment [7]

AMR and pipe condition assessment are shown as examples of information technology and data process achieving more effective and efficient water supply system management. Overall sustainability of the water supply system enhances as well. However, AMR and pipe condition assessment focus on service optimization of the water utility owners. There is no information sharing with customers and hence limited feedback to the end-users. It is noteworthy that IoT framework has to include customers because increasing momentum of sustainability enhancement is impossible without cooperation between owners and customers. Sustainability of water supply system requires significant front-end capital investment that will burden the end-users in the form of increased rates and therefore, long-term sustainable benefits need to be clearer to them for greater willingness to pay.

Some water utility owners independently own sensor network, monitoring, and control system such as SCADA systems. Smart grid has been introduced as a similar concept utilizing sensors for improved leak management, water quality, monitoring, drought management, and energy savings [9]. The smart grid system can be an example of IoT application. The Big Data network system is extended for other fields. As shown in Figure 2, data through myriad of IoT systems can assist other systems. For example, traffic surveillance CCTV imagery can be used for load assessment for pipeline condition evaluation. Electric usage pattern may reveal potential leak detection from pressure fluctuation.

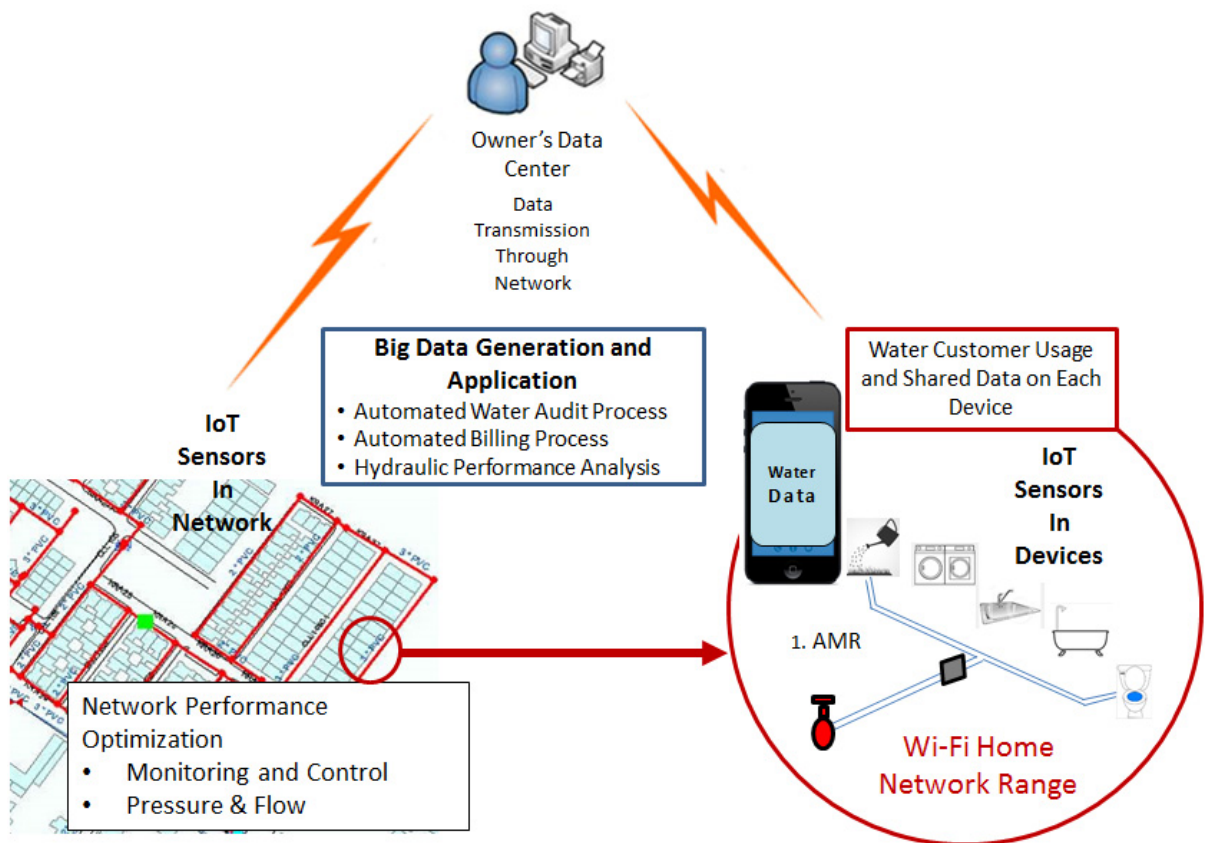


Figure 6. An Example of IoT and Big Data Application

Figure 6 demonstrates a potential example of IoT and Big Data application in water supply system. This application shows data integration between customer's water usage and owner's water supply. Customer's water usage data is collected from wide range of sensors installed on facets, sprinklers, sinks, shower and bath, washer and dishwasher. Customers could utilize existing Wi-Fi Internet network in the house and Smartphone applications that display all data received from IoT. Sensors installed in water supply network provide pressure and flow data along with GIS and asset inventory data. Seamless integration of two different data sets will indicate discrepancies between usage and supply. With detailed and accurate water usage data, in-depth water audits with real-time monitoring becomes plausible. Data analysis provides detailed water consumption patterns and a proposed schedule per each device to maximize water conservation. Owner will collect water supply system network data such as pressure and flow. The water supply system sensors are installed more sporadically, but overall performance model can be developed based on hydraulic data in a pressure zone. The owner, as a main water utility manager and operator, receives two data sets in real-time, through internet network, to monitor hydraulic performance and control a balance between demand and supply in the water supply system. Big Data can provide several benefits: 1) locating leaks identified from data discrepancy; 2) optimizing water production and distribution through water supply system; 3) developing of water consumption optimization algorithm.

This technology is still in its infancy and expected to open a new horizon in many directions. Cyber security must be addressed before fully implementing IoT sensors throughout domestic devices. Open data communication and network platform for IoT devices and Big Data will be vulnerable to hacking. Once hacking is successful, individual's privacy including life pattern and private activity is exposed by tapping into Big Data in a virtual database or IoT device network communication. This new technical paradigm has a great potential to enhance sustainability of using less water and energy resource when it is built on safe cyber network platform. Thus, IoT and Big Data application in water supply system definitely requires enhanced cyber security firewall system from the conceptual development stage.

5.0 Conclusions

The concept of sustainability is well understood and attracts many industry practitioners and policy makers. However, practical and definite implementations that enhance sustainability are not easy. This paper describes a conceptual development of IoT and Big Data in the context of water supply systems highlighting its advantages and limitations. The paper advocates implementing IoT and Big Data technology for saving water resources and energy. It is an imperative task to reduce several billion gallons of treated water loss. Most of public water supply system maintenance is performed in a reactive manner rather than proactive [6]. This new technology will provide a possible solution to make the industry more proactive.

Data is generated from sensors installed in each device, which is called IoT, and transferred through Internet network system. Application of IoT consists of smart sensors capturing water data and sophisticated data analysis to retrieve any useful information to enhance sustainability through virtual data platform and control system. Therefore, two technologies, IoT and Big Data, should be effectively and efficiently integrated. Three main benefits in the water supply system are: 1) automated system condition monitoring including leak detection; 2) optimizing water supply, production, and energy consumption; and 3) optimizing water consumption.

Although the technology seems not available for water supply system at this moment, IoT and Big Data will be key technical components to build smart and sustainable urban infrastructures.

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