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## A review on Internet of Things solutions for enhancing construction equipment fleet productivity

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### Abstract

*The construction business is an ever changing industry facing increasingly bigger challenges, complexity and above all fierce competition. Contractors, in particular those managing fleet of construction equipment, have to cut their margins, increase the efficiency of their work force and assets, and control their total cost of ownership (TCO) to ensure an acceptable return on investment (ROI). As such, the business evolved in many ways to be cost-efficient. For instance, construction equipment manufacturers have focused on optimizing engine productivity, hydraulic versatility, and mechanical robustness, among many others. However, recent trends segued into delivering smart machines capable of reporting and adjusting equipment operators' behavior to achieve a better on-site fleet performance. This was made possible through the Internet of Things (IoT) and visualization tools by instrumenting construction equipment and devising advanced technological and on-board sensory systems as well as allowing the transfer of relevant information over a shared network within a 3D environment. The objective of this paper is thereby two-fold: (1) shed light on the latest approaches developed from tracking systems, load weighing systems, on-board operator assists to help equipment operators in spatial navigation, and (2) examine current virtual systems used to interactively visualize instrumented fleet of equipment and provide proactive on-site monitoring. The review revealed that there is substantial room for improvement and adoption of new tools targeted at reducing inefficiencies, improving fleet productivity, and producing higher quality results, in less time and with less effort.*

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*Keywords: Construction Equipment; Internet of Things; Virtual Systems; Operator Behavior; Tracking; Sensing; Load Weighing*

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### 1. Introduction

In the last two decades, the construction industry has become increasingly competitive. This has thereby enticed contractors to continuously spend effort and resources on technological tools to advance their work and have an edge over their competitors. These technological advancements have been growing exponentially with the emergence of construction automation, Building Information Modeling (BIM) and lean construction [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. In fact, Information Technology (IT) is becoming a major part of construction project delivery and can, as such, greatly help in safeguarding the contractor's key project controls (i.e. time, cost, quality, and safety) as well as aid in risk avoidance and mitigation.

Among several IT advancements in construction (localization, BIM, Virtual Reality/Augmented Reality, 3D printing, cloud computing, etc. [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21]), the Internet of Things (IoT) has emerged widely with several applications, in particular those related to construction equipment. These pieces of equipment require special attention and decision-making as they are critical and costly, be it the cost of buying or renting them, or the cost of monitoring, operating and maintaining them. In addition, equipment's productivity has a major impact on project scheduling and their use has an important safety aspect that needs to be monitored. As such, this paper

aims at reviewing various studies that have applied Internet of Things (IoT) to enhance construction equipment fleet productivity.

## 2. Literature Review

The focus of the literature review is on papers related to IoT applications, primarily in relation to equipment in the construction industry or any potentially relevant industry. Table 1 is a review of 45 research studies related to the topic under study. For each paper, the application/industry is first identified then the objective, tools used, benefits and outcomes of IoT are presented.

Table 1. Summary of research studies relevant to Internet of Things (IoT) applications to Construction Equipment Fleet.

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[22]	Transportation Engineering	- Perform vehicle surveillance	- ArcGIS Engine - Visual Basics (VB)	- Map control - Vehicle orientation - Special data query - Path programming
[23]	Construction Management	- Assess application areas of RFID in project management	- Radio Frequency Identification (RFID)	- Management of material, men and machinery
[24]	Transportation Engineering	- Monitor and collect statistics for Trucks	- Global Positioning System (GPS) - Wireless Sensor Networks (WSN)	- Real-time trucks output
[25]	Tower Cranes	- Improve crane operator performance with smart anti-collision assistance	- Proximity sensors - WSN	- Real-time crane position data - Decision-making support for collision avoidance
[26]	Mobile Cranes	- Create a comprehensive IT system to support mobile crane operation	- Sensors - WSN	- High precision data acquisition - High transmission speed - Facilitate remote monitoring - Accident analysis
[27]	Construction Safety	- Accidents prevention - Improve safety management in underground construction	- Fiber Bragg Grating (FBG) sensor system - RFID labor tracking system	- Real-time detection, monitoring and early warning of safety risks
[28]	Construction Safety	- Workers protection - Accidents prevention	- Radars and ultrasound sensors - General Packet Radio Service (GPRS) - Reading Equipment	- Ensure workers' safety - Advanced safety data collection - Reduce capital and operational costs
[29]	Road Repair	- Prevent accidents during road repairs by using robotic arms	- Robotic arm - Sensors	- Improved work environment - Enhanced safety measures
[30]	Construction Safety	- Establish a hazard energy monitoring system - Generate early warnings and alarms for hazard energy	- RFID - Tracking technology - Ultrasonic detection technology - Infrared access technology	- Achieve a safer underground construction site - Avoid unsafe behaviors for workers and equipment
[31]	Construction	- Develop a Smart Construction Object (SCO) and proactive big data management system - Facilitate the data collection, visualization and analysis for equipment management	- i-core sensor - Data warehouse software - Databases	- Normal equipment turned into smart construction equipment - Automatic collection of cost, environment and safety implications
[32]	Construction	- Address indoor localization of mobile construction resources	- Cloud enabled RFID - BIM - Remote monitoring	- Security control - Safety management - Asset management - Productivity monitoring

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[33]	Tower Cranes	- Accidents prevention	- Sensors - Safety Equipment	- Reduced amount of wireless data transmission - Reduced energy consumption
[34]	Earthmoving	- Improve operation cost and productivity - Enhance automation and safety	- Sensing technology - Equipment tracking - GPS systems - Pattern recognition algorithms	- Equipment tracking and fleet management - Safety management - Remote/autonomous operation
[35]	Construction	- Machine visualization and identification	- Histogram of Oriented Gradients - Support Vector Machine - GPS and cameras	- Individual machine identification - No false positives due to the robust performance
[36]	Heavy Construction	- Integrating equipment management into existing simulation techniques.	- COINS simulation - Enterprise Mobility Management	- Provide learning through simulations for new employees. - Decision support for renting, leasing, and buying equipment.
[37]	Construction	- Measure the operational efficiency of construction equipment	- Machine Learning Algorithms - Accelerometers	- Different stages of machine operations are identified
[38]	Construction	- Quantify and analyze physiological data	- Physiological Monitoring Unit - GPS	- Framework for collecting and analyzing construction equipment operator's physiological metrics
[39]	Construction	- Recognize construction equipment and objects	- Deep convolutional network	- Monitoring of construction equipment in real-time
[40]	Construction	- Visualization of construction equipment in a model	- Finite state machine - Discrete-Event algorithm	- Real-time visualization and monitoring of construction equipment
[41]	Construction	- Vision tracking method using particle filters	- Real-time locating systems	- Track workforce and equipment movement on site
[42]	Cranes	- Develop operator-assistance system	- Motion sensors - 3D modeling - Point cloud	- Increase situational awareness - Improve operator performance - Improve safety
[43]	Construction Safety	- Proactively monitor site accidents	- Accelerometers - Distance sensors - Compass - Wi-Fi	- Mathematical formulation of three types of struck by accidents - Development of tools for site use
[44]	Construction	- Multi-Agent System (MAS) architecture that combines Location Guidance Systems (LGS) technology	- Near real-time simulation - Dynamic Equipment Workspace - Real-time locating systems	- Fleet automated guidance system
[45]	Construction Management	- Enhance operation productivity	- GPS - WSN - Web application	- Provide a guideline to managers - Effective equipment operations - Resiliency and flexibility improvement - Cost reductions
[46]	Tower Cranes	- Workspace 3D modeling - Collision detection - Offer visual assistance	- Wide-angle cameras - Laser scanner - Point cloud - Tracking loop	- 82-94% position accuracy - Enhanced situational awareness
[47]	Construction	- Detect and track construction equipment	- Video recording device - Object recognition algorithm	- Flexible system developed

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[48]	Construction Safety	- Operator errors mitigation - Design operation-assistance system	- Inertial Measurement Unit (IMU) Sensor - Encoder sensor - Laser scanner - WSN	- Automatic hazard detection - Improved lift performance - Safer operation of heavy equipment
[49]	Construction Safety	- Reduced collisions between workers and equipment	- 3D point cloud - Laser scanner - GPS tags	- Provision of safety indicators - Pro-active decision support on personnel management, equipment selection and construction site layout design and planning
[50]	Construction Safety	- Develop a proximity detection and warning system - Enhance safety on site - Develop and test a real-time real time excavator control system	- RFID - Camera - Excavator control technology - Around View Monitor (AVM)	- Real-time control of equipment - Excavator accidents prevention - Hazardous proximity real-time detection
[51]	Construction Safety	- Construction site facilities prevention	- RFID - Directional antennas - Ultrasound waves - Radio transceiver - GPRS module	- Provide accident prevention system - Provide smart alerting system
[52]	Construction Management	- Analyze and measure construction equipment operation - Monitor project productivity	- IMU sensors - Smartphones - WSN - Dynamic time warping	- Automate the measurement of equipment cycle time - Increased measurement precision - Continuous productivity measurement - Automated data collection
[53]	Construction	- Develop a smart construction object-enabled proactive big data management system	- Smart chips - Sensors - WSN	- Provide concurrent decision-making information for equipment management - Enhanced data storage, processing and visualization - Cost savings
[54]	Construction safety	- Measure blind spots dynamically using the head posture of the equipment operator	- Laser scanning - Kinetic range camera - Point cloud	- Identification of potential hazards due to operating equipment next to workers - Enhanced safety on sites - Aid in the design of the equipment cabin
[55]	Construction	- Make informed fleet management decisions - Fleet use assessment - Monitor equipment health	- Transponder units - Code-Division Multiple Access - GSM - GPS	- Preventive equipment maintenance - Dynamic hazard function for each equipment type
[56]	Construction Safety	- Improve construction safety - Provide proactive real-time proximity alert	- RFID - 3D laser scanner - Equipment Protection Unit (EPU) - Personal Protection Unit (PPU) - WSN	- Support to equipment operators - Alert personnel of danger
[57]	Construction	- Recognize and track dynamic	- Cameras	- Improved productivity and safety

Reference	Application	Objective	Tools Used	Benefits and Outcomes
		construction equipment - Aid heavy equipment operation in perceiving 3D working environment	- Laser scanners - WSN - Data acquisition system	- Distinguish dynamic objects from static environment
[58]	Construction Management	- Provide an overview on new IoT technology and how they can be ported to construction sites	- NVivo software - Sensors - Data Mining - Cloud Computing - Digital porting	- IoT technologies update and development progress overview - Analysis of how methods can be sued together and applied
[59]	Construction Safety	- Using Sensor Based technology to enhance construction safety management	- RFID - WSN - Ultra wide band - Zigbee - Sensors	- Discuss the accuracy and usage of each technology - Provide a cost consideration in the studies - Mention the limitations and best application of the technologies
[60]	Mine Production	- Enhance underground safety and security - Improve work environment - Improve job quality - Improve work efficiency	- WSN - RFID and Object Identification - Sensors (chemical and biological) - Portable mobile devices - GPS positioning - Artificial intelligence	- Precise environment perception - Early-warnings for risk factors - Automatic identification - Precise positioning - Equipment management - Staff reduction
[61]	Transportation Engineering	- Improve route choice behavior	- Sensors and detectors - RFID - WSN and cloud computing - GPS	- Route tracking - Route guidance - Vehicle information tracking
[62]	Construction Management	- Improve the communication framework - Fully/partially automate communication functions across construction project lifecycle	- BIM (3D and 4D) - VisiLean - Cloud Computing - Visualization	- Enable lean and close to real-time reporting of production control information
[63]	Lean Construction and Supply Chain Management	- Present a cost-effective and easy-to-use web-based system integrated with RFID technology and Google cloud computing service that increases visibility and traceability of material and information flows of construction supply chains	- RFID - WSN - Google services	- Availability of real-time information - Assistance of computer simulation models
[64]	Electric Power	- Provide a Supervisory Control and Data Acquisition (SCADA) system for substations	- Servers and optical fibers - WSN and cable network - Sensors (temperature, humidity) - RFID - Cameras	- Equipment status monitoring - 3D visualization - Environment monitoring - Identify spare parts location - Asset management
[65]	Mine Production	- Improve decision-making - Improve emergency rescue situations	- Sensors and controllers - Camera - WSN	- Improved data monitoring and analysis
[66]	Oilfield Construction	- Production and management cost reduction	- LAN, Internet, 3G - Sensors, controllers and monitors - Cameras, GIS, GPS, RS	- Better digitization of oilfield construction

### 3. Summary of Main Findings

Following the review of 45 papers on IoT in construction and other related industries, it was found that the field presents diverse applications and uses, primarily in relation to construction equipment. Despite this diversity, common trends can be deduced. First, IoT requires the combination of two components, hardware and software, and the two are equally important. The importance of hardware lies in finding the right pieces needed to collect data from equipment and from the site as well as to transfer this data to the right receivers. On the other hand, the significance of the software component, together with designed algorithms, lies more in analyzing the transferred data to extract relevant information.

As previously mentioned, IoT revolves around information flow. In this case, all the reviewed studies had in common the following workflow pattern:

- **Data collection:** This is the first part of an IoT operation. The needed data is collected using mainly sensors (e.g. proximity, temperature, humidity, speed, etc.), GPS, RFID technology, OIDs, readers, cameras, transducers, etc. Other more advanced examples include drones and robots.
- **Data transfer/communication and storage:** Once the data is collected, it is shared with the concerned parties using various methods such as WSN, Wi-Fi, Bluetooth, 4G, cloud computing, etc. It goes without saying that the data needs to be stored in servers and databases.
- **Data analysis:** Once the data is transferred, it needs to be analyzed to become useful. This analysis is done using simple management concepts such as Earned Value Management (EVM) or using more developed tools such as developed algorithms, simulation models, Artificial Intelligence (AI), virtual models, etc.
- **Information and results:** Finally, following the three previous steps, results are generated converting data into valuable information that can support decision-making, result in warnings or provide any relevant information to the application at hand.

It was noted that many benefits can result from the use of IoT. These include improving workers' understanding, visualization and awareness of the working environment including the present equipment and laborers. Another benefit lies in transferring information in real-time without delay, which can greatly smoothen the project workflow including project monitoring, tracking and control. Not only does the information transfer become timely, but it also becomes much more accurate. In fact, with all the new technologies and cutting-edge IT and communication hardware and software tools, the automated data collection and transfer can become efficient in reducing the error margins, thereby increasing information reliability and transparency and making it comprehensive and integrated across the project. Furthermore, the above enhancements related to information flow can positively impact the project performance as a whole, in particular its safety performance, as accidents can be potentially avoided through issuing early warning signs. Project management activities can also be enhanced by rapidly and efficiently collecting more data from jobsites and thereby reducing project cost and duration. Additionally, project work quality can be enhanced. Other benefits include waste reduction and reduced negative impacts on the environment. Most importantly, it can be concluded that this technology is very flexible and can be tailored to be user-friendly and easily accessible to all concerned parties.

### 4. Conclusion and Future Work

In this paper, several research studies that have applied IoT to enhance the productivity of equipment fleet in construction and other related industries were reviewed. However, it can be stated that the field has not been fully exploited yet. Other industries have yet to integrate their findings and contributions which would result in positive synergies. For instance, transportation engineering applications can greatly benefit equipment fleet management in construction. Moreover, applications within the same industry have yet to be combined to result in comprehensive IoT solutions. Such advancements can eventually lead to the full digitization of construction projects and sites, thereby making it possible for project managers and owners to ubiquitously access and visualize any part of the project with high accuracy.

Future studies will focus on designing integrated, thorough and comprehensive IoT solutions that can potentially maximize this technology's benefits in relation to enhancing construction equipment fleet productivity.

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