A review of IoT applications in Supply Chain Optimization of Construction Materials

A. Kumar[a] and O. Shoghli[a]

[a] Department of Engineering Technology and Construction Management, University of North Carolina at Charlotte, USA
E-mail: akumar28@uncc.edu, oshoghli@uncc.edu

Abstract –

. The timely updates and delivery of construction material on a job site could have a significant impact on the overall duration, quality, and cost of the project. The study focuses on analyzing the role of Internet of things in providing a real-time update on the delivery and data for material handling in supply chain management, and review the role of IoT in the function of value addition that it could bring in the form of management of materials and communication to a project.

It is anticipated that within the next decade, the Internet will evolve into a seamless fabric of classic network and networked objects. The use of IoT coupled with smart sensing devices could help in the communication and material tracking with high accuracy and free of noises such as human error, workforce shortage, cramped budget, adverse weather conditions, and other environmental factors.

The study will explore and identify the various remote sensing devices and technologies that could be integrated and utilized into the live data feed for the information update, with a particular focus on the use of internet of things through electronic devices. The system would help project manager in schedule updates and improve material efficiency

Keywords –
Supply chain management; Internet of things; Material efficiency; Construction.

1 Introduction

In recent years, most of the manufacturing and distribution industries have paid much attention to Supply Chain Management (SCM). By adopting and investing money in the supply chain management, the big and renowned infrastructure companies have significantly reduced inventory and logistics costs. In addition, they have marked increment in the speed with which they respond to customer demand, and improved overall company competitiveness [1].

Due to these benefits and successful cases of the supply chain management, many industries are adopting the approaches of SCM and the construction industry is also one of the industries to adopt SCM [2]. The construction industry is usually characterized as a complex industry because of the high variability in construction environments and the complication of the construction process [3]. Despite the recent improvements in construction technology, material management remains an issue that has a lot of scope for improvement in construction projects [4]. It is relatively difficult to introduce SCM to the construction industry, because of the higher costs, longer-term durations, and complicated construction interface. However, SCM for construction materials is essential to have a successful construction management, because construction materials costs make up a considerable percentage of overall construction budget [2]. The use of the conventional practices might circumvent certain problems such as material shortages and suspensions but early and excessive material entry into the site comes up with whole different direct and indirect costs such as repeated handling, interest loss, and storage cost [5]. In absence of management for material supply operations, issues could reflect in terms of extra cost to the overall project budget, schedule update, and quality of the project.

The supply chain management is in the process of massive transformation from manual data compilation methods to the use of new generation of technologies where it is in the process of abolishing expensive and ineffective practices and embracing newer, faster, and efficient technologies and systems such as building information modelling, multi-dimensional scheduling, computer-aided design, and sensing devices to monitor, estimate, and track its progress and provide real-time schedule update and hassle-free management for the construction and built environment.

2 Literature Review

Supply chain management is in the process of

meeting with newer technologies. Merlino et al. [6] mentioned that today's supply chain is not the same as past few years and in the recent year supply chain is not only impacted from augmented reality in material handlings and other components, but empowered from the newer technologies such as robotics, artificial intelligence, and big data. These technologies/concepts come under the Internet of Things (IoT) which is on the basis of algorithmic process, production decisions, govern automatic devices, and do forecasting and planning.

IoT could help to bridge the communication and technological gap that exists between two most important associates for the project that exists at the extreme ends of the built environment spectrum i.e. manufacturer and customer. IoT could help the industry personnel to get real-time schedule update with astonishingly precise values that could help the project manager to make better-informed decisions and exercise better control on the overall project.

The IoT uses various interconnected smart sensing devices that communicate and share data to solve a problem such as a schedule updating, material tracking, inventory management, transportation, staffing, and resource allocation in the industry. To overcome the problem, several tools such as Radio Frequency Identification Tags (RFID), Global Positioning System (GPS), Wireless systems, Bluetooth technologies, and high-end cameras could be used to maintain real-time information sharing and data gathering.

A review of some of the prior successful cases of IoT technology applications in SCM are as follows:

- Robotics is already revolutionizing all the operational territories in materials handling, providing new roles as supply chain providers to distribution companies such as Amazon or Ali Baba [6].
- By putting assets and endeavors in supply chain management, firms such as Wal-Mart and Dell have altogether decreased inventory and logistics costs, expanded the speed with which they react to the client request, and enhanced general organization competitiveness [1].
- After the implementation of RFID advancements, Procter and Gamble and Wal-Mart simultaneously diminished the inventory levels by 70%, enhanced service levels from 96% to 99%. These companies also managed to curtail administration costs by re-engineering their respective supply chains [7].
- Supply chain information transmission model based on RFID and IoT was utilized in pharmaceutical industry to realize drugs information retrieval [8].
- Application of IoT technology in textile SCM [9].
- Application of IoT in green agricultural products SCM [10].

2.1 Supply Chain Management in General

The Supply Chain Management (SCM) concept is an important development in the corporate logistics first proposed by Houlihan [11]. The concept underwent several modifications over the period of time and received numerous valuable inputs from various scholars. Supply chain management problem has multiple variables that make it a dynamic problem. An effectual and competent SCM can have a significant positive impact on quality, cost, and duration of a construction project [5].

The Supply Chain Operations Reference (SCOR) model is proposed by the Supply Chain Council in the year 2004. It is an exhaustive business process and performance measuring method designed to meet customer requirement from all perspectives. A supply chain model is developed in a hierarchical manner and used to carry out multi-dimensional equivalent comparisons with respect to performance. The user can provide a standard quantitative scrutiny of process performance by studying the behavior of SCM from the model and implementing adequate plans. SCOR helps to integrate internal and external systems. SCOR can likewise be utilized to assess current corporate performance against contenders, in order to enhance performance [5].

The SCOR model is the first standard reference model of supply chain process whose diagnostic tools cover all industries. The PLAN step is the most important component of the SCOR model which measures integration, process, reliability, and information technology (IT) to deliver a plan.

The SCOR breaks down the SCM process into five functions, namely Plan (P), Source (S), Make (M), Deliver (D), and Return (R). The five modules were arranged into an order of hierarchy based upon the fundamental elements. The demand and supply of the modules were planned and controlled. The various functions such as performance measure, applicable software features, and optimum solution were defined. It was found that SCOR model can help the industry personnel in solving management and optimization problems such as setting up periodic targets, trend determination, and property evaluation. The leading studies of SCM on construction applications and other industries are illustrated in Table 2.

2.2 Usage of Internet in SCM

The primary goal of the supply chain systems is multi-dimensional and includes cost minimization, improved levels of service, upgraded communication among supply chain companies, and raises the flexibility in terms of delivery and response time. By combining internet with the SCM can provide benefit to the industry

in terms of numerous cost-saving opportunities and improvement of service for supply chain [12], for instance, traditional logistics practices were very slow due to face-to-face negotiation but owing to internet, the rate negotiation can now be carried out on the internet at a lower cost.

According to Lancioni et al. [12] research, it is shown that based on the ranking, the most popular use of the Internet for SCM is in transportation, followed next by processing, managing vendor relations, purchasing procurement, and customer service. Table 1 represents the ranking of internet applications in supply chain management.

Table 1 Ranking of internet applications by logistics decision area [12].

Application	% Using	Rank
Purchasing/Procurement	45.2	3
Inventory Management	30.1	5
Transportation	56.2	1
Order Processing	50.7	2
Customer Service	42.5	4
Production Scheduling	12.3	6
Relations with Vendors	45.2	3

2.3 Digital Supply Chain

In the era of the global and connected economy, the digital supply chain is becoming a most researched trend and it is also on the ramp to improvement and success [6]. Digital technology is taking place over the traditional operations and now every business has become a digital business and its impact on supply chain management is predominantly great. According to Yan et al. [8], by only applying the traditional way of SCM strategy cannot lead to winning comprehensive advantages in the market competition. Therefore, many companies/industries are understanding the essential factor of these changes and they have already started working to introduce digital technology into their operations, however, just adding technologies into the business is not the answer for all.

There are several digital technologies which could be counted under the Internet of Things (IoT) and could successfully qualify as a future of the supply chain. The digital technologies are:

1. Supply Chain and Augmented Reality (AR)
2. Supply Chain, IoT, and Big Data
3. Supply Chain and Radio Frequency Identification (RFID).

2.4 Augmented Reality (AR) as an aide to Supply Chain

According to Cirulis et al. [13], the prime objective of Augmented Reality (AR) is to augment the real world environment with virtual information that enriches human sense and abilities. AR technology is to combine virtual information with the real world [14]. This technology is usually used in real time and semantic context with environmental elements [13]. AR technology is very common on the TV channels like sports channels. For instance, on the TV sports channel, there would be a score on the captured video and that score is the virtual information that combines with the reality and there are a number of other channels or other daily routines are using AR technologies. Most industries are using this technology to compete in the market and this technology is also used in SCM. AR will provide benefits to the supply chain as listed below [6]:

Picking Optimization: By using AR, any professional can see a 'digital picking list' on a heads-up display. Professionals can select a building material and the digital display will calculate and guide them through the shortest and most efficient path through the warehouse for the package to be picked up. This information can also be saved in the Warehouse Management System simultaneously with the help of the cloud computing.

Freight/Container Loading: AR could replace the need for physical instruction because of the heads-up displays (picture google glass visuals). These displays have step by step instructions with the best methodology to load the container according to the size, dimension, and weight of the building material loaded into the vehicle. The information and data through AR can ensure optimum loading and thus help reduce freight cycles of the supply from warehouse to the construction site.

Dynamic Traffic Support: Most transportation vehicles (e.g. trucks) are equipped with GPS navigation, but AR systems are the natural successors. Heads-up and windshield's displays would allow the driver to re-route shipments in real time without distracting the driver significantly. For example, a truck is loaded with a concrete bags and AR can show the driver critical information including the weight of the concrete bags, gasoline efficiency, the route to the reach to the destination and so on.

Facility Planning: AR can help the professionals to visualize their next facility in full scale even before the construction starts. The project managers can model their workflow through the site, test measurements, and estimate the raw material needed to carry out the various activities. The AR system can also help the planners to select potential suppliers for various building materials while maintaining an online database simultaneously.

Table 2 Key studies and developments of SCM in construction and other industries

Authors	Industry	Application
Walsh et al., 2004 [15]	Construction	Precise material required planning.
Tah, 2005 [16]	Construction supply chain network	Inter-relationship & influence amongst suppliers
Jeong et al., 2006 [17]	Manufacturing	Process control
Tserng et al., 2006 [18]	Steel Factory	Optimized model to minimize inventory cost & decision support system for raw material suppliers.
Klimov & Merkuryev, 2008 [19]	-	Supply chain risk identification & simulation-based risk evaluation
Miao & Xi, 2008 [20]	Dynamic supply chain environment	Artificial neutral networks for quantitative forecasting of logistic demand
Janacek & Gabrisova 2009 [21]	Enriched capacity facility	Formalize & study compactness of location
Miao et al., 2009 [22]	Supply chain reliability (SCR)	Incorporated fuzzy rule & cloud theory
Sarac et al., 2010 [23]	-	Production economics
Shin et al., 2011 [24]	Construction	RFID and wireless sensor networks
Gosling et al., 2012 [25]	Construction	Identification of sources of project uncertainty
Irizarry et al., 2013 [26]	Construction	Integrated BIM and GIS to track supply chain
Taticchi et al., 2014 [27]	-	Decision support & performance measurement
Dubey et al., 2015 [28]	-	Green supply chain
Formentini et al., 2016 [29]	Corporate Sustainability	Governance mechanism
Wu et al., 2016 [30]	Electrical & manufacturing	Green Partner selection
Niu et al., 2017 [31]	Construction	Process, information & decision making
Moon et al., 2018 [32]	Construction	Improve work efficiency of scaffold supply

2.5 Supply Chain, IoT, and Big Data:

The smart sensing equipment integrated with cloud computing and big data could be the next big thing that could provide a multidimensional solution towards supply chain optimization of building materials. Devices such as RFID, cameras, Laser tags, GPS, Bluetooth LE (iBeacon), Low-frequency LF tags, and Battery Assisted Passive (BAP) tags could be used to for an effective management of a project site. The 24/7 availability of real-time information update accessible on a wide variety of devices enhances the level of performance delivery of the industry and provides a firm base for consistent workflow [6].

Some of the most promising areas for the application of the IoT's and Big data in the construction industry are:

Reduce Reaction Time to Stimulation: The ability to readily meet the demands of a customer is one of the major areas of supply chain optimization. Cloud computing coupled with smart communication devices could help reduce the time lag between the order and shipment of the building material [33].

Inventory management: The inventory at a construction site or a warehouse can be tagged with smart sensing devices such as RFID tags which can help maintain a count of the available stock and also trigger a request for more supplies in case of the stocks getting below certain levels [34].

Prediction of Customer Needs: In the age where the customer satisfaction is of paramount value, smart organizations could use the services of the big data to point out potential customers and customize their product and marketing according to customer needs [35].

Locating construction equipment: The IoT can be used to locate and track the various construction devices such as machinery, excavators, scrapers, drilling machines, cranes, and booms. The tracking system can help maintain a count of the resources allocated at a site and formulate a strategic positioning of the equipment on a job site.

Improving the efficiency of Supply Chain: The cost reduction techniques, spending patterns, and material efficiency will continue to be the top priorities in the supply chain. IoT and big data could be used to improve upon these variables.

Remote operation of machinery: IoT enables the technicians to operate machinery from a distant location so that they could avoid potentially hazardous work conditions. The wireless networking of machinery and devices enables the technicians to carry out their work with the help of remote operated machines and robots.

Supply Chain Traceability: Traceability of construction manpower, material, and equipment is directly linked to risk. Big data and Global Positioning System (GPS) can be used to keep a count of the number, location, and database of the active hours at a construction site [12].

Safety and Risk management: The construction and civil infrastructure project sites can use the smart sensing devices to augment the onsite safety standards. Smart locating, imaging, Laser sensors, and tracking devices such as hawk-eye-vision cameras can be used to ensure the safety of the working personnel on a job site.

2.6 Supply Chain and Radio Frequency Identification (RFID)

The IoT expands the application of RFID as an automatic information collection terminal, RFID system is also included in IoT as an information entrance, because it recognizes the information by reading and processing the metadata which is stored in the RFID tags. Yan et al. [8] stated RFID as a "non-contract automatic identification technology named radion frequency identification, which can identify the still or move entities automatically."

Case scenarios for applying RFID technology in construction project management [36]:

Logistics and supply chain management (LSCM): The typical supply chain means the customer's ordered materials were shipped or transported by transportation vehicles from the factory to the material distributor to the on-site warehouse. In this process for every associated professional (e.g. buyers, project managers, truck drivers and so on) should know all the necessary information such as manufacturer, quality of the product, specification etc. and this could be possible by using RFID tags. Similar to any price tag that can be seen to any product and this has been seen in construction to tag the big components. With the addition of the other technologies like adding Global Positioning System (GPS) and Geographic Information System (GIS) with the RFID can add more accuracy in terms of tracking the construction materials [37].

Inventory Management: Maintaining inventory is a big task and has the particular importance in construction. In addition, by maintaining a good material inventory one can ensure the smoothness of construction process [36] and RFID technology can be utilized to improve the inventory management of construction materials. For instance, by keeping RFID reader in a storage area, it is easier to maintain the inventory because it can read the RFID tags that are attached with the materials and it can automatically update the inventory.

3 Advantages of IoT In Supply Chain

The smart sensing equipment integrated with cloud computing and big data could be the next big thing that could provide multi-dimensional solution towards supply

chain optimization of building materials. Devices such as RFID, cameras, Laser tags, GPS, Bluetooth LE (iBeacon), Low-frequency LF tags, and Battery Assisted Passive (BAP) tags. The 24/7 availability of real-time information update accessible on a wide variety of devices enhances the level of performance delivery of the industry and provides a firm base for consistent workflow.

The services of cloud computing and big data can be used to operate, record, and store the raw and processed information from the machines, software systems, sensors, and people. The information stored in the cloud could be accessible through a wide variety of devices such as personal computers, tablets, mobile phones, etc. The information is free from physical limitation of location or time constraints.

The use of IoT coupled with smart sensing devices could help in the communication and material tracking with high accuracy and free of noises such as human error, workforce shortage, cramped budget, adverse weather, and other environmental factors.

Specific information about construction materials that need to be tracked and shared by using IoT technology during the SCM process include:

1. The visualization of the logistic patterns. Track quality, quantity, and cost of the resources. Compare the plans vs actual delivery, and monitor and inspect the delivered product [26].
2. Develop a decision-support system to generate a production and supply plan for the supplier and buyers of steel rebar [2].
3. Handle ready-mix concrete operations by following the position of trucks and observing the motion and status of concrete conveyances in real time [38].
4. Optimize vehicle routing and vehicle scheduling of logistics under uncertain systems [39].
5. Tracking system to improve the work efficiency of scaffold supplies [32].
6. Remote monitoring of the tools and equipment on a job site [40].
7. Facilitating the trouble diagnosis system and maintenance of construction equipment [41].

4 Discussion and Conclusion

In the current scenario, where the human workforce is expensive, scarce, and irregular in terms of performance, the digitization of the workforce and build environment can help the organizations to manage their performance in terms of cost, time, and quality of the end product. An array of smart sensing devices like RFID, LASER technology, BAP tags, and LF tags coupled with communication medium such as the wireless internet network could help boost the overall efficiency of an organization. The smart devices have the capacity to interact and communicate with the environment around them which consists of software systems, machines, devices, and people. Altogether, these systems are capable of providing a customized solution to the problem and help an organization to easily conduct operations such as data compilation, communication, quick response to stimulation and decision making.

The real-time data feed is uploaded to a cloud database and is easily accessible through a vast variety of devices such as mobile phones, tablets, pods, television, and computers. The information available through the digital medium powered by IoT is free from the constraints of location, time, space, adverse weather, human error, and other environmental factors. The real-time data updates can help the project managers and supervisors to track and monitor the operations at a construction site and help them exercise a better control of the overall project.

The ease of application and functions involved with IoT comes up with its own set of unique challenges, the dependency of the entire system over a constant source of power supply can't be negated. In case of power failure, the whole facility could come down and put the organization into disarray. Additionally, the security of the data compiled through these systems is not theft proof. The digital systems and data are prone to hacking which possess a great security risk to the functioning, efficiency, and organizational structure of a firm. Furthermore, the greatest challenge that the digital systems face is the ever-changing and evolving nature of the technology itself. There are numerous numbers of research-work that constantly goes on into the digital field, this transpires into the technology getting sharper and being different with every passing decade. The change in the technology requires constant upgradation in terms of devices, software, and installation of new systems and training of the handling staff. The technological improvements can put transitional challenges, operational shifts, and financial burden on an organization.

The primary factor with respect to the full deployment of new technological advancements has been as of recently the human one. It is because the gap between innovation and human resources culture has augmented, not diminished. Incompetent plans of progress administration in organizations do not help in filling this void. A ton of work must be done in getting ready new trainers and instructors and the gap must be loaded with new floods of "tech-savvy professionals", originating from the local digital youthful generations.

Major barriers to the achievement of success of supply chain optimization using IoT incorporates work environment culture, an absence of senior management commitment, privacy issues, improper support mechanisms and the dearth of education of management philosophy. Learning and training at all level in the industry are paramount to beat these boundaries.

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