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Development of Project Risk Management framework based on Industry 4.0 technologies

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Abstract

Purpose – The purpose of this paper is to identify the risks involved in the construction project based on a literature survey (LS), to develop a project risk management (PRM) framework based on Industry 4.0 technologies and to demonstrate the developed framework using Internet of Things (IoT) technology.
Design/methodology/approach – A comprehensive LS was carried out to know the different risks involved in the construction project and developed a PRM framework based on Industry 4.0 technologies to increase the effectiveness and efficiency of PRM. Heavy equipment and parameters were identified to demonstrate the developed framework based on IoT technology of Industry 4.0.
Findings – This paper demonstrates Industry 4.0 in the various stages of PRM. LS has identified 21 risks for a construction project. The demonstration of the PRM framework has identified the sudden breakdown of equipment and uncertainty of equipment as one of the critical risks associated with heavy equipment of construction project.
Research limitations/implications – The project complexity and features may add a few more risks in PRM.
Practical implications – The PRM framework based on Industry 4.0 technologies will increase the success rate of the project. It will enhance the efficiency and effectiveness of PRM.
Originality/value – The developed framework is helpful for the effective PRM of construction projects. The demonstration of PRM framework using IoT technology provides a logical way to manage risk involved in heavy equipment used in a construction project.

Keywords Internet of Things, Construction projects, Industry 4.0, Project risk management
Paper type Research paper

1. Introduction

The construction industry has a significant role in the fast-growing economy of the country and emerged as one of the fastest-growing sectors of the market, as demand for housing and commercial space has grown drastically. Consequently, the new construction is gaining popularity over traditional construction to improve productivity and quality. The construction industry also contributes heavily to increase greenhouse gas emission, which leads to environmental issues and change in global climate (Wu *et al.*, 2014; Zuo *et al.*, 2015). The construction industry of developed countries exploits almost 30–40 percent of natural resources and consumes 50 percent of energy and 40 percent of materials (Bourdeau, 1999). Comparatively, the same rate of consumption is expected in developing countries. The lack of environmental consideration in the development and exploitation creates environmental issues, frequent change in climate and global warming, which impacts on human health. This situation of the environment has motivated the construction industry to focus on the efficient utilization of water, energy and resources. That helps to achieve sufficient waste management, environmental quality, social health and sustainable site (Sahamir and Zakaria, 2014;

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Zhao *et al.*, 2016). Ecology, landscaping, materials, waste reduction, water conservation and energy conservation are identified as assessment categories for a new highway construction (Huang and Yeh, 2008). A critical discourse analysis approach used to examine the resources and constraints on environmental-communication practices in four construction projects of Sweden (Gluch and Räisänen, 2009) analyzed the risks and their interactions in complex building projects based on stakeholder-associated risk analysis method and developed a Social Network Analysis (SNA) (Yang and Zou, 2014), identified issues associated with the overall sustainability strategies for the post-construction building based on useful information management and aggregation of Building Performance Attribute Data (BPAD) within an Asset Information Model (AIM) (Alwan and Gledson, 2015).

The companies are investing substantial economies in the construction and other processing industries to own and operate heavy equipment fleets (Hildreth, 2018). In total, 36 percent of the construction project cost allocated for procurement of major construction equipment, and it also has effects on project schedule owing to high delivery time uncertainty (Yeo and Ning, 2006). The contractors have regularly faced problems related to high rate of equipment breakdown and accidents in the operation phase of construction projects (Edwards and Holt, 2002; Edwards and Nicholas, 2002). Cann *et al.* (2005) identified equipment exceeding the health standards for the Vibration Dose Value included off-road dump trucks, wheel loaders, scrapers, skid steer vehicles, backhoes, crawler loaders, bulldozers and ride-on power trowels. The current problems and practices in heavy equipment management have been investigated and identified practices for alleviating equipment management problems of highway contractors in Thailand (Prasertrungruang and Hadikusumo, 2007). A time-activity model was used to estimate surrogate values for replacement and maintenance exposure assessment of heavy equipment (Boelter *et al.*, 2007). Waters *et al.* (2008) identified the impact of operating heavy equipment vehicles on lower back disorders of an operator. The main characteristics of the heavy equipment supply chain identified in supporting the construction sector is concerned with procurement and utilization cycles (Simatupang and Sridharan, 2016). The effect of the data collection period length on the resulting period cost-based (PCB) models has been investigated and recommendations have been developed regarding the minimum period length (Hildreth, 2018). The survey shows that the environmental, technical, political, operational and financial risks are involved in the construction projects, owing to which the literature survey (LS) has been continued in project risk management (PRM) domain, and some of them have been discussed in the LS section of the paper. The above LS gives insights and issues related to the construction industry. Thus, this paper focused on to investigate the risks involved in a construction project and to develop the PRM framework using Industry 4.0 technologies for increasing the success rate of the project.

2. Literature survey

In this section, the LS has been performed from period 2000 to 2019, in Risk in construction projects, PRM framework and Industry 4.0 technologies. The first section of the survey gives knowledge of PRM and identifies the risk involved in the construction project. The next section provides a basic understanding of different PRM frameworks and Industry 4.0 technologies.

2.1 Project risk management

PRM is one of the standard research topics in the construction industry and project management. Many researchers have taken efforts in PRM of the construction industry (Tollin, 2011; Yang and Zou, 2014; Hwang *et al.*, 2017). Williams (1995) discussed techniques for the analysis of risk, to schedule (including analytical and more generally applicable simulation techniques) cost and technical achievement, both were separate analyses and the first step toward an integrated analysis. The ontological, epistemological and methodological assumptions are explored and formulated in a research approach that takes a practitioner's lived experience of projects (Cicmil *et al.*, 2006). The risk distribution occurs at three stages of the whole bid-pricing process, and final settlement depends on a set of complex and microeconomic factors (Laryea and Hughes, 2008). The rapid development in the construction industry motivated few researchers to start focusing on PRM and the green concept of a construction project (Zou and Couani 2012; Yang and Zou 2014; Yang *et al.*, 2016). A simple analytical tool that utilizes professional experience could be a viable option and uses risk cost as a common scale to facilitate closing the gap between theory and practice of risk assessment (Taroun, 2014). Aven (2016) reviewed the risk management with a particular focus on the fundamental ideas and thinking. The grounded theory approach used to identify tools for risk analyze selected 25 Australian construction project managers with tool preferences (Jepson *et al.*, 2018). Similarly, many researchers have worked on PRM practices for different applications such as medical product development for dental-product-manufacturing company (Kirkire *et al.*, 2015, 2018). Thirty risks were identified related to just-in-time supply (Jadhav *et al.*, 2015). The risk sources have explored in medical device development process (Rane and Kirkire, 2017). The different risk categories and barriers were represented for risk management in domestic and international projects (Dandage *et al.*, 2017, 2018). Eight different risk categories were explored in international projects and represented the ranking of risk categories based on their importance in project success (Dandage *et al.*, 2018). Threats, opportunities, weaknesses and strengths matrix was used to develop strategies for international PRM (Dandage *et al.*, 2019).

The big data also helps in project risk management. Big data collected from the site of the Chinese town of Wuhan helps to evaluate the tender price of construction projects (Zhang *et al.*, 2015). The usage of big data ensures a more accurate image of study related to objective assessment and eliminates the smaller data sets (Lu *et al.*, 2016). The questionnaire was designed in such a way to know the situation between adopted assumptions at the design stage and the results during the implementation of construction projects (Son and Kim, 2015). Costs and time are the aspects used to orient the survey, and conclusions should serve the future direction of the project at every stage of implementation. The data were collected based on global positioning system (GPS) receivers include data of public vehicles (geographic coordinates, speed, time of drive), personal devices and the onsite employee to ensure the safety and health, but the GPS loses the signals inside the buildings, so it was recommended to use in an open area (Zhang *et al.*, 2015). The technologies like Hadoop, cloud and map-reduce supported to collect the massive amounts of structured and unstructured data within reasonable and close to real time (Latanision, 2014). The system information model can be included in big data analysis based on the object-oriented approach (Love *et al.*, 2017). The different risks involved in the construction project were identified based on the LS and discussed in section 2.2 In the next part, the LS continued in the domain of PRM framework to explore the understanding and applications of the developed framework.

2.2 Risk in construction project

The comprehensive LS in the domain of PRM and construction project has identified 21 risks related to the construction project. Table I represents the identified risks, code assigned and sources of risks. The LS indicates that financial and technical risks are the most prominent risks in the construction industry. The new projects of the construction industry are more focusing on environmental risk as to its consuming maximum energy and natural resources to complete the projects. The LS identified significant risk categories involved in construction projects, which are financial, political, environmental, technical, operational, design and physical risk. Table II shows the mapping of risk categories with identified risks of the construction project.

Table I.
Risk associated with construction projects

Code	Risk	Sources
R1	Technical issues	Zou and Couani (2012), Yang and Zou (2014), Yang *et al.* (2016), Qin *et al.* (2016)
R2	Unclear design details and specifications	Tollin (2011), Zou and Couani (2012), Yang and Zou (2014), Yang *et al.* (2016)
R3	Lack of streamlined tools and processes	Lockwood (2009), Hwang and Tan (2012)
R4	Complex procedures to obtain approvals	Zou and Couani (2012), Qin *et al.* (2016)
R5	Delay in project completion	Chanter and Swallow (2007), Pitt (2013)
R6	Environmental risk	Zou and Li (2010), Chan *et al.* (2011), Ke *et al.* (2011), Yang and Zou (2014), Yang *et al.* (2016)
R7	Lack of availability of materials and equipment	Zou and Couani (2012), Yang and Zou (2014), Yang *et al.* (2016), Qin *et al.* (2016)
R8	New building policies change	Qin *et al.* (2016)
R9	High target	Qin *et al.* (2016)
R10	Import/export restrictions	Hwang *et al.* (2015), Zou and Couani (2012)
R11	Energy saving uncertainty	Lockwood (2009), Yudelson (2010) Penny (2012)
R12	Industry risk	Durmus-Pedini and Ashuri (2010), Drew (2011)
R13	Legal risk	Wibowo and Mohamed (2010), Zou and Li (2010), Chan *et al.* (2011)
R14	Loose control over subcontractors	Hwang *et al.* (2015)
R15	Safety and health	Zhao *et al.* (2016)
R16	Financial risk	Durmus-Pedini and Ashuri (2010), Penny (2012)
R17	Fluctuation in exchange rates	Zou and Couani (2012), Zhao *et al.* (2016)
R18	Unskilled workers	Zou and Couani (2012), Hwang, Zhao, See and Zhong (2015), Zhao *et al.* (2016)
R19	Team performance risk	Durmus-Pedini and Ashuri (2010)
R20	Unclear allocation of roles and responsibilities	Zou and Couani (2012), Yang and Zou (2014), Yang *et al.* (2016), Qin *et al.* (2016)
R21	Poor communication among projects stakeholders	Zou and Couani (2012), Yang and Zou (2014), Yang *et al.* (2016)

Table II.
Mapping of risk categories with identified risks

Sr. No.	Risk categories	Risk
1	Operational risk	R4: complex procedures to obtain approvals, R5: delay in project completion, R21: poor communication among projects stakeholders, R14: loose control over subcontractors, R20: unclear allocation of roles and responsibilities R9: high target
2	Technical risk	R1: technical Issues, R3: lack of streamlined tools and processes, R7: lack of availability of materials and equipment, R18: unskilled workers, R19: team performance
3	Environmental risk	R6: environmental risk, R15: safety and health, R11: energy saving uncertainty
4	Design risk	R2: unclear design details and specifications
5	Financial risk	R16: financial risk, R17: fluctuation in exchange rates, R10: import/export restrictions
6	Political risk	R8: new building policies change, R13: legal risk, R12: industry risk

2.3 PRM framework

The PRM framework was developed and implemented by many researchers in different sectors of industries but discussed only the selected and relevant frameworks. A risk management model was developed by integrating the system hazard analysis with Risk Management Process to assess safety and reliability risks associated with a system (or a project) (Rao Tummala and Leung, 1996). A theoretical framework was developed based on the phases of the risk management process for classifying techniques, phases of the life cycle of a project and corporate maturity toward risk (Cagliano *et al.*, 2015). A PRM framework was proposed to emphasize effective and efficient PRM practices and to support project managers in increasing the cost certainty of projects (Firmenich, 2017). A model was developed for risk management in a project-based organization of Iran (Jafari *et al.*, 2011). An innovative risk management model was presented for the design process of power tunnels projects (Soltani *et al.*, 2018). A qualitative risk mitigation framework was proposed for the risk management of construction project in developing countries (Wang *et al.*, 2004). An integrated framework was developed based on "grey theory, failure mode and effect analysis, and risk management matrices" for comprehensive risk management in the defense sector (Perlekar and Thakkar, 2019). The above survey gives insights and basic outline to develop the PRM framework. The next section of the review helps to understand the concepts and usage of Industry 4.0 technologies.

2.4 Industry 4.0 technologies

In today's era of technology revolution, more emphasis is on Industry 4.0 technologies, which motivates to continue the LS in the domain of Industry 4.0. The term "Industry 4.0" is derived from the project related to digital manufacturing and refers to the fourth industrial revolution of the future in the year 2011 (Tjahjono *et al.*, 2017). The big data, simulation, additives manufacturing, autonomous robots, augmented reality (AR), cloud computing and cybersecurity, Internet of Things (IoT) and system integration are the technologies used for the implementation of Industry 4.0 (Moktadir *et al.*, 2018). A framework was proposed for operationalization of Industry 4.0 in the manufacturing sector (Fatorachian and Kazemi, 2018). The strategic response on Industry 4.0 in the Chinese automotive industry is examined and the critical factors are identified for its successful implementation (Lin *et al.*, 2018). A sustainable Industry 4.0 framework was proposed based on Industry 4.0 technologies, process integration and sustainable outcomes (Kamble *et al.*, 2018). The better quality and flexibility in manufacturing impacted positively on Industry 4.0 supplier performance, but the rate of delivery and cost reduction did not have any statistical influence on the Industry 4.0 supplier performance (Salam, 2019).

AR helps the industry to provide services via information sharing. AR supports the industry to collect real-time data of system/process/customer and improves the decision making (Vaidya *et al.*, 2018). AR system gives a variety of services, such as providing training to employee from a remote location over a mobile device and helps in selecting a product/part from inventory. The individuation of innovative methods for the design of systems/products in production is done through the use of virtual reality in the manufacturing systems (Laudante, 2017). Big data represents a high volume, velocity and variety of data, which required specific technology and analytical method to transform in useful information (De Mauro *et al.*, 2016). Big data technologies are included with virtual reality, robotic systems, cloud computing, IoT, simulation, prototyping and 3D printing as the emerging technologies of Industry 4.0 (Kamble *et al.*, 2018). In today's era, most of the business is on real-time data analysis and cloud computing for gaining maximum profit. Cloud computing is one of the technologies used in Industry 4.0 for storage of large real-time data captured from various sources (Gao and Zhao, 2011). Cyber-security and cloud computing are going hand in hand in Industry 4.0 to enhance cybersecurity. It is essential to connect physical systems to cloud in Industry 4.0 journey for system optimization, quick decision, planning and quality management (Sridhar *et al.*, 2012). The IoT is an industrial internet or ecosystem that integrates the autonomous system, intelligent systems and association of human-machine to achieve improvement in efficiency, reliability and productivity of system/process (Wong and Kim, 2017; Vaidya *et al.*, 2018). IoT provides quick transfer of captured real-time data/information to enhance the decision making and collaboration among the stakeholders/decision makers (Yang *et al.*, 2017). The IoT-enabled smart logistic patents are analyzed using the roadmap methodology to identify technology-related business strengths and strategies (Trappey *et al.*, 2017). Mishra and Singh (2019) developed a framework for carbon management using life cycle assessment, IoT and carbon sequestration to achieve sustainable manufacturing.

Industry 4.0 has the following three dimensions of system integration: horizontal integration, vertical integration and end-to-end engineering across the entire product lifecycle (Stock and Seliger, 2016). In system integration technology, more than one system has been integrated to achieve higher efficiency, reliability and productivity of process/system. Additive manufacturing (AM) was introduced in Industry 4.0 to manufacture complex and lightweight products in small batches of customized products (Rüßmann *et al.*, 2015). Fused deposition method, selective laser sintering (SLS) and selective laser melting technologies are used in additives manufacturing to make faster and cheaper production (Thomas-Seale *et al.*, 2018). Additives manufacturing can reduce material transportation and stock handling (Vaidya *et al.*, 2018). The simulation is mostly used for the optimization of design, and scientific modeling for visualization of the working system (Heilala *et al.*, 2008). Two- and three-dimensional simulations can be created for system/product to estimate cycle time and energy consumption in virtual commissioning. the simulation results helps to know failure probability of the system/product during the startup phase of project. (Simons *et al.*, 2017). Simulation technology improves the ability of decision making with proper justification (Schuh *et al.*, 2014). Autonomous robots are introduced in Industry 4.0 to perform work precisely in such areas where human are restricted or unable to deal with operations (Zhong *et al.*, 2017). Autonomous robots are designed to perform the assigned task accurately and intelligently with versatility, flexibility and safety in a given period (Bahrin *et al.*, 2016). The above survey helps to understand the basic concepts and different applications of Industry 4.0 technologies. In the next section, research gaps are discussed based on an LS.

2.5 Research gap based on LS

The LS shows the need to focus on real-time PRM of construction project, especially for heavy equipment and to integrate the Industry 4.0 technologies in PRM practices for improving project management.

2.6 Problem definition

In this paper, the Delphi method is used for problem identification and selection. The expert panel decided based on an LS (Table III) and selected to demonstrate the Delphi method from different construction industry such as LnT Construction, Hiranandani group and Lodha group. The selected experts further categorized based on year of experience, i.e. 0–3 years, 4–6 years, 6–10 years and above 10 years. The experts were involved in identifying the problems and parameters along with their weights. In the first discussion, experts suggested more than ten problems and a few parameters. In the next discussion, most active and prominent problems with parameters were selected to develop the matrix based on experts suggestion. The matrix was generated (Table IV) and shared with the

Sr. no.	Expert	Number of experts	Percentage
1	Top management	3	15
2	Site managers	7	35
3	Project managers	5	25
4	Procurement managers	5	25

Table III.
List of expert panel

experts to give their preferences based on the scale (strong effect (10), moderate effect (7), low effect (5) and no effect (3) (Potdar and Rane, 2018)). The response received from 20 experts have been sorted and represented in Table II, which shows a particular scale has received the highest response from experts, i.e. 12, 8 and 9 experts suggested strong effect (10) and low effect (5) on business, cost-saving potential and customer satisfaction, respectively, for first problem statement. The analysis identified a significant problem such as project risk management, which has received the highest ranking, i.e. 8.5. In this research, the problem statement has been defined based on the significant problem and discussion with experts as the development of a PRM framework based on Industry 4.0 technologies.

3. Research methodology

The research methodology flow chart has developed and shown in Figure 1. The methodology starts with the selected domain, i.e. construction project followed by an LS and discussion with experts. The literature identified reputed search engines such as science direct, emerald insight, Taylor & Francis online. Similarly, the experts were selected from different organizations having diverse experience. The discussion with an expert started with the question of "what are the problems faced by the construction industry?". In the response, experts have suggested many problems and drivers, but in this research, the most critical problems and key drivers are selected for further study based on experts' judgment. The LS and discussion with experts also help to confirm the problem statement and to derive research objectives as discussed in section 3.1. Section 4 discusses the different technologies of Industry 4.0-based strength, purpose and weakness approach to understand insights of technologies and to explore the usage for PRM. The essential tools and techniques for each stage of the PRM process have identified based on an understanding of the process of PRM. The link has identified between PRM, tools & techniques and Industry 4.0 to develop PRM framework based on Industry 4.0. The developed framework demonstrated heavy equipment of the construction industry (Section 5). The heavy equipment has been selected based on the frequency of usage. The parameters have been identified based on discussion with an expert to know the risk involved in heavy equipment. The sensors and inbuild system (On-board diagnostics) of equipment used to collect the data of selected parameters. In the next step, the data collection plan was developed to collect the data and analyze the collected data by appropriate tools and techniques. Section 6 shows the result, discussion and strategies for PRM; Section 7 represents conclusion, limitations and future directions. In the next section, the PRM framework using Industry 4.0 technologies for the construction project is discussed.

3.1 Research objectives

This research focuses on the following objectives:

(1) Identify the risk involved in a construction project.

		Parameters with weights			
		Business (0.5)	Cost saving potential (0.3)	Customer satisfaction (0.2)	
Sr. no.	Problem	S	S	S	Rating
1	Project scheduling and delayed	10	5	5	7.5
2	Project risk management	10	7	7	8.5
3	Reduce environmental issues	7	5	3	5.6
4	Improve productivity (man, material)	7	7	3	6.2
5	Enhance the safety and reliability	7	7	5	6.6

Table IV. Problem selection matrix (S-scale)

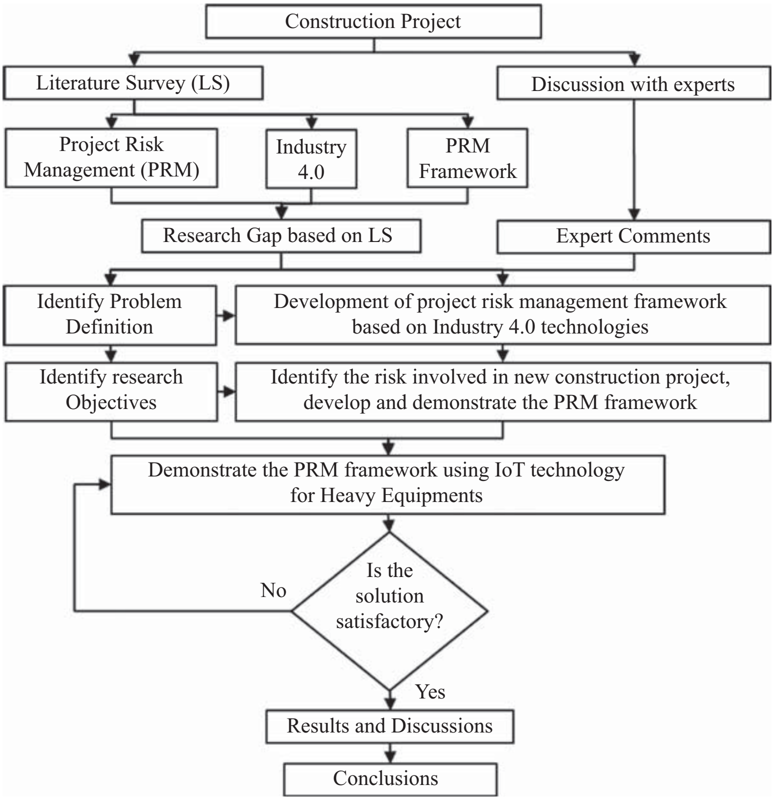

Figure 1.
Research methodology flow chart

(2) Develop a framework for PRM using Industry 4.0 technologies.

(3) Demonstrate the developed framework using IoT technology to manage the risk involved in heavy equipment of the construction industry.

4. PRM framework based on Industry 4.0 technologies

The framework has been developed based on the understanding of Industry 4.0, PRM concepts and working of the construction industry as shown in Figure 2. The framework distributed into different sections such as Industry 4.0 technologies, cloud computing and application layer (AL) for project risk management. Project Management Body of Knowledge (PMBOK) (2008) discussed the PRM process and some required tools to make decisions, which has been shown in Figure 2 by different modules such as tools and technique, risk management drivers, the risk review process, quantitative and qualitative analysis. The theoretical framework was designed for a supply chain network of Industry 4.0 (Sundarakani *et al.*, 2019); some discussed aspect of Industry 4.0 has been used to develop the framework (Rane and Narvel, 2019). Rezaei *et al.* (2017) developed an IoT-based framework for performance measurement of real-time supply chain decision, which has been used to design the framework for project risk management. The developed framework shows that the data are transferred from cloud computing to each stage of the framework to identify, asses, prioritize and monitor the risk. The AL used systems interconnection and focused on process-to-process communication across an internet protocols (IPs) network. It also consists of protocols to provide a secure communication interface, end-user services and shared network

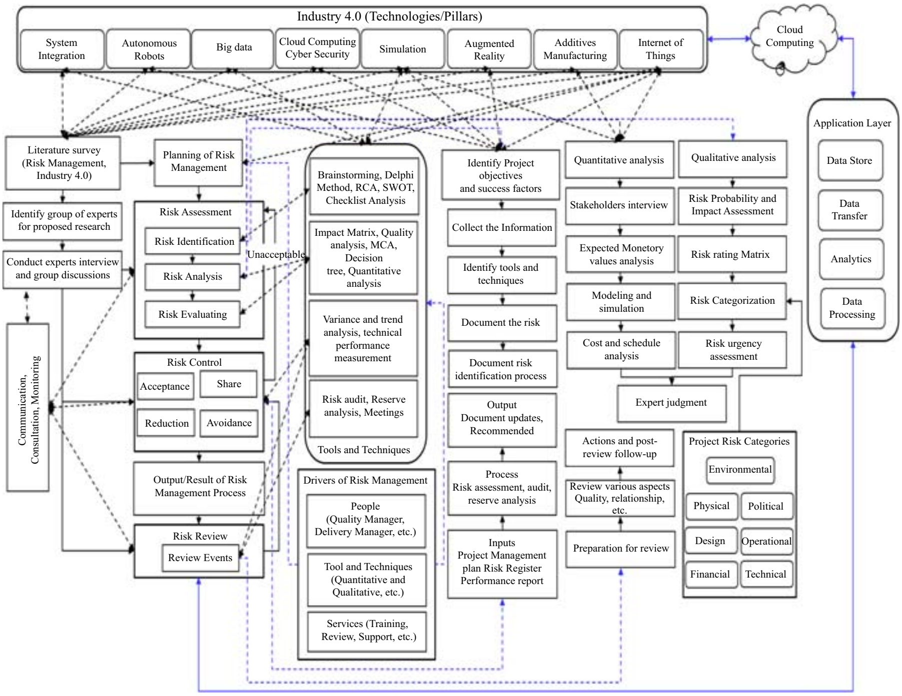

Figure 2.
Project risk management framework based on Industry 4.0 technologies

services with full end-user access for various users. AL is the top layer, where the actual communication has initiated and reflected. It also provides the facility for data transfer, processing and analysis. This layer has many responsibilities such as full network flow, data flow over a network, error handling and recovery. AL provides the information on the current project status, milestones and deviation of the project. This layer is the front end of the system where the user can enter and retrieve the data based on the requirement.

PRM process starts with risk identification and ends at the stage of risk review. The different risks are involved in the process of construction project management, which starts from idea generation to completion or handover of construction to the client. In this process, many people are involved from top management level till worker level to complete the project; different tools and techniques are used to solve the different problems that arise at the time of project execution and take services from clients in terms of training and support to complete the project in a given period. In the idea generation phase of the project, big data, simulation and system integration technologies of Industry 4.0, and brainstorming and Delphi method are helpful in the combination for risk identification. The user has to select the Industry 4.0 technologies to collect the data and choose the appropriate method based on available data to identify the risk involved in the project. If the data are unavailable or insufficient to take a decision, then the user has to select qualitative analysis for risk analysis else to use quantitative analysis, which helps to identify the critical risk involved in the project. In the next step of project risk management, the action plan has been developed based on a comparison between current and historical data; if the data are similar to historical data, the same actions can be implemented, else some new suggestions can be derived based on experts suggestions. The suggestions are derived in a way to accept/share/reduce/avoid the risks involved in the project. At the end of the process, the risk review was performed to know the impact of risk on project management after improvement; if results are positive, then update the document else revise the suggestions. In the review stage of project risk management, the system integration, big data and simulation technologies of Industry 4.0 are useful for decision making with justifications.

In Industry 4.0 scenario, construction site were equipped with sensors, actuators, computational systems with integrated advance and intelligent digital applications to connect various objects present on site, which develops digital networks of objects in the local/global area network. The digital network composed of three layers, such as hardware, communication and middleware or AL (Edirisinghe, 2018). The hardware layer of the digital network includes sensors, tags, tablets, smartphones, embedded chips (Arduino Uno) and smart gadgets for sensing the selected parameters and for communication. In communication layer, a wireless local area network, a GPS, wide area network, IPs, Wi-Fi, Bluetooth and Zigbee technologies needed for communication in the digital network (Edirisinghe, 2018). The middleware or AL of digital network helps for storage, cloud computing, analysis, computation and visualization according to the application requirements. Visualization method has invented, by integrating real and virtual construction, job site objects in a dynamic AR scene in real time (Kamat and Dong, 2017). A depth-sensing device and color camera were used for capturing an image of a construction job site object, a common coordinate system helps for registering the location of images. The CAD data and geographic information system combined to generate the AR scene (Kamat and Dong, 2017). A conceptual model was proposed for automated data collection technology to locate construction workers and developed labor-tracking applications, which was used by sacks (Navon and Goldschmidt, 2003). A system was proposed to automatically analyze workers activities task-by-task, which uses a combination of thoracic posture and real-time location sensors data to analyze worker's activities by encoding material handling, and idle and travel in various zones, including the storage zone, work zone and rest zone (Cheng *et al.*, 2013). A labor consumption measurement system was developed based on GPS, which helps to determine a current laborer status within the boundaries of a predefined construction region (Jiang *et al.*, 2015). The above discussion helps to understand the process of developed framework and method to generate a large amount of data for the construction project. The next subsection discussed the different Industry 4.0 technologies with a suitable example of a construction project.

4.1 Augmented reality (AR)

Strength: it is helpful to collect real-time data of system/equipment/customer, which can enhance the correct decision making with evidence.

Purpose: the purpose of AR technology in PRM is to manage different risks associated with the project by sharing the appropriate data and actions. The AR technology helps to monitor the environmental, design, operational and technical risks of the project.

How to use for risk management: a progress-monitoring system based on AR was always involved in collecting on-site data by using various means such as photogrammetry and laser scanning (Fu and Liu, 2018). The collected data are then organized and further used to compare with planned data provided by model software such as BIM or 4D-CAD, which helps to identify the difference between the planned and current status of the project. At last, results are compared and presented in AR environment in which different colors are used to indicate the status of work as "behind schedule," "on schedule," and "ahead of schedule" (Ahmed, Hossain and Hoque, 2017). This way, the AR helps to monitor risk related to the construction project as a delay in project activities. The AR supports to enhance professional training, leverage customer satisfaction, avoid rework and increase the cost saving as a project gets completed in time, with quality.

Weakness: the installation of AR technology required specialized systems with high computing power and programming skills, and it is also useful to manage only a few risks of the construction project.

4.2 Big data

Strength: it represents high volume, velocity and variety of data, which also shows the variations in data with respect to time.

Purpose: big data provides information related to design, finance, operation, technical and environmental aspects of the project and it is also useful to forecast contemporary issues occurring in the system and suggests the remedial measures to stop from occurring.

How to use for risk management: the big data has been captured and collected at various levels of construction projects such as the design phase, construction phase and operational phase. Environmental data, stakeholder input, survey the construction site (Drones) and social media discussions help to capture big data of construction project. Dozzi and AbouRizk (1993) specified that a low level of productivity is one of the significant challenge faced by the construction industry. The Building Information modeling (BIM) also known Virtual Design used to respond to the significant risk, i.e. productivity. BIM is a conceptual model that consists of object-based design, relational data base and parametric manipulation. The BIM introduced to convert the 2D technical drawing into the 3D design. Further, developments in BIM leverage the capability to convert a 3D drawing in 4D. BIM 4D model used for the visual animation of projects, but fundamentally, it enables progress tracking of construction projects. Similarly, drones are used in construction projects to know the current status. E.g. a flight of 30 mins over a 150 acres site can generate millions of data points in 3D models, which provides the current status of the project. This way, the big data helps to monitor the productivity of a construction project. Big data also helps to identify the different risks involved in a construction project such as unclear design details and specifications, loose control over subcontractors, financial risk and team performance.

Weakness: the big data has some limitation related to security, transferability, correlations and inconsistency in data, and it also needs high configuration systems and advanced technologies to capture, store and analyze the data.

4.3 Cybersecurity and cloud computing

Strength: it supports to share data with authorized users anywhere at any time. It also ensures the secure transaction of data.

Purpose: the purpose of cloud computing and cybersecurity technologies in PRM is to store captured real-time data from various sources and provide security to data. Cloud computing has developed in a recent year and described as scalability, availability, agility, elasticity, extensibility (Paquette *et al.*, 2010; Tisnovsky, 2010; Subashini and Kavitha, 2011).

How to use for risk management: Ashford (2009) stated data lost as Universal Serial Bus (USB) flash drives and laptops lost or stolen. The measurement result shows that 66 percent of USB sticks lost, and ~ 60 percent of those contain financial data. This scenario recognized that data loss is a critical risk involved in the project. In response to the identified risk, the cloud computing has introduced different service levels like Software as a Service (SaaS), Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). IaaS is the lower level of cloud computing where pre-configured hardware was provided via a virtualized interface and PaaS is at the middle level of cloud computing, which consists of operating system and application services. The SaaS has been included in the last level of cloud computing to offer fully functional applications and services such as e-mail management, customer relationship management, enterprise resource planning (Ward and Sipior, 2010). Heiser and Nicolett (2008) said that cloud computing helps for storing and processing data in multiple unspecified locations, often sourced from other, unnamed providers and containing data from multiple customers. This way, cloud computing and cyber security help to provide security to data by encryption logic; this can reduce the risk associated with data loss of the project.

Weakness: cybersecurity and cloud computing is useful to manage only two risks of the project as data security and data loss. It also has few weaknesses as loss of control, insider theft and unsecured application programming interface. The practical implementation of cybersecurity and cloud computing is required to moderate the bandwidth of internet to share or use the data of the project.

4.4 Internet of Things

Strength: this technology is useful for behavior tracking of equipment/system. It is also helpful for increasing situational awareness and promotes sensor-driven analytics.

Purpose: the IoT helps to monitor system/equipment in real time using different layers such as equipment layer, sensor layer, condition monitoring layer, security layer and application layer, which is useful to manage real-time risks associated with the project.

How to use for risk management: in the first step of IoT implementation, identify the equipment on which IoT has to demonstrate. In the next step, find out the most critical parameters to monitor based on the objectives, also find the sensors/systems to monitor the selected parameters (temperature sensors, camera, etc.). Develop the customized system to transfer the data with security and identify the threshold values (range) of selected parameters for condition monitoring. In the last step of IoT, the customized dashboard has been developed for ease of operation. The few situations are discussed below to know the working of IoT for risk management of the construction project. Cameras are placed on the construction site at the appropriate location to monitor inventory, human resource and construction status. The captured photos/videos of the project on a regular interval help to monitor different risks involved in a construction project such as delay in the project, productivity, etc. In case, if the inventory is insufficient to complete the assigned work, then the immediate action can be taken by the system, e.g. identifying the nearest and reliable supplier to supply the required inventory (Rane *et al.*, 2019). The next action taken by the system is to place the order and ask the supplier to supply material on very urgent bases, which can avoid discontinuity of the work. IoT is also useful for decision makers to know the status of construction and can compare with the planning. If there is a deviation in planning, then the system provides remedial action based on historical data. This way, system also helps to enhance the utilization of human resources, which can enhance resource productivity.

Similarly, the smart hard hat has been designed for construction workers to monitor body temperature and heart rate along with ambient temperature and humidity. Also, sound and vibration alert used if the worker is at risk of heatstroke. This way, the IoT enhanced the safety of the on-site worker and reduced the risk. The IoT technology has been adopted by a major manufacturer of heavy construction equipment to capture real-time information of equipment, which helps to reduce the risk such as equipment breakdown and delays in the project. The General Electric's has the latest Evolution Series Tier 4 Locomotive is loaded with 250 sensors that can measure 150 thousand data points per minute. The big captured data get analyzed and suggested corrective actions to enhanced safety, on-time performance, equipment uptime and durability. This way, the IoT helps to assess and monitor the risks associated with the construction projects (quality, safety, lack of availability of materials and health, equipment breakdown and delay in the project).

Weakness: IoT has some issues related to security and privacy of data. IoT develops a diverse network to connect various devices, and a single loophole can affect the entire system.

4.5 System integration

Strength: it helps to develop the communication and working environment between all horizontals and verticals of an organization for the entire life cycle of a product.

Purpose: system integration is a process of combination of various computing systems and software packages to create a more extensive system, and this helps to monitor and manage the project risk. System integration is useful to increase system value by creating new functionalities through the combination of sub-systems and software applications.

How to use for risk management: enterprise resource planning and IoT technology have been integrated to identify the risk involved in the construction project. In IoT implementation, sensors are used to capture real-time data of selected parameters for system/equipment. The threshold values are required to monitor the performance of system/equipment, which can be identified from the ERP system. As the value of selected parameters breaches to the threshold value, the system helps to identify the risk involved in the project, also suggest few remedial actions to overcome from the issue. The system integration helps to identify the different risks related to the construction project as the unclear allocation of roles and responsibilities, complicated procedures to obtain approvals, design risk. System integration that has been identified as a complicated procedure to obtain approval is a critical risk based on criteria as the completeness of project and time required to take approval from higher authority, it also makes delay in project activities. The actions are suggested to reduce the intensity of risk such as to distribute the approval authority appropriately based on the importance and eliminate unnecessary steps for taking approval, which is possible by using SAP system in the organization as it has been used in most of the world-class organization. In SAP system, all the departments of the organization, from the design department to the manufacturing section, are integrated to share the information related to project, which can reduce the rework and enhance the success of the project. Therefore, system integrator used to develop the project requirements during the preliminary or conceptual design phase, which can drastically reduce project costs and risks, also increase the likelihood of a successful project.

Weakness: system integration implementation is complex and challenging, which needs substantial high investment. It also involves high vendor dependency and inflexibility at the time of operations.

4.6 Additives manufacturing

Strength: this technology increases the use of 3D printing, rapid prototype, SLS used for the prototype. It is also helpful to reduce the development time of the product.

Purpose: AM technology is used to produce personalized products with lower development costs, shorter lead times, less energy consumed and less material waste. It also helps to manufacture complex parts and enables manufacturers to reduce inventory, make products on-demand and even reduce supply chains; this way, additives manufacturing helps to manage project risk.

How to use for risk management: the construction project is facing few risks such as a decrease in productivity, a decrease of a skilled workforce, safety during construction, producing large amounts of waste material and on-site transportation of materials. Shahtaheri *et al.* (2017) and Kalasapudi *et al.* (2015) observed that the available elements or modules on the construction site are not as per precise dimensions or tolerances, which increased the complications of the assembly process and consumed more time as required on-site modifications. Also, the integrity risk of the structure increased as fabricated components cannot maintain the tight tolerances, which introduced error in assembly. The AM helps to overcome from the above issues as it can produce the components with precise dimensions based on the drawing. Busta (2016) represented labor costs for the Dubai Future Foundation building was reduced by 50–80 percent using AM. AM allows customized parts to be printed on-demand from a 3D model without significant lead time. Instead of having multiple companies or trades producing different structural or non-structural components, each component can be produced directly using AM after design. During the construction project, there may be a case where components are lost or damaged and waiting for a replacement, which causes a delay in construction activities. Owing to this reason, the loss or damage of components identified as a critical risk and developed the technical issues. Additives manufacturing can manufacture components on site using material jetting and material extrusion method with minimum time consumption. This way, the AM helps to manage risk related to the project. Similarly, there are some risks involved in construction projects such as feasibility check and design validation after the design developed by the architect as per the specification. The risks involved in construction project increase, if ignored the feasibility check and design validation of design, which can develop financial and operational risk. The AM helps to make a prototype of design and confirm the feasibility of construction and validate the design. This way, the AM helps to mitigate the risk associated with a construction project.

Weakness: the AM consumes high production cost, required post-processing, poor mechanical properties and limited component size/small build volume.

4.7 Simulation

Strength: this technology provides a virtual environment for system analysis and optimization, which can help to reduce the development time and cost of system/product.

Purpose: simulation technology has been mostly used for predicting and evaluating the performance of complex and stochastic systems, which is having interactions analytically. It is also useful for decision making in different scenarios, and for optimization of design and operations of the system, which can help to manage some risk of the project.

How to use for risk management: the Simulation is a process that runs in a virtual environment with the help of appropriate tools and techniques to gain the desired output. Ganame and Chaudhari (2015) used Monte Carlo simulation for risk analysis of construction building at the time of project scheduling. The quantitative analysis of construction project schedule is shown in Table V. In the simulation phase, Monte Carlo simulation was used and run for 10,000 iterations. The result shows that the minimum completion time of the project is 264 days and maximum time 319 days. The simulation identified that 292 days are required to complete the project by taking into account all uncertainties and risks. The results clearly show that it is doubtful to complete the project within 282 days (0 percent). Moreover, there is a 100 percent chance to complete the project in 294 days (Ganame and Chaudhari, 2015). This way, the simulation helps to monitor and mitigate the risk associated with construction projects. The simulation also identifies the risk related to a construction project in the domain of design, scheduling, planning and manufacturing. The identified risks for the construction project are technical issues, unclear design details and specifications, and project scheduling.

Table V. Quantitative analysis of construction project scheduling

Activity	Optimistic (time in days)	Most likely (time in days)	Pessimistic (time in days)	Simulated (time in days)
Foundation	27	28	33	30
Plinth	33	34	52	43
Ground floor work	23	23	32	28
1st floor	49	55	70	60
2nd floor	47	53	75	61
3rd floor	48	54	87	68
4th floor	48	53	74	61
5th floor	49	55	77	63
6th floor	49	55	77	63
7th floor	71	81	119	95
Above 7th floor	84	99	124	104
Completion of the project	264	282	319	292

Source: Ganame and Chaudhari (2015)

Weakness: the simulation needs model validation, which can take a long time. Simulation cannot give a guarantee of accurate results; it is a compromise between accuracy and time of result gaining.

4.8 Autonomous robot

Strength: this technology assists high flexibility and versatility for different operations, and also ensures the safe environment to perform a complex and challenging operation.

Purpose: autonomous robots are useful to perform work intelligently and accurately with high safety, versatility and flexibility for a given period. It is also used to perform work of critical areas where works are restricted or unable to deal with operations. This way, the Autonomous robots are helpful to manage the risk of the project.

How to use for risk management: increase in construction projects leverages the use of autonomous robots to serve the client and environment. The different robots are used on site to perform various works such as a concrete distributor, concrete floor finishing robot and attaching the ceramic tile with hybrid construction robot system (Elattar, 2008). The use of the above-mentioned robots reduce the risk related to human health and safety, also they complete the work efficiently with quality. The autonomous robots are also useful to identify risks such as safety and health, unskilled workers, delay in the project, quality, environmental risk. Robotics and automation systems can achieve the following benefits in the construction industry:

(1) Enhance the safety of workers and the public by developing and deploying machines for dangerous jobs.

(2) Leverage the quality with higher accuracy.

(3) Increase productivity and reduced cost.

Weakness: autonomous robots required a high initial cost for complex operations and structure. It is economical only for mass or massive construction and useful for managing a few risks of the project.

4.9 Risk mapping with Industry 4.0 technologies

In this section, identified risks associated with a construction project have mapped with Industry 4.0 technologies as shown in Table VI. In the mapping table "Y- The technology helps to monitor the risk associated with a construction project," and "N- The technology does not help to monitor the risk associated with a construction project." The risk R1-Technical issues, monitor and mitigate by augmented reality, big data, cloud computing cyber security, system integration, additives manufacturing, simulation and autonomous robot. Similarly, all risks are mapped with suitable technologies of Industry 4.0 based on the understanding of purpose, strength and weakness of each technology. Table VII shows the mapping of Industry 4.0 technologies with the PRM process. IoT, system integration, big data, cybersecurity and cloud computing technologies help to manage most of the identified risks associated with a construction project.

5. Implementation of PRM framework using IoT technology

In this phase of the paper, IoT technology has been selected for demonstration of the developed framework, as IoT technology covers different technologies of Industry 4.0 such as big data, cloud computing, simulation and system integration. The construction industry also needs different types of heavy equipment (excavator, bulldozer and many more) to perform different functions (soil excavation and leveling) and to complete the project on time with quality. Heavy equipment also involved different risks, which can reduce the success rate of the construction project. This situation motivates to select IoT technology and heavy equipment to demonstrate the developed framework. In the demonstration stage, experts

Risk	Augmented reality	Big data	Cloud computing cybersecurity	Internet of Things	System integration	Additives manufacturing	Simulation	Autonomous robot
	Industry 4.0 technologies							
R1	Y	Y	Y	Y	Y	Y	Y	Y
R2	Y	Y	N	N	Y	N	Y	N
R3	N	Y	N	N	Y	N	Y	N
R4	N	N	Y	N	Y	N	N	N
R5	N	Y	Y	Y	Y	N	Y	Y
R6	Y	Y	Y	Y	Y	N	Y	N
R7	N	Y	Y	Y	Y	N	Y	N
R8	N	Y	Y	Y	Y	N	Y	Y
R9	Y	Y	Y	Y	Y	Y	Y	Y
R10	N	Y	Y	N	Y	N	N	N
R11	Y	Y	Y	Y	Y	N	N	Y
R12	Y	Y	Y	Y	Y	N	Y	N
R13	N	Y	Y	N	Y	N	N	N
R14	N	Y	Y	Y	Y	N	N	N
R15	Y	Y	Y	Y	Y	N	Y	Y
R16	N	Y	Y	Y	Y	N	N	N
R17	N	Y	Y	N	Y	N	Y	N
R18	Y	Y	Y	Y	Y	N	N	N
R19	N	Y	Y	Y	Y	N	Y	N
R20	N	Y	N	Y	Y	N	N	N
R21	N	Y	Y	Y	Y	N	N	N

Table VI.
Risk mapping with Industry 4.0 technologies

have suggested few parameters (vibration, noise and fuel consumption (Potdar and Rane, 2018)) for real-time risk management of heavy equipment and only considered particular risks that can be monitored using selected parameters. The detailed IoT process has shown in Figure 3 with the PRM process for heavy equipment.

The IoT process starts with the equipment layer and ends at the application layer. The equipment layer helps to identify the different equipment associated in the construction project, and the sensor layer of the framework supports to monitor the selected parameters of equipment. The IoT framework is also integrated with the PRM process to monitor the risk associated with the construction project. The detailed PRM process discussed below and also demonstrated the IoT framework.

5.1 Risk identification

Risk identification is the initial stage of risk management, which helps to investigate the different risks involved in a construction project, especially in heavy equipment. Equipment layer, sensor layer and monitoring layer of IoT framework are useful layers to identify the risk involved in heavy equipment. In this research, excavator and bulldozer are considered in risk identification stage. The details of the risk associated with heavy equipment are as shown in Table VIII. The given parameters have mapped with the risk, as shown in Table VIII, which represents that most of the risks monitored by vibration and noise parameter.

5.2 Data collection plan

Data collection plan is useful to answer a few questions related to data collection. The data collection plan has been developed and shown in Table IX. Eight heavy equipment were selected from each category to optimize the time and computation efforts. The data were captured in an interval of 5 min to reduce the data volume and velocity, which helps to run the system smoothly.

Table VII. Mapping of industry 4.0 technologies with the PRM process

Sr. no.	Industry 4.0 technologies	Steps for project risk management				
		Risk identification	Risk assessment	Risk prioritization	Respond the risk	Risk monitor
1	Augmented reality	Delay in project activities and breakdown of heavy equipment	Assessment based on cost, time and effort	Identify the breakdown of heavy equipment as a critical risk	Identify alternative for equipment and arrange mechanic for maintenance	Develop a system to monitor equipment health
2	Big data	Unclear design details and specifications, loose control over subcontractors	Compare with standard design	Identify potential risk as unclear design details and specifications	Review the design critically from all aspects.	Develop a mechanism for critical design review
3	Cloud computing cybersecurity	Technical issues and financial risk.	Data and information shared used for assessment. Assessment based on the number of sanction project	Recognized technical issues as a critical risk	Integrate the One Time Password mechanism to share the data and information	Develop an encrypted coded system for security of data
4	Internet of Things	Lack of availability of materials and equipment, team performance risk	Assessment based on project completeness	Identify lack of availability of materials and equipment as a critical risk	Identify the nearest material supplier	Develop a system for live tracking of inventory and equipment
5	System integration	Unclear allocation of roles and responsibilities, complex procedures to obtain approvals	Project completeness and time required to get approvals	Complex procedures to obtain approval as critical risk	Eliminate the unnecessary steps for approval and distribute the approval authority appropriately	Develop a system to check pending approval and speed up the process of approval
6	Additives manufacturing	Technical issues, unclear design details and specifications	Assess based on implementation point of view and to check the feasibility of the design	Technical issues recognized as a significant risk	Identify alternative material for product and check all GD & T and CTQs	Develop a system to check all CTQ and GD & T critically
7	Simulation	Technical issues, unclear design details and specifications	Used stress analysis and GD&T for assessment	Technical issues detected as a critical risk	Change the GD & T, Identify alternative design/material for the product	Develop a methodology for simulation
8	Autonomous robot	Safety and health, unskilled workers	Assessment is done based on accidents and quality of work	Critical risk as safety and health	Conduct safety training regularly to increase awareness and confidence. The robot used for risky operations	Develop a mechanism to monitor frequency and type of accident

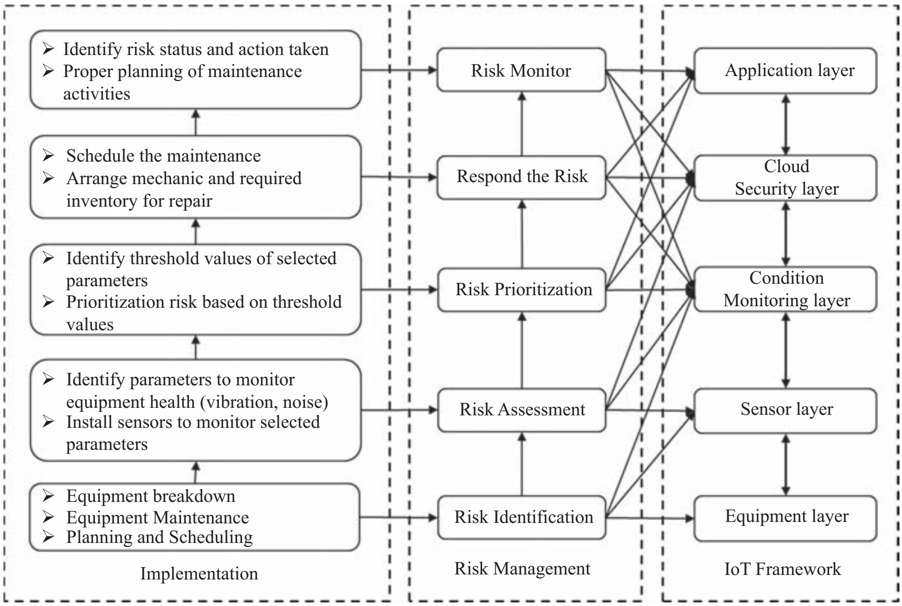

Figure 3.
PRM framework based on IoT technology

Table VIII.
Risk associated with heavy equipment

Risk category	Risk code	Risks associated with heavy equipment	Parameters help to identify risk
Physical risk	P-1	Sudden break down of equipment	Vibration and noise
	P-2	Critical damage to the equipment component	Vibration and noise
Financial risk	F-1	Delay in a project owing to equipment break down	Vibration and noise
	F-2	Increase in maintenance cost	Vibration and noise
Operational risk	O-1	Fuel theft	Fuel consumption
	O-2	Increase in vibration level of equipment	Vibration and noise
Environmental risk	E-1	Increase in CO_2 emission	Fuel consumption
	E-2	Increase in noise level	Vibration and noise
Technical risk	T-1	Uncertainty in equipment	Vibration and noise
	T-2	Unavailability of equipment	Vibration and noise

Table IX.
Data collection plan

Sr. no.	Subject head	Details
1	Select the heavy equipment	Bulldozer and excavator
2	How many heavy equipment must be selected for each category?	Collected data for 8 heavy equipment of each category
3	How to capture the data of selected parameters?	Using sensors
4	What is the frequency of data collection?	5 min
5	Who has collected the data?	GPS, Wi-Fi module, Smartphone
6	Which type of data has been captured?	Continuous stream

5.3 Data collection method

Data collection process ends with the step of the data collection method, which use to develop the check sheet and collect the relevant data as shown in Table X. The sensors are placed on the existing eight heavy equipment of each category to capture the data in the time interval of 5 min, which generates a maximum of 288 entries per day for a single parameter. The same number of entries expected for other parameters, which generates big data. In the next step, the captured data by sensors are available on the local area network. Then, it is sent to cloud with the help of the transmitter and receiver mechanism. The data have been securely stored on the cloud and shared with the construction manager, design engineer and mechanic to make a decision, which is known as the AL of the system.

5.4 Risk assessment

Risk assessment is the process of identification of critical risk that could negatively impact on organizations. There are two approaches to assess risks such as qualitative and quantitative methods. In this research, the qualitative method is used for risk assessment. The experts are also involved in assessing the identified risk in the scale of low to the high impact of risk and probability of risk. The different layers of the framework are useful to assess the identified risk, such as sensor layer, condition monitoring layer and cloud computing. The finalized risk assessment matrix is shown in Figure 4, which shows the probability of risk on the horizontal axis and the impact of risk on the vertical axis in the range from low to high. The assessment shows that the risk code P-1 and T-1 involved a high probability of risk, and the impact of risk on human and equipment is high. Similarly, risk P-2 and O-2 have a medium probability of risk with the high impact of risk on human

Equipment	ID no.	Fuel consumption (liters)	Vibration (m/s^2)	Noise (dB)
Bulldozer	B-1	138.7	1.3	94.6
	B-2	128.3	17	101.6
	B-3	120.4	1.8	138.8
Excavator	E-1	112.7	1.3	119.6
	E-2	104.8	1.4	121.5
	E-3	108.6	1.9	119.2

Table X. Data collection check sheet

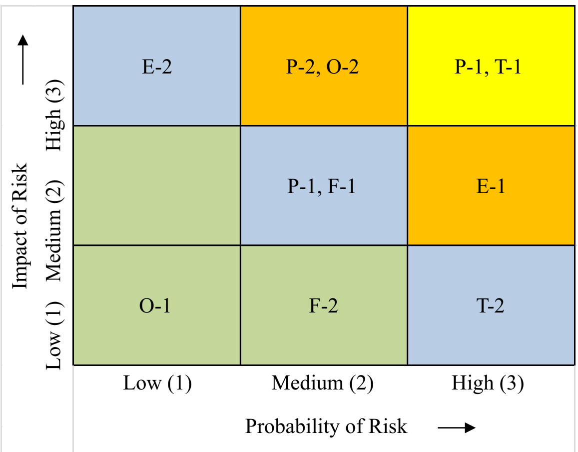

Figure 4. Risk assessment Matrix

and equipment. This assessment identified risk P-1, and T-1 are critical risks for heavy equipment, i.e. the sudden breakdown of equipment and uncertainty in equipment.

5.5 Risk prioritization

The risk prioritization is also a significant step in the PRM process. Many MCDM methods and decision tree technique are available for prioritization of risk. In this paper, the Analytical Hierarchy Process (AHP) method has been demonstrated as it is one of the most popular analytical techniques for complex decision making and also compares the alternative with each other. The weight of each risk has been computed by adopting the standard steps of AHP method discussed by Rao (2007). The different layers of the framework, such as the application layer, cloud computing layer and condition monitoring layer, are useful for risk prioritization. The AHP method computed weights for each risk are shown in Figure 5, which shows that the risk T-1 has received maximum weight, i.e. 0.493. Similarly, weights of other risks are P-1 (0.171), E-1(0.094), E-2 (0.0745) and O-2 (0.0745). The analysis identified the top five risks involved in heavy equipment are uncertainty in equipment, sudden breakdown of equipment, increase in CO_2 emission, increase in noise level and increase in vibration level of equipment.

5.6 Respond the risk

Risk response is the method for controlling identified critical risks by planning and decision-making process. There are different types of risk responses, such as avoid, mitigate, reduce, transfer, accept, share and contingency. The developed response for critical risk discussed in Table XI, which helps to reduce the intensity of critical risk.

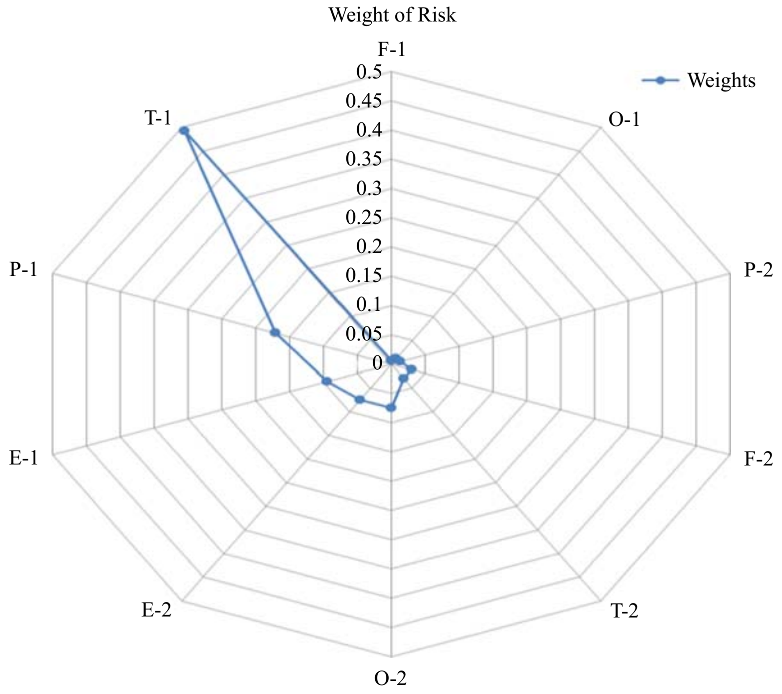

Figure 5.
Radiated diagram for risk weights

Sr. no.	Risk	Response
1	Uncertainty in equipment	Develop a system for real-time monitoring of equipment performance Monitor the equipment parameters (fuel consumption, noise and vibration) on real time Monitor the equipment maintenance activities intensively
2	Sudden break down of equipment	Develop a mechanism to monitor performance parameters of equipment Perform and check schedule maintenance activities
3	Increase in CO_2 emission	Develop a system for real-time monitoring of fuel consumption and CO_2 emission
4	Increase in noise level	Monitor noise and vibration level of equipment
5	Increase in vibration level of equipment	Monitor noise and vibration level of equipment

Table XI. Response for critical risks

5.7 Risk monitor

Risk monitoring is an ongoing process of managing and tracking of PRM execution. It is also continuing to identify and manage new risks. In this work, the developed framework has been used to monitor the parameters of the equipment, which helps to identify the risk and actions. The parameter threshold values are identified and monitored, such as noise level range for equipment varies from 80 dB to 120 dB. If the noise level of equipment breached to the upper limit, then the framework has identified the risk as well as gives the action to reduce the intensity of risk. E.g., the noise recorded as 132 dB for Bulldozer "B-2" identified different risks such as P-1, P-2, F-1, F-2, O-2, E-2, T-1 and T-2. In the next step, the critical risk has been identified based on the impact and probability of risk as discussed in section 5.4. The first response is given to critical risk to reduce the intensity and impact of risk on the project. Further, the response is given to all identified risk to reduce the risk probability as less as possible, which can ensure the success rate of the project. This way, the framework monitors the risks associated with heavy equipment, as shown in Figure 6.

6. Results and discussion

The paper illustrates PRM for the construction project and Industry 4.0 technologies based on purpose, strength and weakness approach. It also shows the usage of Industry 4.0 technologies for PRM of construction industries, as the growing demands of customers, stakeholders and professionals increased complexity in projects. However, the construction industry has a positive impact on saving energy and resource consumptions over the period. In the PRM process, the construction industries must identify, assess, monitor and control

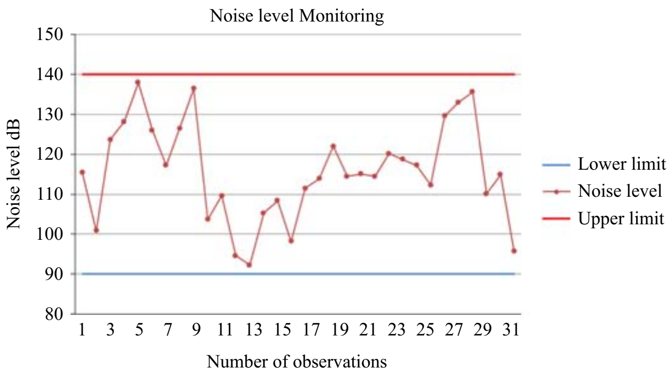

Figure 6. Noise level monitoring

risks throughout the design and development process of a project to minimize the likelihood of risk hazards. The effective PRM can be achieved based on understanding the risks related to the project and their interactions with Industry 4.0 technologies, which helps to integrate Industry 4.0 technologies with PRM for real-time risk management. In the demonstration stage of the developed framework, IoT technology has been implemented to manage risk associated with heavy equipment of the construction industry. The suggested parameters by experts help to monitor equipment health and performance, which also supports to monitor different risk associated with equipment. In risk identification stage, ten risks have been identified for heavy equipment in five categories of project risks. The AHP method has identified top five risks involved in heavy equipment that are as follows: first, uncertainty in equipment, second, sudden break down of equipment, third, increase in CO_2 emission, fourth, increase in noise level and fifth, increase in vibration level of equipment, in the prioritization stage of project risk management. Uncertainty in equipment and sudden break down of equipment identified as the critical risks based on computed weights by AHP method. The action plan has been developed to leverage the usage of Industry 4.0 technologies for PRM. In the monitoring stage, the real-time data have been compared with the upper and lower limit of selected parameters to monitor the risk involved in the project.

Industry 4.0 has few barriers for implementation, such as sensor technology, process digitization, data analysis, fog computing, infrastructure standardization, semantic interoperability, smart devices development, cyber-physical systems (CPS) modeling and modeling integration, CPS standards and specifications, automation system virtualization, collaboration and coordination, design challenges, interfacing and network, compatibility, investment cost, smart services, product technology improvement, eco-efficiency of technological processes, global standards and data sharing protocols and security (Rajput and Singh, 2019). These barriers develop some challenges to implement Industry 4.0 in the construction industry, which has discussed below in section 6.1, and few strategies are proposed for PRM based on Industry 4.0 technologies.

Financial challenges: Industry 4.0 technologies are still growing and facing financial challenges for implementation beyond laboratory experiments (Khoury and Kamat, 2009). The technology adoption in the industry involves a huge cost of equipment, which acts as a barrier for technology adoption (Wu *et al.*, 2010).

Technology standardization: Technology standardization is an essential need in construction industry to implement Industry 4.0 technologies, such as the standardization of RFIDs and tags are highlighted as a need in construction industry. Goodrum *et al.* (2006) and Erdogan *et al.* (2010) emphasized the requirement of standardization of regulations and policies for adoption of Industry 4.0 technologies. In the market, there are various suppliers and service providers of hardware and software with different specifications and capabilities owing to which it is challenging to develop standardization of technology for the adoption of Industry 4.0 technologies in practice.

Technology limitations: The main technological layers of the future smart construction site are sensor/hardware, communication and application/software. However, hardware and sensors are the most essential part of smart construction, but limited battery life, sensitivity, low reliability, accuracy and computation power present challenges, for example Yi *et al.* (2016) used smart bracelet for heart rate monitoring, but malfunction during site testing and (Jiang *et al.*, 2015) reported accuracy of hardware/sensors depends on external systems.

6.1 Strategies for PRM using Industry 4.0 technologies

The following strategies have been suggested for PRM using Industry 4.0 technologies.

Strategy 1: Integrate technologies of Industry 4.0, such as big data, system integration, simulation, augmented reality, cloud computing and cybersecurity to develop a clear vision and mission statement of the project.

Strategy 2: Risk identification must be started at an early stage of project management where big data, system integration and simulation technologies are used in combination for effective project risk validation.

Strategy 3: AR must be used to build awareness related to PRM efforts by training the employees to understand the impact of risk in projects using the virtual environment.

Strategy 4: Industry 4.0 technologies such as IoT, big data, simulation and system integration must be used in combination to develop a systematic real-time PRM process.

Strategy 5: Project team members must combine cloud computing, cybersecurity and system integration technologies in practice for effective communications within and outside the organization with respect to project risk management.

Strategy 6: Integrate simulation and system integration technologies of Industry 4.0 to motivate cross-functional teamwork and to improve the efficiency of collaboration and open communication.

Strategy 7: The simulation, big data and system integration technologies of Industry 4.0 must be combinedly adopted in project management practices for a realistic estimation of project cost and time.

Strategy 8: Integrate system integration and big data technologies to revise the PRM proposal, teams and responsibilities for effective project risk management.

Strategy 9: System integration must be used to derive rewards and incentives to be offered for managing the significant risk associated with the project.

Strategy 10: System integration and big data technologies must be used to establish risk management structure of an organization for defining roles and responsibilities of project team members.

7. Conclusion

The construction industries are aligning towards the smart city, and Industry 4.0 technologies have the potential to encash the opportunities for PRM of smart city and digital world. This paper aims to represent the general scenario of PRM using Industry 4.0 technologies and identify 21 risks of the construction project based on a comprehensive LS. The strength and weakness approach gives useful insights into Industry 4.0 technologies and understands its applicability. The demonstration of a developed framework was more straightforward and effective by using IoT technology for PRM of heavy equipment used in a construction project.

In the monitoring stage, the identified parameters have to monitor on a real-time basis for risk management. The risk identification should be made in the initial phase of the project, which can help the organization to develop strategies for PRM. The risk management team has to define risks clearly and proactively address risks consistently throughout the project. PRM practitioners must adopt suitable technology of Industry 4.0 to reduce the adverse effect of risk management efforts. If industry experts give attention to identified challenges, then the issue related to data sharing across the system/process would be error-free with minimum human involvement. Adoption of the developed framework makes PRM more efficient as all the departments are integrated, and data are readily available on the cloud. Integrated Industry 4.0–PRM framework helps construction industry experts to monitor labor activities, equipment and raw material status and safety to complete the project in stipulated time. The usage of developed strategies can leverage PRM in the context of Industry 4.0.

7.1 Limitations and future directions

The identified risks are specific for the case under consideration and may vary with respect to project complexity and geographical location. The primary focus of this paper is to develop the PRM framework based on Industry 4.0 technologies.

Risk prioritization and categorization are specific to the case, but can be modified and efficiently applied for other cases.

For future research actions, an assessment model can be designed to assess the risk index in a new construction project. Also, risk measures can be proposed to mitigate risk. The derived conclusions are based on a particular case; hence, some similar studies need to be carried in the future. The risk analysis can be performed using other techniques, and the results can be compared.

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