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PMI Research & Academic Virtual Conference 2021

Enhancing project performance: Application of AI and Decision Science

3 - 6 March, 2021

HOSTED BY

PMI Research & Academic Conference

(Virtual Conference 2021)

3 – 6 March, 2021

Theme:

Enhancing project performance: Application of AI and decision science

Conference Proceeding

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First Impression: 2021

Project Management in the Emerging World of Disruption
ISBN: 978-81-926239-9-3

Published by:
PMI Organization Centre Pvt. Ltd.,
#105, WeWork, 1st Floor, Oberoi Commerz II,
International Business Park, Oberoi Garden City,
Off Western Express Highway,
Goregaon (East), Mumbai 400063

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Preface

Advancements in the domain of Artificial Intelligence (AI) and Decision Science is creating revolutionary changes in different spheres around the world. Project management is of no exception, and has become more indispensable to embrace these new paradigms to enhance the handling of complex projects. Therefore, high end research in this domain is essential and could be a game-changer for better project management. However, the conventional principles of project management cannot be overshadowed by the advent of new tools and techniques. A progressive up-gradation synchronised with project management's well-established fundamentals should be enabled through quality research and development. AI is a broad term that encourages to rethink how information and data are processed and how these results can be used to better the existing practises. AI is more of an algorithmic technique as compared to a statistical analysis method such as decision science which involves huge amounts of data processing. AI tries to replicate human behaviour based on the information obtained, creating more response-based decisions. A combination of both creates an ideal mix for better decision making for complex problems that are influenced by a multitude of factors.

Introducing such modern techniques could have two spectrums of impact on project management. On one hand, these technologies will increase the demand for new complex projects and the need to execute them in shorter time frames. On the other hand, these technologies also have the potential to disrupt the fundamentals of traditional project management. For a 60-year-old profession such as project management, continuous evolution has provided solutions to handle complex projects ranging from large Olympic venues to skyscrapers and several other massive infrastructure projects. Project management's future looks to battle even more complex challenges ranging from human-crewed space missions, hyperloop technologies, and high-speed rails. Therefore, a mere facelift of project management approaches might not suffice and AI and decision sciences can enable the effective management of these challenges.

The PMI RAC conference of 2021 tries to bring in meaningful insights to enhancing project performance by applying AI and decision science techniques. Of the 74 papers received for the conference, these proceedings present 25 high quality selected papers that provide interesting insights on the transformation of Project Management with the advent of AI and Data Science.

Bill Gates once said that "The advance of technology is based on making it fit in so that you don't really even notice it, so it's part of everyday life". Therefore, AI and decision science-based techniques should be smoothly moulded into the existing practices to make it as a way of doing, then a forced practice in project management. We hope that this PMI-RAC 2021, would enlighten the project management community to upgrade themselves to embrace modern innovative tools and techniques for better performance and delivery.

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Acknowledgements

We are happy to bring out the proceedings of the PMI South Asia Research and Academic Conference 2021 on the theme, "Enhancing Project Performance: Application of AI and Decision Science" hosted by IIT Bombay, Mumbai. We congratulate all the authors who have contributed to this volume. We are confident that both practitioners and researchers will be able to derive benefits out of this proceeding. We thank the reviewers whose inputs helped in enhancing quality of the papers. The administrative support and encouragement given by PMI South Asia India officials is also gratefully acknowledged.

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CONTENTS

Section I

DATA ANALYTICS IN MANAGING PROJECTS

Editor's Note

This section presents five interesting studies that investigates on various data analytics techniques in managing projects. For instance, Jadhav et al. focuses on the extent of implementation of AI, its familiarity or awareness, and advantages in project management activities in building services, where a lot of time is spent in planning prior to execution. This study also discusses various AI applications that are currently used in the infrastructure development and building services. Through many semi structured interviews of the stakeholders, the paper features the degree of AI adoption and preferences in building services, which serves as a set of key insights for all the AI application developers related to the building and building services industry.

Meanwhile, Mathur et al. discusses various design principles to be adopted in the delivery framework of data science initiatives (DSIs) that would potentially increase the obtained value against the investment. The study explains the proposed framework with five core domains which is intended to deliver higher value from implementation of DSIs.

With the introduction of many mega projects across countries to promote economy while addressing the concern to build environmentally fit society, Devkar et al. investigates in monitoring and creating maximum public value from these projects through big data analytics. The study also addresses various challenges faced by governments and public agencies to effectively use big data. The authors also identified opportunities where big data analytics could play a greater role in enhancing public value creation in mega projects. Likewise, Iyer and Gupta discusses the application of blockchain technology to automate the contractual processes, performance and administration of construction projects. This study provides a more collaborative and transparent framework to address the challenges in contractual management in the construction sector.

Similarly, Kedia et al. analyses the knowledge obtained from a building construction site featuring near-miss safety observations. The analysis tests the suggestions that different ML algorithms are highly efficient in automatically classifying three types of site findings - "Unsafe Act," "Unsafe Condition" and "Good Observation." The research utilizes a supervised approach to machine learning using F1 scores, and tests six different algorithms. Analysis of errors are also performed to identify the techniques for increasing the precision of the forecast.

Integrating Artificial Intelligence in Project manager's decision-making process: A look at Built Environment projects

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ABSTRACT

The applications of artificial intelligence (AI) can be seen in many areas, predominantly in information technology, financial services and automotive industries. There is also increasing interest on use of AI for agriculture, education and healthcare services. However, the role of AI seems to be modest in the construction sector. The construction projects at present lacks the requisite digitization which can minimize the complications of completing these projects within the framework of schedule, cost and quality. The main emphasis of this paper is to address the applicability of AI tools in decision making process of built environment projects. The outcomes of this paper will provide significant insights to the stakeholders involved in the development of AI software tools. The study will also benefit the end users (project managers / project management consultants) interested to integrate and leverage AI more effectively and efficiently in their projects.

KEYWORDS: Artificial intelligence; built environment; project management; building services

1. INTRODUCTION

In recent years, the term 'Artificial intelligence' has gone from being a buzzword to the core interest amongst industries and research communities. The most common understanding about artificial intelligence (AI) is replication of human intelligence in machines. AI offers a variety of applications that can offer promising solutions for sustainable development (Goralski & Tan, 2020). Across the globe, there is an increasing economic and social trend towards development and application of AI (Aayog, 2018). The role of AI in construction projects was limited to use of single technique in the early research. However, the last decade saw use of multiple AI techniques to address the complexity in construction projects (Xiao, 2018). The Engineering and Construction (E&C) sector is worth more than $10 trillion a year. However, it lacks the required digitization. The adoption of AI seems quite low in E&C in comparison with other industries (Blanco, 2018).

2. RESEARCH OBJECTIVES AND METHODOLOGY

The objective of this paper is to investigate the application of AI in project management with specific emphasis on building services. Considerable time is spent by architects and engineers in the planning phase of infrastructure building projects which certainly involves lots of iterations. This paper discusses the role of AI in the decision-making process of various project management activities.

The present study investigates the applicability of AI for built environment projects (specifically building services) and is divided into four parts. The first part presents literature review of various application of AI in project management as well as combination of AI with Building Information Modeling (BIM). The second part of this research provides insights from the semi structured interviews of stakeholders working on built environment projects. In the third part, a case study of air conditioning system is presented utilizing Autodesk Revit software. Finally, discussions and research directives are specified in the last part.

3. LITERATURE REVIEW ON AI AND BUILT ENVIRONMENT

The literature review is divided in to four parts. In the first part, the literature review presents the application of AI for project management in general. In the second part, literature review related to the application of AI along with BIM tools is presented. In the third part, studies related to AI and BIM tools specifically for building services are discussed. Lastly, in the fourth part, research focusing on AI for building performance is highlighted.

3.1 AI for Project Management

The project managers dealing with construction projects has to deal with the complexities in terms of various phases of the project as well as coordinating the various knowledge areas involved in a given project. The project managers are required to make very dynamic decisions involving various levels of expertise, prediction and judgment. AI can assist project managers in multiple ways (Munir, 2019). The role of AI is finding increasing application in project management tools and techniques thereby offering multiple benefits to the project managers (Schmelzer, 2019). The study also highlighted the benefits of AI in minimizing the time spent by project managers in various administrative tasks. In the past, few researchers have attempted to find the role of AI in making construction project plans (Levitt, 1988), modeling site layout (Tommelein, 1992) and predicting project success (Ko, 2007). Cost estimation is one of the tricky tasks in construction projects. This is one of the criteria for project feasibility study and decision making during the initial stages of the project. Juszczyk (2017) has discussed the non-parametric cost estimation of construction projects using AI. Elmousalami (2020) has identified the most common AI techniques for parametric cost estimation of construction projects. Fuzzy Logic (FL), Artificial Neural Network (ANN), regression models, Case Based Reasoning (CBR), Supportive Vector Machine (SVM), Genetic Algorithm (GA) were some of the commonly used AI techniques. The study made a comprehensive literature review on the use of AI techniques for estimating the cost of construction projects such as highway projects, building projects, water treatment cost, structural steel buildings, tunnel construction, field canal improvement projects, pavement maintenance, pump stations, bridge construction projects, etc. An Analytic Hierarchy Process (AHP) model can assist in appropriate selection of project delivery method (Al Khalil, 2002).

3.2 AI and BIM

The increasing complexity of building technologies has resulted towards in depth analysis of architectural modeling (Mahdavi, 1998). Building modeling as well as building performance simulation is a time consuming process. It involves defining the relevant building parameters as well as the impact of variations in the building components and systems on the overall performance of the building. BIM offers multiple benefits to project managers in terms of coordinating various project management knowledge areas. BIM is way forward for management of construction projects. Petrova (2019) demonstrated the role of AI to formulate complex engineering knowledge and help in decision making of sustainable design using BIM. Cost management is seen to be one of the significant benefited knowledge areas by implementation of BIM (Bryde, 2013). Sacks et al. (2019) illustrated framework for automated design review using AI and BIM. Sacks et al. (2020) focused on the key elements of BIM and AI that needs basic research to support commercial development. There is also increasing trend in construction management towards integrating Life Cycle Assessment (LCA) and BIM. Though BIM has the requisite potential to enhance the performance of LCA of buildings, yet an adequate framework is necessary that can be adopted efficiently in Architecture, Engineering and Construction (AEC) industry (Nwodo, 2017). Arunkumar (2019) highlights the role of AI in BIM to be more predefined and precoded. It involves the use of vast construction knowledge database. The findings of the study reveal that the construction industry will have to implement AI in its distinct form.

3.3 AI and BIM for building services

Coordination of building services (or commonly called as Mechanical Electrical & Plumbing (MEP) services) is a major challenge in industrial and commercial buildings and involves locating equipments, finalizing the route, detecting clashes, etc. This activity being a multi-disciplinary in nature needs requisite knowledge of each system over the project life cycle (Korman et al., 2003). The number of equipments and components in the MEP systems makes it more challenging while constructing the MEP model in BIM. It is also important to make a logical chain between these MEP components to make the facility management more effective. Instead of doing these activities manually, Xiao et al. (2019) proposed an automatic generation of logic chain of MEP systems in BIM. Kwon et al. (2019) developed a model based on GA and CBR to estimate the service life of MEP components. Construction managers have found BIM useful for visualizing the project, in reducing the overall cost and assisting in conflict resolution (Gerges et al., 2019). In order to have efficient schedule and cost planning of building fabric maintenance, Chen & Tang (2019) proposed an innovative workflow which integrated BIM with digital programming. The paper emphasized on the need of AI in Building Life cycle Management (BLM) across various stages. Some of the organizations working in building services (or MEP services) have started realizing the potential benefits of using AI as a tool for effective coordination of these services.

3.4 AI for building performance

It has been observed that most of the project managers constantly concentrate on the triple constraint of time, cost and quality while working on the project. However, in case of a building project, it is equally important to understand the behaviour of the building during post occupancy. Therefore during planning and execution of construction of state-of-the-art buildings, it is necessary for the project managers to have a comprehensive understanding of the life cycle cost. Ustinovičius et al. (2015) proposed research directives in the area of BLM. The use of artificial intelligence algorithms such as swarm intelligence, neural networks and evolutionary algorithms can be used in the architectural practice (Cudzik & Radziszewski, 2018). Use of AI for buildings (Loveday & Virk, 1992) and building management systems (Clark & Mehta, 1997) has also been an area of interest in the past for few researchers. Dounis

(2010) conducted a review of various AI technologies for energy conservation in buildings. Among the various AI tools for Heating Ventilation and Air Conditioning (HVAC) control, more emphasis is seen on weather forecasting, optimization and predictive controls (Cheng & Lee, 2019). The authors (Cheng & Lee, 2019) also investigated the performance of AI assisted HVAC controls for six water cooled chillers. Recently Mehmood et al. (2019) conducted a review on use of AI for design and operation of energy efficient building. The authors observed that GA, FL and AHP are the most commonly used AI techniques. The contribution of AI can be limited to monitoring the performance of building. However, integrating Big Data (BD) with AI is more effective to decide the mode of operation of various building components. Several building performance simulation tools are available that can perform the building simulation. ANN can be used as a significant tool towards predicting the energy performance of the building (Krarti, 1998) as well as for comparison of various building performance simulation tools (Yezioro, 2007).

As can be seen from the above literature review many researchers have leveraged AI (in combination with and without BIM) to tackle issues of technical nature as well as issues related to project management.

In the next section we present point of view of selected stakeholders working in building services domain and the applicability of AI to the issues faced by them.

4. SEMI STRUCTURED INTERVIEWS

Though the literature review addresses the various applications of AI for buildings and building services, its use amongst AEC industries is uncertain. Therefore the authors have tried to investigate what are the current practices adopted while managing building projects and to what extent is the use of AI and BIM for project management of building projects.

The authors are actively involved in training programmes for working professionals in construction project management and building services. Therefore, to understand the issues and challenges faced by the project managers for building projects, semi structured interviews were conducted with the participants during the training programme.

The profile of respondents is specified in Table 1.

Table 1 Profile of Respondents

Organization	**'A'**	**'B'**
Background	Company A is one of the leading MEP companies in Asia providing end-to-end solutions for building services (MEP services).	Company B is one of the public limited company owned by Government of India and has high rise office buildings in various parts of India.
Respondent's profile	The respondents are into planning and coordination of MEP projects, energy retrofit projects, etc.	The respondents are involved into coordination of facility management, building retrofits, new building projects, etc.
Designation of respondents	Area manager – Estimation / Project / Sales / Planning / Procurement	Executive Engineer
Number of respondents	27	25
Respondent's experience	Min: 3 years, Max: 14 years Average experience (27 respondents): 8 years	Min: 6 years, Max: 35 years Average experience (25 respondents): 16 years

4.1 Observations:

Following are the salient observations based on the interactions with the respondents.

1. The project managers from company 'A' were having some technical understanding of HVAC but respondents from both company 'A' and 'B', agreed that they needed more comprehensive understanding about the mechanism of building services (MEP services), especially HVAC as it constitutes the major part of building services.
2. The fundamental understanding about MEP services and its integration in the overall scope of project was seen missing. Therefore, majority of the respondents were unable to understand the impact of some changes in the system design and selection, on the overall project in terms of cost, risk and procurement.
3. The engineers and project managers from company 'A' and company 'B' were using planning software such as Microsoft Project, Primavera. Respondents from company 'A' were also aware of design software such as Carrier Hourly Analysis Program (HAP), psychrometric calculator, duct sizer, fan selection, chiller selection, etc. But

these software are mostly standalone software and the integrated approach is missing when one uses such software. BIM on the other hand offers an integrated approach towards designing, scheduling, costing and other project management activities.

4. The average industrial experience of project managers from company 'A' was 8 years whereas from company 'B' was 15 years. Yet, the respondents were not aware of the benefits of BIM and how to use BIM for project management activities such as system sizing, costing, scheduling, etc. Majority of them were also of the view, that AI is mostly suitable for non-construction projects.
5. Lack of good project management practices while doing the cost estimation, was another major observation revealed during the interaction.
6. Respondents from company 'B' were also involved in the facility management of buildings. However, the awareness and implementation of asset management of building services was missing in their project activities.
7. Though the respondents were handling multiple projects, yet the technical project management was seen as an area that needed significant improvement. Majority of the respondents were lacking the requisite skills of the elements of technical project management such as schedule, cost, quality, risk and procurement. Therefore, in many cases they had to rely on the analogous data, some thumb rules and unnecessary oversizing the systems to avoid operational failures.
8. The majority of the respondents admitted the missing of integrated approach during their project implementation.

5. CAN AI ASSIST IN TECHNICAL PROJECT MANAGEMENT?

The three key skill sets necessary for a competent project manager includes technical project management, strategic & business management and leadership (PMBOK guide, 2017). Technical project management plays a key role in construction project management. Technical project management is influential in knowledge areas such as schedule, cost, quality, risk and procurement. The objective of this case study is to demonstrate the applicability of AI in technical project management. To address the role of AI, the authors have selected a case on air conditioning system (as a part of HVAC system) as specified in Fig. 1. This case addresses the current process in BIM and the possible future role of AI in BIM. It is to be noted that the model suggested in Fig. 1 is for discussing the HVAC challenges while using BIM and hence detailed architecture (doors, windows and other supplementary building components) is not provided.

The elements for discussion include building envelope, HVAC system sizing and selection, air distribution, duct layout, duct schedule and costing.

The authors have used Autodesk Revit software (BIM software) to illustrate the specific challenges faced by architects, engineers and project managers working on building project.

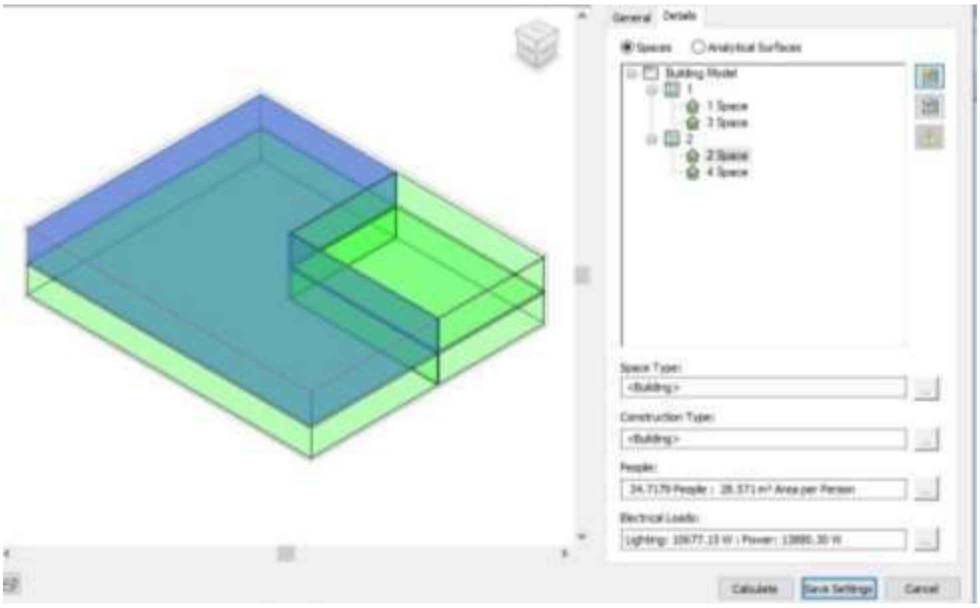

Figure 1 Building layout under study

5.1 Selection of building envelope

Several combinations can be made while selecting the building envelope as shown in Fig. 2.

Analysis Properties

By default, analysis properties are generated from information in model elements.
Properties of Analytic Constructions are used when override is selected or model information is missing.

Category	Override	Analytic Construction
Roofs	☑	4 in lightweight concrete (U=1.2750 W/(m²·K))
Exterior Walls	☑	8 in lightweight concrete block (U=0.8108 W/(m²·K))
Interior Walls	☑	Frame partition with 3/4 in gypsum board (U=1.4733 W/(m²·K))
Ceilings	☑	8 in lightweight concrete ceiling (U=1.3610 W/(m²·K))
Floors	☑	Passive floor, no insulation, tile or vinyl (U=2.9582 W/(m²·K))
Slabs	☑	Un-insulated solid (U=0.7059 W/(m²·K))
Doors	☑	Metal (U=3.7021 W/(m²·K))
Exterior Windows	☑	Large double-glazed windows (reflective coating) - industry (U=2.9214 W/(m²·K), SHGC=0.13)
Interior Windows	☑	Large single-glazed windows (U=3.6898 W/(m²·K), SHGC=0.86)
Skylights	☑	Large double-glazed windows (reflective coating) - industry (U=3.1956 W/(m²·K), SHGC=0.13)

Figure 2 Selection of building envelope

When the process of building envelope is carried out, the software does not indicate whether the building envelope will comply with the energy conservation standards / green building standards. The architect / engineer has to physically check the selected Overall heat transfer coefficient (U) values and Solar Heat Gain Coefficient (SHGC) values for the building envelope with the available energy conservation standards / green building standards.

5.2 HVAC system sizing and selection

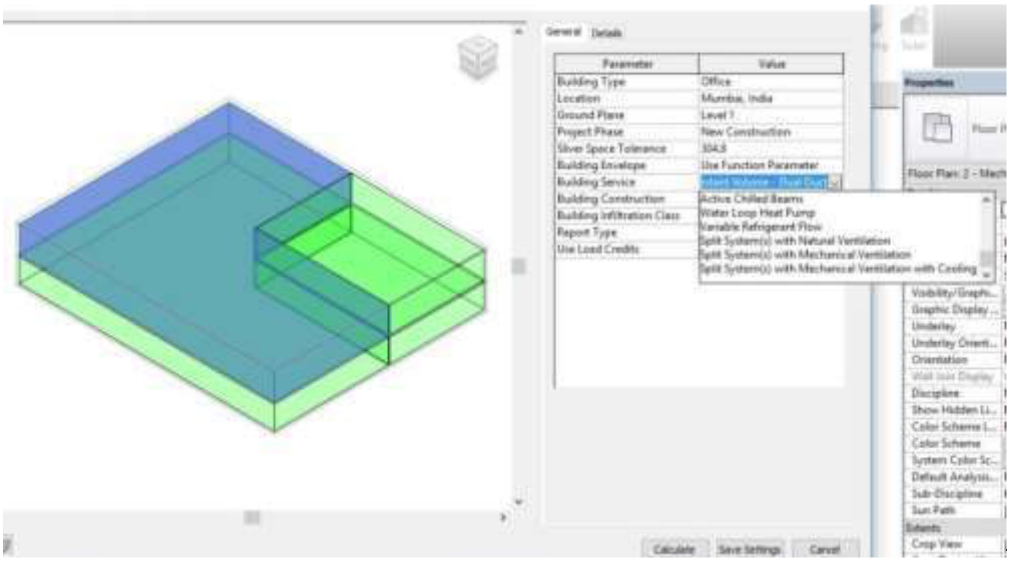

Figure 3 HVAC system sizing and selection

HVAC designer performs the air conditioning load calculations considering the factors such as location, internal loads and external loads. The designer then decides the type of system depending upon the total capacity, occupancy schedules, budget, space constraints, etc.

It is to be noted that selection of parameters indicated in Figure 2 and Figure 3 is not a part of AI. However, after the selection of relevant parameters as indicated in Figure 2 and 3, the further steps such as air conditioning load calculations, energy simulations are performed with the help of building algorithms (Fruin, 2019).

5.3 Air distribution

For centralized air conditioning system, the designer has to decide on the type of air outlets (supply and return) such as grilles or diffusers and their location (Refer Fig. 4).

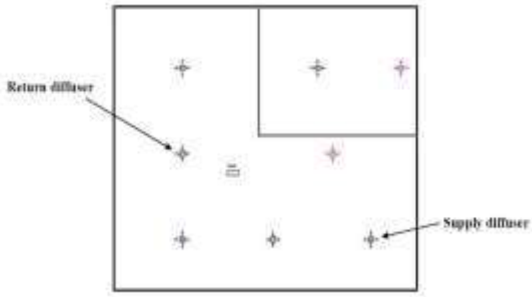

Figure 4 Air outlets (supply / return) positioning and selection

5.4 Duct layout

Once the location of air outlets and air handling unit is finalized, the software provides the various possible combinations of duct layout as shown in Fig. 5.

5.5 Duct schedule and costing

The duct sizing is then performed in Autodesk Revit (Refer Fig. 6). The finalization of duct layout (as seen in Fig. 7) is made based on the costing (Table 2), space available and checking the clash with other building services and building components.

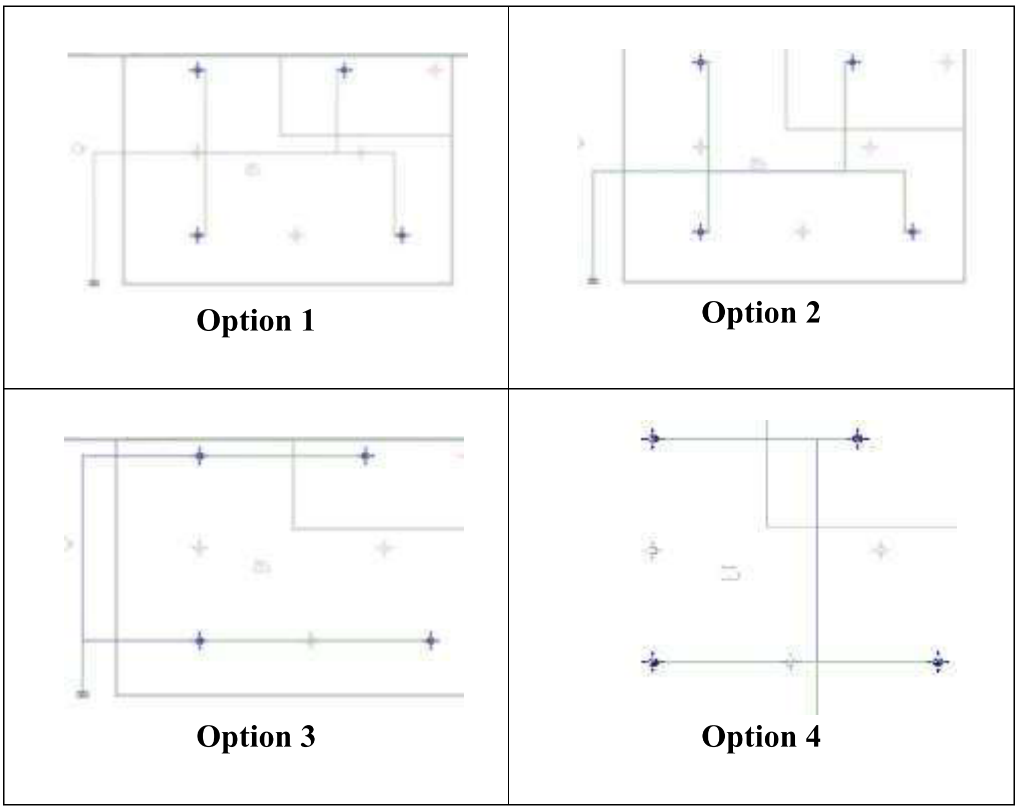

Figure 5 Various combination of duct layout

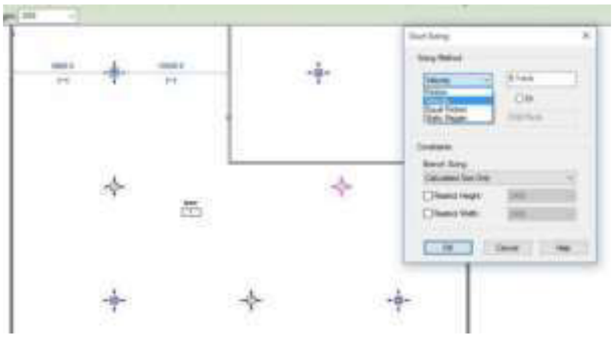

Figure 6 Duct sizing

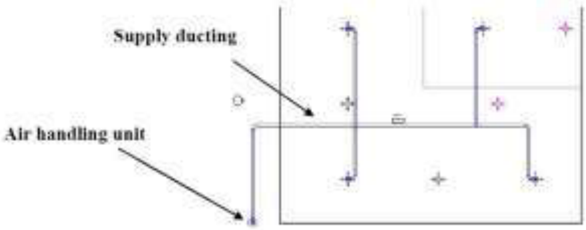

Figure 7 Duct layout

Table 2 Duct costing (for layout specified in Fig. 7)

Area	Size	Flow	Pressure Drop	Unit Cost in INR per square metre	Total cost INR
3 m²	300x300	235.0 L/s	0.7 Pa	750	1979
3 m²	300x300	235.0 L/s	0.7 Pa	750	1979
3 m²	300x300	235.0 L/s	0.7 Pa	750	1979
3 m²	300x300	235.0 L/s	0.7 Pa	750	1979
24 m²	406x356	470.0 L/s	5.2 Pa	750	17944
18 m²	406x356	940.0 L/s	14.0 Pa	750	13408
19 m²	406x356	940.0 L/s	15.2 Pa	750	14563
1 m²	406x356	940.0 L/s	1.0 Pa	750	1005
15 m²	300x300	235.0 L/s	3.7 Pa	750	10915
15 m²	300x300	235.0 L/s	3.7 Pa	750	10915
7 m²	300x300	235.0 L/s	1.9 Pa	750	5604
7 m²	300x300	235.0 L/s	1.9 Pa	750	5622
8 m²	300x300	235.0 L/s	1.9 Pa	750	5743
				Total cost INR	**93634**

5.6 AI and decision making

In this section we attempt to answer the question, can AI assist in decision making? The authors have summarized the current role of BIM (Fig. 1 to 7 and Table 2) in technical project management activity for the above case. The last column of Table 3 summarizes the expectations from AI in the decision making process.

Table 3 Challenges in building projects – A look at few HVAC activities

Activity	**Current BIM process**	**Role of architects, engineers and project managers**	**Associated major project management knowledge area**	**Can AI take the decision?**
Building envelope	Iterations is possible in selecting building envelope materials	Planning	Cost and Procurement management	Can AI decide the optimum selection of building envelope? (Refer Fig. 2)
HVAC system sizing and selection	Iterations is possible in HVAC sizing	Planning	Schedule, Cost, Risk and Procurement management	Can AI decide the selection of best air conditioning system and its components for a particular project? (Refer Fig. 3)
Duct layout and costing	Various possible layouts are generated	Planning and Execution	Schedule, Cost, Risk and Procurement management	Can AI decide which layout is relatively better considering the factors such as cost, space, etc? (Refer Fig. 5 to 7) Can AI perform the cost calculations specified in Table 2? Can AI completely design the air distribution? (Refer Fig. 6 and 7)

5.7 Inferences from the case study

There is no doubt that AI can assist project managers in technical project management. However, from the above example it is very clear that at present AI has a limitation in terms of decision making. ‘Expert Judgment’ is considered as one the significant technique in various knowledge areas of Project Management (PMBOK guide, 2017). At present, AI can assist the AEC team, but whether it can entirely deliver the role of Expert Judgment is uncertain at the moment. AI can assist architects, engineers and project managers in the decision making process but 100 percent replacement of humans by AI seem to be doubtful in the current era. For example, in the above case, the basic understanding of fluid flow, fundamental of air conditioning, system fundamentals, guidelines specified in the standards, project constraints such as space, cost, etc is interpreted by the architects, engineers and project managers before arriving at the final conclusion. Thus it involves an integrated approach of multiple stakeholders with specific expertise. Integrating such comprehensive data into software and validation of the same will be a challenging task for researchers in near future.

6. RESEARCH DIRECTIVES

AI certainly will have an impact on the current project management practices (Kerzner, 2018). Most of the IT related companies such as Microsoft, Google, IBM, Amazon, etc are considered to have excellent project management practices but their knowledge interface is limited to software industry. The construction industries are in the transformation phase trying to adopt more digitalization. AI is expected to play a significant role throughout the entire value chain of building projects (Schober, 2020). Tatum (2018) has highlighted that different application of modeling tools would be a promising alternative for future research in construction projects. In another investigation, the author also specified an increasing trend towards the technical content and specialization for successful implementation of project (Tatum, 2018). The lack of trained personnel in BIM and willingness to learn this new software are few of the limitations why BIM is not yet popular in majority of the construction companies (Gerges et al., 2019). The role of AI cannot be ignored in the future research in construction project management. AI will play a significant role in future design of buildings through the concept of generative design (Rao, 2019). Data collection and standardization will be one of critical step while using AI in BIM for generative design (Fruin, 2019). Lahmann (2018) has specified the transformation of project management methodology due to AI.

Following are the some of the specific research questions that need to be addressed in near future to integrate AI more effectively in construction project management.

1. What must be the framework for integrating AI in construction project management?

2. What type of case studies must be developed to have in depth understanding of AI in construction project management?
3. What must be the role of academic institute towards integrating AI in construction project management?
4. What are the various mechanisms to be adopted by AEC industries towards use of AI in their project management activities?
5. What must be the process flow for synchronization of work, by companies working in development of AI tools and project management companies who wish to use these tools for their project management activities?

7. CONCLUSIONS, LIMITATION AND FURTHER RESEARCH

At present there are several AI tools that support the project managers in their daily administrative task (Lahmann, 2018; Munir, 2019). However, the focus of the present study was towards use of AI for BIM.

The purpose of this paper was to provide significant insights into the use of AI for built environment projects. The authors have attempted to address the current issues faced by the AEC personnel through semi structured interviews and by illustrating few examples from building services.

The semi structured interview clearly identified that most of the respondents were not aware of and were not using latest techniques such as BIM in their project management activities. This is where the academic institutes need to contribute in educating the project management personnel on use of AI and BIM. Similar observation was also pointed out by Goralski and Tan (2020) while promoting AI for larger section of business. AI certainly can contribute towards streamlining the project management activities. There is some degree of uncertainty amongst AEC industries on the impact of AI and BIM in construction project management (Pampliega, 2019). The accuracy of data and integrating the data in standardized form will be one of the significant challenges for the future developments of AI in BIM.

Since the built environment projects are quite exhaustive, the present study limits its research only on buildings and attempts to find the significance of AI in dealing with the project management for building projects. The present study has a limited role towards the mechanism of various types of AI tools. As identified by Goralski (2020) AI can come up with further complex problem that must be thoroughly studied. Further scope of research extends to developing in depth case studies on integrating AI in construction project management. Whether AI can fully replace the role of project managers in future will be an interesting area for investigation.

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A Framework to Manage Data Science Initiatives

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ABSTRACT

Data is increasingly ubiquitous in organizational life and Data Science Initiatives (DSIs) have emerged as a popular mechanism for extracting value from it. However, the track record of these programs has drawn substantial criticism. For example, the success rate of delivering DSIs is not perceived as high with Gartner estimating that 85% of projects fail. DSIs have unique characteristics and pose challenges delivering the envisaged value when using traditional processes for managing ICT-enabled programs. There are occasions when DSIs should be managed as Exploratory Projects.

In this theoretical paper, we review the related delivery frameworks and propose a framework synthesizing program management, change management, scaled agile, data management and data science domains. The framework covers people and processes and specifically excludes products and technologies. The framework may enable consistency in how the practitioners plan and execute the initiatives potentially leading to an improvement in the success rate of DSI implementations.

KEYWORDS

Exploratory Projects; Program Management; Change Management; Scaled Agile; Data Management; Delivery Framework.

Declaration of Conflicting Interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding: This research is supported by an Australian Government Research Training Program Scholarship.

INTRODUCTION

Data Science Initiatives (DSIs) have unique characteristics and pose challenges delivering the envisaged value when using traditional processes for managing ICT-enabled programs. Due to uncertainty they carry in data, scope and schedule, DSIs often present themselves as candidates to be managed as Exploratory Projects. Furthermore, the Waterfall approaches to program management adopted by peak bodies, set up structural tensions between business case development, program design, delivery and benefits realizations that decouple value creation from capture and thus undermine coherent governance across the investment life-cycle. In this paper, we expand on existing frameworks proposed in the program management, change management, scaled agile, data management, and data science domains and propose a synthesized framework to deliver DSIs as Exploratory projects. In context of this paper, we use the term Data Science Initiative (DSI) to include investments in Data Analytics, Business Intelligence and Data Science including Machine Learning and Artificial Intelligence.

Balancing exploration and exploitation is key to organizational success and survival (March, 1991). Exploitative projects focus on optimizing cost-quality-time triple constraints to deliver new products and services whereas exploratory projects are those projects where neither the goals nor the means of attaining them are clearly defined from the outset (Lenfle, 2008).

In this paper, we draw on in-depth case-studies of six Data Science Initiatives (DSIs) delivered over last four years at Transport for NSW (Transport). Transport is a state government enterprise responsible for delivering safe, integrated and efficient transport systems to the people of NSW. Figure 1 provides an overview of the six DSIs used as case studies which includes the delivery timeline and complexity. Case Study of six DSIs has showed that they have unique characteristics (Mathur, 2019) around degree of uncertainty; enablers for decision-making; unclear goals; interdependency and skills requirement.

We aim to contribute to project and program management research by proposing a synthesized framework explicating the different logic (Lenfle, 2016) required to deliver DSIs as exploratory projects and incorporating program management, change management, agile delivery, data management, and data science domains.

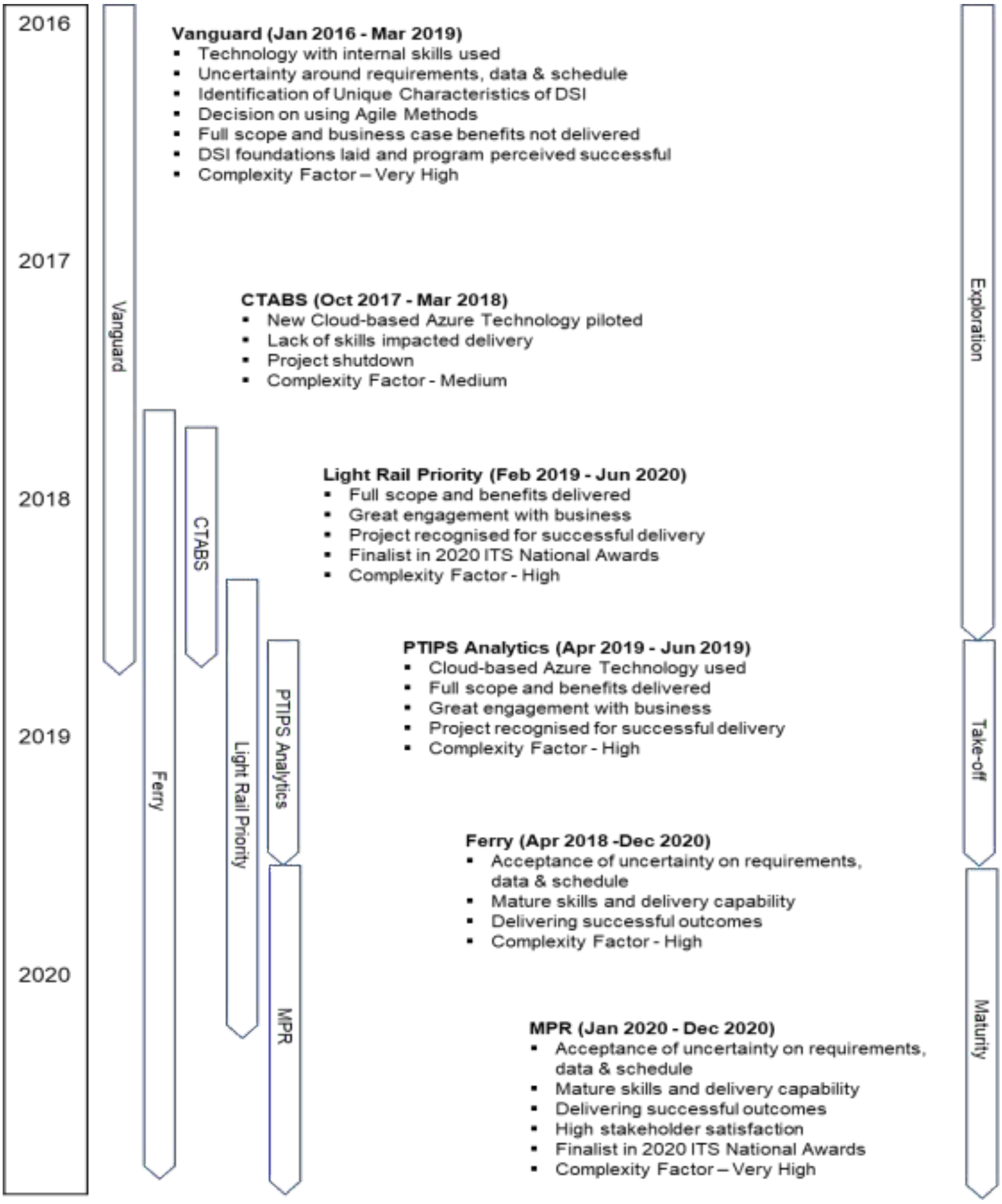

Figure 1. **Overview of six Transport for NSW DSIs**

MOTIVATION

Creation of a comprehensive program delivery framework for DSIs requires understanding of several domains and this section attempts to cover all such domains.

We see DSIs being typically implemented as a Program on a continuous spectrum rather than a single one-off project and will focus on Program Management rather than Project Management processes for delivery. A review of Program Life Cycle has identified gaps in using it for delivery of DSIs. Both PMI (Project Management Institute, 2017) and Managing Successful Programmes (MSP) (OGC, 2004) standards are widely accepted and used in the industry with PMI being principle-based and OGC providing detailed guidance on program management.

Value realization for any program occurs when the product and service created is adopted by users. Change management is a systematic approach that includes dealing with the transition or transformation of organizational goals, core values, processes or technologies. Kotter's Change Management Model (Kotter, 2007); McKinsey's 7-S Change Management Model (Lorenzi & Waterman, 1985); ADKAR Change Management Model (Hiatt, 2006) and Kübler-Ross Five Stage Change Management Model (Kübler-Ross, 2009) are some of the popular models used because of the simplicity in understanding them.

A need for large projects which are often globally distributed with teams requiring collaboration and coordination has led to popularity of scaled-agile frameworks such as Scaled Agile Framework (SAFe), Large-Scale Scrum (LeSS) and Lean Scalable Agilty for Engineering (LeanSAFE) (Ebert & Paasivaara, 2017; Leffingwell, 2007). In context of DSIs, we see the relevance of scaling is high as often multiple geographically spread teams within an organization are involved in delivering data science outcomes. A comparison of various five scaled agile framework shows each of them have strengths depending upon the use case in an organization.

Data Management is the development, execution, and supervision of plans, programs, and practices that deliver, control, protect, and enhance the value of data and information assets throughout their lifecycles (Earley, 2017).

Development of a DSI Delivery Framework requires good understanding of Data Mining and Data Science delivery processes. The Knowledge Discovery in Databases (KDD) (Fayyad, Piatetsky-Shapiro, & Smyth, 1996); Cross-Industry Standard Process for Data Mining (CRISP-DM) (Chapman et al., 2000); Sample, Explore, Modify, Model and Assess (SEMMA) model (SAS Institute, 2009); OSEMN model (Mason & Wiggins, 2010); Team Data Science Process

(TDSP) (Severtson, Franks, & Ericson, 2017) and Foundational Methodology for Data Science (FMDS) methodology (Rollins, 2015) are models considered appropriate in this context.

This view of the literature motivated us to ask the following research question: *"What design principles should be incorporated in a Data Science Initiative (DSI) Delivery Framework so that program managers can adopt a predictive path to realize value from such investments*?".

RESEARCH SETTING AND METHODS

Our research insights emerged from primary author's desire to deliver DSIs effectively underpinned by Future Transport 2056 Strategy to embed technologies such as big-data, internet of things, machine learning and artificial intelligence to deliver and improve customer journeys. Taking a practice lens on delivery of DSIs guided us to focus on full life-cycle of DSIs. Such a focus requires deep engagement in the field, observing and interacting with decision-makers, business stakeholders, program managers and delivery team members. As a result, we chose to study delivery of DSIs within a single organization (Transport) where the primary author of this paper is employed full-time and is setting up DSI delivery capability while delivering DSIs. This gave him access to data to conduct the case studies. To obtain granularity of program life-cycle as well as variation for analytical comparisons, we used an embedded case design (Yin, 2018) to track the unfolding of six DSIs in Transport, each of which provided a unique scope and opportunity to build DSI delivery capability. The six DSIs provide us with an opportunity to use an embedded case study research method covering all three purposes – exploratory, descriptive and explanatory (Scholz & Tietje, 2002; Yin, 2018). Our interest was to understand DSI delivery as experienced by the organizational participants themselves and identify uniqueness with this portfolio of initiatives to bring in improvements within the organization.

We used a variety of evidence including documents, artifacts, and participant observations from each DSI. Consistent with inductive research approaches, our research question emerged over time, as we engaged iteratively with evidence from the field and extant research that helped us make sense of what we had found.

The primary author is the program manager of the six DSIs chosen as case studies which were delivered between January 2017 to December 2020 or are still being delivered and thus brings in-depth insights of the program life-cycle.

This paper organizes the case by bracketing it into three project-stages: Exploration, Takeoff and Maturity stages Transport went through while six DSIs were delivered. The stages can be roughly mapped to DSIs delivery timeline of Exploration stage mapping to Vanguard & CTABS; Take-off stage mapping to Ferry, Light Rail Priority and PTIPS Analytics; and Maturity stage mapping to MPR. *Figure 1* shows the timeline and highlights of the six DSIs indicating author's journey from uncertainty and frustration of not being able to deliver program outcomes as per the schedule to acceptance of exploratory nature of DSIs and ability to plan the uncertainty and engage the stakeholders effectively. While each of the six DSIs were unique, this paper focuses on first (Vanguard) and sixth (MPR) as they represent boundary conditions of story presented here i.e., we present details of initial Exploration stage and close with that of Maturity stage.

DATA COLLECTION AND ANALYSIS

Six DSIs from Transport managed by the author have been used to collect data. Four DSIs are closed and two are still being delivered which has allowed us both real-time and retrospective data collection. While the scale of the DSIs is different, together they paint a good picture of unique characteristics and business cases. Table 1 shows the gaps and issues identified across three program phases.

DSI DELIVERY FRAMEWORK

In this section we review the design principles used to build the framework, the framework, and processes of the framework.

The Design Principles

Considering the exploratory nature of DSIs, the framework will conform to the following design principles:

- End-to-end delivery of solution and value realization;
- Core and non-core domains identification;
- Use agile methods to support exploratory nature of DSIs instead of waterfall;
- Support both single team and scaled agile delivery of data science capability;
- Specify people, process and deliverables; and
- Agnostic to tools and technologies

Table 1. Program Life-Cycle Deliverables & DSI Gaps & Issues

Key Phase Deliverables	Gaps & Issues for DSIs
Program Definition Phase	
Key deliverables of this phase are Business Case, Program Charter and Program Management Plan.	• For DSIs, risks associated with both costs and benefits are high. Considering the time it takes to develop and get a Business Case approved in both public and private sectors, the accuracy of the documents is questionable. • Unless the Program Management Plan stays at a high level, the accuracy of scope and schedule is low. The delivery mechanism will evolve as the Components are identified and executed.
Program Delivery Phase	
In this phase, individual Components are initiated, planned, executed, transitioned, and closed while benefits are delivered, transitioned and sustained in accordance to the Program Management Plan.	• For DSIs, identification of all Components upfront is difficult at the time Program Management Plan is developed and hence only limited planning can be done due to high degree of uncertainty • The Benefits will be discovered as the Components are planned & executed again due to high degree of uncertainty
Program Closure Phase	
In this phase, the Program Benefits are transitioned to sustaining organization and program is closed.	• While sponsor and stakeholders are continuously communicated and kept informed on both the costs and benefits delivered, for an un-initiated stakeholder the value delivered by the program may be questionable. The outcomes are often enablers to organizational decision-making capability rather than absolute financial and non-financial metrics.

The **F**ramework

The proposed framework has five core domains and integrates PMI's The Standard for Program Management (Project Management Institute, 2017) for program management; Proscii Framework (Hiatt, 2006) for people change management; Scaled Agile (SAFe) (Scaled Agile,

2020) for solution delivery; DAMA's DMBoK (Earley, 2017) for data management; and CRISP-DM (Chapman et al., 2000) for data science processes as per Figure 2 representing methods for the five domains.

As the domains are modular, it allows organizations to replace methods. For example, in program management domain PMI's methods (Project Management Institute, 2017) can be replaced with MSP (OGC, 2004). Furthermore, the framework is flexible to allow integration with other organizational domains such as Risk Management, Procurement Management, Asset Management, etc. Each process in the domain has been described in detail for the framework to be adopted by an organization implementing DSIs.

CONCLUSION

Limited availability of methods and standards in delivery of DSIs has caused the business managers and program managers to chart their own path and thus introduce inconsistency in how DSIs are treated and delivered in different organizations. With emergence of research such as this, it is expected that the standardization on DSIs will increase and provide guidance to the practitioners in efficient delivery of the DSIs.

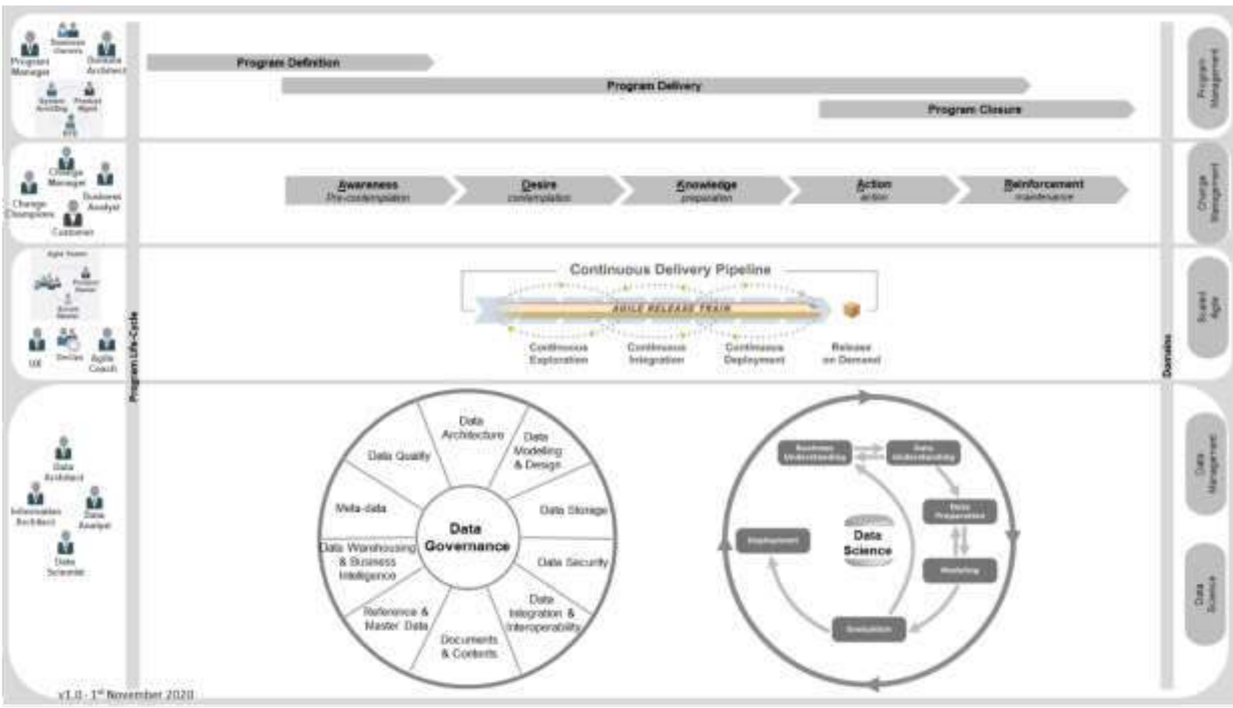

Figure 2. **DSI Delivery Framework**

Program Management for ICT-enabled Programs has rich literature and proven delivery frameworks which have matured over the past three decades (Project Management Institute, 2016, 2017; OGC, 2011). This paper makes a significant contribution to the theory and practice of the emerging field of data science.

The current Program Management literature does not adequately support delivery of DSIs and instead focuses on risk elimination and rapid delivery of business outcomes. We propose a DSI Delivery Framework which has five core domains and integrates PMI's The Standard for Program Management (Project Management Institute, 2017) for program management; Proscii Framework (Hiatt, 2006) for people change management; Scaled Agile (SAFe) (Scaled Agile, 2020) for solution delivery; DAMA's DMBoK (Earley, 2017) for data management; and CRISP-DM (Chapman et al., 2000) for data Science processes as per *Figure 2* representing methods for the five domains.

We suggest additional research to fine-tune the proposed DSI Delivery Framework which currently has been used for one public sector organization (Transport). The authors of the paper already intend to validate the trustworthiness and reliability of the framework through monitoring the use of framework at Transport as well as semi-structured interviews with practitioners and portfolio managers from other organizations. The framework proposed in this research will deliver a significant contribution to the body of knowledge for Program Management relevant to both literature and practitioners. Without this work, there will be more failed programs, dissatisfied sponsors and delay much needed investment in this emerging field as well as delay the benefits that will flow from harnessing the data and the nuggets in it.

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Data Analytics to Evaluate Public Value from Megaprojects

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ABSTRACT

The unprecedented investment in megaprojects that has been witnessed in recent years seems likely to accelerate post Covid-19 with several countries, like Australia and the United Kingdom, announcing large infrastructure projects for economic revival. COVID-19 has also created social challenges due to increased unemployment that could result in increase in poverty which could be helped when these projects become a reality. However, some scholars caution that rapid urbanisation and inappropriate development of infrastructure could work against containing a pandemic like COVID-19. The creation of value delivered by megaprojects has been gaining a lot of interest by scholars studying megaprojects. Big data sets are increasingly used to help public managers derive real-time insights into behavioural changes, public opinion, or daily life. Big data has been used to evaluate customer agility and responsiveness for public value creation. Based on this need this paper we would like to address the following question in our paper: How can data science enable evaluation and monitoring of delivery of public value over the life cycle of a megaproject?. Some work towards this aim has already been carried out by the authors but more is needed. The authors have been collected and analyzed social media data from transport projects from Australia and India to see how large amounts data collected from these media can aid in the evaluation of benefits realized from these projects

KEYWRODS
Public value, Big data, Megaprojects, Metro Rail

INTRODUCTION

The unprecedented investment in megaprojects that has been witnessed in recent years seems likely to accelerate post Covid-19 with several countries, like Australia and the United Kingdom, announcing large infrastructure projects for economic revival. COVID-19 has also created social challenges due to increased unemployment that could result in an increase in poverty which could be helped when these projects become a reality. However, some scholars caution that rapid urbanisation and inappropriate development of infrastructure could work against containing a pandemic like COVID-19. The environmental damage caused by rapid urbanisation has prompted urban planners to rethink the ways in cities can be developed in the future. Future cities need to foster both individual and collective wellbeing, with realization of ambitions, aspirations and other immaterial aspects of life and providing contentment and happiness. How do we ensure that such aspirations are not neglected in a rush to build more infrastructure? How do we ensure that social and environmental issues will be taken into account while responding to an urgent economic need for building more megaprojects? This brings us to be concerned about how public value will be taken into account and monitored in the building of new infrastructure in post Covid-19.

LITERATURE REVIEW

The centrality of public value in the spheres of public service delivery has been increasing over the years owing to the emphasis and debates over "substantive values" the organizations, involved in public service delivery, should be producing (Alford et al. 2017). These debates have immensely contributed to the conceptualization of the term "public value" as well as ways and means of imbibing, enhancing and assessing the public values. There exist diversity in the construct of public value, proposed by different scholars. Reynaers (2014) has created this construct in the context of infrastructure project delivered via PPP mode, which includes elements like accountability, transparency, responsiveness, responsibility and quality. The ambiguity over what constitutes public value and need for greater clarity, was the foundation of a paper by Andersen et al (2012). This paper has classified and empirically tested values of public managers and identified distinct public value dimensions alike public at large, rule abidance, balancing interests, budget keeping, efficient supply, professionalism and user focus. Alford & O'Flynn (2009) have made good sense of the concept of public value, by revisiting the origin of the term public value and current state of debates, and discussed emergent meanings of public values as paradigm, retheroic, narrative and performance. While the researchers are striving towards the better and more clearer conceptualization of public values, the another stream of literature has been elaborating on creation of public values in infrastructure development and value conflicts faced by public managers in the areas of infrastructure development and megaprojects implementation. For example, how stakeholder engagement in co-creation sessions helped in cocreation of public values in front end of infrastructure development programs has been discussed by Liu et al (2019). In similar vein, Thøgersen et al (2020) discussed the value creation through public innovation from the perspective of Danish public sector managers. Another set of empirical studies indicate dilemmas and trade-offs faced in pursuing public values and come up with various strategies or coping behaviour to manage or tide over these value conflicts (Oldenhof et al. 2014; Steenhuisen and van Eeten 2008).

While discussing the foundational issue over the use of the concept of "public value" or that of "public values", Alford et al.(2017) have aptly drawn attention towards an interesting aspect of "created public value - CPV" and "recognizing public value - RPV". They mention this aspect as follows:

> *'The utility notion of value suggests that what is being 'created' (as in CPV) and should be 'recognized' (in RPV, now in the sense of being 'measured') is an aggregate, a net resultant of what in reality are a wide range of concepts of utility or worth, which moreover can pertain both to the content of the service being delivered and the manner in which it is being produced.'. (p. 593).*

The authors of this paper are of the opinion that this aspect - CPV and RPV mentioned by Alford et al.(2017), indicates the emergent trend in the direction of "evaluation", "assessment" and "measurement" of public value. Interestingly, this paper is also focusing on evaluation of public value and is in line with this emerging trend.

The creation of value delivered by large infrastructure projects in the transport sector has been gaining a lot of interest by scholars studying megaprojects (Merrow 2011; Vickerman 2013). These scholars have explored diverse facets like stakeholder engagement in the megaproject delivery process; evaluation of social responsibility; cocreation of commercial, intellectual and collaborative values; and value creation in megaprojects through jointly planned and governed design principles, and value leveraging activities. A common concern of scholars researching in megaprojects is how to measure value perceived by the public from these projects (Lehtinen et al. 2019).

Simultaneously big data sets are increasingly used to help public managers derive real-time insights into behavioural changes, public opinion, or daily life (Mergel et al. 2016). Big data has been used to evaluate customer agility and responsiveness for public value creation. It is predicted that new smart technologies and strategies will shape and will be shaped by the future of public organizations and management and could lead to transformative practices in the public sector. Thus, there is a growing need to examine how smart technologies, such as Internet of Things (IoT), can be installed to collect large amounts of data to help in the measurement of value from megaprojects.

Based on this need this paper we would like to address the following broad question:

How will big data and data analytics help us to take into account and monitor public value creation from megaprojects?

And to delimit the scope for this paper based on reviewer comments we like to ask:

What are the barriers and opportunities for using big data and data analytics in public value creation from metro rail projects in Australia and India?

Big Data

According to Mergel et al. (2016)

> *Public administration researchers and practitioners for most of the fields history have bemoaned the lack of data for analysis and operations. In the space of roughly two decades, the Internet has turned this problem on its head. Now, scholars and practitioners are scrambling to realize the opportunities and face the challenges that "big data" presents. These "big" data sets are increasingly used to help public managers derive real-time insights into behavioural changes, public opinion, or daily life. p. 928*

However according to Kim et al. (2014)

> *Although the business sector is using bigdata in decision making the public sector is also catching up to support decision making in real time by fast growing dynamic data. But there is scepticism about Government's use of big data as it takes time to develop new capabilities and adopt new technologies. There are also difference in the way business and government use big data based on their attributes. p.80*

While big data seems to have enormous potential for public administration there is scepticism about whether this can be realised in practice. There are also differences in which big data is can be valuable to public organizations compared to private organizations

Let us examine some key differences between how businesses and governments get value from big data. See Table 1.

Table 1 Comparison of value created by big data for private and public enterprises . (Adapted from Kim et al. (2014), p.80)

Attribute	**Business Firm (Private)**	**Government (Public)**
Value	Profit to stakeholders by achieving value for money	Promoting domestic tranquillity and sustainable development
Achievements	Achieving competitive edge, customer satisfaction	Enabling security of basic rights (equality, liberty, justice), promotion of general welfare and economic growth
Decision Making	Maximizing self-interest and minimizing cost for short term gain	Promoting public interest through long-term decision-making
Financial gains	Revenue	Taxes
Collective activities	Competition and engagement	Cooperation and compliance verification

The three qualities of big data that make it difficult to make sense from it are (Kim et al. 2014):

Volume: Big Data can be generated in large volumes in terabytes, even petabytes requiring enormous storage and capacity to handle data.

Velocity: The data can be generated and processed in a very short time making it easier to make decisions faster. However, the pace of decision making may not be commensurate with the pace of generation and processing of big data.

Variety: It can be collected in a variety of forms – structured, semi structured and unstructured from a variety of sources posing problems for sensemaking.

While big data is a term used in several disciplines, a report proposed by the National Science Foundation is adopted by the US Government (Favaretto et al. 2020). According to this definition, big data is:

> *large, diverse, complex, longitudinal, and/or distributed data sets generated from instruments, sensors, Internet transactions, email, video, click streams, and/or all other digital sources available today and in the future p. 3*

On the other hand, the European Commission defines big data with a broader perspective (Favaretto et al. 2020)

> *large amounts of different types of data produced from various types of sources, such as people, machines or sensors. This data includes climate information, satellite imagery, digital pictures and videos, transition records or GPS signals. Big Data may involve personal data: that is, any information relating to an individual, and can be anything from a name, a photo, an email address, bank details, posts on social networking websites, medical information, or a computer IP address P. 2/3*

However, Favaretto et al. (2020) who recently carried out a survey of researcher's' understanding of big data as the phenomenon of the decade suggested that the definition varies across disciplines but overall there is an agreement that big data '*as huge amounts of digital data produced from technological devises that necessitate specific algorithmic or computational processes in order to answer relevant research questions*' (p.14). However, they found some challenges in advocating a precise definition due to the flexible meaning that big data provides to social science fields as opposed to computational science. Therefore '*Big Data in its current cultural meaning it's a tremendously vast concept that includes different subcategories and specifics that are characterised by different technical and regulatory challenges'* (p.16).

A similar sentiment was expressed by Mergel et al. (2016) on the disparity between how big data is defined across disciplines. See Table 2. You can see that as the disciplines change the tone of the definition changes.

Table 2: Differences in defining big data across disciplines (Extracted from Mergel et al. 2016, p. 929).

Source	**Discipline**	**Definitions**
(Janssen and van den Hoven 2015)	IT	"massive quantities of information produced by and about people, things, and their interactions" (p. 662)
Lazer et al (2020).	Computational Social Sciences	"Second-by-second picture of interactions over extended periods of time, providing information about both the structure and content of relationships" (p. 2)
George et al.(2014)	Management	"Big data is generated from an increasing plurality of sources, including Internet clicks, mobile transactions, user-generated content, and social media as well as purposefully generated content through sensor networks and business transactions such as sales queries and purchase transactions" (321)
Clark and Golder (2014)	Political Science	"Technological innovations such as machine learning have allowed researchers to gather either new types of data, such as social media data, or vast quantities of traditional data with less expense" (p. 65)
Pirog (2014)	Public Policy	New formats, quality, and availability of administrative data (volume, velocity)

Mergel et al. (2016) argue that:

> *These perspectives from across related fields highlight the need for cross-isciplinary collaboration among social scientists, who have substantive depth on research methods and theory, and computer scientists, who have the computational and methodological skills to construct and analyze algorithms on data structures p. 930*

Next we discuss the challenges that will be faced by governments and public agencies to make effective use of big data.

Challenges to the Use of Big Data

The challenges faced by governments and public agencies to derive benefits are summarised in Table 3.

Table 3: Challenges to effective use of big data

Source	Nature of challenge	Specific challenges
Kim et al. (2014); Kilevink et al (2017)	Comes in many forms	Multiple channels (web, crowdsourcing, social networks) and sources (institutions, agencies, departments and other countries
	Silo	Government divisions may have their own data warehouses without integration
	Format	Lack of a cohesive format even when structured as agencies may use different types of solution that make it difficult for extraction
	Security	The sources may hold confidential information about the public. Legality and privacy issues. Autonomy may create increased responsibility for results.
	Capability	Availability of data scientists and statisticians. Lack of competence among public officials to make sense of big data and opportunities. Lack of tools and readiness to make clear judgments and organizational maturity.
Azzone (2018); Klievink et al.(2017)	Speeding up legislation	How to avoid violating democratic principles while changing laws
	Equity	Deciding on fair level of service
	Dark side	Unleashes the dark side of big data.

Andrews (2019) carried out a 18 month qualitative review of various sources including papers, media, reports to look at algorithmic risks arising from the use of big data and listed six broad challenges to the use of big data to create public value:

1. Selection error that could be caused by facial recognition data which could lead to targeting specific communities and even sacking people unfairly.
2. Law breaking by using special devices to create data to show positive results or avoid penalties as it happened with the recent Volkswagen scandal with emission data.
3. Manipulation of data that creating less reliable news and influencing the public as it is happening in national elections.

4. Propaganda based on false information similar to how elections are being influenced from foreign countries.
5. Contamination: Triggering buying decisions such as targeted advertising.
6. Complexity: Fear that data science techniques such as machine learning may make it very difficult for humans to make sense of decisions being made.

Big Data Opportunities

Despite all the challenges several opportunities have been identified, which has made several governments develop national strategies to promote big data applications.

Mergel et al. (2016) pointed out that:

> *Public administration researchers and practitioners for most of the field s history have bemoaned the lack of data for analysis and operations. In the space of roughly two decades, the Internet has turned this problem on its head. Now, scholars and practitioners are scrambling to realize the opportunities and face the challenges that "big data" presents. These "big" data sets are increasingly used to help public managers derive real-time insights into behavioural changes, public opinion, or daily life. p. 928*

Azzone (2018) pointed out the following opportunities using big data to improve government policies:

1. Design of personalized policies with precision moving away from polices developed for an average population. As an example, relief can be targeted to more vulnerable populations in risky situations instead of doling out funds uniformly.
2. Using weak signals to anticipate policy changes: Use of even unintentional signals to evaluate socio economic trends or identify threats such a position data by tracking mobile phones.
3. Anticipating and creating new services: Sentiment analysis of social media data can help in this strategy. Also helps in testing out co-designed services.

Klievink et al. (2017) added that using big data in the public sector would enable better decision support; informed policymaking; a better picture of evolving reality; and even help to solve lingering social issues such as more equitable healthcare provision, sustainable energy production and alleviating transport congestion.

Government Initiatives

According to Kim et al. (2014), several countries are now collaborating with major technology providers like IBM to establish large scalable infrastructure for big data. The US government is an example of how they launched data.gov with the help of IBM. In Europe, a digital agenda has been formed to overcome challenges in handling big data. The UK set up the Horizon Scanning Centre as a way of working across disciplinary challenges. Asian countries like Japan, Korea and Singapore have been at the forefront with the use of big data. The Australian Government Information Management Office is taking the lead on big data for public use. The Indian Government has rolled out a big data initiative called project insight. Thus governments are exploring how open data can bring national benefits.

Big data and public value in the context of megaprojects

How can big data assist in the quest for public value? According to Mergel et al (2016) '*the ambiguous, multifaceted, and contested 'bottom line' of creating 'public value' (Bryson, Crosby & Bloomberg 2014, Moore 1995, Moore (2014) generate a set of important questions and concerns*'. They suggested that in the context of big data these issues must be paid special attention.

Despite these concerns project management researchers, are demanding expectations from megaprojects to create social and societal value which are also in line with the expectations of public value. Ma et al. (2017) argued that 'The prolonged lifecycle and heterogeneous stakeholders of megaprojects have posed great challenges for the governance of the economic, social, and environmental issues involved' (p. 1365). Wang et al. (2020) raised another concern about megaprojects - sustainable development. They suggested that the boom in megaprojects is having 'a significant impact on social and economic developments (e.g., immigrant settlement, poverty eradication, and public health) as well as the natural environment (e.g., ecological processes and biodiversity)' (p. 831). This is also echoed by Lin et al. (2017) who have developed 'a holistic indicator system' by 'integrating project life-cycle dynamism, stakeholder heterogeneity, and social responsibility interactivity' (p. 1415). Such indicators can help us to find ways to evaluate the creation of public value from megaprojects.

This paper looks at five dimensions of public value based on a public value framework (Reynaers 2014)

1. Accountability
2. Transparency
3. Responsiveness
4. Responsibility
5. Quality

Accountability denotes the ability of the procurer to account for the project to the responsible minister in terms of the financial, juridical, and technical content of the project and the actual performance of the consortium. Transparency means the availability, accessibility, and accuracy of the information on juridical, financial, technical, and operational aspects of the project. Responsiveness is the ability of elected officials and public servants to determine, influence, and adjust the contractual agreements and the output specifications before and after contract closure. Responsibility measures the degree to which the consortium complies with the contractual agreements and the output specifications. Quality denotes the degree of satisfaction of the procurer in relation to the asset and the actual exploitation as provided by the consortium.

Some work towards this aim has already been carried out by the authors, but more is needed. The authors have been collecting and analysing social media data from transport projects from Australia and India to see how large amounts of data collected from these media can aid in the evaluation of benefits realised from these projects

Big data can be generated from a wide range of sources to create value in infrastructure megaprojects. Sensors can record the people movement in stations (Alawad and Kaewunruen 2018) and can help decision-makers increase or decrease the frequency of trains for certain periods of the day. The way people move within the stations can also help decision-makers allocate commercial space in the stations effectively. Another source of big data generated by infrastructure users is the data available on social media. Social media data can enable us to understand megaprojects better as many conversations relating to projects are only evident online and they are not currently captured or analysed (Ninan 2020). Even though there are large amounts of data generated in the social media regarding infrastructure projects daily, researchers have not explored the scope of using this big data for decision-making in infrastructure projects. It is in this context that we situate our research to understand the scope of using social media to generate public value in infrastructure megaprojects.

METHODOLOGY

To understand how big data from social media can be used to create value in infrastructure megaprojects, we chose a qualitative research methodology. Scholars have suggested that such a method is apt for exploratory research when the aim is to gain familiarity with a problem or to generate new insights for future research (Eisenhardt 1989; Scott 1965). Within the qualitative research methodologies, we chose to use multiple case study method as it provides excellent opportunities to enhance contextual understanding and simultaneously enable the generalization of findings (Flyvbjerg 2006; Yin 2017).

We chose the case study of a metro rail project in Australia and India to understand the scope of using big data for creating public value. We selected the Sydney metro rail project from Australia and the Chennai metro rail project from India because of their similarities. Both the projects started operation around the same time and had similar track length, 36 kms and 45.1 kms respectively. All twitter posts of the Sydney metro rail project and Chennai metro rail project was captured through a Twitter search API. The keywords are the titles of two projects, i.e. “Chennai Metro” and “Sydney Metro”. It is acknowledged that some tweets would not be retrieved if they discussed the two projects without using the keywords. No duplicates were observed on checking the unique ID of each tweet, and the collected data were stored as a comma-separated values (CSV) file. We collected the tweets for a 90-day period from 1 July 2019 to 30 September 2019, during which both the metro rail projects were operational. There were 5960 tweets relating to the Sydney metro rail project and 1064 tweets relating to the Chennai metro rail project. All the tweets were in English.

For analysis, we used content analysis and open coding of the tweets collected to understand what each tweet conveyed. The process was very iterative and we took multiple readings of the tweets as some categories are often not obvious until the second or third reading (Steger 2007), due to the focus on content and meaning. We employed manual coding as automatic methods could create a barrier to understanding in this exploratory study (Kozinets et al. 2014).

FINDINGS AND DISCUSSION

For the analysis of the social media tweets collected from the Sydney metro rail and Chennai metro rail, we find that there is potential in using social media for generating value in infrastructure projects. Value can be created by using big data in social media for addressing real time operational issues, collating the suggestions to improve, and capturing the live sentiments associated with the project.

1. Big data for addressing real time operational issues

Issues relating to operation of the infrastructure service have to be addressed as soon as possible for smooth service. The users widely shared operational issues relating to the project on Twitter across both projects. In Chennai metro rail, one user complained in Twitter that the doors were not opening in one of the stations as below,

> *"Crazy. @chennaimetro rail's doors didn't open when it stopped @Pachaiyappas metro station, at around 11am today, putting the passengers to hardships. What's happening?" (2 Sept 2019)*

Similarly, in the case of Sydney metro rail, a user complained about lifts being out of service in one of the stations.

> *"The lift between the concourse and the platforms at North Ryde is out of service"* (29 Sept 2019)

Social media provides an excellent platform where users of the infrastructure service post day to day operational issues surrounding the projects. We can create more value in infrastructure projects if we can systematically collect this big data, analyse them through algorithms, and efficiently communicate it to the service team to mitigate the current issue through timely action.

2. Big data for collating suggestions to improve

Many users are active stakeholders offering multiple suggestions to improve the services. In contrast to operational issues, suggestions to improve are more than addressing an operational defect on a particular day. For example, in the case of the Sydney metro, a user offered a suggestion to fix the 15 second door opening duration before people get hurt, as below.

> *"@SydneyMetro Your 15 second door opening is stupid and dangerous. People cannot get off the train in the fifteen seconds. Fix it before people get hurt"* (16 Sept 2019).

Similarly, in the case of Chennai metro, a user suggested to bring down the ticket costs and this will lead to more traffic and hence revenue, as below.

> *"Volumes shud b the mantra & increased patronage vl automatically bring in more revenue & help in bridging gap btw cost & income."* (30 Sept 2019).

Collating such suggestions to improve can help the project create more value for the society as decision makers would know the main issues raised by the community.

3. Big data for capturing the live sentiments associated with the project

The users also communicated their feelings regarding the project on social media. They posted selfies and took pride in the megaproject being in their city. In one instance, a user in the Sydney metro rail claimed they are having fun and feel like they are on a holiday, as below.

> *"Tbh going on the Sydney metro makes me feel like I'm on holidays ... So fun"* (30 Sept 2019)

In the case of Chennai metro rail, a user claimed that the project is a step towards public transport as many are leaving their cars and choosing to travel by metro. The user also claims that the metro rail is a safe, convenient and clean means of transport, as highlighted below.

> *"Yes, of course. It's getting there. It's visible in office as there are many of us who leave our cars at the station and take the Metro. So many people exercising this option that safe and convenient and clean"* (20 Aug 2019)

Capturing live sentiments can give guidance to investors to make long term strategic decisions such as which route has to be expanded. It can also help the project take suitable steps to improve the sentiment associated with the project such as offering complimentary rides for school children or celebrating a regional festival (Ninan et al., 2019). By using big data from social media to analyse sentiments, decision-makers can take proper strategic decisions to create more value to the public.

While the analysis of the big data from social media can help create value in infrastructure projects, there are certain challenges in analysing the data. Challenges such as the predominance of negative tweets and presence of interest groups can bias the findings from the big data.

1. Predominance of negative tweets

People generally log into social media to criticize rather than to praise (Park 2015). There were more tweets with complaints about the infrastructure service than compliments about it. In the case of the Chennai metro rail project, the community complained about different aspects of the project such as its unaffordability and poor design. Similarly, in the case of the Sydney metro rail project, besides complaints about specific facilities such as USB points, air conditioning, thermometers and escalators, the most common complaints were about train delays. The community often had fun at the expense of the infrastructure project often trolling the project. The predominance of negative tweets can offer challenges to extracting sentiments from the big data.

2. Presence of interest groups

One of the pressing issues of public infrastructure projects is a change for the most vocal instead of most affected. The most vocal opposition tend to challenge infrastructure development and often get what they want from the project (Bornstein 2010). In the case of the Chennai metro rail project there was an interest group campaigning against land acquisition often posting the same message daily on social media. Similarly, some tweets were often re-tweeted and this can also create a challenge in analysing the big data and making decisions relating to suggestions to improve.

DISCUSSIONS

As mentioned in the beginning of this paper, the conceptulizations of big data varies across disciplines, however, there is no doubt over the fact that big data has immense potential to add public value. In the context of megaprojects, we have made an attempt to indicate big data (structure, semi structured and unstructured) which can be harnessed for public values in megaprojects. We have provided examples of these data types with reference to Australian and Indian megaprojects. See Table 4.

Table 4: Examples of Big Data in Megaprojects

Public Value	Structured	Semi Structured	Unstructured
Accountability	Project Reports Cost and Schedule Business Case Risk Management Plans Performance Scorecards / Dashboards (GoI 2020)	Case Studies Surveys	Social Media handle of responsible minister
Transparency	Policy Dcouments' Procurement Reports Electronic Toll Collection Records Ridership records	Interviews	Public information Media
Responsiveness	Post Contract Management Reports Performance Report of Service Providers(TRAI 2020)	Incident reports	Social Media handle of public entity, service providers, interest groups and general public Media
Responsibility	Audit Reports	Interviews	Media
Quality	Project Review	Post project evaluation	Social Media handles of users

CONCLUSIONS

We tried to address two questions in this paper:

How will big data and data analytics help us to take into account and monitor public value creation from megaprojects?

A review of the literature on big data and its application in public affairs clearly shows that big data (structured, semi structured and unstructured) has the potential to enhance public value in megaprojects. There are already some examples from around the world that big data has been useful in providing more transparent information to the public and citizens such as. healthcare (Raghupathi and Raghupathi 2014; Ziora 2015); public sector performance (Bovaird and Loeffler 2015) and smart cities (Al Nuaimi et al. 2015).

However, challenges remain as governments are unprepared for using big data effectively due to availability of technology, capability, funding and expertise. The data collected by government departments are also in silos and data integration is not easy. It is also difficult to justify the cost of investment as the costs and benefits cannot be predicted. Despite these concerns several governments including the Australian and Indian governments are investing is open data being available to the public.

The second question we asked is

What are the barriers and opportunities for using big data and data analytics in public value creation from metro rail projects in Australia and India?

We have reported on two case studies in the paper which we analysed social media data to see if we can get an indication of how value created is perceived by the public from two metro projects – one in Sydney, Australia and the other in. Chennai, India. The evidence collected shows that sentiment analysis of tweets could provide an indication of how the user of transport infrastructures derive value from these projects. However, a more detailed study of structured and semi structured data is required.

The authors are also planning to conduct further research into how big data is currently being used by governments to contribute to provide public value information from metro projects.

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Classification of safety observation reports from a construction site: An evaluation of text mining approaches

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ABSTRACT

With the advent of new sophisticated machine learning (ML) algorithms in the field of language processing, the horizons of generating insights from textual data have broadened exponentially. The application of these natural language processing tools is not new in the field of construction safety. However, specific gaps yet remain in the applications pertaining to analysing the near-miss observation reports obtained directly from a construction site, which has been explored in detail in this study. This study utilizes the data obtained from a construction site containing near-miss safety observations. The study aims to test the proposition that a high efficiency of different ML algorithms in automatically classifying the observations from the site into three categories - "Unsafe Act", "Unsafe Condition", and "Good Observation" can be achieved. The study uses supervised machine learning approach and evaluates six different algorithms using F1 scores. Error analysis is also conducted to identify the strategies to increase the prediction accuracy. It is found that Random Forest classifier has high prediction accuracy with F1 score being 0.74 initially and improved to 0.77 after refining the stop-words that are excluded in the data cleaning process. Further, the reasons for the wrong prediction related to data quality are identified that could help improve the efficiency of the classifiers in future studies.

KEYWORDS

Construction; Safety; Safety Observations; Text-mining

1. INTRODUCTION

Managing risk of accidents and injuries at the construction site is one of the essential tasks for which the project managers bear utmost responsibility. While construction continues to be among one of the most dangerous occupations around the world, some examples of good construction sites achieving very high levels of safety also exist (Oswald et al., 2018). In such safe sites, the emphasis is on a proactive approach for safety management. As part of that, importance is given to observing and reporting safety-related concerns, commonly known as Safety Observations (SOs), at the site (Oswald et al., 2018). However, academic evidence has also pointed out that sustaining a reporting culture, where workers at the site actively contribute to observing potentially hazardous events and are willing to report them, is extremely difficult (Oswald et al., 2018). When workers start reporting, the project managers soon find it very difficult to cope with the cumulative volume of reports that they receive from the workers. In the absence of timely follow-up and feedback on each of these reports, the worker's motivation to report quickly decreases, and the reporting culture is not sustained (Oswald et al., 2018).

To solve these practical issues faced by the project managers at the site, efficient processes for the analysis of the text-based information (such as the SOs) at a construction site are therefore deemed necessary (Goh and Ubeynarayana, 2017; Tixier et al., 2017, 2016b, 2016a). The current study aims to develop an efficient strategy for analysis of SOs obtained directly from the construction sites. To remove the need for manual analysis of the SOs, the objective of the study is to test the proposition that a high efficiency of different Machine Learning (ML), and Text-Mining based approaches in automatically classifying the text in SOs obtained from a construction site into different categories can be achieved.

Section 2 of the study presents a summary of the existing literature on usage of ML and Text-Mining based approaches in classifying various reports related to construction and other industries. Section 3 presents an overview of the data used and the methodology adopted in this study. Main analysis results have been summarized in Section 4. Discussions of the study focussing on ideas for improving the accuracy of the various ML methods, as well as the implications for the management are then discussed in Section 5. Overall conclusions from the study are discussed in Section 6.

2. LITERATURE REVIEW

As highlighted by the several recent review papers, the importance of the ML-based techniques in analyzing a variety of safety-related observations for enhanced efficiency in safety management is gaining momentum (Sarkar and Maiti, 2020; Tixier et al., 2016a; Yan et al., 2020). With reference to the literature mentioned in the review papers, salient features of the literature pertinent to the objectives of the present study are described here.

Text mining is an Artificial Intelligence (AI) technique that uses Natural Language Processing (NLP) in transforming textual data into meaningful information. Using such tools and the data from the past hazard reports, Wang et al., (2018) could identify the causal factors for a hazard and therefore was able to develop a method to improve workplace hazard prediction. However, the efficiency of such a comprehensive causal prediction tool, enabling end-to-end automation for safety management decision-making is yet very low, and most other studies focus on improving the efficiency of the individual steps that could support management decisions. For example, Tixier et al., (2016) predict the safety outcomes such as type of injury, the body part affected, and injury severity utilizing two ML algorithms on the textual reports. Overall, they found high-predictive skills reached by a variety of models, relying on commonly occurring "attributes" at the construction sites, and concluded that underlying patterns and trends affecting construction safety do exist and with sufficiently large datasets, the construction safety could be studied empirically. Goh and Ubeynarayana (2017) implemented an automatic classification scheme for classifying the construction accident narratives into accident categories provided by Workplace Safety and Health Institute[1] using various supervised machine learning algorithms (refer Table 1). The algorithms that are experimented in this study can be evaluated based on three measures known as precision, recall and F1 score (Goh and Ubeynarayana, 2017). Precision measures how accurate the actual predictions are whereas recall measures the proportion of actual positives that are identified by the classifier. F1 score, an overall measure of the prediction efficiency of a given classifier, combines both precisions and recalls. F1 score could typically range between 0 and 1, and a high F1 score corresponds to better prediction efficiency. Goh and Ubeynarayana (2017) relied on F1 scores to evaluate the performance of the different ML algorithms. Typical F1 score of the best performing classifier in Goh and Ubeynarayana (2017), ranged from 0.55 to 0.92 for different labels. Further, they highlighted the importance of tokenization and hyper-parameter tuning for improving the F1 score of different classifiers. Literature also provides evidence that the performance of the automatic classifiers is generally low. The prediction performance of the classifiers can be significantly enhanced (F1 score up to 0.95) when manual inputs such as the classification rules, lexicons etc., especially about expert's review on rare and ambiguous observations, are assimilated with the automated classifying techniques (Marucci-Wellman et al., 2017; Tixier et al., 2016b).

[1] https://www.wsh-institute.sg/

Table 1 Description of various ML Classifiers

Classifier	Description
Support Vector Machine (SVM)	Hyperplanes are generated based on the training set and optimized which form the basis for the classification among classes,
Logistic Regression (LR)	The data is fit to a logit function to calculate the probability of occurrence of an event.
Naïve Bayes (BNB)	Utilizes bayes rules with an assumption of independence among features. The probabilities of each feature belonging to a given class label are considered independent of all features.
Multinomial Naïve Bayes (MNB)	Multinomial Naive Bayes classifier is a specific instance of a Naive Bayes classifier which uses a multinomial distribution for each of the features.
Random forest (RF)	A random forest classifier constitutes a set of decision trees. Each tree in the forest predicts its final class label. The collection of trees then voted for the most popular class as the final class label.
Decision Trees (DT)	The decision trees classifier forms a tree structure by breaking down data set into smaller and smaller subsets while at the same time developing an associated decision tree, eventually creating a tree with decision nodes and leaf nodes.

The quality and quantity of the text data being used also affect the prediction efficiency of the classifiers. Generally speaking, more data is deemed necessary to improve the prediction efficiency of the classifiers (Goh and Ubeynarayana, 2017; Tixier et al., 2016a). On the other hand, before analyzing the textual data, it needs to be cleaned for training the classifier. For any study, steps for data cleaning such as removing punctuations, converting all letters to lower case to maintain uniformity, spelling correction, tokenization, etc. need to be incorporated (Goh & Ubeynarayana, 2017). In this regard, several previous studies have used structured, high-quality data available from various web sources. For example, Goh and Ubeynarayana (2017) used accident narratives (1000 out of 4470 available) from a regulatory agency in the USA.

Similarly, Tixier et al., (2016b) used various online resources such as terms from regulatory agencies for the enhancement of the dictionary to be used in ML classification. Tixier et al., (2017) used 5298 injury reports which are obtained from more than 470 private construction organizations for identifying safety critical associations.

However, in many large-scale construction sites, often involving workers from several different countries, the safety-critical textual description could be provided directly by the workers. In such cases, the quality of the data itself could be jeopardized, both in terms of quality of the textual descriptions, and the content of the description (Oswald et al., 2018). None of the databases used in previous studies was such that they required extensive pre-processing steps (such as the spell-checking), as the original databases were stored in English language and were adequately managed by individual agencies, ensuring the quality of the textual descriptions. Hence, the research gap yet remains in testing the efficiency of the ML classifiers for the "real" data obtained directly from a construction site, as opposed to the "databases" maintained by regulatory agencies.

On the other hand, several of the above-mentioned studies have relied on data about "lagging indicators", such as after the mishap has happened. However, Sarkar and Maiti, (2020) have stressed on the scarcity of the literature focussing on the analysis of accident precursors, near-miss reports from construction sites using ML techniques. The near-miss reports obtained from accidents are commonly categorized into labels such as Unsafe Act (UA), Unsafe Condition (UC) or Good Observation (GO). The time-series analysis of UA, UC and GO then forms the basis for the construction managers to proactively take corrective actions, such as the focus on worker's training or improving the safety management practices at the site, etc. (Oswald et al., 2018).

Based on the description provided above, several critical research gaps can be identified. For example, while the idea of improving the prediction efficiency for the ML classifiers for data related to construction safety is not new, the review suggests that rarely have previous studies relied on near-miss observation data as well as the data obtained directly from the sites. Naturally, implementation of the ML algorithms to automate the processing of the textual data in such "real" conditions will be a significant contribution towards enhanced safety management. The current study then aims to contribute to the gap, by testing the proposition that high efficiency of different ML approaches in automatically classifying the text in SOs obtained from a construction site ("real" data) into different categories can be achieved.

3. DATA AND METHODOLOGY

The data is collected from a large-scale construction site on a natural gas plant in Kuwait. At this site, the workers from several non-English speaking countries gathered and, have provided SOs in a textual format while also providing a classification of the SOs, such as being UA, UC or GO. Some essential attributes available in the data obtained are summarized in Table 2.

Table 2 Attributes and their description for the data obtained from the site

ATTRIBUTE	***DESCRIPTION***
OBSERVATION	Worker describing the incident he observed on the site.
Corrective Action	Worker describes the action taken to make the situation better.
Category (UA, UC, GO).	Worker classifying the incident observed among the three.

The data contains about 12000 statements made for 3 months at the given site (See Figure 1). This is a large data set compared to the data used in previous studies. For example, Wang et al., (2018) used 165 hazard data sets containing a total of 29,002 observations for 3 years between 2013 and 2015. Such trends illustrate the vastness and complexity of the data being utilized in the current study.

The study presents a quantitative evaluation of the classification prediction efficiency of different types of ML classifiers. It demonstrates the steps that could be taken to enhance the efficiency of the classifiers. The novelty of the study lies in its attempt to utilize the ML approaches for automatic classification for "real" data on near misses, obtained directly from a construction site. Such "real" data contains the description provided by the workers "as is", and thus contains elements which could negatively affect the efficiency of text-mining classifiers, such as grammatically incorrect descriptions, site-specific abbreviations etc. In contrast, previous similar studies had relied on large-scale standard "databases" having information on injuries, where many issues from the "real" data are not present. The differentiates between the "real" and "database" information quantitatively to demonstrate the challenges of implementing ML-based data processing in site locations. For example, Table 3 shows that the "real" data obtained from the field had a larger percentage of unknown words as per the commonly used English dictionaries used in ML analysis, emphasizing the necessity of additional pre-processing steps required in the overall analysis.

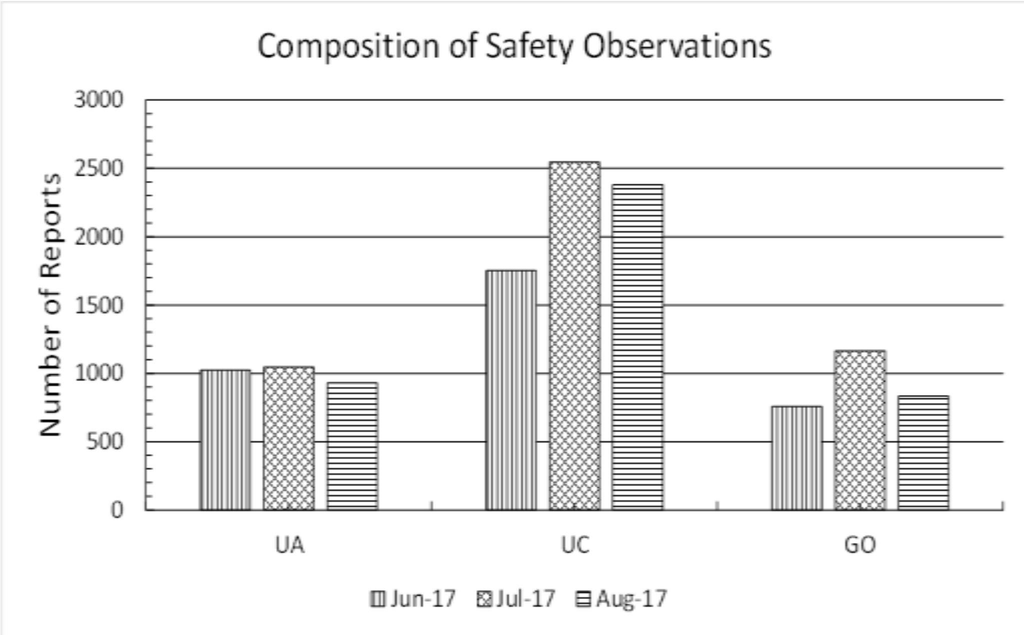


Figure 1 SOs obtained from site by observation type

Table 3 Comparison of the "Real" data used in this study and "Database" data in previous studies

	"Real Data"		***"Database Data"***
Data After Removing stop words.	***Before spell-check***	***After spell-check***	
Total number of words	109657	109657	67974
Percentage of unknown words	7.26%	2.24%	1.87%
Average word count	8.8	8.8	50+

3.1 Methodological Steps

Data pre-processing steps, steps for analysis are discussed briefly in this section. The entire methodology is demonstrated through the help of two flow charts, namely Figure 2 and Figure 3. Figure 2 describes the steps taken in the initial data pre-processing block. Figure 3 depicts the steps taken in the model generation and error analysis.

3.1.1 Data Pre-Processing

The “OBSERVATION” column of the data had the information about the incident which formed as the base for the classification of the experience into – UA, UC, or GO. The whole entry in each row was stripped to individual words, and all these individual words were lowercased to ensure uniformity. This process of stripping a longer string into individual words is known as ‘tokenization’, and the individual words are referred to as tokens (Bird et al., 2009). The next step employed was ‘lemmatization.’ This process involves obtaining the “lemma” of each of the token produced from the above step (Bird et al., 2009) to ensure uniformity in the text . An example for lemmatization is: “the boy's cars are different colours” ⇒“the boy car be different color.”

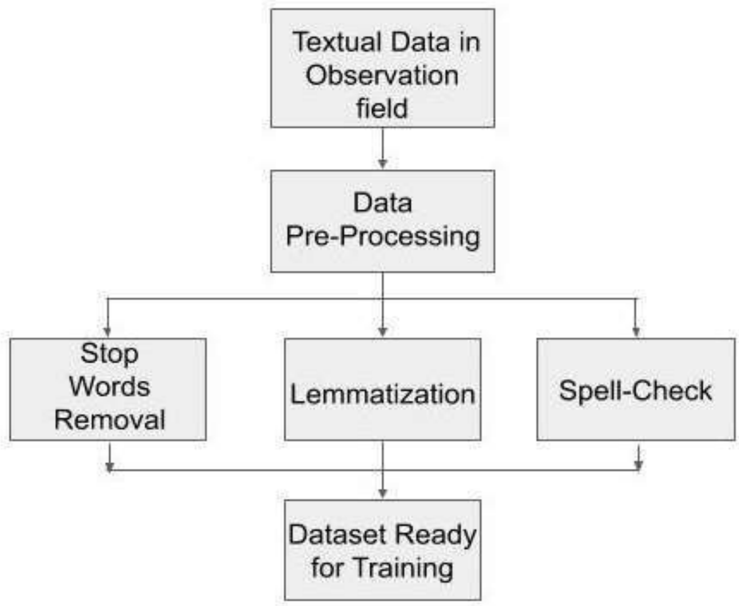


Figure 2 Steps followed in data pre-processing

This set of lemmatized tokens had punctuations, numbers and many other words which added significantly less to no meaning to the overall textual observation. It is, therefore, necessary to remove these punctuation, numbers and stop-words which do not have much lexical significance, using the commonly used list of stop-words (Bird et al., 2009). This step ensures that only meaningful tokens are taken further as features.

There are a lot of spelling mistakes and other unknown words that existed in the dataset which need to addressed to improve the quality of the text. Levenshtein distance was utilized to find similarity between the unknown words and the known set of words and replace them with the best alternative[2]. Levenshtein distance between two words is the minimum number of single-character edits (insertion, deletion or substitution) required to change one word into the other. In addition to the inbuilt English dictionary, a manual external dictionary was created focussed on specific terms pertaining to construction. This dictionary, in addition to the English dictionary, was then compared with all the tokens produced and a significant proportion of the unknown words were corrected (see Table 3). Few examples of the transformed data, after the pre-processing have been provided in Table 4.

Table 4 Safety observations before and after pre-processing

OBSERVATION	**OBS (after pre-processing steps)**
Observed sparking tools using inside running Unit in ST-0 Unit-12 for structural erection,	observed sparking tool using inside running unit st unit structural erection
WORKER FOUND NOT WEARING HIS SAFTY GLASS	worker found not wearing safety glass
Fire watch is continously available on welding site.	fire watch continuously available welding site

3.1.2 Model Generation and Error - Analysis

The cleaned dataset obtained after the data pre-processing steps were then split into two sets of training and testing data. Stratified sampling was used to take 20% of the 12428 observations as the test set to evaluate the performance of the machine learning classifiers. The stratified sampling ensures an equal percentage of observations across the three categories (GO, UA, UC). Goh and Ubeynarayana (2017) used a stratified split of 25% of data as the test set. Considering the size of their dataset. The number of data points we have in this study is enormous; hence 20% split ensures sufficient data points for testing. The algorithms used in this study were derived from the scikit-learn library (Pedregosa et al., 2011), Natural Language Toolkit (nltk) library (Bird et al., 2009) and Pyspellchecker library[3].

The first step in processing this data is to convert it into a corpus of words from which uni-grams, bi-grams and tri-grams can be chosen for further steps. Words, “uni”, “bi” and “tri” refer to the number of items in a given token, where the item can be considered as an individual unique word. Bi-grams and tri-grams are essential and need to be analyzed to understand the difference between specific terms like "not proper" and "proper".

[2] https://pypi.org/project/pyspellchecker/
[3] https://pypi.org/project/pyspellchecker/

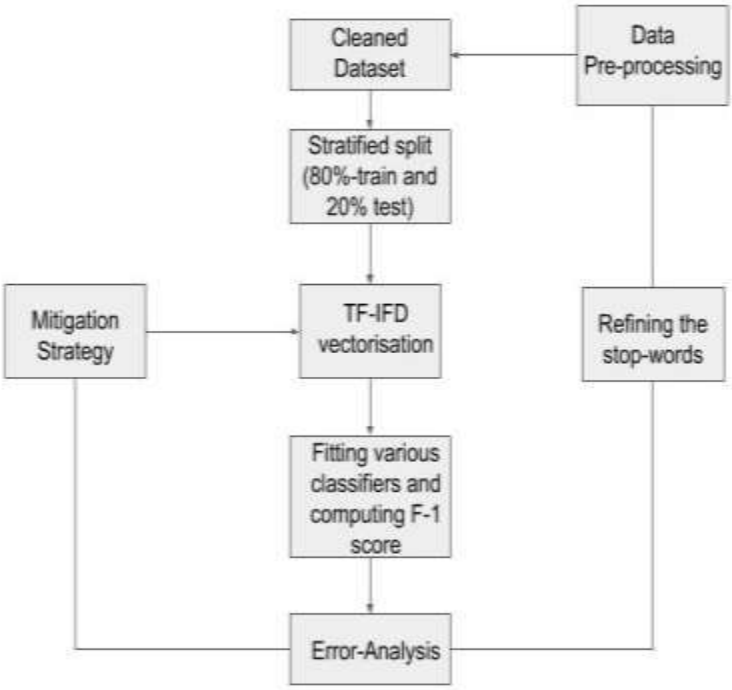


Figure 3 Model generation and error analysis

Term Frequency Inverse Document Frequency (TF-IDF) vectorizer (Peng et al., 2014) was then used to convert this meaningful text into an array which can be used as features to develop the model. TF-IDF is the measure of the originality of a word by comparing the number of times a word appears in a document with the number of documents the word appears in. The measure (TF-IDF), which is calculated for all the uni-grams, is taken to build a supervised learning model. This vectorization creates an array with each token (uni-gram or bi-gram) having a specific id and each column according to the availability of the token had an associated TF-IDF value associated and was assigned that value. A visual representation of a sample text before and after TF-IDF vectorization is shown in Figure 4.

The supervised learning approach is generally taken when there is a clear definition of the dependent and independent variables. This tool then uses this defined input-output pair to build a model using the training set and predicts the output pairs on the testing set. Supervised learning approach was carried out with many classifiers listed in Table 1 (Bishop, 2006). Average F-1 scores, for 100 random 20-80 splits of data are then tabulated in the subsequent sections.

$$W_{x,y} = tf_{x,y} \times (1 + \log(N+1/df_x+1))$$

TF-IDF

Term x within document y

$tf_{x,y}$ = frequency of x in y
df_x = number of documents containing x
N = number of document containing c

Before:

Document ID	Text
0	Tom's family includes 5 kids 2 dogs and 1 cat
1	The dogs are friendly The cat is beautiful
2	The dog is 11 years old
3	Tom lives in the United States of America

After: Out of 22 uni-grams the table below shows for 9 of them

Features → / Document - ID ↓	11	america	and	are	beautiful	cat	dog	includes	family
0	0	0	0.412	0	0	0.325	0	0.412	0.412
1	0	0	0	0.392	0.392	0.309	0	0	0
2	0.445	0	0	0	0	0	0.445	0	0
3	0	0.377	0	0	0	0	0	0	0

The TF-IDF vectorizer in sklearn normalises the IDF scores in the fashion as shown below to smoothen the weights.

$$\text{Normalized value of '11'} = \frac{idf(11)}{\sqrt{idf(\text{the})+idf(\text{dog})+idf(\text{is})+idf(11)+idf(\text{years})+idf(\text{old})}}$$

Normalised values of 11 = 0.445

Figure 4 Visual representation of TF-IDF vectorization of sample text

Once the F-1 scores have been computed, the cause of wrong predictions by the model needs to be identified through detailed error analysis. The wrongly predicted observations from the SVM (just as an example) classifier was compiled and the observations (587) along with the labels were manually analyzed, independently, by the first and the second authors, to find the reason behind the wrong predictions. The primary objective of error-analysis was to classify the wrongly predicted observations into four categories - "Mislabelled", "Wrong Prediction", "Doubtful", and "Inconclusive". Mislabelled observations denote the observations for which the label assigned by the worker itself is wrong. The Wrong Prediction observations denote the observations for which our classifier failed to predict the correct label. Doubtful observations are the observations for which the authors are unable to provide a suitable classification. The inconclusive category refers to the observations for which the description was either incomplete or was vague for authors to understand the context. Results of the error analysis then help the authors to identify take future decisions to improve the F-1 score. Naturally, error analysis is a subjective process. In order to minimize the biases, the study always adopts check by multiple authors independently and based on thorough communication between the authors.

4. RESULTS

Distributions of F1 scores for all the classifiers used in this study, for 100 random stratified samples, for each of the categories UA, UC, GO and for the Total Score are shown in Figure 5. Results in Figure 5 demonstrate the robustness of mean F1 scores summarized in Table 5, as the overall F1 score do not vary much.

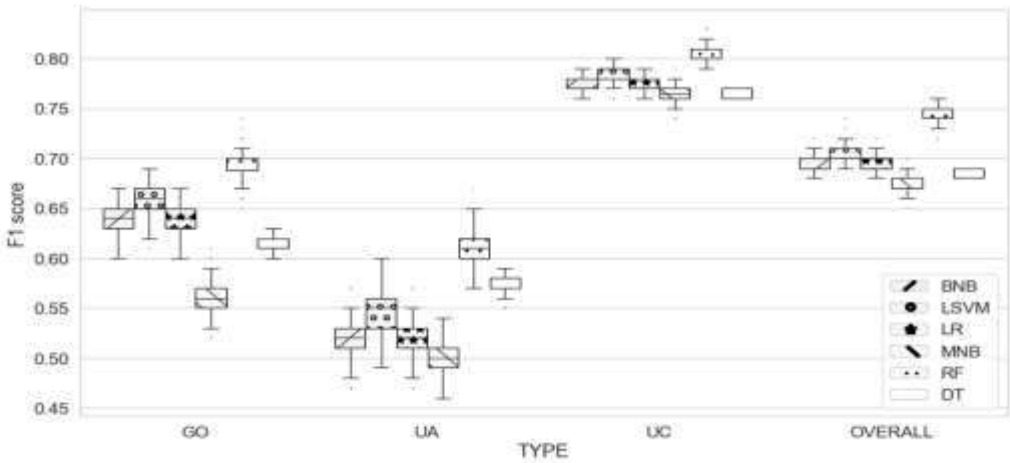


Figure 5 Box whisker plot for 100 repetitions of random stratified sampling (Base-case)

Comparatively, high variation is observed in the UA category of all the classifiers. Potential reasons for the same are then discussed in the error analysis. In the original data, approximately 54% of the observations are labelled as UC, explaining the high accuracy in its prediction. Although the proportion of data available for GO and UA are approximately the same, GOs are relatively easy to classify due to certain positive features that are repetitive (refer error analysis).

The analysis suggests that MNB classifier ranked the least, and RF classifier ranked highest in all the categories. In contrast, results from Goh and Ubeynarayana (2017) had reported a high accuracy with Linear SVM model for accident data, with a highly sophisticated underlying neural network. Developing such a neural network for the large volume of data used in this study will have several practical limitations related to computational requirements. Hence, LSVM model in our study may not have performed as better.

Overall, RF classifier gives an average prediction accuracy of approximately 74%. Such a result is also consistent with the F1-scores reported in previous studies for similar contexts relying on only automatic classification schemes (Goh and Ubeynarayana, 2017; Marucci-Wellman et al., 2017). Hence, an ML-based technique could prove to be a promising practical tool for analyzing the large volume of SOs obtained directly from the site.

Table 5 Average F1 scores for the base case

Classifier	GO	UA	UC	OVERALL
BNB	0.64	0.52	0.78	0.70
MNB	0.56	0.50	0.76	0.68
RF	**0.70**	**0.61**	**0.81**	**0.74**
LR	0.63	0.52	0.77	0.69
L SVM	0.66	0.55	0.78	0.71
DT	0.61	0.57	0.76	0.69

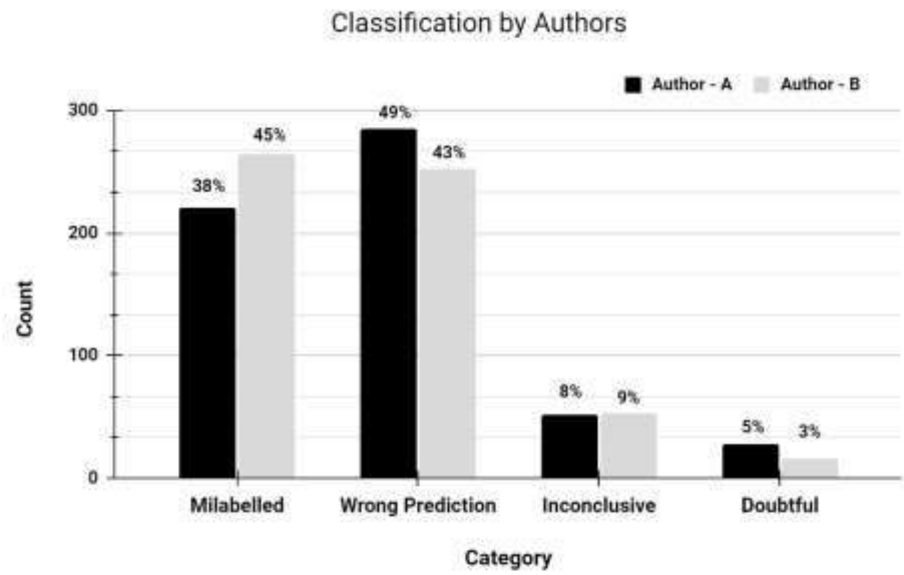
4.1 Error analysis and subsequent modifications

The results from the error analysis, along with a few example cases have been summarized in Figure 6. A major proportion i.e., approximately 46% of the errors were classified to be "Wrong Prediction", by the two authors. Upon an in-depth examination of these observations in detail, authors realized the issues relating to the exclusion of certain important words, as part of the stop-word removal process. Such exclusion of certain stop-words could affect the meaning of certain observations. For example, upon removal of stop-word "No", the issue of having no-sign board at the site, changed to the presence of a signboard at the site. Such an observation could have then been wrongly classified as the GO by the classifier, instead of the original UC (See Figure 6). Hence, a need to refine the selection of stop-words was deemed necessary to improve the F-1 score. A list of excluded stop-words, compared to list of commonly used stop-words even in previous applications, is summarized in Appendix A. The F1 scores of all the classifiers after modifying the stop-words are shown in Table 6.

Table 6 Average F1 scores after excluding some stop words

Classifier	***GO***	***UA***	***UC***	***OVERALL***
BNB	0.74***	0.54***	0.79***	0.73***
MNB	0.60***	0.51***	0.77***	0.69***
RF	**0.77*** **	**0.62*** **	**0.82*** **	**0.77*** **
LR	0.74***	0.54***	0.79***	0.73***
L SVM	0.76***	0.56***	0.80***	0.74***
DT	0.72***	0.57	0.77***	0.72***
**** p< 0.0001 (t-test, compared to the base case)*				

The results from the modified list of stop-words suggest that there was an improvement of about 2-3 percentage points in the F1 scores when compared to the base case. Such an improvement was also found to be statistically significant, suggesting that indeed the careful selection of the stop-words could be beneficial for further improving the efficiency of the ML classifiers. The results also suggest that a generic set of stop-words may not be suitable for all applications of ML, and more construction-specific stop-words, distinguishing between UA, GO and UC may need to be developed. It is important to note that, despite the exclusion of several stop-words, the F-1 scores are still in the mid-efficiency range and not on high-efficiency, as reported by a few studies, and several data quality-related issues could be the reason for such.



OBSERVATION (before)	OBSERVATION (Ater Cleaning)	Worker label	Predicted label	Category
No sign board at hydro test area.	sign board hydro test area	UC	GO	Wrong Prediction
safe access siganges to be provided in col 9 of U-151	safe access siganges provided col u	UC	GO	Wrong Prediction
Observe seobon crew maintain and following swp of excavation safety.	observe seobon crew maintain following swap excavation safety	UC	GO	Mislabelled
As heat is raising there is a need of supply of ors to the workers	heat raising need supply worker	GO	UC	Mislabelled
While debling after hydro test vaccum tanker shoulder be available for sucking oily water while deblinding called vaccum tanker.	dealing hydro test vacuum tanker shoulder available sucking oily water deblinding called vacuum tanker	UA	UC	Inconclusive
Found hot work area. Fire both not maintained properly. Grinding flying particles going out side booth.	found hot work area fire not maintained properly grinding flying particle going side booth	UA	UC	Doubtful

Figure 6 Result of Error Analysis

5. DISCUSSION AND FUTURE WORK

The discussions here focus on providing practical recommendations on how the ML-based report classifications can be assimilated at the project sites to optimize the work for project managers. The study discusses whether the practice of SOs classification by worker's themselves, a relatively inexpensive method, can be continued at the given site or inputs from safety experts, a rather costly approach, is necessary to enhance the efficiency of the ML classifiers. The results here demonstrate that despite having considerable problems related to data quality (such as the grammatical/ spelling issues in the description provided by workers, not having high familiarity with the English language), reasonable prediction efficiency could be obtained by a variety of ML classifiers on the site data. This is particularly relevant to the developing country context, where site documentation is often present in the form of written documents, and software systems are rarely put to extensive use. In this context, our results show that projects managers can still rely on data analytics and ML to improve safety performance on sites. Certainly, a large volume of information helped in enhancing the prediction efficiency. Such a result then highlights the value-addition of adopting ML/AI tools for automatic classification of the observations in a short span of time and demonstrates the potential of such tools to be adopted in safety management practices.

On the other hand, prediction efficiency could be further enhanced. The current study demonstrated the possibility of improvement, through suitable selection of "stop-words". Such results also highlight, that generalized lexicons, commonly used in ML applications, may not be suitable as-is for their applications in the classification of different types of SOs. Particular attention must be given for developing lexicons which can differentiate between seemingly "positive" SOs from that of "negative" SOs. The recent safety-theories have also emphasized on learning not only from "what went wrong", but also to learn from "what goes right" despite their potential of going wrong, in a complex system such as construction (Hollnagel, 2012). Hence, such an improvement in the lexicon, will also help bring the current ML practices in alignment, with the state-of-the-art safety theories.

In addition, through error analysis, our study finds that approximately 41% of the error observations could also be attributed to being mislabelled. At this site, worker's themselves are responsible for providing a classification of the report. From a manager's perspective, such a practice could be resource effective. However, our study suggests that it could have an effect on the data quality, and therefore on the prediction efficiency. At this stage, a rough estimate suggests that a further increase of about ten percentage points could be achieved in F1 scores, once the issues of mislabelling could be rectified. However, it requires significant resources on behalf of the analysts. Hence, as a future study, authors are aiming to correct the labels of the GOs.

6. CONCLUSION

The study presents a quantitative evaluation of the classification prediction efficiency of different types of ML classifiers, for near-miss SOs obtained from a real construction site. Further, it demonstrates the steps that could be taken to enhance the efficiency of the classifiers. The novelty of the study lies in its attempt to utilize the ML approaches for automatic classification for a "real" data on near misses, obtained directly from a construction site. Despite the potential limitations to prediction efficiency due to data quality issues, such as the grammatically incorrect descriptions, site-specific abbreviations etc., the study demonstrates a prediction efficiency of about 70%, which is at par with other previously reported numbers even for the data obtained from standardized datasets. Such results demonstrate that ML techniques hold significant potential to further enhance pro-active safety management at construction sites. The study also demonstrates that through suitable modifications in the stop-words, the prediction efficiency can be enhanced. The results of the study could be greatly affected by some of the data quality issues such as the mislabelling in the original data, and in future, such mislabels should be corrected. Future studies could also focus on increasing the proportion of test-data in the overall split, to assure the robustness of the results. The usage of ML techniques could be further improved to synthesize more details from the valuable information that has been gathered from real-site about the near-misses.

APPENDIX A

The stop words excluded in the study

"no", “wouldn't", "during", “didn't”, "above", "below", "did", "shouldn't", "before", "after", "had", "have", "will",” against

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Blockchain Technology in Project Management

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ABSTRACT

Advancement in technology and rapid digitization have resulted in a fast-changing landscape for the construction sector and are all set to bring a paradigm shift in how we manage and execute construction projects. Blockchain, a type of Distributed ledger technology (DLT), is becoming increasingly main-stream in the corporate world. The aim of this research is towards automation of the contractual processes, performance and administration using blockchain and smart contracts. The paper explains the key concepts underpinning DLT and smart contracts; looks into the application of this technology in construction sector; presents a semi-automated contractual framework with underlying blockchain technology for construction contract management, and identifies the platform most suitable for this purpose. The intention is to provide a more collaborative, transparent and faster contractual framework which addresses administrative and governance challenges in project execution, streamlines the implementation of construction contracts, simplifies the contract execution, identifies and automates certain bottlenecks in the process, all keeping in view the cultural mindset of the stakeholders and technological expertise available.

KEYWORDS

Blockchain, Digitization, Automation, Construction Contracts

INTRODUCTION

The advent of the Fourth Industrial Revolution (Industry 4.0) has opened an entirely new outlook on how businesses work. Industry 4.0 comprises of various upcoming disrupting technologies like Artificial Intelligence, Machine Learning, Blockchain Technology, etc. with the potential to reshape the business practices. It has already fundamentally altered the working of various industries from finance to healthcare (Schwab, 2016). Covid 19 pandemic has made us re-think on making our industry and businesses more robust and resilient. It has fast-tracked the process of digitization and automation across the world.

One of the biggest industries in the world is the construction industry. It constitutes 13 percent of global GDP but has seen a meager productivity growth of 1 percent annually for the past two decades, which is even outside of the crises. Most of the projects suffer from time and cost overruns, and overall earnings before interest and taxes (EBIT) are only around 5 percent despite the presence of significant risk in the industry (McKinsey, 2020). Industry 4.0 has the potential to revamp the Construction Industry to what we can call as Construction 4.0 (Sawhney, 2020; Winfield, 2020). Blockchain Technology is one of the key technologies in the process of trustworthy digitization. It started with cryptocurrencies and is spreading into a myriad of other sectors from healthcare to construction. In this paper, we explore its application in construction project management using the following tools: Intelligent and collaborative contracting, decentralization of the databases, transparency of transactions, and smart asset management (McNamara and Sepasgozar, 2020). This will enable greater collaboration, better efficiency, cost and time savings, and bring more transparency on board.

LITERATURE REVIEW

In this section, we present a review of literature pertaining to construction management, construction contracts, blockchain technology and smart legal contracts, and how they fit together combining construction with computation.

Construction Contract Management

Management of contracts in the construction sector is a long and tedious process governed by a multitude of stakeholders, processes, and procedures that involve a large number of third parties and intermediaries. The process involves decision making at various levels from the preparation of the contract, bidding and award of contract, design and execution to commissioning and handover of the project. The multi-contractual links and involvement of multiple stakeholders make the process of contract administration and the time needed for each stage of the process extremely onerous (McNamara and Sepasgozar, 2020).

The level of collaboration across the value chain is low with the tendency to risk aversion and blame culture. This results in a siloed ecosystem with huge frictions at risk interfaces. There is a reluctance to share information with employees of different divisions in the same company, or different companies in the same consortium working on a common project. Misaligned contractual structures with failure to read, understand or operate construction contracts as intended is a major cause of global construction disputes which remain unresolved for decades (Arcadis, 2019)**.** The owner's or the contractor's attitudes to distort the language of the contracts with their adamant and rigid attitude in going by the 'content' of the contract rather than 'intent' of the contract is seen as the main source of dispute in the construction sector (Iyer, Kalidindi and Ganesh, 2002). However, this fragmented landscape has the potential to change if the cultural fundamentals and contract management practices are reformed.

Blockchain introduces 'smart contracts', (also called chaincode) enabling real-time coordination of activities in real-world conditions by streamlining and automating the contract administration process which in turn could save the industry an attractive percentage of project costs (Cardeira, 2015). Before we explore the application of Blockchain within the field of Construction and Contract Management, we first look into the current state of the technology and the key concepts linked with it.

Distributed Ledger Technology (DLT) and Blockchain

A distributed ledger technology (DLT) enables a decentralized network in which each participant can interact or transact with one another in a peer-to-peer manner without intermediaries and the ledger is updated simultaneously and is available with each one of them. Blockchain is an advanced version of DLT with immutability and higher security achieved using cryptographic hash-linked blocks in a sequential chain. Blockchain was the underlying technology behind Bitcoin which was first introduced in the Bitcoin whitepaper by Satoshi Nakamoto (Nakamoto, 2008). It intended to remove the need for trust in third party or bank to process payments using an electronic money transfer system based on cryptographic proof (Turk and Klinc, 2017).

Core Features of Blockchain

The main features of Blockchain technology are its **distributed and digital nature** where information is stored chronologically and can be viewed/accessed by a community of users in **real-time** (Thomson Reuters, 2018). It is **immutable** so that the information once published on the blockchain, cannot be changed or tampered with. It is **decentralized** that is not managed by a central authority rather available to all the stakeholders (Li *et al.*, 2019). Blockchain has the potential to automate away the middle man **(disintermediation)** without affecting the workers on the ground (Balint, 2018). In nutshell, we can say that "Instead of putting the taxi driver out of a job, Blockchain puts Uber out of a job and lets the taxi drivers work with the customer directly" (Savelyev, 2017). It resolves the so-called 'trust problem' in the construction industry (Mathews, Bowe and Robles, 2017).

Smart Contracts and Intelligent Contracts

The term 'smart contract' was coined in 1994 by Nick Szabo, a cryptographer who defined it as "A computerized transaction protocol that executes the terms of a contract" (Szabo, 1994). Vitalik Buterin released a white paper in 2013 on Ethereum, which proposed a system through which blockchain technology could be used in applications beyond Bitcoin and cryptocurrencies using 'Smart Contracts' (Buterin, 2013). Smart contracts are **digital programs**, based on the **blockchain consensus**, which will s**elf-execute** when the terms of the agreement are met, and due to their decentralized structure are also self-enforcing and tamper-proof (Fig.1). A smart contract functions as the business logic of a blockchain application. There can be many smart contracts running concurrently on the blockchain network.

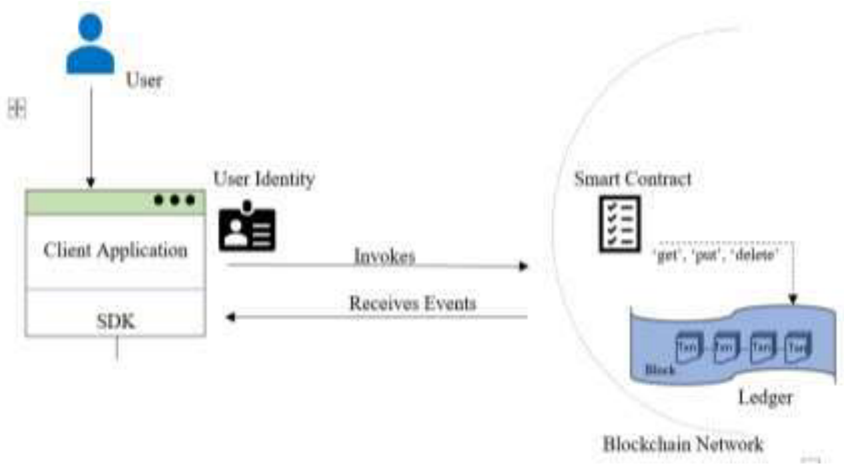

Figure 1 Smart Contract and Blockchain

Intelligent Contracts or **Smart Legal Contracts** are partially automated contracts comprising of automated 'smart clauses', which are self-executing with clear functionality. These clauses are written in both legal language as well as their respective coding. This makes them interpretable by both human and machine. Jim Mason defines Intelligent contract as "software code to implement human intentions by dynamically carrying out instructions associated with a contract, rather than relying on legal texts interpreted by courts, regulatory bodies or other legal institutions" (Mason, 2017; 2019).

The control of data and assets, as well as defining of smart clauses happen at the time of drafting of the contract. It has pre-defined conditions which once met, can trigger execution of payment or obligation of payment, thereby allowing contracting parties to operate beyond boundaries of trust (De Filippi and Hassan, 2016).

RESEARCH METHODOLOGY

Based on the extensive literature review of academic research papers and industrial initiatives, it is understood that in order to realize the full potential of digitization and automation in construction industry on ground level, the construction contracting and administrative process needs to be revamped. However, little research is found in this area. This paper looks into the drawbacks in the traditional contracting system and how they can be resolved using an Intelligent semi-automated contract administration and performance system with attributes of Blockchain Technology and Smart legal contracts (summarized in Table 1).

With this background, we propose an Intelligent Contracting System (ICS) using a permissioned and private blockchain network with the potential to solve various open issues in traditional construction contracting and project management. This system would not only automate and digitize the construction contracts but would also bring a fundamental disruption and shift to the current approach by leveraging the benefits of blockchain technology into the traditional contracting process.

The Blockchain platform identified for this purpose is **Hyperledger Fabric V2.0 by Linux.** Given the nature of construction contracts and projects, the need for privacy of data in the contracting system along with varied access controls to different stakeholders was identified as the key requirement to implement the system. Permissioned Blockchain ensures this privacy and security. Hyperledger Fabric is an enterprise-grade, distributed ledger platform that offers modularity, confidentiality and versatility needed to accommodate the complexity and details across construction business (Nawari and Ravindran, 2019).

Table 1: Traditional Contracting System: Drawbacks and Potential Solution

Drawbacks in traditional contracting system	**Blockchain Feature**	**Potential solutions in the proposed Intelligent Contracting System**
• On-field project progress and on-paper project progress vary. • Time and cost over-run • Manual claims due to market price or design variations, etc.	Near Real-Time	• Real-time status • Well-defined and updated project timeline. (Wang et al., 2020) • Simultaneous project evaluation, monitoring and cost optimization • Contract terms adjust to the physical world in real-time
• Silo mentality • Information gap • Different interpretation of contract clauses by parties leading to disputes.	Distributed and De -centralized	• Improved collaboration • Better trust • All stakeholders have access to the ledger of transactions without discrepancy • Smart legal contracts enable more clarity, automation and better contract adherence
• Lack of accountability • Improper risk allocation	Transparent and Traceable	• Certain and verifiable record of every payment, transaction, business interaction and execution done with due consensus. • Transparent and followable contracting process.
• Payment held ups for contractors and sub-contractors.	Digital Transaction	• Real-time automated payments based on the work or activities completed as per pre-defined contract conditions (Hamledari and Fischer, 2020; Luo et al., 2019)
• Poor record keeping i.e., Certain records incomplete or not found. • Double spending or frauds in digital transactions • Digital rights and policies on 3 D and 4D models unclear	Immutable, secure and Reliable	• Immutable record • Contract Audit trail sharing and managing lifecycle of the contract. • Improvised governance • Past transactions cannot be tampered with thereby alleviating risk of double spending, fraud and manipulation • Digital data and intellectual property protection
• A long and tedious administrative process	Dis -intermediation	• Reduced administrative and overhead costs of the project

The ICS Framework

The proposed semi-automated framework for Intelligent Contracting System comprising all stages of the contracting process is shown in Fig. 2. The areas where automation and digitization of the process can save time and cost, and improve efficiency are identified and included in the process.

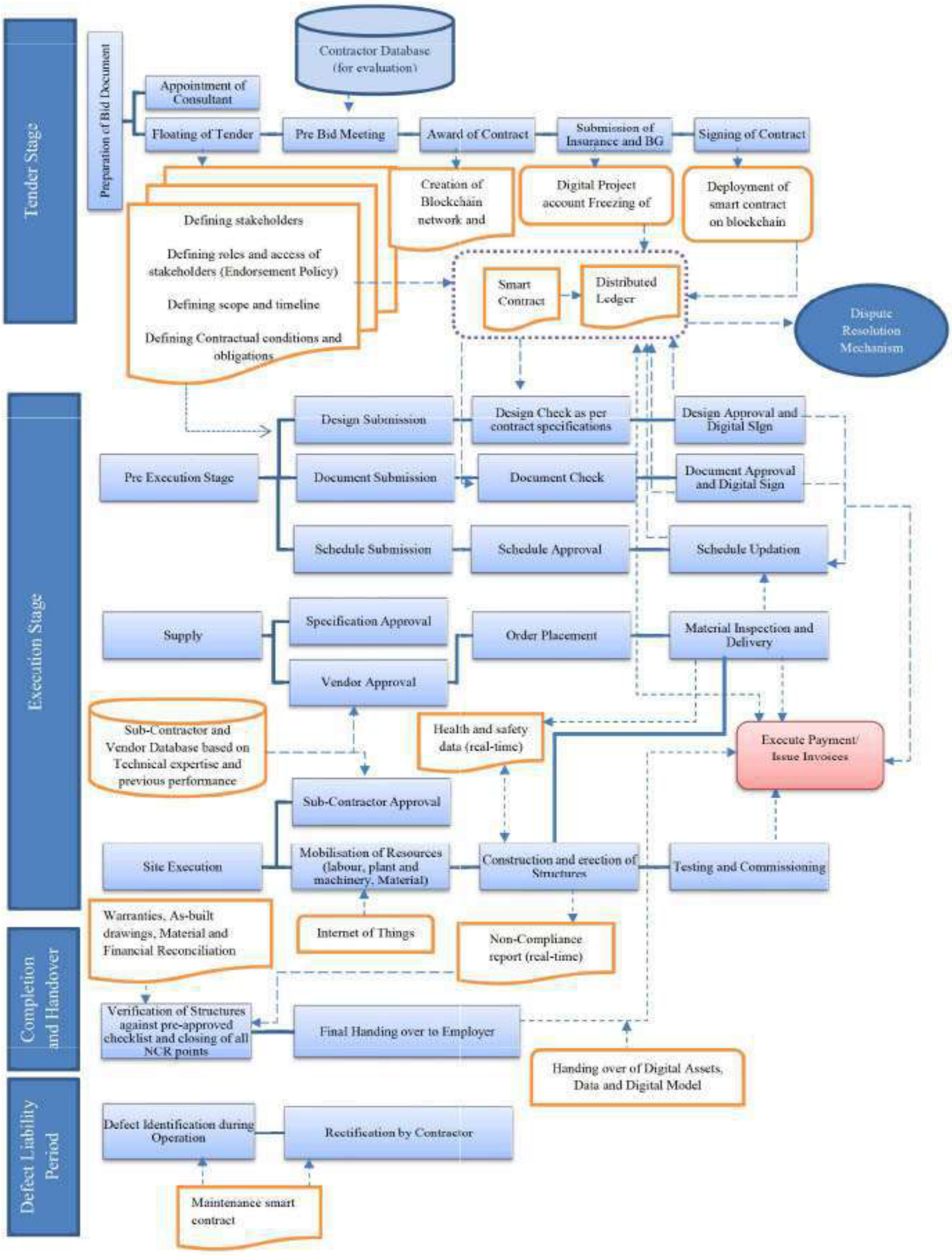

Figure 2 Intelligent Contracting System

The proposed Blockchain-based system engages every stakeholder in a collaborative manner as compared to the central management of the main contractor in traditional system. The exchange of information is transparent and real-time among all stakeholders. ICS encourages thorough contract management giving better cost control, faster payment mechanisms and effective project delivery. Furthermore, incorporation of intelligent smart contracts would reduce repetitive claims, ensure better delay accountability, and save cost and time lost in dispute resolution.

DISCUSSION AND FUTURE WORK

'We tend to overestimate the effect of technology in the short run and underestimate the effect in long run' - Roy Amara, President of the Institute of Future.

Blockchain is a promising technology with the potential to longstanding accountability and efficiency issues in our industry. Still, like any other new and upcoming technology, it has its own challenges. Not just the technological proficiency, but a strong cultural shift is needed to overcome the barriers of reliability and interoperability. Also, wide-scale adoption of the technology needs workable solutions for storage and compatibility issues (Li et al., 2019). Till the technology and the mindset mature, a semi-automated approach is preferred to make widespread adoption achievable and acceptable.

The paper proposes a contract management framework with intelligent legal contracts at the heart of the semi-automated framework. The research provides a foundation on which further work can be done in terms of identifying suitable smart clauses whose automation would leverage maximum benefit and prevent disagreements thereby improving efficiency and transparency of the contract and project management process with incremental and need-basis coding.

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Section II

ADVANCED CONSTRUCTION PROJECT MANAGEMENT

Editor's Note

Construction projects contribute to the nation's growth, and advanced techniques to manage those needs special attention. This section describes about six papers that discuss advanced techniques in construction project management. For instance, Kapoor and Sharma emphasises on reducing the commonly occurring biases in decision making process involved in long gestation projects while recommending the suitable project management tools and techniques to achieve the same. The paper mainly addresses cause and effect of the cognitive, framing, and emotional biases that unmasks at different stages of the project life cycle. It also highlights the remedies for all these biases across project life cycle which helps in establishing a sound decision-making process in an organisation.

Having known that power transmission is a significant part of power projects, Ghatak and Garg investigates on the key factors responsible for the success of power transmission projects. With a questionnaire-based survey conducted among experts across countries and a structured data sampling, the authors quantify the relationship between the critical factors known to lead way to power transmission success.

Meanwhile, Kumar and Trivedi developed an integrated framework attempting to reduce the vulnerability of equipment management system in construction projects. The study ends with the business model and implementation plan for successful product delivery. Similarly, a research was carried out by Jacab and Dave to classify various applications for UAVs in the construction field, and established a set of guidelines for the use of UAVs in construction using a design science analysis methodology. Likewise, the main objective of the study by Patel et al. is to understand the advantages of automation in construction by comparing the different modern tools available in the market.

Enhancing Decision Quality to Manage Risks in Complex Long Gestation Projects

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ABSTRACT

Decision making in long gestation project is complex since the context in which decision is made is different from the context in which it is executed. The VUCA (Volatile, Uncertain, Complex, and Ambiguous) environment necessitates the project manager to undertake decisions with limited amount of data. Behavioural economics theory reveals that under conditions of ambiguity and where decision making has to be quick, managers use the System 1 thinking pattern for decision making. Since System 1 is prone to heuristics, fallacies and biases, Project Managers have to be wary of its influence while taking decisions under such conditions. This paper specifically deals with biases which impact decision making and hence Project outcomes. The three categories of biases being explored are cognitive biases, frame biases and emotional biases. Typical situations and cases of such biases in each of the stages of the project are discussed. It is also proposed that the influence of these biases can be minimised by use of specific Project management tools and techniques. The paper discusses some of these tools and techniques and advocates the institutionalisation of these tools in the project management systems and structure of the organisation so as to reduce Project risks due to biases.

KEY WORDS

Biases, Decision making, Long Gestation, Project Life Cycle, Tools and Techniques

INTRODUCTION

Over the past couple of decades, the complexity and uncertainty in projects has increased exponentially due to globalization, technology, disruptions, climate change etc. In such an environment the capabilities of the Project Manager are tested at every crucial stage and phase of Project decision making. The decisions, made in the current context, have an impact that is noticed and judged at a later point in time. In long gestation projects like infrastructure, aviation, ship building etc., the time gap between decision making and execution may sometimes be between 2-4 years. Long gestation projects normally need high upfront commitment and investment in capital equipment, machinery, freezing of specifications etc. Considering the size of the program and the gestation period, it is very much plausible that the Project Manager who takes the decision is different from the Project Manager who executes the decision. The business environment in which the decision was made itself undergoes changes.

Typical of projects is the uniqueness of the product, service or result. Accordingly, the processes are new and have to be developed for each project. There are not many existing rules and protocols to be followed for decision making. The Project Manager has to use his intuitive abilities, experiential understanding and personal judgement while making decisions. Such discretionary decision making may be influenced by the past experiences and biases which the Project Manager uses for taking decisions thus making it highly subjective in nature. Further, in Complex projects with multiple stakeholders, it is required to tackle the inputs of the primary stakeholders and obtain the approval of the key stakeholders while formalising any decision. Hence, effective, structured and logical decision-making process is paramount for long gestation projects to achieve decision quality.

The quality of a decision is generally evaluated in terms of the impact or the result of the decision made. If the outcome becomes favourable the quality of the decision is lauded while if the outcome is not so desirable, the project manager who made the decision faces flak. However, it is to be borne in mind that uncertainties are inherent in any project however well it is conceived or executed. The outcome is influenced by various Enterprise Environmental factors outside the reasonable control of the Project Manager. Hence it is vital to judge the quality of the decision based on the process adopted to arrive at the decision rather than on the outcome thereupon. A well framed structured decision-making process is more probable to yield better outputs when practised consistently.

Henry Mintzberg the great Management Thinker has said "Organizational effectiveness does not lie in that narrow minded concept called rationality. It lies in the blend of clearheaded logic and powerful intuition". Since data collection is difficult and time consuming in each and every situation many short and long term decisions are made based on "gut instinct". The Project Manager has to optimally blend the logical thinking process with the intuitive thinking process. This paper examines the two types of thinking processes propounded by Daniel Kahneman in the context of decision making for long duration projects and proposes adoption of structured tools & processes for decision making so as to improve decision quality.

LITERATURE REVIEW

System 1 and System 2 thinking:

Daniel Kahneman (2011) has undertaken extensive research in the field of behavioural economics and how economic decisions are not purely rational but influenced by cognitive dissonance and emotional constructs. He won the Nobel Prize in Economics in 2002 for his ground breaking work in applying psychological insights to economic theory, especially in the field of decision making under uncertainty.

Kahneman (2011) attributes the decision making anomalies to behavioural fallacies of the human brain. In his seminal book "Thinking Fast Thinking Slow" Kahneman identifies two different systems operating in the human brain: The System 1 thinking and the System 2 thinking. Commenting on the book, Mark Looi (2019) states that System 1 is the intuitive system and is always functioning and cannot be switched off. It makes decisions fast by neglecting ambiguity and supressing doubt. It frames decision processes narrowly and in isolation of one another. Whenever a project manager has to give quick decisions or take decisions under a lot of uncertainty, he resorts to System 1 thinking. By contrast, System 2 thinking involves more about of logic, judgement, quantitative reasoning and attention to effortful mental activities. While System 2 thinking is more likely to give consistently favourable outcomes, a Project Manager may not always be able to apply it fully due to insufficiency of information, uncertainty, complexity and ambiguity inherent in a project environment. Especially in large gestation projects, the level of lack of adequate information in the long time frame necessitates the project Manager to go in for System 1 decision making. This may lead to the creeping in of biases which the project Manager needs to address while taking decisions. Considering that project decisions many a times are restricted by time and have to be made with limited information, especially in long gestation projects, there is a tendency System 1 based decisions (what is called the 'gut') and unless supported by tools and techniques of System 2, chances of falling into the trap of biases and fallacies is enhanced. The characteristics of System 1 and System 2 are given in the Figure 1.

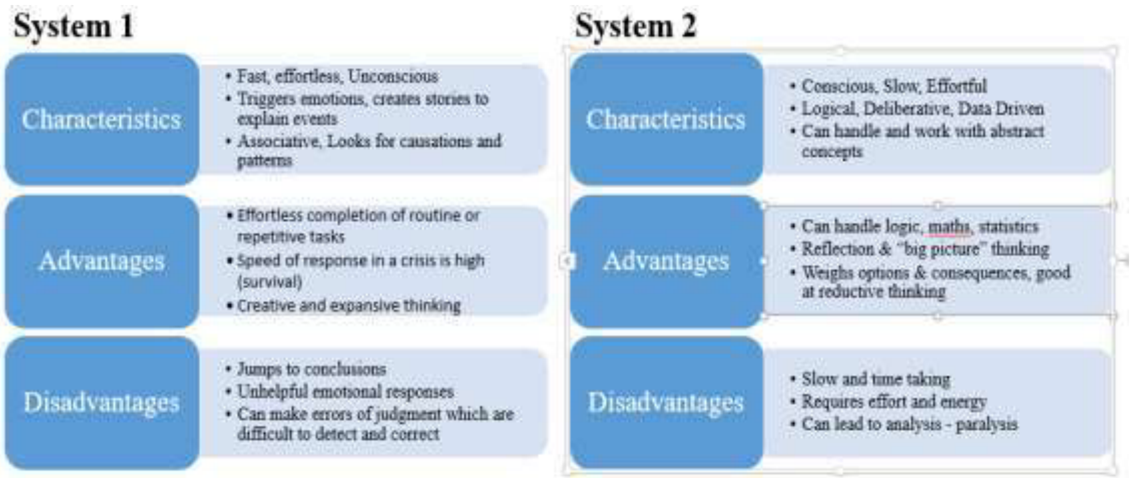

Figure 1: System 1 and System 2 thinking

Prospect Theory

Kahneman and Tversky (2013) have provided a critique of traditional utility theory to decision making which propounds that project managers make decisions purely rationally to maximise utility of the investment to the project. They proposed an alternative model – the Prospect theory, which says that choices of decision making under risk are influenced by several intuitive, cognitive and emotional factors which the classical economic theories cannot explain. This has an import on the decision-making process in Projects with respect to risk management. Prospect theory brings out that faced with a risky choice leading to gains, Project Managers are risk averse preferring solutions that have lower expected utility but higher certainty. By contrast, faced with a risky choice leading to gains, Project Managers are risk seeking preferring solutions that lead to a lower expected utility but with a potential to avoid losses. In-line with the above, the prospect theory implies that Project Managers might attribute excessive weight to events with a low probability and conversely attribute lesser weight to events with high probability. This skews the decision making when using the Probability - Impact Matrix approach. It also leads to Project Managers trying to adopt mitigation strategies for low-risk events while ignoring high risk events.

Biases in Decision making

Biases in decision making is a tendency to make decisions which may not have any rational justification or have been taken in the absence of sufficient supporting evidence and based on implicit assumptions. Biases occur either due to overdependence on system 1 thinking approach or a flawed input to the system 2 thinking approach. March & Simon (1993) bring out that project Managers when confounded with limited data and fast decision requirement tend to reduce problems into simpler constructs and use information selectively based on their beliefs, assumptions, metamodels and preferences. With the result they create solutions which reflect their experiences and support and preserve their beliefs.

Biases can broadly be classified into three categories based on their origin:

a) Cognitive
b) Framing
c) Emotional

Cognitive bias is defined by Amor Tversky & Kahneman (1972) as a systematic error in thinking which occurs when people processing and interpreting information in the world around them tend to simplify information processing based on their past experiences and beliefs and arrive at decision with relative speed. The Project Manager having a cognitive bias creates his own subjective reality from his perception of the input leading to distortion and inaccurate judgement. His perception is clouded by his experiences and beliefs about their own self, the business context, stakeholders and the project being handled. Cognitive biases include optimism bias, confirmation bias, planning fallacy, to name a few. A further discussion on these cognitive biases and use of structured project management tools and techniques to overcome the same will be discussed in subsequent paragraphs.

Framing bias refers to the observation that the manner in which data or information is presented affects the decision-making process as opposed to the facts themselves. The options are worded differently either by the presenter or by the decision maker himself so that it appeals to his/her preconceived notions or expected outcomes. The decision maker interprets the decision according to a decision frame chosen by him/her based on their subjective opinion. Narrowly framed problems or situations lead to looking for data or interpreting data selectively to confirm the assumptions of the frame overlooking important alternatives to the frame. Anchoring, optimism bias and sunk cost bias are three frames that will be discussed in this paper which affects decision making at various phases of the project life cycle. Martinsuo (2014) has identified the need to reframe biases in the context of managing uncertainties in projects in a systematic manner.

Emotional biases are spontaneous impulsive responses of a project Manager based on his personal feelings at the time the decision is made. It may be backed by a background of experience in similar situations and the effects thereupon. Emotional decisions are not based on sound reasoning or judgement. It is held very firm by the decision maker and it takes effort to acknowledge and then to review such decisions. Hence emotional biases are more difficult to address as compared to cognitive biases and framing biases. It is not possible to delineate emotions completely from the decision making process but being aware of the biases it creates may prompt the Project Manager to seek additional data or rationality to the situation. Some of the emotional biases which a project Manager may come across include loss aversion or endowment effect, illusion of progress, halo effect, overconfidence bias etc. It may be necessary for the Project Manager to obtain views from different persons so as to avoid his individual emotions affecting the decision process. Alternately tools may be adopted or systems put in place to provide alternate propositions for the Project Manager to take rational decisions. These will be discussed in the subsequent paragraphs.

Project Life cycle

Project Management Body of Knowledge (PMBOK) has adopted a life cycle approach to describe various tools and techniques used in project management. The project life cycle is divided into five phases: initiation, planning, execution, monitoring & control and the closing stages, refer Figure 2. Each of these stages comprise of various processes across ten knowledge areas. The processes involve deployment of specific tools and techniques following the ITTO (Input, Tools & Techniques, and Output) framework of PMBOK.

The Project Manager along with his project team takes various decisions across the project life cycle. The decisions in the initiation stage focuses on project appraisal, contract formulation, establishing of rough order baselines and milestone identification. The decisions in the planning phase include resource allocation, time estimation, scheduling, risk identification and evaluation of alternatives among others. During monitoring & control, execution and closing phases, the project manager takes decisions with regard to expediting, foreclosure, trigger point reviews and resource re-allocation. Long gestation projects, like those in Aerospace, have two unique characteristics. Firstly, the Project Manager who takes decisions during the planning phase may be different from the project manager who takes decisions in the execution phase due to the elongated timelines of the project. Secondly, organisations involved in long gestation projects have a functional organisation structure where the planning group does the planning, the contracts group does the contract finalisation and separate execution groups execute portions of the project. All these necessitate that structured approach to decision making is vital so that the information flows seamless across the project life cycle and no undue risks crop up over the timeline.

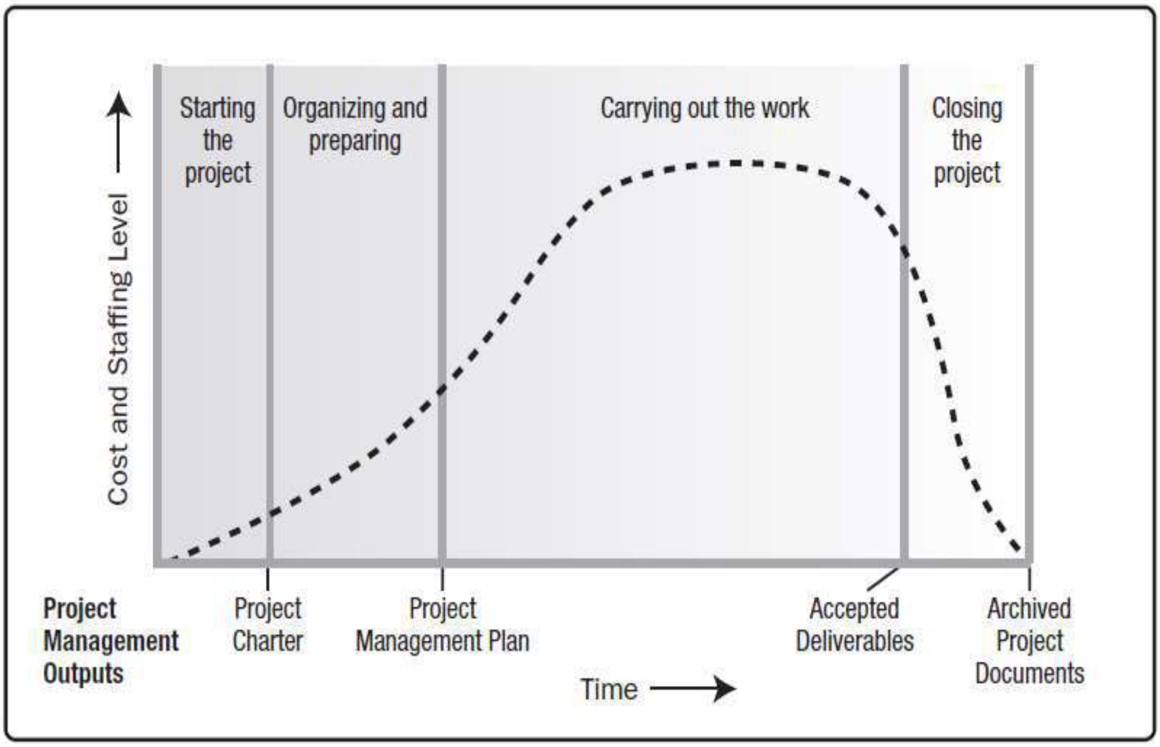

Figure 2: Project Life cycle stages

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ENHANCING DECISION QUALITY TO REDUCE PROJECT RISKS

The Project Manager makes different types of decisions in different stages of the project life cycle. Accordingly, the nature of biases affecting the decision making process vary based on the stage of the project in the life cycle. We shall analyse the biases under the three categories defined in para 2.3 and discuss use of specific tools and techniques of Project Management described in the PMBOK which can be used to mitigate the risks due to improper decision making in the succeeding paragraphs. A summary of the types of biases being discussed is provided in Table 1:

The table has been developed based on the authors experience in managing projects as well as their interaction with various levels of Project Managers as part of Learning and Development initiatives within the organization. The proposed approaches, tools are techniques are based on phenomenological research methodology. The project names and other details have not been stated due to reasons of confidentiality.

Table 1: Summary of biases and their remedies across the project life cycle

Biases/Stage of Project	Initiation phase	Planning phase	Execution , M & C phase
Cognitive Biases	**Optimism Bias** *Probabilistic thinking, Scenario building, Back casting method*	**Planning Fallacy** *Contingency planning, PERT methodology, Planning bias uplift*	**Confirmation Bias** *Internal audits, Expert consultation, Devil's advocate method*
Framing Biases	**Availability Bias** *Assumption validation, Lessons learnt document, Risk register archives*	**Anchoring** *Bottoms up estimating, Cross validating with historical evidence, Avoid benchmark trap*	**Sunk Cost bias** *Defined Kill point, Phase gate approaches, Residual ROI approach, PMO intervention*
Emotional Biases	**Halo effect** *Delphi method , Murder board , Sociocracy technique*	**Loss aversion bias** *Decision Tree methodology, Price cum incentive contracts*	**Illusion of progress** *Earned value methodology, Milestone slip chart, Use of Gantt chart dash board*

Biases in Initiation Phase:

Optimism Bias:

Optimism bias is defined as the difference in the expectations of a Manager and the actual outcome. This is a cognitive bias reflected in the overestimation of the likelihood of getting a positive outcome and underplaying the chances of a negative outcome. (Sharot, 2011). The reason for undue optimism among Project managers is self enhancement, self-preservation and perceived self-control. Both experienced project managers as well as fresh project managers fall prey to this bias, albeit for different underlying factors. An experienced Project Manager recalls instances of success in taking risks selectively and estimates that the current decision will also lead to successful outcomes. A fresh Project Manager, in his enthusiasm to perform under strict control limits over estimates the capacity of the project team and situations and underplays the risks involved.

Optimism bias is prevalent in projects needing technical expertise like design projects, those linked to market retention like new product launch and social welfare projects like road construction. In long gestation projects, the very distance of completion date makes the Project manager callous compounded by the probability that it may be a different person leading the project in that phase. A desperate bid to grab the project by all means during the pre-initiation stage of the project makes the Project Manager to quote lesser cost and timelines for the project which then gets carried into the Project Charter.

Optimism bias can be reduced by carrying out a scenario analysis during the initiation stage of the project in a brain storming session. This will enable assessing multiple options before taking a decision. Scenario analysis will then to be followed by a back-casting exercise to identify the gap between the existing state and the deliverables required for the project. Use of probabilistic methods to arrive at time baseline and cost baseline will reduce the risks due to optimism bias. The project Team should have a balanced composition with at least one member playing the role of devil's advocate so that the decision is put to rigorous test before implementation and risks, if any come to the fore early on in the project.

Use of scenario analysis and probabilistic thinking to avoid optimism bias has been demonstrated in the naval medium lift helicopter indigenisation project. The customer projected a time period of three months to operationalise the project. The project analysis was carried out using the PERT methodology. It comprised four major activities of fault diagnosis, spares availability, snag rectification and flight testing. Since each was a new activity, a three point estimating technique was adopted to obtain an expected time frame of 150 days. Further planning was carried out using back casting method. By avoiding the optimism bias, it was possible to plan helicopter deployment activity and base readiness realistically and ensure operational effectiveness.

Availability bias (Recency effect):

Availability bias or recency effect refers to the mental shortcut that relies on immediate examples that comes readily to the mind while taking decisions. The ease of recall may be either because it had happened recently or because one felt very emotional about it. The availability heuristic is a framing bias that gives more importance to events in a fame of recent past than for events in the distant past. It operates on the presumption that if an event can be recalled easily, it must be more important than the ones that are not recalled easily.

Accordingly, project managers assess probability by giving more weight to current or easily recalled information instead of processing all information. For example, while estimating the cost or time required for a project, the project manager accesses information of the immediate past projects or the projects he was intensely involved and arrives at a decision. While selecting a particular equipment or capita item or software to be used for a project, exemplars come into play. Exemplars are solutions which come immediately to mind by availability heuristics. Advertisements, frequent discussion on a particular product leads to exemplars coming to mind more often while taking decisions.

There are two Project management tools to address this bias. One is assumption analysis. While the scope statement is being prepared, all the assumptions have to be documented as an assumptions log. These have to be then analysed for validity with a presentation to the sponsor or customer. Organisations need to systematise the process of lessons learnt document for every project so that whenever a new project is being initiated, the lessons learnt from projects across the time spectrum can be used for better prediction of time and cost estimates. Archives of risk registers should also form part of the lessons learnt document so that it provides a reality check the perception of the project manager can be compared with the actual record of what has happened in the past.

The availability bias was noticed in the twin engine helicopter prototyping project. The organisation had full-fledged manufacturing facilities for a single engine helicopter project which was in operation for more than two decades. When the prototyping of the twin engine helicopter project was taken up, it was assumed that the existing machinery and equipment will cater to the prototyping project and no further investment is required. Accordingly, manufacturing of the 2500 critical components were launched. Mid-way through the project it was realised that some of the gear grinding capabilities, 3-D milling machinery and co-ordinate measuring metrological facilities were not available. A thorough assumption validation at the beginning of the project could have avoided the delay in the project of six months and cost overruns due to emergency equipment purchases and outsourcing to Proprietary firms.

Halo effect:

Halo effect is an emotional bias in which one tends to give more importance to a person's opinions in all fields just because he is proficient in one domain of knowledge or is occupying an important position in the Project hierarchy. Edward Thorndike (1920) first coined the term to describe the constant error in psychological ratings on all characteristics of a person based on one or few of his characteristic. For instance, a designer proficient in embedded systems is also assumed to have in-depth knowledge in aviation systems as well and his opinions are valued unduly high in project cost estimation. The report of a technical consultant firm incorporating a footnote on organisational structure recommendation for your project may receive more than required importance just because it has come from a specialised agency. Another example is to attach more importance to the suggestions of an influencing member or team leader or sponsor without subjecting it to analytical dissection. The Design Director set up an estimate of 36 months for drawing board to tarmac of a trainer aircraft. Just because the estimate came from a Design head, it became the baseline for the project. Later the project had an overrun up to 60 months leading to loss of potential orders. Another example is the estimate given for developing a Vaccine for Covid given by a popular leader politician against which the country's laboratories were working on.

There are many structured brain storming techniques in Project Management to overcome the Halo effect bias depending on the culture and openness to discussion in the team. If the proposer is a senior person, Delphi technique can be adopted. Since this is a blind evaluation approach, the halo of the proposer does not come in the way of objective evaluation. If the culture provides a little openness, the murder board method can be used in which the proposal will be subject to intense scrutiny and the proposer will have a chance to give his justification. The proposal can be accepted if it passes the scrutiny. Where consensus forming is essential for project success sociocracy technique may be preferred. Each of the team member has a voting right by lifting the appropriate number of fingers of his right hand (from 0 – 5) to indicate the level of acceptance. An average of 3 from all members will be required for the proposal to be incorporated in the project. By these methods the bias due to halo can be minimised.

Planning stage

Planning fallacy:

The planning fallacy refers to a prediction phenomenon, wherein Managers underestimate the time it will take to complete a future task, despite knowledge that previous tasks have generally taken longer than planned. The tendency to overpromise and under deliver is known as planning fallacy. It occurs in both time estimates as well as cost estimates. One explanation for planning fallacy is “focalism”: that is the Project Manager tends to focus on the future task and do not consider similar task in the past which took longer time to complete. Planning fallacy results in students’ syndrome during execution stage. With the result, activities start getting delayed assuming they still have time to complete the same.

There are four sequential steps to be adopted to avoid planning fallacy. Each of these four steps are described in the PMBOK. The first step is a comprehensive Work Breakdown Structure broken down to sufficient detail that the time and cost can be estimated to a greater degree of precision When the project team has to estimate durations for a higher order of activity set, the errors will be more than when the tasks are subdivided into smaller pieces for which standard rates can be applied. The second step is to have early team buy-in during estimating resources for each element of the activity. Subject matter experts can give more realistic estimates, especially with a fully differentiated WBS. Use of the PERT methodology for project time estimates following a beta distribution will ensure that optimistic time estimates are moderated by the most likely and pessimistic values also. The contingency reserves can be added after accounting for this.

When time and cost estimates have to be carried out at a macro level and a detailed work breakdown structure cannot be prepared at that point in the project, Kahnemann and Lovallo (2003) propose to develop a reference class of similar projects and establish a probability distribution for the parameter being estimated. Flyvberg (2008) takes this further to propose what he terms as “Planning bias uplift”. Under this method, similar projects are studied with respect to estimated costs (or time) and actual costs (or time) and the average factor of actual to estimate is determined for that class of projects. This factor is then used to give an uplift to the planning estimates to arrive at more realistic figures. Of course, this method is applicable for similar projects in complexity, time domain, geography etc.

Anchoring effect:

Anchoring is a framing bias when the project manager tends to rely too heavily on the first piece of information (Anchor) he receives about a subject, holds on to it and makes adjustments about the first piece of data. Once an anchor is established, all subsequent decisions and negotiations will centre and be informed by the initial suggestion. There will be a bias to interpret subsequent data around the anchor. M Lorko(2019) suggests that such relatively uninformed suggestions or expectations play a role in the estimation of project resources. Self-anchoring effect is the process in which future estimates of a Project Manager are anchored around his own first estimates. Mc Gray et al (2002) go on to further state that no amount of subsequently generated data will do little to offset the initial anchor.

This phenomenon is more in long gestation projects where the planning cell may be different from the execution cell. The results of the deviation from the planned estimates to the actuals are rarely communicated back to the planner that in the next project the planner again holds on to his anchor without realising that the estimate was negated in the previous project. It is necessary to provide feedback to the planners on the estimation accuracy so that they can recalibrate their anchors.

Another method of avoiding anchoring bias is to undertake bottoms up estimating for the project phase using templates drawn from the organisational process assets and validate the same using historical data. Halkjelsvik & Jørgensen (2012) bring out that the planning group should isolate itself from the expectations of the customers or the higher management while carrying out the estimating activity. Illustrating the effect of anchoring, the rough order initial time lines for developing a turbo prop engine was pegged at 36 months. After initial go ahead the project team carried out a detailed work breakdown structure and bottoms up estimate revealing that the project could take up to 50 months. However, the sponsors were anchored onto the initial value of 36 months (3 years) and continued to monitor against the initial time frame resulting in improper control efforts and the project was 60 % complete at the end of 50 months.

Loss Aversion bias:

Given multiple options, Project Managers tend to choose that alternative which minimises their risk rather than that option which maximises their profits (Schindler & Pfattheicher, 2016). Losses hurt more than their equivalent gains (Kahneman & Tversky, 1979).This is known as loss aversion bias. The pain of losing is about twice that of the pleasure of gaining an equivalent amount. Hence Project Managers expect to have twice the returns to venture into an innovation project than a safer routine project. Another manifestation of loss aversion is in risk management planning where the project manager tries to address risks even with low PI values leading to unnecessary expenditure on Annual maintenance contract, insurance premium, redundancy etc.,.

Loss aversion leads to risk aversion and is more predominant in long gestation projects executed by bureaucratic organisations. Swalm (1966) attributes this to the corporate incentives and control processes in large projects that actively discourages taking risks on behalf of the corporation. This means that the Project Manager needs to rationalise and prove to a degree higher than in his individual capacity the choice of a risky project.

Hullet (2006) proposes the widespread use of the decision tree approach to put on paper the multiple options, evaluate each and present pictorially to the stakeholders the rationale behind the choice. This approach uses the concept of Expected Monetary Value (EMV) of each approach and factors the probability of success of each approach. Organisations with slightly lesser risk appetites may use the expected Utility (E(U)) in place of the Expected Monetary Value (EMV) for arriving at decisions.

Adoption of Price Plus Incentive Contracts instead of fixed rate contracts will enable the Project team to reap the benefit of positive risks, incentivise the contractor to perform effectively and also reduce the high prices inbuilt in a fixed price contract.

A typical example of loss aversion bias is the training campus project planned at Rs. 70 crores with 2 years' time frame for completion. However, even after 5 years the project had not moved from planning to execution phase. When finally, the contract was awarded for execution, half way into the project, the contractor refused to further the work quoting cost over runs due to delay in award of contract. Since lot of money had already been invested into the project, the organisation was forced to put in another Rs. 27 crores and the project was completed in 7 years. During this period, the utilisation envisaged for the campus was no more existing resulting in a sub optimal use of project deliverable. A timely contract award along with a price cum incentive contract could have salvaged the project to some extent.

Execution Phase:

Confirmation Bias:

Nickerson (1998) defines confirmation bias as the tendency of seeking or interpreting evidence in ways that is consistent with the existing belief, expectation or hypothesis in hand. The Project Manager seeks information and data to reinforce held perceptions and ignores contrary information which tend to imply otherwise. With the result they maintain their stand even when confronted with information that should take them to a new decision. This can lead to systemic errors in decision making process where more effort is made to seek information that confirms previous preference

Confirmation bias can happen either at the individual level or at the group level. In order to overcome this, it is necessary to constitute Audit Committees and Project Review Boards with multiple stakeholders to review the progress of the project. Audit committees utilise check lists and templates to ensure that biases do not enter into the evaluation process. Project Review Board will have stakeholders with different points of view for a 360-degree assessment of project progress. Carrying out periodic project review with one or more team member playing the role of devil's advocate will enable bringing onto the table issues which otherwise tend to get hidden during the project execution.

Customer sponsored aerospace projects have a robust inbuilt mechanism of Program Management Group (PMG) to eliminate confirmation biases. Domain experts like designers and developers look for evidence to support their strongly held ideas while ignoring contra indications. Regulatory bodies, with limited implicit interest in the project further aid this process. Having a cross functional project Management group, for the Advanced helicopter program for instance with representatives from manufacturing, sponsors and pilots ensured that performance characteristics emanating from prototype trials were not ignored but methodically addressed leading to successful certification of the helicopter deliverables.

Sunk Cost Bias:

Sunk cost bias is defined by Olivola (2018) as the general tendency for pursuing an inferior alternative merely because of previously invested significant but non recoverable resources in it. Rationally this investment may not be justifiable and if the situation would have been related to similar investment is a new project, the decision would have been different. Sunk cost bias is significant in long gestation projects because a lot of resources including time would already have been invested irrevocably in the project and it would be difficult to abandon the project at this late stage. Further, where multiple project managers come and go in long gestation projects, the incumbent project Manager would not want to take the blame of pulling the project down but would rather keep funding the same in the glimmering hope that it may eventually complete. The effect of Sunk cost bias is that the project team continues riding dead horses potentially wasting money and blocking resources, which are not available to other, strategically more important projects, and leading people into a frustration over not really moving forward.

It would be prudent to have predefine kill points at various stages of the project in consultation with the sponsor, so that the project does not cross the stage gate without due evaluation and decision making. At the phase gate, a few high level risks would have become certainties resulting in no further business justification to continue treading the path. At these kill points, alternate strategies to salvage the project may be deliberated. One method is the use of Residual Return on Investment appraisal (RROI). If the project return on investment is more than the additional resources that need to be expended to complete the project, it may still be viable to go ahead with the project since it would at least salvage image of the company, but if the additional investment is not recoverable, it would be prudent to kill the project.

The decision on continuing or otherwise of the project phase has to be taken by the Program Management Office (PMO) based on a portfolio level perspective. The PMO review can carry out a due diligence analysis along with the project team, owners, sponsors and other stakeholders still identifying with the project. The PMO review will enable eliminating the sunk cost bias, release resources to more strategic projects and serve as a good example to other running projects to be evaluated on factual criteria and not on individual emotions.

Examples of legacy design projects continuing to be funded and manned long after its utility has been eroded are seen in large multi project organisations. For example, the aircraft design division of an organisation continued to put in resources for an unmanned aerial vehicle and unmanned combat aircraft project even though the deliverables were nowhere in sight since already a substantial fund had been sunk into the project.

Illusion of Progress:

Project Managers sometimes ignore structured tools and techniques and go by the rule of the thumb method to monitor and control projects. They rely on their expertise, experience and gut instincts to understand the progress of the project. As long as machines are clattering and people are moving and team members appear busy, the project Manager gets a wrong sense of progress. However, even though work is being done, the right work may not be being carried out or the work may not be adding value to the project. To get a sense of the track of the project, Project Managers use colourful dash boards displaying various numbers and graphs and they get an illusion of progress; but it is essential to identify the right metric for measuring the progress of the project. For example, using percentage completion may not give idea of completion of significant milestone which results in stage payments.

One way to avoid the illusion of progress is the use of Earned Value Methodology (EVM) to track the progress of the project. The Project Manager can monitor the value generated against the baselines and can make meaningful conclusions. Generating the "S" curve achieved against baseline enables the Project manager know the trend of progress of the project. Use of Critical Path Methodology enables tracking whether critical activities are being progressed or only easy but subcritical activities are being undertaken. Linking progress to milestones and milestone slip charts will clearly reveal progress against committed deadlines. Use of Gantt chart is another pictorial method to track progress of project on a continuous basis without getting affected by the illusion of progress.

A successful example of utilising Gantt charts to have visible display of project progress and critical delaying activities has been in the turbo trainer project. Methodical use of Gantt charts coupled with critical path methodology enabled unearth the effect of engine delivery delay likely to cause project delay resulting in proactive back up plan initiation and execution mitigating project delays.

CONCLUSION:

With increasing expectations of customers, complexity of projects are increasing. Long gestation projects need decisions to be taken in the present context which will have impact at a later point in time. The Project Manager who has taken the decision in one phase of the project will not be there in another stage of the project. In the wake of uncertainty, when Project Managers take decisions with limited data, biases tend to creep in. It is essential for the Project

Manager to be aware of the various biases that can cloud the decision-making process in various phases of the project. Use of structured tools and techniques as discussed in the paper will minimise the adverse effect of decision biases, more so in a VUCA environment. The paper has identified specific tools and techniques to be adopted to overcome specific types of biases and at various phases of the project. This paper serves as a checklist for a Project management practises audit to be undertaken by the PMO to ensure sound decision-making processes in the organisation.

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Success Traits of Power Projects: Empirical Analysis

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ABSTRACT

Power Transmission constitutes an essential part of power projects, which, in turn, are more like construction projects. Thus, power projects' success becomes a significant concern with the increased boundary and volume of the power transmission sector in the recent decade, especially in India. This study emphasizes the need to investigate and comprehend the success traits of power transmission projects. The research objective is to identify power transmission projects' critical characteristics and study their relationship with project success. This study discusses a set of 43 variables into six groups of factors vis-a-vis Strategy, Risk, Supply Chain, Information Communication Technology, Environment, and Project Success. The research tool comprises a survey questionnaire, and personal interviews with experts of power transmission projects actively involved in the projects at various levels, and 414 valid responses are received. The statistical analysis comprehends that all five critical factors significantly affect the Power Transmission Project Success. These findings are likely to contribute significantly to achieving the project's success in management and social perspective to the Indian power transmission industry.

KEY WORDS

Critical Success Factors (CSFs); Strategy; Information Communication Technology (ICT); Power Transmission (PT).

1. INTRODUCTION

The power sector contains three areas: power generation, power transmission (lines & substations), and power distribution. Power Transmission, a vital part of the power transport value chain, dissipates power from the generating stations to its delivery to the load centers. So, more transmission power projects need in India. The power transmission project characteristics are quite similar to the construction projects, and the primary concern of the project team is on project success. Substation in PT projects activities such as control building, pump house, drain, road, dormitory is similar to a non-power construction project. PT project and other infrastructure projects like road projects, oil and Gas projects face similar challenges: ROW problem, land acquisition, and land development. Over the most recent five years, the India transmission segment has indicated robust growth. Essentially, the state, center, and the private utilities' rule the power transmission segment, while long before, private utilities had control of just 3-4 percent on the power transmission area. According to Center Electricity Authority (CEA), a two lakh sixty thousand (2.6 lakh) crore venture would occur in the power transmission segment from FY18 to FY22, shown in Table-1.

Table-1: Projected Investment in Power Transmission sector in India between FY 18-22

Total Investment	2.6 lakh crore
Transmission Line	100000 Circuit KM
Substation: Transformer Capacity	200000 MVA

Source: Central Electricity Authority, India, 2018

In terms of GDP and power consumption, India is now among the fastest-growing countries in the world. The challenge is to address the energy needs of around 1.3 billion people with fast economic growth and electricity use. To ensure reliable, accessible, uninterruptible (24x7) and quality power for all, effectiveness, organized, affordable and stable electricity system is necessary for the smooth supply of power from the generating station to the load centers (as per the Electricity Act, 2003) and for the optimal utilization of resources. India has set a 9 percent target growth rate that would put it on a track to become a USD 5 trillion economy by 2024-25, making it the world's fastest-growing large economy. Sustained economic growth in India puts a massive pressure on its energy resources, energy systems, and infrastructure.

The PT project area's significance necessitates recognizing CSFs and their effect on India's PT projects venture accomplishment. Various researchers have estimated the capability of the power sector in India. However, their examination is constrained to potential, arrangement, difficulties, and possibilities of the power division. Some factors are identified for reducing power shortage, which is including Properties, reduction of losses in distribution and transmission, supply - site management by maximum electric energy efficiency, policy shifts in pricing models, switch and focus on renewable energy for power generation, total energy systems, latest energy storage devices (Kumar, et.al., 2014). It is decoupled, and open up to private entrepreneurs for involvement, with the prerequisite of investing heavily and in order to provide competitiveness in the overall structure. Therefore, it has opened the way for business opportunities to be used for investment (Mukhopadhyay, 2004).

1.1 Research Objectives

This research aims

- To identify critical success factors (CSFs) for power transmission projects in India.
- To study the relation and impact of all those CSFs to project success for PT projects in India.

1.2 Organization of The Study

The study has organized as following manner:

- Introduction
- Literature Review
- Research Methodology
- Result and Discussion
- Conclusion and Recommendation

2. LITERATURE REVIEW

This piece of the exploration subtleties analyzes the past literature in critical success factors (CSFs), strengthening the present study to discover the CSFs for the power transmission projects.

2.1 Project Success

For the last numerous years, researchers concentrated on achieving the iron triangle targets (time, cost, and quality). The achievement of the project is frequently shifted among various partners. The project, within time and cost, are dealt with, has failed on the likelihood that it does not accomplish the organization's vital goals (Frefer, 2018, & Cooke-Davies, 2002), and it is referred to that project achievement which has three diverse gatherings of goals, i.e.

- Project objective (the iron triangle of cost, time, and scope).
- Business objectives (Owner's expectation) and

- Social and Environmental objectives (local community's expectation)

2.2 Finding Critical Success Factors

Critical Success Factors (CSFs) are mainly those that demonstrate an indispensable activity in achieving an association through the project. The possibility of "success factors" is created in 1961 by D. Ronald Daniel of McKinsey and Company. It is refined into critical success factors in1981 by John F Rockart. From that point forward, numerous creators have distributed arrangements of "CSFs."

After a comprehensive literature audit, it is essential to explore the success traits of PT projects to view the potential of and expenditure on PT projects in India. The primary success traits are proposed for power transmission projects in India, as Strategy, Risk, Supply Chain, Information Communication Technology, and Environment.

The past literature and current study discuss the following factors in power sector projects in Table-2.

Table-2: Critical Factors in Power Sector Projects

S. No	Author	Location	Research Variable/CSFs	Current Study Variable Identified
1	Aziz, (2013)	Egypt	1) consultant, 2) contractor, 3) design, 4) equipment, 5) external, 6) labor, 7) material, and 8) project	**Strategy:** nine (9) sub-factors which include :1) Leadership strategy(S-CSF1), 2) Bidding strategy(S-CSF2), 3) Strategy of addressing risk(S-CSF3), 4) Clear Objectives and understanding(S-CSF4), 5) Cohesive procurement strategy(S-CSF5), 6) Strategy of effective communication(S-CSF6), 7) market intelligence strategy(S-CSF7), 8)
2	Bhattacharyya and Dey (2007)	India	1) political, 2) financial, 3) economic, 4) legal and regulatory framework, 5) management failure	

3	Choudhury (2014)	India	1) conception and feasibility studies, 2) project planning,3) bidding and contracting 4) project implementations	Strategic execution plan align with project scope(S-CSF8), and 9) Human resource strategy (S-CSF9). **Risk:** nine (9) sub-factors for risk factor dimension include: 1) fund flow of client(R-CSF1), 2) control of scope creeping(R-CSF2), 3) team conflict resolution(R-CSF3), 4) timely subcontractor payment(R-CSF4), 5) clear and unambiguity scope(R-CSF5), 6) Justified penalty clause(R-CSF6), 7) timely document and drawing approval(R-CSF7), 8) price variation clause(R-CSF8) and 9) test list with less frequency(R-CSF9). **Supply Chain**: six (6) sub-factors dimension are: 1) early assortment of supplier (SC-CSF1), 2) selection of appropriate vendor (SC-CSF2), 3) clear responsibility matrix between supplier and purchaser (SC-CSF3), 4) relationship with suppliers & client (SC-CSF4), 5) proper co-ordination between supplier and client (SC-CSF5), and 6) clear terms & condition (SC-CSF6). **Information Communication technology**: five (5) sub-factors for information communication technology are; 1) e-tendering (ICT-CSF1); 2) improve design
4	Doloi, et. al., (2012)	India	1) project, 2) site, 3) process-related, 4) human, 5) authority and (6) technical	
5	Hermawati and Rosaira (2017)	Indonesia	1) Planning, 2) community 3) communication and beneficiaries, 4) technology, 5) project management, 6) stakeholders support and network development.	
6	Mohan, A., and Topp, K., (2018)	Pakistan	1) communication factor, 2) team factors, 3) technical factor, 4) organizational factor, and 5) environmental factor	
7	Maqbool, et al. (2018)	Pakistan	1) communication, 2) team, 3) technical, 4) organizational, 5) environmental	
8	Nundwe, and Mulenga (2017)	Zambia	1) late advance payments, 2) financial mismanagement by the contractor, and 3) irregular payments to sub-contractors	
9	Pall et al. (2016)	Not Specified	1)administrative, 2) employer 3) servicer, 4) advisor, 5) sketch, 6) material, 7) apparatus, 8) worker, 9) miscellaneous	

10	Tsiga, et. al., 2016	Not Specified	1) External Challenge, 2) Client knowledge and experience, 3) Top management support; 4) Institutional factors, 5) Project characteristics, 6) Project manager competence; 7) Project organization, 8) Contractual aspect, 9) Project team competence, 10) Project Risk Management; 11) Requirements Management	(ICT-CSF2); 3) planning & monitoring software (ICT-CSF3); 4) integration of project activities (ICT-CSF4) and 5) standardization of process (ICT-CSF5). **Environment**: six (6) sub-factors for environment and third-party factor include: 1) available encumbrance free land (E-CSF1), 2) accessibility of site (E-CSF2), 3) environment clearance and obtain permit (E-CSF3), 4) stable government (E-CSF4), 5) availability of construction material (E-CSF5), and 6) safety measure at site (E-CSF6).
11	Zhao et al. (2010)	China	1) viability, 2) set-up, 3) company, 4) servicer, 5) suppliers	

2.3 Research Gap

The analysis of literature identified the significant gap as given below:

- In the past literature, the success of PT projects has not been studied concerning Strategy, Risk, Supply Chain, Information Communication Technology and Environment as the CSFs.
- There is no study on PT projects in India.
- There is no holistic framework for PT projects, which can be considered standard.

2.4 Hypotheses

The above writing sets up five significant traits as the success factors for power transmission projects: strategy factors, risk factors, supply chain factors, information communication technology factors, and environmental factors. Thus, the researcher proposed the following hypotheses for this study to be tested here:

H_1: Strategy factor effect Project success.

H_2: Risk factors effect Project success.

H_3: Supply chain effect Project success.

H_4: Information communication technology effects Project success.

H_5: Environment effects project success.

3. RESEARCH METHODOLOGY

A logical approach is drawn for a robust research design that contains new empirical evidence along-with the prevailing theory. A questionnaire survey design is used to collect quantitative data in a random sample of project management team members, forming a wide range of respondents to achieve the derived theory's extensive analysis. The research method for the present study is given in Figure-1.

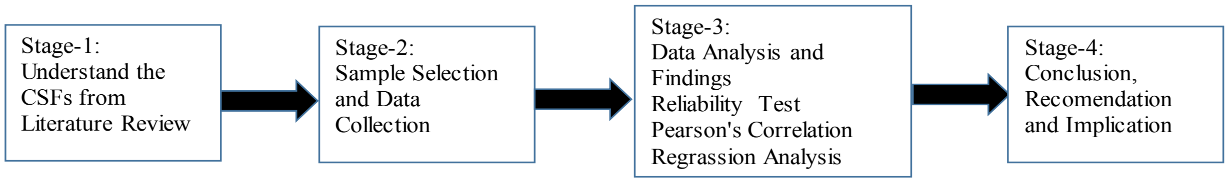

Figure-1: Research Methodology

Source: Self Design of Author

3.1. Questionnaire development

Identifying of critical success factors for the study and development of a questionnaire is a significant step for the research's conclusion. In the present study, six variables are being studied, which comprise of one dependent factor, i.e., project success, and five independent factors, namely: 1) Strategy, 2) Risk, 3) Supply Chain, 4) Information Communication Technology, and 5) Environment. The questionnaire is based on five-point Likert Scale, with ‘1’ as "no impact," ‘2’ as "negligible impact," ‘3’ as "marginal impact," ‘4’ as "moderate impact," and ‘5’ as "major impact".

3.2. Population, and sampling technique

The project team members include project managers and top management of various organizations taking power sector projects in India, is the "unit of investigation" for this exploration. Table-3 shows a concise portrayal of respondents' profiles regarding experience, function, and company (Public & private) who partook in this study. An aggregate of 485 surveys was sent out, of which got 414 substantial responses with a response rate of approximately 85 percent. Different techniques, such as email, web, and telephonic conversations, are used to gather specialist's data.

Table-3: Respondents Profile

Characteristics	Category	No. of respondents	In Percentage (%)
Experience	1-5 years	35	8
	6-10 years	52	13
	11-15 years	74	18
	16-20 Years	85	21
	21-25 years	102	25
	Above 25 years	66	16
Function	Strategy	135	33
	Operation	279	67
Company	Private	339	82
	Public	75	18

Source: Authors Own

4.RESULTS AND DISCUSSION

4.1 Mathematical validity of factor analysis

Utilizing the statistical tool SPSS-25, ascertaining the Pearson correlation, the researcher evaluated the relationship among different variables. Pearson correlation is given in Table-4. It is found that the Pearson bivariate correlation is more prominent than 0.4 in the vast majority of the cases among various variables in all the factors. These outcomes show that factors structured in factor analysis contain most related variables.

Table-4: Correlation matrix for the Success Traits

Factor I: Project Success

	PSCSF 1	PSCSF 2	PSCSF 3	PSCSF 4	PSCSF 5	PSCSF 6	PSCSF 7	PSCSF 8
PSCSF1	1							
PSCSF2	.374**	1						
PSCSF3	.597**	.428**	1					
PSCSF4	.376**	.486**	.479**	1				
PSCSF5	.479**	.572**	.540**	.465**	1			
PSCSF6	.510**	.450**	.414**	.408**	.356**	1		
PSCSF7	.501**	.489**	.539**	.448**	.398**	.458**	1	
PSCSF8	.445**	.392**	.505**	.520**	.556**	.300**	.403**	1

Factor II: Strategy

	SCSF1	SCSF2	SCSF3	SCSF4	SCSF5	SCSF6	SCSF7	SCSF8	SCSF9
SCSF1	1								
SCSF2	.332**	1							
SCSF3	.484**	.347**	1						
SCSF4	.354**	.430**	.383**	1					
SCSF5	.492**	.472**	.546**	.527**	1				
SCSF6	.431**	.376**	.395**	.522**	.412**	1			
SCSF7	.379**	.444**	.362**	.460**	.470**	.367**	1		
SCSF8	.384**	.443**	.392**	.438**	.543**	.426**	.375**	1	
SCSF9	.354**	.417**	.406**	.426**	.379**	.517**	.456**	.462**	1

Factor-III: Risk

	RCSF1	RCSF2	RCSF3	RCSF4	RCSF5	RCSF6	RCSF7	RCSF8	RCSF9
RCSF1	1								
RCSF2	.300**	1							
RCSF3	.449**	.315**	1						
RCSF4	.462**	.448**	.487**	1					
RCSF5	.393**	.420**	.325**	.322**	1				
RCSF6	.487**	.458**	.492**	.416**	.400**	1			
RCSF7	.312**	.365**	.479**	.428**	.438**	.398**	1		
RCSF8	.386**	.485**	.314**	.351**	.379**	.422**	.350**	1	
RCSF9	.450**	.302**	.462**	.435**	.442**	.493**	.366**	.390**	1

Factor IV: Supply Chain

	SCCSF1	SCCSF2	SCCSF3	SCSCF4	SCCSF5	SCCSF6
SCCSF1	1					
SCCSF2	.487**	1				
SCCSF3	.531**	.452**	1			
SCSCF4	.472**	.484**	.506**	1		
SCCSF5	.525**	.427**	.537**	.478**	1	
SCCSF6	.569**	.593**	.498**	.529**	.523**	1

Factor V: Information Communication Technology

	ICTCSF1	ICTCSF2	ICTCSF3	ICTCSF4	ICTCSF5
ICTCSF1	1				
ICTCSF2	.475**	1			
ICTCSF3	.473**	.535**	1		
ICTCSF4	.523**	.549**	.588**	1	
ICTCSF5	.467**	.568**	.527**	.524**	1

Factor VI: Environment

	ECSF1	ECSF2	ECSF3	ECSF4	ECSF5	ECSF6
ECSF1	1					
ECSF2	.391**	1				
ECSF3	.504**	.594**	1			
ECSF4	.524**	.441**	.460**	1		
ECSF5	.480**	.533**	.564**	.495**	1	
ECSF6	.428**	.562**	.612**	.459**	.526**	1

As thumb rule applies to most situations with the following ranges: Cα>0.9 indicates excellent, 0.9>Cα>0.8 as good, 0.8>Cα>0.7 as acceptable, 0.7>Cα>0.6 as questionable, 0.6>Cα>0.5 as low, and 0.5>Cα denotes unacceptable (Doloi, et. al., 2012). The value of Cα for all variables are greater than 0.8 as shown in Table-5.

Table-5: Reliability Cronbach's Alpha for the Factors

Factors		**Cronbach's alpha (Cα)**
Project Success	Factor I	0.872
Strategy	Factor II	0.871
Risk	Factor III	0.81
Supply Chain	Factor IV	0.86
Information Communication Technology	Factor V	0.846
Environment	Factor VI	0.86
All Factors Are Selected		0.947

Source: Authors Own

4.2 Regression analysis

The independent variables (Strategy, Risk, Supply Chain, Information Communication Technology, and Environment) and dependent variable (Project Success) used are the factors that resulted from the factor analysis, as shown in Table 4. These factors are entered into a regression model stepwise as categorical variables are shown in Table-6. In this way, can communicate the regression model framed to measure the overall impact of project success by singular traits part as:

$$\mathbf{Y= a + b_1X_1+b_2X_2+.... b_nX_n+ e} \text{ -------------- } \mathbf{(1)}$$

Table-6: Regression Model

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**
1	.642[a]	0.413	0.406	0.5641	2.18
		Sum of Squares	**Df**	**Mean Square**	**F**	**Sig.**

Source	**Coefficient(β)**	**Std. Error**	**t**	**Sig.**
Intercept	1.183	0.186	6.369	0.000
Strategy	0.166	0.049	3.355	0.001
Risk	0.19	0.053	3.574	0.000
Supply chain	0.12	0.045	2.664	0.008
Information communication technology	0.147	0.043	3.432	0.001
Environment	0.138	0.046	3.022	0.003

Source: Authors Own

The proposed regression model for impact of success can be explained as:

Impact of Success = (+1.183)

Strategy(X_1) = (+0.166)

Risk(X_2) = (+0.190)

Supply Chain (X_3) = (+0.120)

Information Communication Technology(X_4) = (+0.147)

Environment(X_5) = (+0.138)

Error (e) = (+0.186)

From the above it was derived the following equation:

$Y=1.183+0.166X_1+0.190X_2+0.120X_3+0.147X_4+0.138X_5+0.186$ ---------- (2)

From this result of regression analysis, independent variables; Strategy, Risk, Supply Chain, Information Communication Technology, and Environment all put together have a 41.30 percent impact on India's power transmission project success. One-unit change of project success happens by change 0.166-unit Strategy, 0.190-unit Risk, 0.120-unit Supply Chain, 0.147-unit Information Communication Technology, and 0.138-unit Environment.

4.3 Hypotheses

From Table-6 below hypotheses are drawn;

H_1: Strategy factor has significant ($p=0.001<0.05$ and $t=3.355$) affect Project success.
H_2: Risk factor has significant ($p=0.000<0.05$ and $t=3.574$) effect on Project success.
H_3: Supply chain factor has significant ($p=0.008<0.05$ and $t=2.664$) affect Project success.
H_4: Information communication technology factor has significant ($p=0.001<0.05$ and $t=3.432$) effect Project success.
H_5: Environment factor has significant ($p=0.003<0.05$ and $t=3.002$) affect project success.

5. CONCLUSION AND RECOMMENDATIONS

This study has identified 43 sub-factors into 6 groups and shown the relationship between CSFs and project success in India's power transmission project. The proposed model of this study claims the idea of project success with the support of CSFs in PT projects, which scarcely investigated in the existing published literature. The present study would enhance the CSFs information base by enriching the research conclusions concerning their impact on transmission power projects' success. PT project management practitioners can use this model to generate efficient results in terms of organizational and business goals.

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Developing an Integrated Framework for Heavy Construction Equipment Management Platform

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ABSTRACT

There is growing need for better project management techniques within the disciplines of engineering, business, and technology. With the advent of industrialization, the projects of humankind took on increasing complexity. To keep pace with advances in information technology and business processes, the organizations must change their strategy of traditional work management, which will enhance project productivity. Contractor's organization always suffers of productivity issues. Significant contributions of issues are from the equipment department, due to ineffective management. By emphasizing practical applications, the study targets the ultimate purpose of project management: to unify and integrate the interests, resources, and work efforts of many stakeholders to accomplish the overall project goal. There is a need of centralized solution to manage the equipment. A literature study extracts the factors which have a direct influence on EMS. To know the absence of factors in the study, a comparison study is made between factors of literature review and factors of commercially available EMS's. It leads to generate a framework to include and combine all the factors which are missing in existing standalone EMS's. The problem is around the real-world practice, a constructive based design-science research method is adopted for the research. A top construction company in India is shortlisted for the case study to extract the factors and incorporation of the EMS in the company. The research outcome is used in creation of an integrated framework for EMS, which is a set of guidelines that include, required inputs for EMS, visualization framework, user interface design, implementation plan, incorporating innovative ideas in the proposed framework.

KEYWRODS

Equipment Management System (EMS), Information Technology, BIM (Building Information Modelling, GA (Genetic Algorithm)

INTRODUCTION

A contractor company in the construction industry strives for the efficiency of the tasks. Equipment in construction companies is always prone to ineffective utilization. Half of the success is achieved by effective management of equipment during the life cycle. The information technology is developed in such a way that the projects are being executed rely heavily on the asset management system of the company. The research is focused on the integration of available technologies and equipment management platforms during the operational phase of the equipment. The manual errors could be reduced by integrating the available technologies. The Objectives of the research are: Identification of problems in Standalone EMS tools. Identification of factors responsible for operation of existing EMS. Development of a framework to show information flow. Implementation plan for EMS as a product delivery. The Scope of the research work is choosing a Case study to check the evolved level of EMS in the organization and the presence of factors as per literature review. Study of heavy construction equipment used, and the research is limited to two shortlisted factors.

LITERATURE REVIEW

Equipment in the construction industry plays a very important role in finishing the tasks in given constraints viz. budget, time, quality, safety environment etc. 36% of the construction costs are of equipment costs. (Hadikusumo & Prasertrungruang, 2016). The equipment management system in a contractor company is governed by following factors: *Information***:** Updated and accurate information availability of equipment in organization, like serial number, date of purchase, Service life, vale of the equipment etc. (Tavakoli et al., 1990). *Tracking:* Tracking of equipment and its tasks. *Planning:* Equipment planning based on its tasks. *Maintenance:* Periodic maintenance of the equipment. *Equipment management platform:* Modern and user-friendly EMS will be a better solution to manage the equipment in a contractor company. (Room, 2019)(Tatari & Skibniewski, 2006). The equipment management system in the contractor company is an important asset for efficient management of operations of equipment. The productivity of the project team and time would be saved by equipment sharing between two contractors within the project.(Liu et al., 2018). *Existing Integrated Platforms and Frameworks:* (Ren et al., 2017) Efficient utilization of equipment will happen from effective equipment management. (Niu et al., 2017) proposed data management system architecture for construction equipment management. *Methods of data analysis* : (Sharma, 2013) explains and demonstrates the role of the genetic algorithm in different domains of computer science. Working with GA aims to get a better solution from the number of available solutions. (Thengade & Dondal, 2012) said the working of GA is depended on the following major operators viz. selection, crossover, mutation.

Factors in Equipment Management System

The factors are building blocks of EMS, each factor is constituent of equipment, associated task and manpower which is associated with the task. Its denoted as following: Equipment (E), Task(T) and Manpower (M) The uses of factors are explained based on whether its related to Equipment, Task or Manpower as explained in Figure 1. Finding all the factors which are responsible for operation of EMS in literature review.

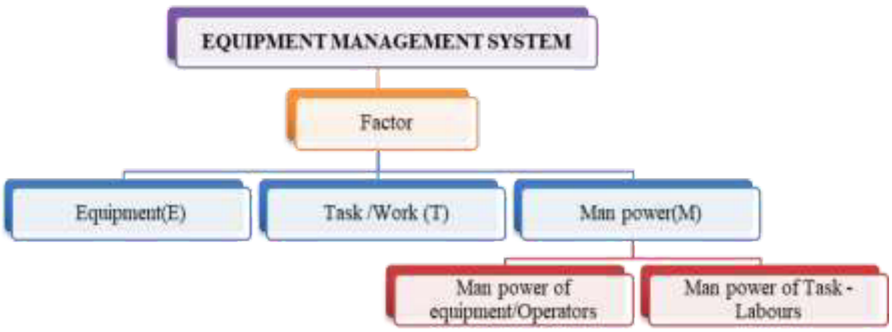

Figure 1 Factor configuration in EMS

If ‘Location tracking’ is a factor, if task information is related to equipment then, suffix is **E** (Real time location), likewise **M** (Labors associated with equipment) and **T** (Tracking of assigned task) are marked. As per the usage five different categories of factors are made. A) Information Category: Description, Cost, Efficiency, Manuals. Research Gap: BIM Based integrated manuals. B) Planning Category: Projections, Equipment planning. C)Tracking Category: Location tracking, Detection, Positioning & orientation, Equipment Statistics, Task based monitoring, Operating assistant system, Equipment operation, Automation in works. *Research Gap: Tracking of task's location with BIM visualization is not completely developed, Realtime data entry vs task progression, Live data of equipment failure*. D)Maintenance Category: Performance surveillance, Energy optimization, Periodic maintenance and insurance data. *Research Gap: This information should be kept in the server for faster access and immediate action and resolution plan.* E) Safety Category: Accident prevention / Equipment break down prevention system, Hazard energy monitoring system. *Research Gap: Alert to get* *alternative equipment which is available nearby – Equipment sharing platform within the project.*

RESEARCH METHODOLOGY

Constructive based design science research method is chosen, as research is around the real-world practices and problems. Understanding of the topic using a case-based project & using literature review. Collecting the data from case study and literature review and analyzing the data to arrive at a framework in terms of guidelines. Creating a framework includes a set of guidelines which are needed for creating an IOT & cloud-based product development. It integrates available platforms or ERP's.

DATA COLLECTION

The data collection from the case study was required to find out the benchmark of the integration of the existing standalone software. The information regarding technologies used in current EMS will be known. Available factors in EMS in the selected project in comparison with factors that are found out in the literature review is found. There was dedicated plant & machinery division and establishment of software which was used to track and monitor all the equipment at the site. All the information in the company was tracked and maintained in 8 divisions of *SAP-HANA1709*.

DATA ANALYSIS

Two factors are shortlisted for further data analysis. Viz. *Equipment statistics, Task based monitoring.* The shortlisted factors are from Tracking Category as per literature review. An excavator is shortlisted to carry out the analysis for the shortlisted factors.

Required Data Input

The Required data input for *equipment statistics* and *task-based monitoring*, which is to be loaded for the successful working of integrated equipment platform for equipment statistics. In the case study, all the data is not loaded in Realtime. By end of the day data is collected and synched in the central server. The cost and time impact from the data input which is qualitatively analyzed. Texts in Italics shows the desired solution vs current practice. As per the case study,

Equipment Statistics: Equipment distance was tracked offline through odometer. *Sensor and Realtime synchronizations of data with the platform.* Location tracked manually. *GPS trackers* *will avoid De routing of the equipment.* Productivity tracking was manual. *Sensors which tracks the current productivity.* Manual fuel tracking through empharical methods. *Sensors synced with the central platform to avoid fuel thefts*.

***Task-Based Monitoring*:** Description of the work was conveyed verbally at site. *Automatic integration of project schedule. Task details on equipment operator's dashboard.* Work hours were tracked manually. *Realtime tracking of the equipment.* Human resource integration with work was manually tracked. *Automated workers entry in the server through mobile/tablet platform.* Task based assistant system was not present. *The platform should be able to guide automatically to workforce. Reduces communication errors.*

Visualization Framework

As shown in Figure 2 Visualization framework, It consists of following main components: *Access Medium:* The medium of information accessibility, it can be mobile app, web portal or desktop application. *Data cloud:* The data cloud is pool of information where the data is retrieved from the cloud based on the query. The type of information is segregated and fetched based on the following division: Preconstruction, Realtime data, Post construction data. The data cloud is interlinked with other main components. *Site input:* This component is for retrieval of information from the site and it is decided by the interference. There are mainly three types of information retrieval are: 1) Equipment data, 2) Operator data, 3) Workforce data.

Results: Results are real-time data or Prediction. *Output:* The output will be in the form of Visualization, Charts, analytics & Reports. *Hardware and software:* There are various types of hardware & software which will help in connecting all the components, for smooth run of the main product. As the product designed in different components, the solution can be applied to any plants & equipment at the organization. The software can be customized for both existing and new equipment.

Query Example

Requirement of information like *"Fuel Status",* Conventionally the project manager asks site manager via phone call then the reply will be given via call/ text messages/ mail. Usually the process takes around 1- 24 hrs. If they use SAP severs (case study) to send the data, takes up to 24 hrs. to give the complete information. The concerned factor for this information is *"Equipment statistics".* The main challenges in the conventional methods are: Manual errors due to human interventions and Unavailability of right person during the information exchange. As per the software solution it will take seconds to address the query including predictive analysis. *Additional results of the solution:* 1) The solution gives the fuel tank health: It will be helpful in knowing till when does fuel lasts based on the type of work it involved. 2)Upcoming task and fuel requirement can be predicted, so scheduled fuel filling can be known by background calculations. Nearby fuel station or method of filling can be predicted by syncing the productivity and nearby location analysis.

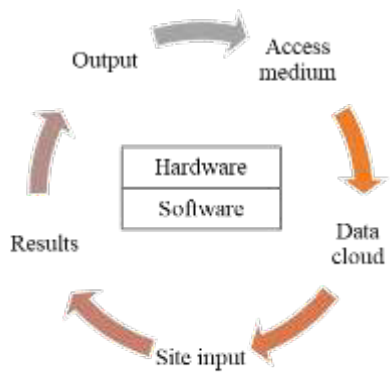

Figure 2: Visualization framework

Predictive Analysis

The fuel factor is considered for the predictive analysis. The related data is collected from 334 excavators from the case study. 4 aspects are considered for the analysis i.e. fuel issued quantity in liters, work done in cum, total working time and idle time in hrs.

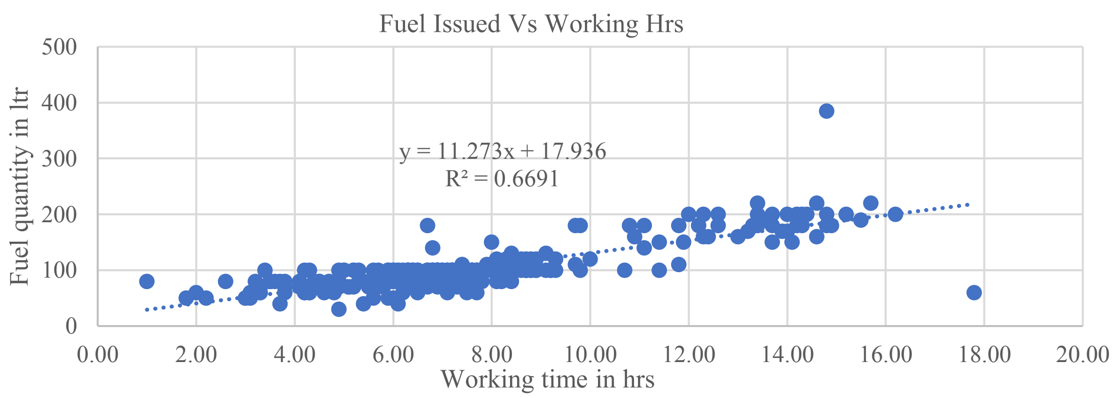

Figure 3 Fuel vs Working hrs. correlation

As shown in Figure 3, the fuel issued quantity is directly proportional to the working hours with r^2 value being 0.66, fuel quantity which is issued is dependent on the working hrs of the excavator in the data set considered. Similarly, the fuel issued quantity is directly proportional to the work done of the excavator with r^2 value being 0.14 and its directly proportional to idle time of the excavator with r^2 value 0.18. The genetic algorithm is used to find the alternative for given factor using the given constraints. *Optimization and Analysis:* As per the first factor 'Equipment statistics', the 'Fuel factor' must be minimized using the working hours, work done and idle time as constraints.

As per the second factor 'Task-based monitoring', the 'work done' must be maximized by using fuel consumed, working hours and idle time as constrains. To optimize the factors 'GA Optimization for Excel-Version 1.2' is used as part of the genetic algorithm analysis. (Schreyer, 2006)(Trivedi et al., 2012). *Optimization - Fuel Minimization***:** The objective function for applying in GA is given by *"Eq (1)"*

$$Y= a0 + a1 (X1) + a2 (X2) - a3(X3) \qquad (1)$$

Where, Y = Fuel consumed in ltr and a0, a1, a2, a3 are constants. X1 = Working hours in hrs, X2 = Work done in cum, X3 = Idle time in hrs. Its solved using multi linear regression (MLR) with the help of built-in add on of MS excel data analysis tool pack. The resulted data is substituted in *"Eq (1)",*

$$Y= 16.50 + 10.24 (X1) + 0.01 (X2) - 2.53 (X3) \qquad (2)$$

R^2 = 0.68, which implies dependent values can be explained by the regression model. *"Eq (2)"* is used in addon, GA software in excel as mentioned earlier to get optimized values. Dependent variables considered 1 unit. The minimization function is processed for independent value that is **fuel consumption**.

Table 1 Optimized values vs Site values

Sl	Variables	Site values (As per MLR)	Predicted values
1.	Fuel consumed in ltrs	24.22	355.96
2.	Working time in hrs	10.24	42.95
3.	Work done in cum	0.01	320.09
4.	Idle time in hrs	2.53	23.59

Optimization - Work done Maximization: The objective function for applying in GA is given by,

$$Y= b0 + b1\ (X1) + b2\ (X2) - b3(X3) \qquad (3)$$

Where, Y = Work done in cum and b0, b1, b2, b3 are constants, X1 = Working hours in hrs, X2 = Fuel consumed in ltr, X3 = Idle time in hrs. Using MLR, the coefficients are generated. The resulted data is substituted in *"Eq (3)"*

$$Y= 121.40+ 19.46\ (X1) + 0.60\ (X2) - 0.85\ (X3) \qquad (4)$$

$R^2 = 0.17$, very smaller number of depended variables can be explained in regression model. *"Eq (4)"* is used for maximization function for work done by excavator.

Table 2 Optimized values vs Site values factor 2

Sl	**Variables**	**Site values (As per MLR)**	**Predicted values**
1.	Work done in cum	140.61	1814.36
2.	Working time in hrs	19.46	692.97
3.	Fuel consumed in ltrs	0.6	1000
4.	Idle time in hrs	0.85	0.01

All the predictive analysis happens in background when the integrated EMS is fully functional.

User Interface and User Experience

Where the scheduled is synced in server, the operator gets notified in the interface provided to them. Figure 4, shows the description of various fields that are planned in the interface, where operator access multiple real-time information. *"Simulation field"* helps in clarifying the doubts and shows work related videos. For some of the tasks, the method statements are kept in the internal sever in video format or doc for specific task. *"Scan field"* is to scan the QR codes in the designated work fronts before or after the completion of the works so that the process and course of completion of the work will automatically synced in the server. The *"Translation field"* is dedicated for the language translation for operator.

Figure 4: Equipment Operator user interface

Implementation Plan

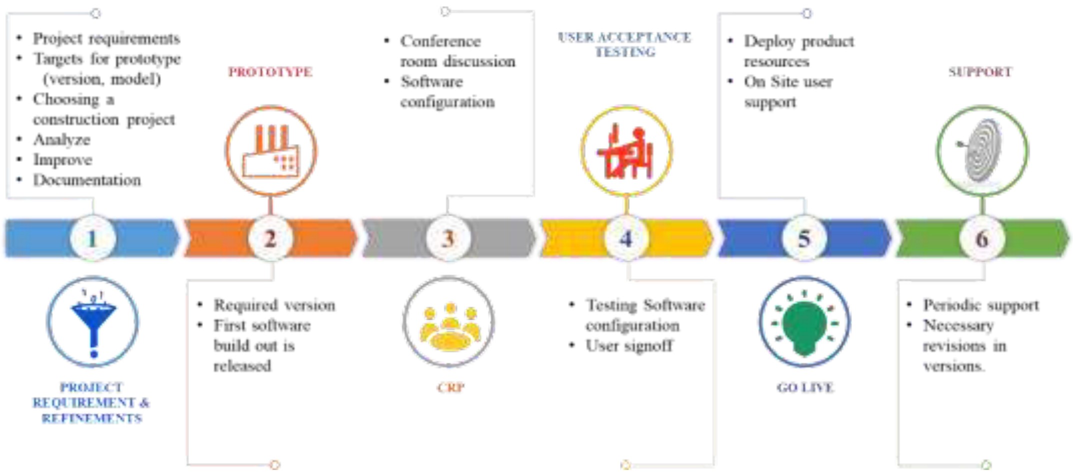

Figure 5: Implementation plan of the integrated EMS

Figure 5 shows the implementation plan for the integrated software from the stage of the project start. Initially the processes are refined by functional team and technical team. After the first build out, reviewing of the product in front of the board panel (CRP) Conference Room Pilot will be completed. The issues are addressed, and CRP's are conducted to completely develop the issue free product before it goes onto the field. The product is helpful in reporting an issue at the site. Risk is reduced by ensuring right person present at the right Workfront and time. It analyses the accidents, near misses by reporting it to ensure safety of workforce and reduces future accidents. Mitigates the risk of over allocation or under allocation of resources. *Creating a value chain:* The solution helps in creating a value chain to other related businesses like maintenance, service sector, parts manufacturers, sub-contractors through proper analytics.

CONCLUSION

The research outcome is used to provide a better solution to the vulnerability of efficient EMS. There will be reduction of manual interventions in decision making, operation management and advancement in managerial thinking. Maximization of productivity and utilization of equipment. Predictive analysis that will help in knowing the additional results which are profitable. A query example is considered to show the way of working of these components, and its results. The optimization is used for the predictive analysis of the integrated equipment management platform. This is a background process which can run in the future software, where it will be helpful in predicting the values. An app-based interface for worker and end labour is designed, which shows the incorporation of the drawings and simulation or BIM models with labour to ease the speed of work and communication. The product not only benefits the equipment owner, it creates value chain among subsidiary businesses. The Implementation plan is made for the successful delivery of the product. The data analysis is carried out considering only two factors i.e. Equipment statistics and Task based analysis. *Future scope:* One of the small jobs is taken up and a basic user interface is prepared for testing purpose at the site. The product is used for one specific project to check the credibility of the product. Applied to varied type of the equipment within the project to check all types of analysis and its results.

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Development of a Feasibility Study Framework for UAVs in the Indian Construction Industry

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ABSTRACT

Civilian applications of Unmanned Aerial Vehicles (UAVs) started very recently. Exploring the applications of UAVs in the construction industry has been of importance ever since. Finding the feasibility of UAVs in the Indian construction industry has been relatively unexplored. In this regard, a study has been carried out to find out different applications of UAVs in the construction industry, to find out the feasibility of UAVs in the Indian construction industry, and to develop a set of guidelines and a framework to use UAVs in construction. Design science research methodology was adopted for this study as the method is very rigorous in testing the solution. Semi-structured interviews were conducted with professionals who are closely related to this field. Different applications of UAVs in construction were identified from interviews and literature studies. Interview data were analysed using thematic analysis and a deductive approach was used to find out different factors for the development of the framework and guidelines. The guidelines were integrated with the framework to make it handy and robust. The feasibility of UAVs in the Indian construction industry was established by analysing different factors such as legal and financial aspects in India considering the current scenario. It was inferred that the UAV enabled method is feasible when the scope of the project is very large or when the time is a constraint. The study explored the benefits of UAVs in construction. Major benefits include visualization and ease in decision making in different stages of a project. Real-time visualization using UAVs helps in monitoring different aspects of a project like safety and quality inspections, progress monitoring, 3D mapping, volumetric estimations, material tracking, and even helpful in tendering purposes. This enhances the decision making capability of top management in a project without physically accessing the site. UAVs can save considerable amount of time, manpower, and money which ultimately leads to better project management. The framework can guide a professional through the financial, legal, and operational feasibility for adopting UAVs in construction which helps in choosing or declining the use of UAVs in a project considering the characteristics or purpose of the project. The

checklists incorporated will ease the burden of the professionals as well as the operators in performing UAV operations.

KEYWRODS

Unmanned aerial vehicle, Fesibility of UAVs, Application of UAVs, Visualiztion and Decision making

INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly termed drones were used only in military operations in the earlier days. Recently, people started using this technology for civilian applications. Although legal constraints in each country restricts the use of UAVs up to an extent, researches are going on regarding the applications of UAVs in different sectors. In accordance with this, a few studies have been carried out regarding the applications of UAVs in construction industry. These studies have listed several applications such as construction monitoring, job site logistics, safety conditions, quality inspections, building inspections, damage assessment, site surveying, 3D mapping and other technical aspects (Irizarry & Costa, 2016; Zhou & Gheisari, 2018). All these applications use visual data generated by UAVs for review and analysis according to the respective application which is chosen in the particular study. The effectiveness of UAVs in these applications will depend upon the technology used in the UAVs in terms of automated computer systems with digital automation of data process and integration of visual tools. This study aims to explore the applications of UAVs in construction industry, to check the feasibility of UAVs in the Indian context, and to develop a framework and a set of guidelines for using UAVs in construction.

LITERATURE REVIEW

Many studies have explored the applications of UAVs in construction. UAVs are small aircrafts which do not need human operators on board for operation. UAVs are mainly divided into three types; Fixed wing, Vertical Take-off and Landing (VTOL) vehicles, and Rotorcrafts. Fixed-wing is similar to a traditional aero plane and are more effective in covering large areas. Rotorcrafts have propellers attached directly to its body or individually to the arms which are extended from the body which helps in vertical take-off and landing, hold its position, rotate in its position, and have flexible mobility. These types of UAVs can thus be used for applications which require precise vehicle placement and mapping complex three-dimensional features. VTOL UAVs are a mix of Fixed-wing and Rotorcraft. That is, it can take-off and land vertically, but horizontal movement will be like a fixed-wing UAV (Greenwood et al., 2019).

UAVs are unlocking a lot of challenges in the construction industry and practitioners are still testing the limits of this technology. Major applications explored in this regard are construction progress monitoring, 3D mapping, inspections, crack detection and volumetric estimations.

Visual documentation of the entire construction site which has major progress deviations, limited visibility of images due to static and dynamic obstructions, and incomplete documentation at the site are the major challenges for progress monitoring (J. Lin et al., 2015). Automated progress monitoring using UAVs is an innovative way to tackle this challenge. In one of the literature, geometry and appearance based reasoning methods used to track the progress from an aligned BIM-3D point cloud model detected more than 90% BIM elements. Geometry based reasoning detected the BIM elements and appearance based reasoning detected the materials used (Han et al., 2018). In another literature, superimposing systematically updated 4D BIM information on a 3D point cloud generated by UAVs at a particular stage of construction monitored the progress of project efficiently and tracked the deviations (Álvares & Costa, 2019).

UAVs have been used in mapping 3D models from UAV imagery which can provide a 3D view of the site to enhance the construction management tasks (Álvares et al., 2018). Inspections using UAVs have also been a major research area. The application of UAVs in safety provided a visualization on safety inspections and increased the effectiveness of safety inspections (Costa et al., 2016). Liu et al. (2016) used UAVs for inspection of curtain walls of a commercial building. Lei et al. (2018) developed a method for crack detection using UAVs called Crack Central Point Method which could reduce the noise of the images effectively and accurately extract the cracks from the collected images. Digital Terrain Models (DTMs) derived from UAVs were tested for its accuracy by stock pile volume estimation. This study concluded that large projects having massive stockpiles may need LiDAR or camera mounted UAVs as the physical survey may not be possible because of the size or shape of the stockpile (Hugenholtz et al., 2015).

RESEARCH METHODOLOGY

This research used Design Science Research (DSR) method as the research strategy which follows the constructive approach of research. For research problems which talks about practical problems, using conventional qualitative methods like interviews or surveys exclusively will give unsatisfactory or low results. The organizations may not get much benefit for giving their efforts in participating in the research. This may lead to poor participation from the organization level which subsequently leads to unsatisfactory results. Thus, DSR method is the right strategy to adopt as the study requires practical functioning of the solution.

This method attempts to develop an artefact followed by implementing the artefact for testing its applicability. The developed artefact is iterated in a loop till the desired artefact is generated and thus giving a practical solution to the problem as well as theoretical contribution to the study. This helps in reducing the gap between research and practice (Lukka, 2003). Figure 1 shows the process flow for the research methodology structured to meet the objectives of this study.

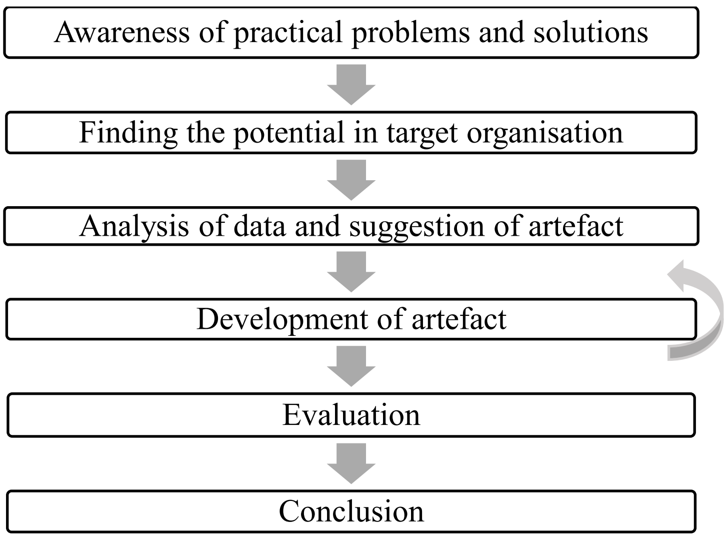

Figure 1. Methodology adopted

- ***Awareness of practical problems and solutions:*** Literature study on the applications of UAVs in construction industry as well as semi-structured interviews targeted on construction industry professionals which helps in finding the problems and solutions.
- ***Finding the potential in target organization:*** Finding an organisation with a practical problem which can be solved using one of the applications of UAVs to test the final framework.

- ***Analysis of data and suggestion of artefact:*** Data is analysed using thematic analysis and based on this, the artefact is suggested. In this study, suggested artefact is the framework and a set of guidelines for using UAVs in construction.
- ***Development of Artefact:*** Developing the framework and the guidelines based on the data analysis.
- ***Evaluation:*** Validation of the framework and guidelines with construction industry professionals in an iterative manner. The suggestions were incorporated and it was revalidated again.
- ***Conclusion:*** Stepping back from the empirical work and documenting the learning process. The results were interpreted and conclusions were derived. The framework and guidelines were formalized in this stage.

DATA COLLECTION

The first part of data collection involved semi-structured interviews which were targeted on two types of people. One being the project specific personnel who have used UAVs and the other being the people who work in organizations giving UAV services for construction related applications. As a part of data collection, 11 persons were interviewed. The details of the interviewee are mentioned in table 1.

Table 1. Details of interviewee

Name	Designation	Type of Organization	City
		Project Specific	
A	Project Manager	Contractor	Gandhinagar
B	Construction Professional	Project Management Consultant	Ahmedabad
C	Director and Founder	Project Management Consultant	Ahmedabad
D	Manager	BIM Consultant	Pune
E	Planning Manager	Contractor	Mumbai
		Organizations Providing UAV Services	
F	Manager - Operations	UAV Consultants	Ahmedabad
G	Assistant General Manager	Geo Spatial Consultants	Bangalore
H	CEO and Founder	BIM Consultants	Gandhinagar
I	Director	UAV Consultants	Ahmedabad
J	Owner and Director	UAV Consultants	Ahmedabad
K	Owner and Director	Geo Spatial Consultants	New Delhi

Efforts were taken to find a target organisation for testing the framework. As a part of this, a discussion was held on the corporate office of organization A. Researcher presented his findings to the senior officials of the company. The company never used UAVs for any construction related applications in the past and was positive minded in exploring new technologies and incorporating it in their projects.

One of the ongoing projects under the company was a slum rehabilitation project near Ahmedabad. Majority of the people have been temporarily relocated. But one of the plots was still not relocated because of the resistance from residents. This plot was not surveyed due to this reason. This was considered an opportunity for both the company and the researcher to test the framework. Figure 2 shows the existing survey map for the project.

The highlighted area in the survey map shows the incomplete survey details of the plot mentioned above. It was decided to do an aerial survey and map the entire area. Organization F agreed to do the survey for organization A. After a meeting with the Directors of both the companies, the requirements from the contractor was finalised and the commercial aspects were approved after negotiations. Documents were submitted to the local police authority for permission. But, unfortunately at this stage, COVID 19 pandemic happened and the researcher was not able to do the survey during the research period.

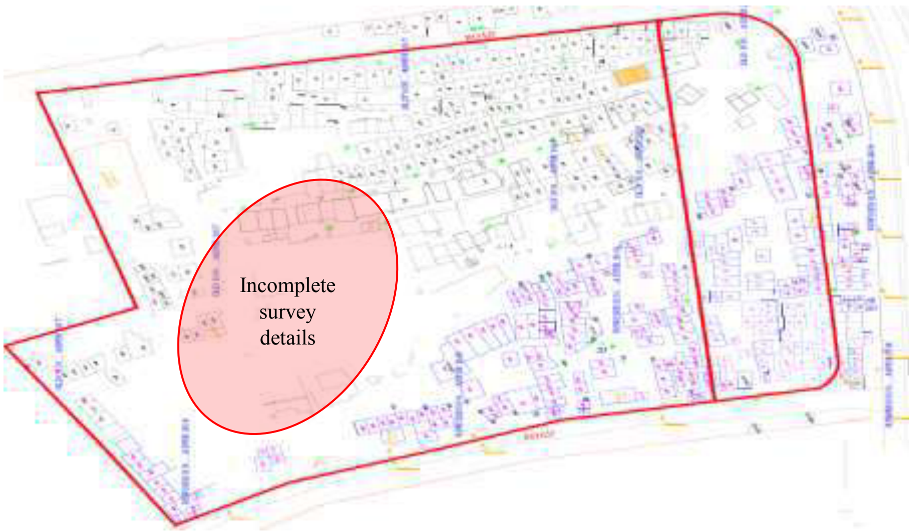

Figure 2. Existing survey map

ANALYSIS AND FINDINGS

Thematic analysis approach was adopted in this study for data analysis. Interview transcripts were coded and a deductive approach was used for the analysis. The findings are given below.

Applications of UAVs

A total of 24 applications were identified in this study. The applications were segregated based on the output needed from UAVs and the use of each output. Of the total 24 applications, 8 applications were identified exclusively from interviews and 2 exclusively from literature study. The applications are listed in table 2.

Table 2. Applications of UAVs

Output	Uses	Applications
Orthomosaic	2 D Measurements	*(1) Alignment and planning of roads, railway corridors and metro projects *(2) Encroachment Measuring *(3) Counting and detection of objects *(4) Site inspection for tendering (5) Mining Surveillance *(6) Tax Collection *(7) Change Detection #(8) Jobsite logistics
	Surveying	(9) Land Survey
Digital Terrain Model/ Digital Surface Model	Volumetric estimations and Contour mapping	*(10) Storm water management (11) Stock pile measurements/ Material Tracking (12) Earthwork estimations
3D point cloud	Mapping	(13) 3D mapping (14) Land Mapping (15) Heritage Mapping
	Progress Monitoring of buildings, road and infrastructure	(16) Progress monitoring without BIM (16) BIM integrated automatic progress monitoring
Images/ Videos	Progress monitoring	(16) Progress monitoring with images/videos

Output	Uses	Applications
	Inspections	(17) Site Monitoring (18) Safety Inspections (19) Façade Inspections
Thermal images	Inspections	(20) Crack detection (21) Bridge Inspections *(22) Solar inspection
Ultrasonic waves, LiDAR sensors		(23) Quality inspections #(24) Structural Damage Assessment

The applications marked * are exclusively from interviews and # are from literature review. Applications without any mark were identified both in interview and literature review.

Regulatory Environment in India

As per Indian regulations, UAVs are categorized in accordance to its weight into Nano (<=250 g), Micro (250 g to 2 kg), Small (2 kg to 25 kg), Medium (25 kg to 250 kg) and Large (> 250 kg). Nano can be used only till 15 m from ground level and Micro till 60 m from ground level. No UAVs are allowed to fly more than 120 m height from ground level for civilian purposes. The major requirements for UAV operations are,

- Unique Identification Number (UIN) from Directorate General of Civil Aviation (DGCA). The UIN should be affixed on the UAV. Permission from Digital Sky Platform before undertaking any flight operations. (Exception – Nano category)
- Flying operations are permitted only on daylight.
- No UAV operations should be performed in the restricted areas mentioned by DGCA.
- Operators should have an Unmanned Aircraft Operator Permit (UAOP) to operate the UAVs for commercial operations. Digital Sky No Permission No Take-off (NPNT) compliant. (Exception – Nano and Micro category)
- Local police permission is required for all the UAV operations.

The fee for issue of UIN is INR 1000 and for UAOP, it is INR 25,000. Fee for renewal of UAOP is INR 10,000 (Office of the Director General of Civil Aviation, 2018).

Feasibility of UAVs in the Indian Construction Industry

Establishing the feasibility of a technology mainly depends on the feasibility of alternate technologies as well. The following are the main reasons why UAV technology was chosen over other alternate methods.

- Accuracy requirement is much higher
- Project is not having the liberty of time and manpower
- Surveying of very big land parcels in square kilometre range where normal surveying methods are much tedious and time consuming
- Better visualizations needed for the top management

In the current scenario, the Indian construction industry is unaware of different outcomes of UAV based survey. But, a few companies are well updated on these technologies and are using advanced applications like 5D BIM integrated automated construction progress monitoring. Other than just visualisation and top management reviews, this method helps to reduce considerable amount of human effort in documentation. Mapping huge land parcels using UAVs are 2 to 3 times faster than the conventional surveying methods.

Financial Feasibility

The cost of services range from INR 3000 to INR 3,00,000 per sq.km. The cost will depend on the type of output and the level of accuracy required. The initial investments needed for buying UAVs may depend on the process adopted for survey. The two major technologies adopted, are Post Process Kinematic (PPK) and Real Time Kinematic (RTK). In PPK, the data is collected with Global Positioning System (GPS) tagging and then processed to get the required output. RTK is much more advanced and have capabilities of real time processing in cloud while data is being collected. High quality PPK drones cost INR 2 to 3 lakhs whereas RTK drones costs INR 8 to 10 lakhs. Based on this, the insurance covers approximately ranges between INR 50,000 to INR 1,75,000 for the entire system per year.

Preferring UAV mapping for small land parcels may not be feasible as the cost may not reduce proportionately corresponding to the decrease in area. Considering a UAV can cover 3 sq.km per day, mapping a land parcel less than 3 sq.km also costs the same as the resources and manpower used are the same. If the area to be surveyed is considerably larger than 3 sq.km, the cost per square kilometre may get reduced. The rough cost ranges of different outputs of

UAVs are given in table 3. The cost may vary with respect to the economy and future developments of the technology.

Table 3. Rough cost ranges

Sl. No.	Applications	Cost Range
1	Progress Monitoring	INR 20,000 to 80,000 per day
2	Land mapping	INR 20,000 to 1,20,000 per day
3	Images and videos with annotations	INR 3,000 to 4,500 per sq.km
4	Detailed orthomosaic and 3D point cloud	INR 20,000 to 1,30,000 per sq.km
5	Detailed analysis with engineering drawings and 3D models	up to INR 3,00,000 per sq.km

Legal Feasibility

The regulations for UAVs in India are liberal in the current scenario. Most of the regulations are applicable from 'small' UAV category to 'large' UAV category. Nano UAVs are exempted from almost all the regulations and Micro UAVs from some of the regulations. It is understood from the interviews that the specific UAV model Phantom 4 Pro of DJI series can be considered as a bench mark for almost all the applications identified in this study. This UAV weighs 1388 grams which makes it fall under Micro UAV category. Micro UAVs have the following relaxations of laws which are (i) No requirement of UAOP if the UAV is operating below 60 m, (ii) No need to file flight plan 24 hours before operations, (iii) The equipment capability features needed are lesser compared to other categories, (iv) Age restriction (18 years) and academic qualification (10th pass in English) requirement for the operator is not applicable (v) Ground training from DGCA approved flying training operation is not mandatory. Most of the relaxations are favourable for the Indian construction industry and thus the legal aspects in India in the current scenario are highly feasible for construction.

Comparison with Alternate Methods

For establishing the feasibility of UAVs, checking and comparing the feasibility of alternate methods are also a major concern. Most of the applications of UAVs are related to surveying and mapping. Total station surveying and satellite image processing are the major alternate technologies in this field. The suitability of these technologies may highly depend on the accuracy required, area to be surveyed and the time with which the survey have to be completed. For surveying small land parcels with very high accuracy, total station is preferred as it has an accuracy of 1.5 mm. For large area in the range of square kilometres, UAVs can be used, and for much larger area like covering an entire city in a short span of time, satellite images can be used. Table 4 given below shows a comparison of these three methods in terms of accuracy, area covered, time for processing and cost.

Although total station is highly accurate, the cost is higher, area covered is much lesser and the time for processing is much greater. Satellite image processing can be carried out in very less cost and huge areas can be covered in a very short time. But the accuracy is highly compromised. All parameters of UAV are in an optimum range.

Table 4. Comparison with alternate methods

Parameters	**Total Station**	**Satellite Image Processing**	**UAV Survey**
Accuracy (mm)	1.5	Greater than 500	10 to 30
Area covered/day (sq.km)	0.1 to 0.2	-	3
Time for processing (hrs/sq.km)	30	1.5 to 2	3
Cost (INR/sq.km)	1,00,000 to 2,50,000	2000 to 3000	30,000 to 1,20,000

Framework and Guidelines

The final framework is divided into two phases. The first phase is the planning phase where the UAV method is checked for its feasibility and then the initial requirements of the survey are finalised. The second phase is the data collection and processing phase which describes the requirements needed to be fulfilled during UAV operation and further stages. The framework is shown in figure 3, 4 and 5. The guidelines are an integral part of the framework developed in this study. The guidelines are linked to each stage of the framework. The factors to be looked-upon for each guideline is given in table 5. The serial numbers referred in table 5 are corresponding to the guideline numbers given in the framework. 5 checklists were developed and linked to the required stages of the framework to make it more reliable. Checklist 1 is a list of locations in India were UAV operations are restricted which is adopted from DGCA's guidelines. Checklist 2 should be referred for on-site reconnaissance where the site to be surveyed is inspected in prior for proper flight planning. Checklists 3, 4 and 5 should be referred at the time of site visit before starting the UAV operations at site. Checklist 2 is given in table 6 and checklist 3, 4, 5 are given in table 7, 8 and 9 respectively.

Phase 1 – Planning

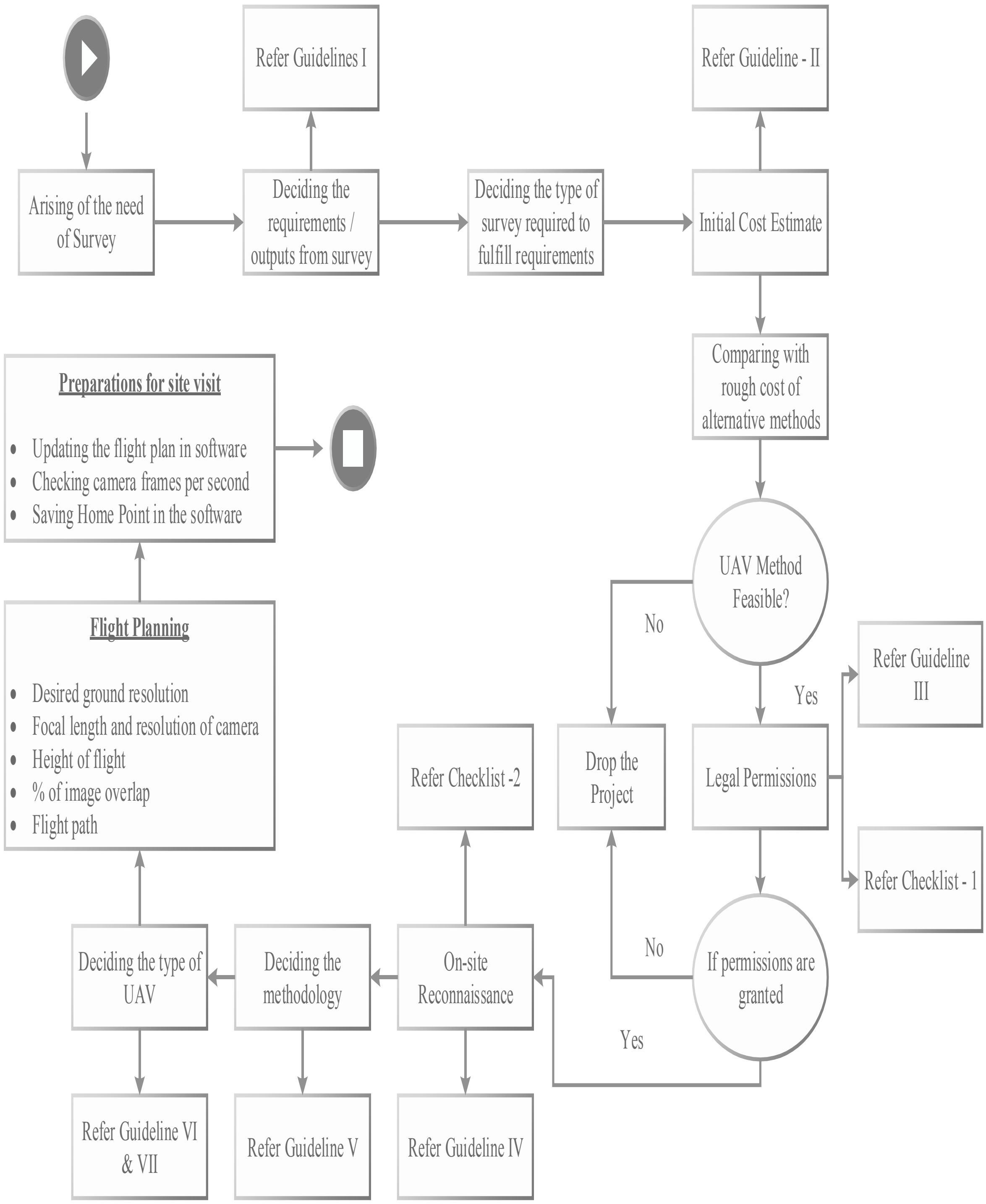

Figure 3. Framework: Planning Stage

Phase 2 – Data Collection and Processing

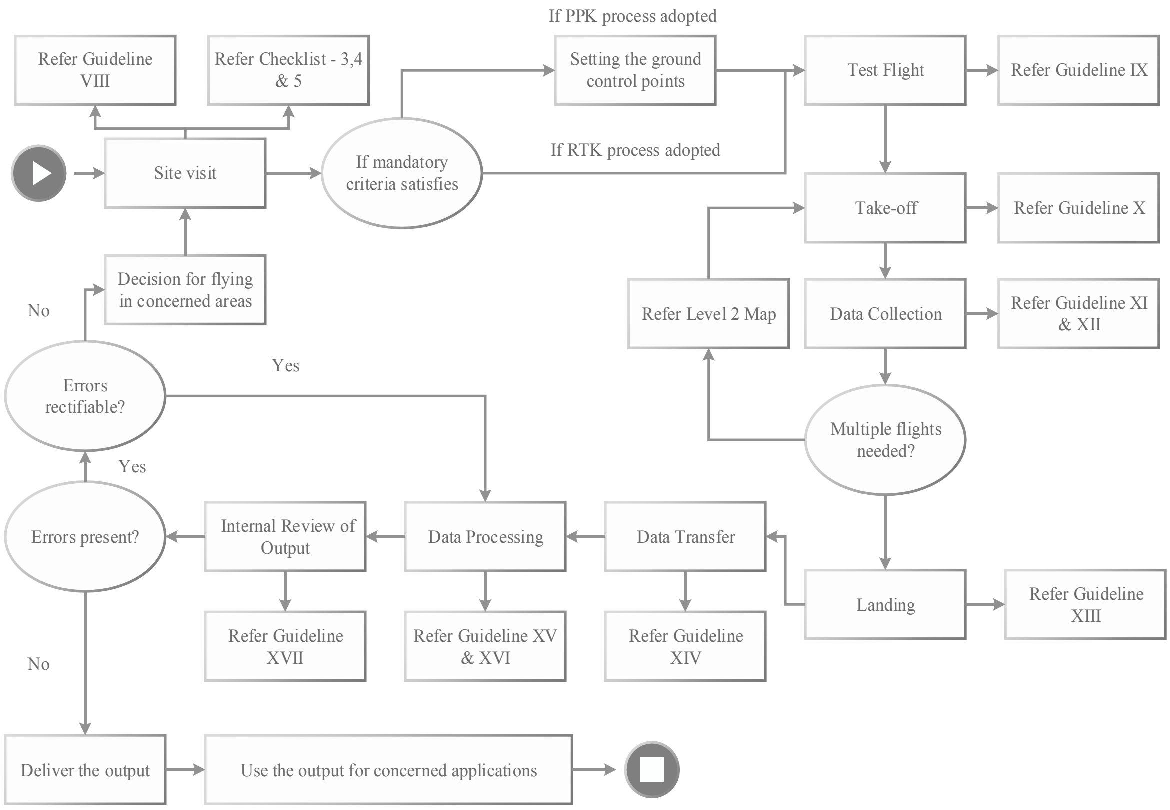

Figure 4. Framework: Data collection phase

In the data collection stage, if one flight is not enough because of the larger area to be covered, then the UAV may have to be landed in between to change the battery. This is referred in level 2 map below.

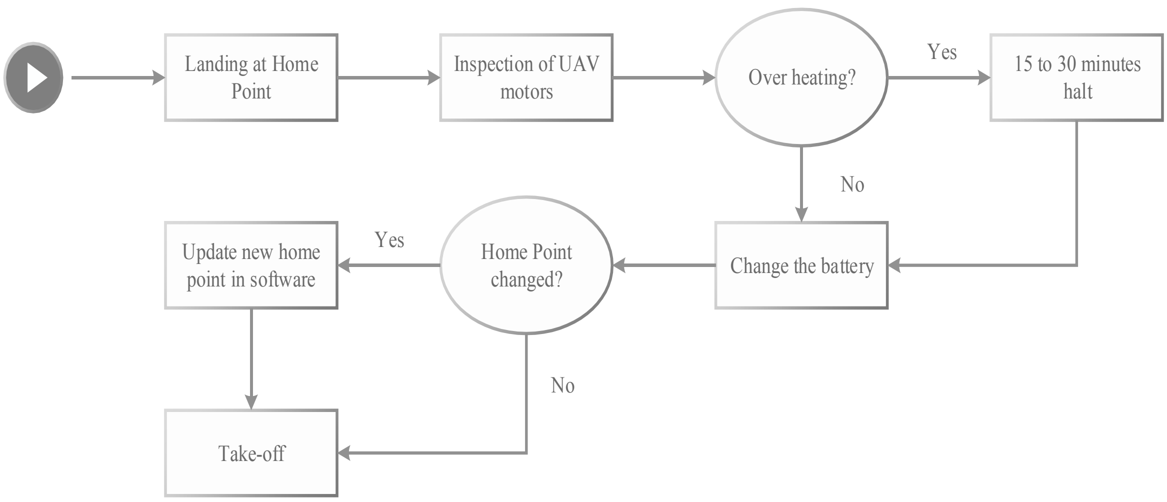

Figure 5. Framework: Level 2 Map

Table 5. Guidelines

Sl. No.	**Guideline**	**Factors**
I	Applications of UAVs	Refer Table 2
II	Factors affecting cost of services	Accuracy required, Level of detailing, Duration, Scope of work, Area of delivery, Type of solution required, Urgency of work, Solution or output required, Type of process used (PPK/RTK), Type of location.
III	Legal compliances	Permission from Digital Sky platform (except Nano), UIN affixed in UAV (except Nano), UAOP handy during operations (except Nano and Micro), Digital Sky NPNT compliance (except Nano and Micro), Flying operations only on daylight, No operations in the restricted areas, Local police permission for all operations.
IV	On-site Reconnaissance	Open central location for take-off and landing, Identifying obstructions in site for safe flight planning.
V	Factors for selecting methodology of survey	Initial cost of UAV and operating system, remote range, Ground Control Points(GCP), processing method, accuracy, time taken for survey, cost
VI	Factors for UAV selection	Accuracy required, Flight stability, Type of survey to be done, Level of detailing of output required, Area of survey, Type of camera or sensor required, Weight of camera/ sensor to be mounted, Weight of UAV, Vertical take-off and landing, Flight duration, Ability of system to mount sensors
VII	Sensors / Equipment Used	RGB Camera – Orthographic models, LiDAR Sensors – Forestry, 3D mapping, Thermal radiometric sensor – Solar inspection, Crack detection
VIII	Safety precautions	Workers should be made aware of UAV operation in advance, Preferred when workers are not present at site or when they are having a break, Detailed SOP to be provided the client (Contractor/PMC) before operations, Risk assessment and mitigation plan, Space for take-off and landing (minimum 3m x 3m), Follow safety features instructed by DGCA.
IX	Test flight	Manual mode of operation preferred, Test the radio interference and secure communication between RC transmitter and UAV, Flight should be operated along the planned flight path, Identifying the nearest and safest emergency landing sites.

Sl. No.	Guideline	Factors
X	Factors to check before take-off	Saving home point before take-off, Turn on SRT file logging option for saving GPS to data collected, In between the survey, Changing home point in case of landing in a new location.
XI	Challenges faced during time of flight	Obstructions in land, Inability of getting live feed for inspections at in-accessible places, Electromagnetic fluctuations due to presence of metallic objects, Battery Limitations, Battery problems in winter, Reflective surfaces in ground (eg: water bodies), Heating problems in high temperature (summer), Moving objects in flight path, Accessibility constraints, Signal losses due to limitation of range or network issues, Flying in a circular path , Adverse weather, conditions like precipitation or high wind
XII	Risks at time of flight	Power failure, Circuit failure, Crashing, Bird hitting, Collision with any incoming object in flight path, Collision with workers/people, Privacy invasion, Connection between UAV and control system lost, Interference of UAV in project activities, Distractions while working
XIII	Factors to check before landing	Minimum battery requirement to land at the home point, Identification of emergency landing points in case of insufficient battery, Runway space needed in case of Fixed wing UAVs.
XIV	Data transfer	High capacity memory card takes more time for data transfer which results in heating issues of memory card as well as card reader. 64 GB memory card is preferred for data transfer. If the memory card gets corrupted or data is lost, it's preferred that no other data is copied in memory card till the lost data is retrieved.
XV	Software used	Pix-4D, Agisoft Photoscan, Drone Deploy, Bentley Context Capture 3D, Autodesk ReCap, 3DF Zephyr, Precision Hawk, Agisoft Metashape, Open Drone Map, PhotoModeler, Map Made Easy Simactive Correlator3D™
XVI	Factors affecting processing time	Number of images collected / Volume of the data, Computer specifications, Size of the data, Type of survey, Area of survey, Level of detailing, Resolution needed to achieve
XVII	Possible errors in output	No GPS values in data, Wrong GPS values in data, Camera might not have clicked. Glitches or patches if the flight path is not well defined, Blurry images, Sufficient ground control points not available, Insufficient amount of images, Errors due to issues in flight
XVIII	Benefits achieved	Predicting Site Conditions, Easier documentation, Real time information to the higher authority, Creates more clarity while decision making, Time saving, More accurate than satellite images, Economic in large surveying projects, Better visualization, Cost of man power is saved, Economic Progress monitoring method in case of big projects

Table 6. Checklist 2: On-site reconnaissance

Sl. No.	Criteria	Yes/No	Remarks
1	Obstructions at site? (trees, power lines, buildings)		The flight path should be clear from obstructions while flight planning.
2	Electromagnetic equipment or HT lines at site?		UAV should be selected accordingly. (e.g.: DJI Matrice 210 RTK can be used near HT lines)
3	Reflective surfaces at site? (materials or water bodies)		If yes, then processed images might have errors because of reflections. The operations preferred only if there is no requirement of data processing.
4	Site having any accessibility issues?		The home point of UAVs should be an accessible point and the other areas of survey should be in visual line of site from home point.
5	Site having excessive high wind conditions?		UAV manual contains the specifications for the amount of wind it can withstand. Select UAVs accordingly.
6	Site situated under any geo-fenced area?		Permissions should be taken to open the geo-fence in the area to be surveyed from the concerned authority
7	Continuous bird movements/ Site a migratory bird zone?		UAV operations in migratory bird seasons should be avoided if possible. Sounding alarms should be used to keep the birds away.
8	Minimum 3m x 3m clear space for take-off and landing at site?		If no, by taking permissions from the concerned person, space should be identified outside the site and the operations should be in visual line of site.

Table 7. Checklist 3: Regulations

Sl. No.	Criteria	Yes/No	Remarks
1	Local police authority permission taken for drone activity?		If no, then the UAV operations should be stopped till the required permissions are granted.
2	All concerned authority permissions taken (If applicable)?		
3	UAV having a valid UIN (For UAVs not under Nano category)?		If no, then that specific UAV cannot be used for any operations until the UIN is issued by DGCA.
4	Operator having a valid UAOP (For UAVs not under Nano/Micro category)?		If no, then the operator should be switched with a person who is having the license.
5	Height of flight greater than 15 m? (requirement for Nano category)		If yes, then the relaxation of regulations for Nano and Micro category will no longer be applicable. The specific UAV should have all the requirements mentioned by DGCA before flight operations.
6	Height of flight greater than 60 m? (requirement for Micro category)		

Table 8. Checklist 4: Weather conditions

Sl. No.	**Criteria**	**Yes/No**	**Remarks**
1	Is it raining?		If yes, then the operations should be stopped till the rain is over.
2	Site having sufficient daylight?		Sufficient day light is needed for operations. Additionally, the quality of data collected may badly affect due to insufficient day light.
3	Site having high wind conditions above the specification of the UAV?		If yes, then the UAV operations should be stopped.
4	Is there a minimum ground visibility of 5 km?		This is a preferred criterion. If this is not satisfied, then sufficient safety precautions should be taken at the time of planning and in terms of identifying emergency landing sites.
5	Is the cloud ceiling greater than 450 m?		This criterion is preferred for identifying other aircrafts in the air space. If the cloud ceiling is lesser, the height of operations should also be lesser according to the weather conditions.

Table 9. Checklist 5: Safety

Sl. No.	Criteria	Yes/No	Remarks
1	Are the workers (if any) moving around in site?		Operations in the absence of labours or when all labours are inside the building or during intervals is preferred.
2	Are the workers (if any) made aware of the UAV operations?		If no, then workers should be made aware of the UAV operations.
3	SOP of UAV operation provided to client?		It is preferred that SOP should be provided before the operations so that the client can have better understanding about the methodology carried out.
4	Flight path planned and assigned in the software (if manual flying is not required)?		This is preferred to be done before carrying out the operations.
5	Is there any other aircraft movement nearby?		If yes, then the operations should be immediately stopped. No two UAVs should be operated in the same area. Manned aircrafts should be always given priority during the operations.
6	UAV battery fully charged?		Preferred for more flight duration.
7	Extra set of battery and blades taken?		In case of emergency, extra pair is preferred.
8	Is the height of flight decided?		Preferred in case of automatic flight operations. Accuracy can change according to height variations.
9	Is the height of flight greater than 120 m?		The maximum height limit for civilian operations is 120 m. Permissions needed for operation at further heights.
10	All GCPs set (if required)?		Depends on the technology adopted. GCPs are necessary for accuracy of the output.
12	Radio, command and control link working?		If no, then operations should be stopped

CONCLUSIONS

The applications of UAVs are considerably increasing in the construction industry. The research identified 24 applications of UAVs in construction from literature review and semi-structured interviews. From interviews, it was found that, majority of the applications in India were based on photogrammetric technique where images taken from UAV platforms were merged using this technique to form an orthomosaic and then further processed to get DSM/DTM or a 3D point cloud.

Interviews with professionals in this field helped in establishing the feasibility of UAVs in Indian construction industry partially. The feasibility was explored by analysing the financial as well as legal aspects in the Indian context. Regulations in India are found favourable for adopting UAVs in construction industry as there were some relaxations in regulations for the Nano and Micro category of UAVs. From the feasibility study, it was inferred that this method is feasible when the scope of project is very large or the time is a constraint.

A framework and a set of guidelines were developed for using UAVs in construction industry and the guidelines were integrated to this framework. The framework can guide a professional through the financial, legal and operational feasibility for adopting UAVs in construction. The checklists incorporated will ease the burden of the professionals as well as the UAV operators. The guidelines and framework were validated with professionals in the industry and are found to be effective in guiding professionals who wish to integrate UAVs in construction and give a standard and safe methodology to follow which complies with all major regulations in India.

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Role of Modern Tools in Construction Projects

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ABSTRACT

The Construction Real Estate Infrastructure and planning (CRIP) sector is a prominent sector among the industries worldwide. It plays a vital role in contributing to any country's economy. Mainly several sub-sectors of the CRIP sector that contributes to country's economy are highways, railways, airways, waterways, irrigation, power generation, government buildings, residential buildings, etc. Many public sector projects add a push towards the development of CRIP sector in India. In this CRIP sector the project activities also involve multi-tasking and multi-activity with different types of people at different levels. Mostly, exchange of inter-departmental information utilizes vast amounts of data throughout the construction project activities. The efficiency of transformation of data depends on several factors. Mainly the outcome of the efficiency depends on the way in which data was handled, data was transferred and data was communicated and also the timely information transfer between different stages, and participants involved in a project. So, the influence of factors plays a predominant role in delivering the efficiency of the crucial data amongst the team players involved in the construction projects. This efficiency can be improved by implementing modern tools like automation – Internet of Things framework, mobile application, computer software, etc. In this research study, an initiative was taken to look into the role of automation tool in improving the efficiency of the construction project activity like quality, safety, etc. Among the different automation tool, the most familiar and most common tool used in several developed countries are mobile applications. Even though several mobile applications are in practice all the applications are not performing with full outcome. Many applications are lagging with data security, user friendliness, training intensity, etc. The main objective of this research study is to understand the benefits of automation compare various modern tools available in the market and examine those modern tools to check if they rectify negative impacts of automation. This was achieved by performing a qualitative analysis among selected mobile applications. By carrying out the performance analysis best suitable modern tool can be ascertained. It was *inferred from this research study the adoption and integration of automation technologies in the construction activities will prove beneficial in enhancing efficiency and productivity along with profits*.

KEYWORDS- Construction Project Activities, Automation, Mobile Applications, Project Efficiency.

1. INTRODUCTION

The role of CRIP sector in infrastructure development of any country is highly significant. Especially in developing countries like India. It plays a vital role in nation building and also it is one of the sectors contributing to country's economy. Based on the recent survey conducted by India Construction Industry Analysis by Construction Type (Residential, Non-Residential and Infrastructure) & COVID-19 Impact with Market Outlook 2017-2030, it is said that the construction industry contributes 8% to India's GDP [11]. However, looking at the current pandemic scenario the construction industry along with other industries has been affected drastically. It is high time to look in to issues in CRIP sector finding out suitable strategy or mechanism to overcome the crisis. It can be ensured by effective project accomplishment needs a coordinated work among construction workers, supervisors, architects, managers and even with external parties in the communication process [5]. This can be achieved through better project planning, management, improved execution, new financial policies, adoption of new technologies, automation, etc. Automation is one such strategy that promises better planning, coordination & communication with the team, improved quality, better safety, more accuracy, forecasting of risks, data analysis, etc [1,2,3]. There are various ways to implement the automation strategy in different sectors of construction activities such as autonomous machines on site, drones to perform surveying, robotics in concrete works, internet of things (IOT) framework using sensors, mobile applications, computer software, mobile/cloud BIM technology, virtual reality technology, etc [13]. Among the different automation tool, the most familiar and most common tool used in several developed countries are mobile applications [4,6,7]. Mobile information systems and cloud computing offer solutions to the delivery of fast and real time information and services in project management. [8, 9, 10] They will increase the effectiveness of collaboration and the reliability of the information whilst reducing information delays [11, 12,]. Several research studies pertaining to CRIP sector among the workers community in developing countries highlights that usage of modern tools like mobile app among workers is very poor and more than 60% of workers were unaware of mobile applications and also lack of knowledge in using the mobile application. [4]. In this digital era, it is mandatory that automation tool must be implemented in the CRIP sector and it is going to dominate entire sector in near future [20]. So, it is high time to find an effective strategy to overcome lapses with respect to modern tools needs to be identified [21]. This research study examined the role of mobile technologies in improving the communication support for the construction project site of CRIP sector and to increase efficiency and productivity in the project execution process and also to identify the better strategy for the same [14,15,16,17]. The main aim of this study is to understand the benefits of digitalization for effective on-site communication, to compare various mobile applications available in the industry, to rectify the negative impacts of digitalization in the construction project site of CRIP sector [11,12]. Tools adopted to achieve the objective are by floating the questionnaire among the CRIP sector community. Based on the questionnaire outcome both positive and negative aspect was inferred with respect to automation and the qualitative analysis of data was carried out with the help of a qualitative data analyzing software called NVivo [4, 5, 16]. The outcome of the research study was mainly based on a live case-study of Pune based construction firm.

2. METHODOLOGY

To achieve the objective and to procure suitable data to perceive the conclusion, a questionnaire was floated [4,9,13]. The detailed methodology adopted in order to carry out the research to fulfill the end goal was stipulated in **figure 1** below:

3. RESULTS AND DISCUSSION

To ascertain the impact of automation among the construction community a questionnaire was floated. This was done to get a clear understanding of what role does automation play and how its implementation affects construction projects. Respondents to the questionnaire belonged to the CRIP sector community such as construction professionals, construction managers, employees working at different designations and interns. Following statements were stated in the questionnaire to which the participants responded on a scale from strongly disagree to strongly agree:

- Modern technology increases productivity & efficiency of work.
- Modern technology has a complex interface.
- Modern technology proves to be cost beneficial.

- Modern technology proves to be time saving.
- Modern technology requires a lot of training to get adapted to it.
- Modern technology proves to be effective on-site communication.
- Modern technology proves to useful in Quality Control.
- Modern technology proves to be useful in Health Safety Environment (HSE).
- Regular input is given by user while using Mobile Applications.
- Modern technology increase stress among workers.
- Do you think digitalization or automation has negative impacts? If yes, then give reasons based on your experience.

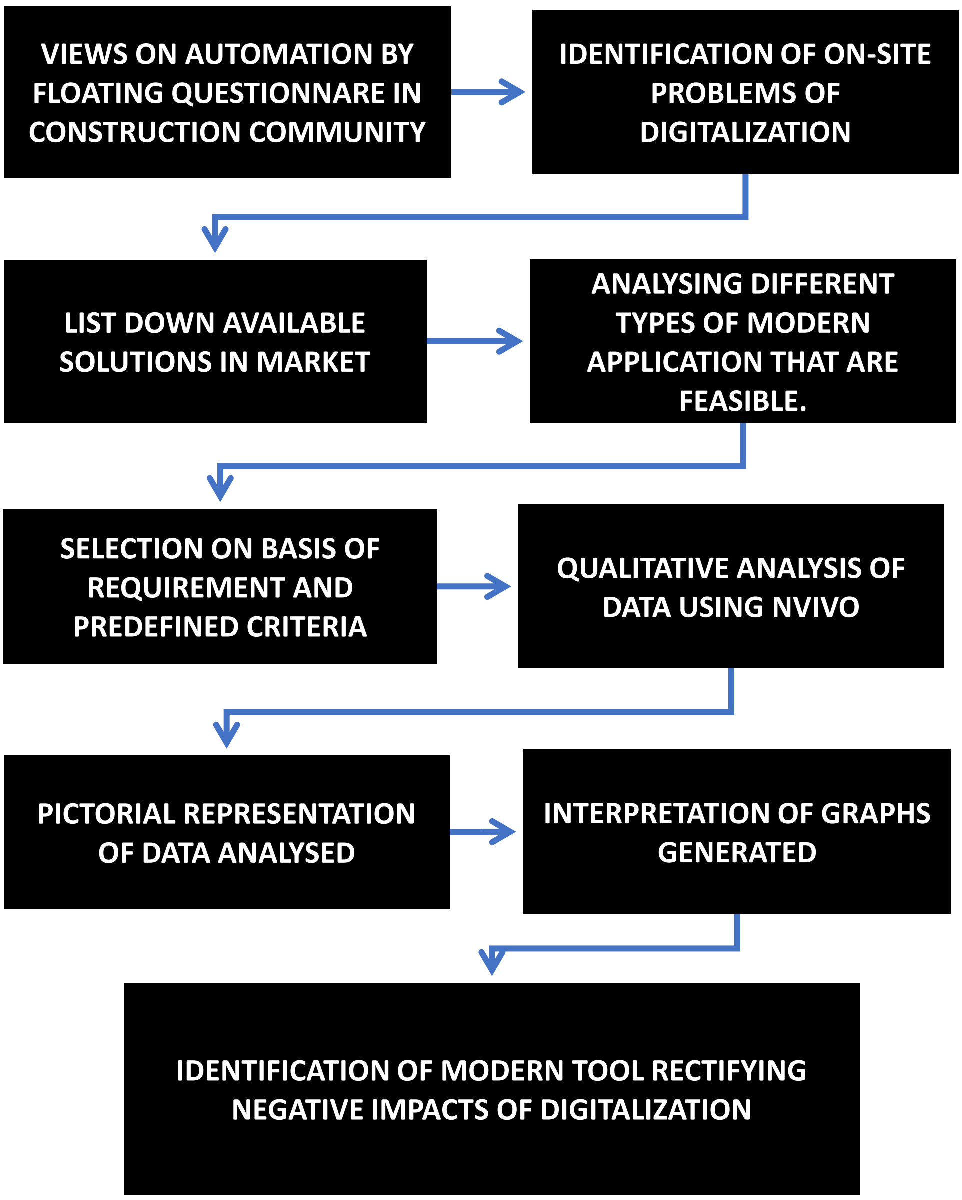

Figure 1: Methodology Adopted

Based on the questionnaire floated, responses were received and the output of the questionnaire has been replicated in the following numbers. 58.6% agree that automation increases productivity and efficiency of work, 49.5% agree that it proves to be time saving, 51.1% agree it provides effective on-site communication and 49.5% agree it proves to be useful in Quality control and Health Safety & Environment. From the above numbers it can be understood that automation is advantageous which will help in development of construction industry.

The outcome of the questionnaire was then substantiated by means of a case study based on a Pune based well established real-estate company. Experiencing the current pandemic scenario, this real-estate company wanted to adopt digitalization on their 400-acre township project being executed. The company wanted to digitalize its construction processes of quality department in order to achieve better quality control [6,18]. Keeping this case-study in mind, this research outcome talks about how mobile applications and software solutions as mentioned in **table 1** with respect to quality management, checklists and inspections in achieving improved productivity, ensuring safety etc., also analyzed.

3.1 Mobile applications

The software was scrutinized based on the methodology are listed below in the table: -

Table 1: List of Software

Mobile Application	**ERP/SAP/Customized IT Sol n**
P	A
Q	B
R	C
S	D

NOTE:

- Here, **P**, **Q**, **R** & **S** are construction mobile applications and in context of construction **A**, **B**, **C** & **D** are construction software solutions such as ERP, SAP or customizable IT solutions.
- The mobile applications and construction software solutions are renamed as alphabetical letters to maintain its **confidentiality.**

Out of the solutions identified, **A** & **B** (ERPs and SAPs respectively) were eliminated from the quantitative and qualitative analysis to be carried out. The reason behind doing this was that maximum construction firms are using ERPs or SAPs for accounting, material procurement or other such departments. Finding another ERP or SAP solution just for quality management will require the firm either to adopt two different ERP or SAP solution or move on to a completely new ERP or SAP solution to manage all their departments. Software developers such as **C** & **D** that provide customized IT solutions were also eliminated. This was done because getting a customized product after multiple discussions and meetings with the developers would be time consuming. Therefore, ready to use mobile applications like **P**, **Q**, **R** & **S** are preferred and required so that users could be created, upload basic data and commence using them in order to save time.

3.2 Parameters to measure efficiency

The parameters represented in **figure 1** and discussed in **table 2** & **3** were used to measure efficiency of mobile applications. The user interface of the mobile application must be simple or user friendly and smooth. The application must not crash and lag. The application should be compatible both with Mobile and PC. The application should be secured (i.e., no data theft). It must possess analytical dashboard (most preferably hyperlinked). It would be better if pre-installed checklists are provided. The report generated must be in pdf or excel. Intimating system is a must through the application (i.e., intimate by email via app and app notification). The application must not be expensive.

The following **tables 2 & 3** gives out information associated to different parameters of all four mobile applications. This material was gathered after receiving demonstrations from their developers: -

3.3 Outcome of Quantitative Analysis

To select the most effective mobile application and to meet with the objective, it was decided to prepare a ranking matrix as represented in **table 4**. Different mobile applications were rated on common parameters to measure their efficiency. Ratings were provided on the basis of interface observed and information collected during the demonstration delivered. Total sum of all average score was calculated for every mobile application on the basis of which they were finally ranked.

Table 2: Information of app P and Q

S. No	Particulars		P	Q
1	Notification		Mobile Push Notification + Email Intimation	Email Intimation
2	Dashboard	Real time update	Available	Available
		Analytics	Analytical Dashboard with varied filters	Non-Analytic Dashboard
3	User Experience		Complex to adapt and intense training required	User friendly, Simple interface and works smoothly
4	Additional Features		1) 3D model viewer and walk though 2) Isolate items 3) Upload drawings & attach links to it 4) Dimension measurement, area calculation.	1) Separate comment box is provided at the end of checklist for caption 2) Responses available - Yes, No.
5	Available Modules		Plan viewer, Task Manager, Schedule, BIM viewer, Punch-list and Inspection.	Quality Assurance, Non-Conformance, Material Module, Work Done Confirmation
6	Available Platform		Android & iOS	Android
7	Reports		PDF, PDF detailed & CSV	Excel, Web console report
8	Subscription		User Based	Tower Based
9	Cost		Rs. 2175 / user / month (Business Plan)	Rs. 5000 / tower / month

Table 3: Information of app R and S

S. No	Particulars		R	S
1	Notification		Mobile Push Notification + Email Intimation	Mobile Push Notification + Email Intimation
2	Dashboard	Real time update	Available	Available
		Analytics	Analytical Hyperlinked Dashboard	Analytical Dashboard
3	User Experience		UI is good and app runs smoothly	Too complex to adapt and understand
4	Additional Features		1) Time taken to fill a checklist by user and their location can be tracked via in-built GPS.	1) Reminders on late items schedule automatically 2) Pre-loaded Checklists 3) Offline Mode

S. No	Particulars	R	S
		2) Users will get notified in prior to their upcoming inspections 3) Offline mode	
5	Available Modules	Inspections, Schedule, Actions, Sensors and Incidents	Inspections, Punch-list, Reports, RFIs & NCRs, Performance & Task Management
6	Available Platforms	Android & iOS	Android & iOS
7	Reports	PDF, CSV, JSON, DOC & Web reports	Excel (.cvc) only
8	Subscription	User Based	User Based
9	Cost	Rs. 975 / user / month	Rs. 1683 / user / month (Professional Plan)

Table 7: Ranking Matrix based on the parameter's outcome

No	Category	Particulars	P	Q	R	S
			Score Card (1=lowest; 4=highest)			
1	**Client base**		4	2	3	4
2	**Cost**		1	4	3	2
3	**Dashboard**		2	3	4	1
4	**User Interface**	**User Experience**	2	4	3	3
		Training Required	1	4	3	1
		Interface Smoothness	3	3	4	3
5	**Modules**		3	2	4	4
6	**Security**		4	2	4	4
7	**Customization**		3	4	3	3
8	**Additional Features**	**Offline Mode Available**	4	4	4	4
		Other Modules	4	2	3	3
9	**Total Sum of all Average Score**		**2.81**	**3.1**	**3.45**	**2.9**
Final Position			**4th**	**2nd**	**1st**	**3rd**

Effective outcome of the qualitative analysis was interpreted using qualitative analyzing software called NVivo. The analysis was carried out by coding the parameters to measure efficiency based on the ranking. The outcome of the ranking was represented in the form of histograms as stipulated in **figure. 2**, **3**, **4** & **5**.

3.4 Interpretation of qualitative analysis outcome

The interpretation of the histograms was done as follows. The x-axis represented parameters that highlight efficiency. Values '1' and '0' of a particular parameter in the y-axis signified either 'yes' or 'no' respectively. For instance, the 'iOS' parameter stipulated in f**igure. 2**, **4** & **5** showed '1' on the y-axis which signified **P**, **R** & **S** are available on iOS platform whereas **figure. 3** showed '0'which signified **Q** is not. Similarly, the 'Features' parameter that had values greater than '1' on the y-axis stipulated in **figure 2**, **4** & **5** showed that application **P**, **Q**, **R** & **S** possessed 5, 5, 9 & 6 major technological features respectively.

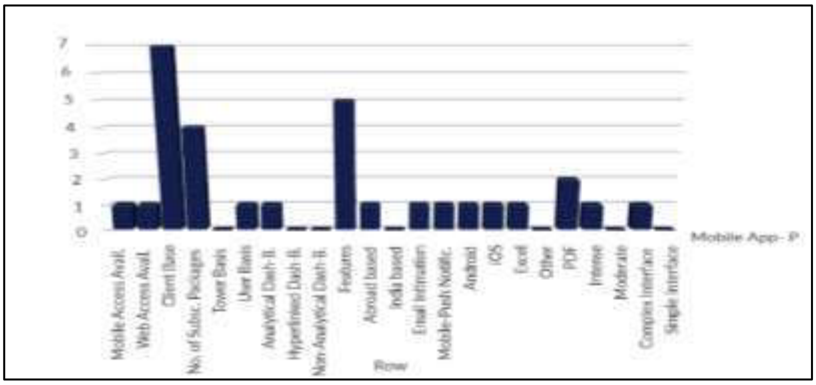

Figure 2: Pictorial Representation of Parameters of Mobile Application P

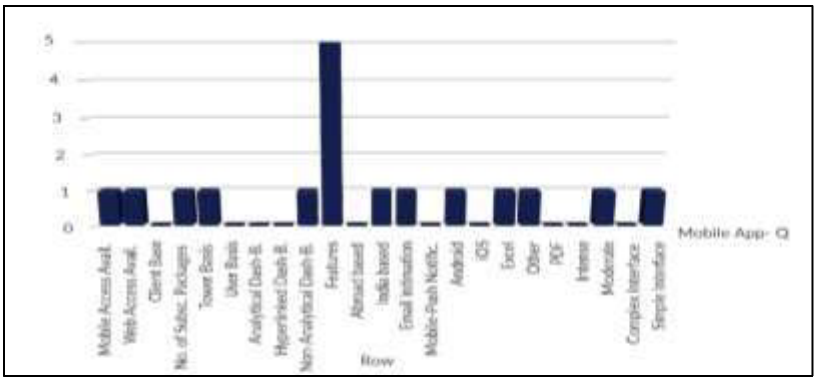

Figure 3 : Pictorial Representation of Parameters of Mobile Application Q

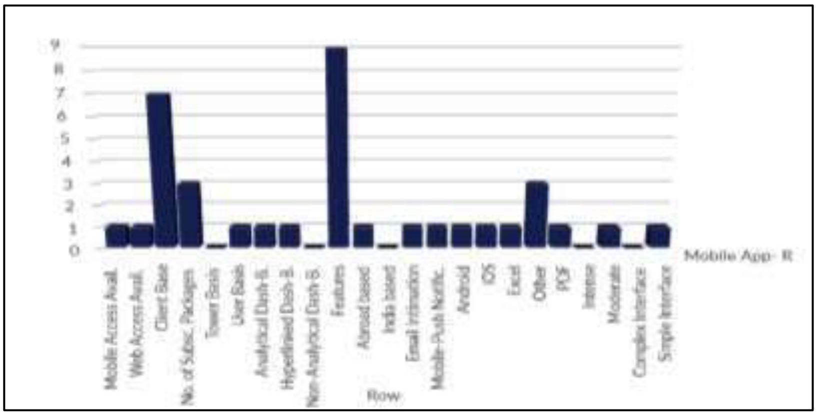

Figure 4: Pictorial Representation of Parameters of Mobile Application R

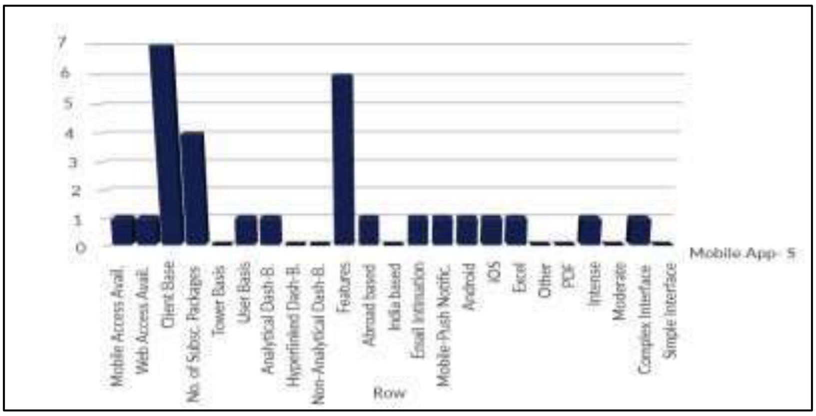

Figure 5: Pictorial Representation of Parameters of Mobile Application S

Based on the interpretation of **figure 2**, the following information has been arrived from the quantitative analysis. For example, let us consider for mobile application P.

- It can be accessed through a mobile-phone as well as a web-console.
- It has a client base of 7 major construction companies.
- There are 4 different subscription packages offered by the developer having different costs and benefits.
- The client is charged on user basis and not on tower basis by the developer for the subscription package they select (i.e., cost / user).
- The mobile application possesses an analytical dashboard. It is analytical only and not hyperlinked.
- It has 5 major technological features that make it attractive to use.
- The developer company is based in abroad and not in India.
- The users on the platform can be intimated through both email and mobile-push

notification.

- The application is available on both android and iOS platform.
- The report system of the application generates PDF format reports and no other formats.
- Intense training is required to get adapted to the application since the interface is complex.

Similarly, the information was interpreted for mobile application **Q**, **R & S** as represented in **figure 3, 4 & 5**.

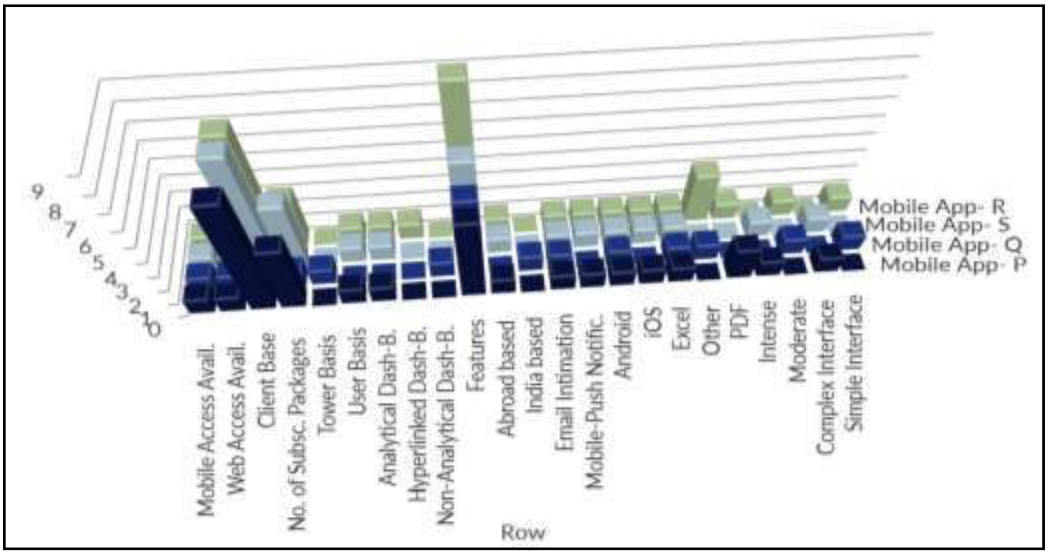

Figure 6: Cumulative Result of all applications

3.5 Discussion

The main outcome of the study was arrived by comparing all four mobile applications and the same was represented in 3D as stipulated in **figure 6,** for better decision making and interpretation. It can be clearly seen that all four applications can be accessed via Mobile and PC. Application **R** possess both analytical and hyperlinked dashboard whereas **P** & **S** possess only an analytical dashboard. Application **Q** has a non-analytical dashboard. Major technological features offered by application **R** are maximum as compared to **P**, **Q** & **S**. Intimation system for application **P**, **R** & **S** consists of both email intimation and mobile-push notification whereas its only email intimation for **Q** [12]. Similarly, applications **P**, **R** & **S** are available on both android and iOS whereas **Q** is only available on android [15]. The report system of application **R** looks the best amongst others because it provides reports in different formats such as PDF, Excel, etc. Applications **Q** & **R** would be easier to use since they have a simple interface which will require moderate training to get adapted to in compariso n to **P & S** [19]. Thus, the 4 applications have been compared and interpreted to learn more about their functionalities highlighted according to the parameters.

4. CONCLUSION

It was identified that with respect to quality management, checklists and inspections there are many solutions like **A**, **B**, **C**, **D**, **P**, **Q**, **R** & **S** which are available in the market. The challenge is to find the most suitable, easy to use, simple and economical application for your construction project. After performing a detailed quantitative and qualitative analysis on applications **P**, **Q**, **R** & **S** it can clearly be seen that the application **R** stands out and the same has been ranked 1st in the ranking matrix. The following are the advantages of application **R:**

- It helps in improving co-ordination and communication by bringing all the team members on the same platform.
- Its analytical-hyperlinked dashboard will help track project and employee performance.
- Users will not miss out on their tasks since features like 'schedule' and 'mobile-push notification' will intimate them in prior.
- In-built GPS location and time tracking system will increase accuracy of work.
- Its flexible reporting system will help exchange digital reports in multiple formats on both android and iOS devices.
- Above all the most important advantage is that the application has a simple interface which will require minimal training to get adapted and is cost-beneficial.

In order to increase the efficiency and productivity of construction projects it is mandatory to adopt the automation (mobile application) criteria like **R** which possess several advantages.

5. ACKNOWLEDGEMENT

Authors are thankful to National Institute of Construction Management and Research (NICMAR), Pune for providing facility and support to do this research work.

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Section III

ICT IN CONSTRUCTION MANAGEMENT

Editor's Note

This section comprises of studies in the domain of Information and Communication Technologies and related technical innovations in the construction sector. Srinivas and Dixit used the Delphi approach to gather expert opinions on the application of digital technologies in Indian building industry. Technology Organization Environment (TOE) Model is used to classify the variables influencing the implementation of technologies in AEC Industry, and DEMATEL technique is used to segregate the relevant cause and effect factors.

Similarly, Hire et al. examined BIM's existing adoption primarily for construction to eliminate on-site collisions. A systematic review of current literature is carried out, and it is found out that BIM will help to manage the safety of construction in different ways, consisting of planning for site protection, detection of hazards prior to construction, familiarity with working conditions by visualisation, coordination and co-ordination, protection design, and automatic on-site security checking,

Likewise, the goal of the study by Anand et al. is twofold: firstly, to understand how to simulate BIM and energy modelling early in design and secondly, to understand how to optimize the design in terms of cost, safety and energy. The results demonstrate the advantages of the green building construction technique. Similarly, Malla et al. developed a Lean Agile Based Construction System through a questionnaire, and this model is projected to improve the organizational work efficiency. Similarly, the goal of the paper by Kunjam and Jayakumar is to provide a framework for optimally managing assets during the time of service, and to build a database to support future maintenance and repair work decisions.

Integration of Project Management in Construction Industry 4.0 Framework

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ABSTRACT

The current Industrial revolution with main and prime emphasis on digitalization influences all industries which includes Architectural Engineering and Construction (AEC) Industry. Construction Industry 4.0 (CI4), which is synonymous with Industry 4.0 (I4) framework, is proposed by some researchers to explore digital implementation possibilities in AEC Industry. The project Management framework is already established and available which guides and manages various projects which includes AEC projects. However, during current I4 revolution, it is necessary for Integration of both Project Management framework with CI4 framework. The current paper reviewed the literature pertains to technology advancements and its suitability to construction industry. Authors used Delphi technique to collect expert opinions on implementation of digital technologies in construction industry in Indian scenario. Technology Organization Environment (TOE) Model identified through literature was used in identifying the factors influencing the implementation of technologies in AEC Industry and DEMATEL technique was used to segregate the causal and effect factors. Considered few project sites of one of the big construction conglomerates of India as case study and expert opinions were collected and discussed regarding implementation of digital technologies in AEC Industry.

KEYWORDS:

Project Management, Construction Industry 4.0, CI4, Technology Organization Environment Model

INTRODUCTION

Industrial Revolution 4.0 (or) Industry 4.0, emphasizes on digitization, advancement, production customization, robotic automation and human-machine interaction are being implemented in almost all industries and has picked up momentum since 2014. Architecture Engineering and Construction (AEC) Industry which normally adapt improvements from Manufacturing Industry, is currently in the process of implementing Industry 4.0 standards, which attracts researchers to explore the research possibilities to formulate Construction Industry 4.0 Framework.

Construction Project Management is vast which starts from Conceptualization stage to Commissioning stage of any construction project. PMI's PMBOK specified and elaborated ten knowledge areas which covers entire Project Management Framework. Current research focuses on Integration of all ten knowledge areas of Project Management into Construction Industry 4.0 framework. Current state of the art of the technologies in construction associated with the notion of Industry 4.0 (e.g., BIM, virtual reality, augmented reality, Drone, etc.) is explored through extensive literature studies. The proposed framework incorporates current technological advancement related to construction industry and applies to construction project management through improved value chain and productivity.

Motivation for the Study

Currently many construction companies in AEC Industry are adopting ERP (Enterprise Resource Planning) Software like EIP, SAP etc, are basically databases which integrates all functionalities of project management for managing Projects, Programs & Portfolios. However, these ERPs are limited to data recording and usage for future reference and minimal analysis for decision making. These ERPs have a maximum manual intervention for capturing the data which is laborious and time-consuming. However, due to fast growing world scenario, it is very much essential to capture the real-time data as well as real-time analysis for quick decision making. These ERPs are also generating huge & BIG data. However, proper data analysis using advanced statistics & data mining techniques are missing. Hence, with this view in backdrop motivated to study on Integration of all knowledge areas of Project Management with Digital applications for effective Project Management by capturing real-time data and analyzing the same for effective & quick decision making.

Literature Review

From the literature review done so far, Artificial Intelligence (AI) & Machine Learning (ML) applications in structural design was first studied during 1985 to 1988 and subsequently extended to construction safety. Tomasz A & Mumtaz U (1993) applied "AI & ML applications to learn about the accidents and measures to prevent the same using theory of rough sets. The use of AI is growing across many industries. Bernstein (2017) focuses on the evolving role of an architect of the intersection of design & constructions, including subject such as alternative delivery systems & value generations. AI clouds help the construction industry work faster and keep its workforce accident free (Woyke, 2018). In her article she tagged important key words viz: Big data, wearable technology, data science, analytics, future work, jobs. Bharadwaj (2018) classified the major applications for AI in construction & building. These are; (i) Planning & Design (ii) Safety (iii) Autonomous equipment, & (iv) Monitoring & maintenance. Wadlow (2018) explained importance of planning stages, construction underway, after construction, BIM & Virtual Assistant as key categories of AI in the CI. Ilter and Dikbas (2018) reviewed application of the AI in construction, dispute resolution. In his paper, he analyzed and categorized in to three groups as settlement oriented system method, selected oriented system & dispute evaluative oriented systems. Gayatri (2019), reviewed the application of Robotics, AI, and the Internet of Things can reduce building costs by up to 20 percent. AI is being used to track the real-time interactions of workers, machinery, and objects on the site and alert supervisors of potential safety issues, construction errors, and productivity issues. Aslam & Abid (2019), opinioned that implementing the Industry 4.0 digital standards in construction will benefit the construction industry in achieving the higher productivity. Literature survey was done on Industry 4.0 technology implementation in construction industry by various researchers such as Flávio Craveiro et.al (2019), Robert Klinc & Ziga Turk (2019), Farah Salwati Binti Ibrahim et.al (2019), Christopher J. Turner et.al (2019), Omoseni Oyindamola Adepoju & Clinton Ohis Aigbavboa (2020), Zhijia You & Lingjun Feng (2020), Nathalie Perrier et.al (2020)". It is found that research focus is more on identifying the various digital technologies from other industries in Industry 4.0 framework and mapping them into Construction 4.0, identifying the challenges & opportunities.

Authors also checked the literature and found that Davis et.al (1989), "developed technology acceptance model (TAM) based on the Theory of Reasoned Action (TRA). The same model was developed shifty with inclusion of various factors at various instances. Later on, with inclusion of social influence processes, cognitive instrumental processes and a detailed account of key forces underlying judgement of perceived usefulness and behavioral intention, TAM was expanded to TAM2 by Venkatesh and Davis (2000). Later in 2003, Venkatesh et al. (2003) identified and discussed eight models related to behavioral intention to use information technology and proposed the Unified Theory of Acceptance and Use of Technology (UTAUT). TAM3 was proposed by Venkatesh and Bala (2008) based on TAM2 with an inclusion of the effects of trust and perceived risk on system use. X. Qin et al. (2019) proposed TAM-TOE model for BIM acceptance based on the Technology Acceptance Model (TAM) and the Technology-Organization-Environment (TOM) framework”. An Interval DEMATEL method was applied to analyze the relationships between a set of factors and their influencing levels to each other.

In view of literature survey done so far, Out of all emerging technology hitting the market today, AI is a new technology that is on track to revolutionize the construction industry. Hence, in the current study, proposed to use AI & ML Applications in Project Management in Construction Projects. Although significant research studies exist on Project Management in Construction, there exists a gap in exploration & implementation of Technology driven Advanced Applications (TdAa) in effective implementation of Project Management in Construction organizations in Industry 4.0 Framework.

The authors propose three fold objectives: Firstly to review the Digital applications in Construction Project Management from the existing literature related to AEC Industry. Secondly, to identify the influencing factors through Technology Organization Environment (TOE) Model and to identify Cause & Effect Variables. Thirdly, to develop an “Digital Application based conceptual framework for Integration of all ten knowledge areas of Project Management with Industry 4.0” using Technology Acceptance Model (TAM).

Research Methodology

The research methodology includes the content analysis from relevant literature to identify the various digital applications & related technological advancements in the proposed area and specific to construction domain. A structured questionnaire-based survey (quantitative study) was be floated to the construction industry experts to identify the effect of factors influencing technological advancements in AEC industry as well as the effect of digital technologies already implemented and their interactions with ERPs. With the identified applications from the Literature and first round of questionnaire survey, expert opinions, a second level of structured questionnaire-based survey will be floated to the construction industry and academic professionals and the identified technological advancements shall be analyzed using various statistical & machine learning tools to create a digital application based conceptual framework.

Expert opinion survey on Implementation of Digital Technologies (Case Study)

Authors contacted few experts preferably planning managers and project managers belongs to various construction projects of one of the big construction conglomerate in Indian AEC Industry, which has implemented some digital initiatives in their organization. These digital initiatives were linked to their existing ERP system. The projects belongs to various sectors such as construction of buildings, factories, transmission lines and water treatment plants.

It is observed on an outset from the respondents that the implementation of digital technologies into AEC industry indeed a very good move which actually has positive impact on both schedule as well as on cost parameters. For example, electronic document management system linked with the cloud server and accessible to all stake holders helps in identifying the latest revision of the drawing. The system also provides real time alerts whenever there is an updation in the deliverable list, which enables the stakeholders to access to the latest updates immediately. This will helps in avoiding miscommunication and keeping all stakeholders in same platform always.

Another respondent opinioned that, point of sale concept was introduced in their store management system which helps them in real time stock status of the material at any point of time. This helps them in real time material reconciliation and effective inventory planning. The store management system is already available in ERP, however it takes time in getting real picture due to manual intervention in updating the details of already issued material. Construction sites being dynamic, it is highly difficult to have real time stock status with manual intervention in updating the required details in ERP. Hence, integrating the ERP system with point of sale concept helps in getting the real time stock status.

Mobile app implemented for quality control is found useful as per some other respondent. It reduces the effort in updating the status in excel daily. All the details of inspection, engineers comments etc are being recorded in real time through mobile app and status report can be generated at any point of the time from the app itself. This helps in minimizing effort duplication, real time status monitoring can be done by any stakeholder.

Convolutional Neural Network algorithm based app is being used to ensure compliance to PPEs by all people on site. Surveillance cameras were linked to Safety app, which identifies and sends alert to all stakeholders if any workmen is not wearing any required PPE such as Helmet, Safety Shoes etc. This will help in strict compliance and more surveillance to ensure implementation of EHS standards.

CI4 technologies mapping to Project Management Framework

Based on the observations from the case studies, identified some CI4 technologies which are being used and mapped to project management framework which are as indicated in the table 1 below. However, extensive survey needs to be done with big sample size across various organizations in AEC Industry to identify the technologies being used as well as suggestions to implement various other technologies.

Table 1 CI4 Technologies Mapping to PM Framework

PM Knowledge Area	CI4 Technologies
Project Procurement Management	Radio frequency identification (RFID) Barcode Global positioning system (GPS)
Project Resource Management	Mixed reality/Virtual reality (MR/VR) Internet of Things (IOT) Radio frequency identification (RFID)
Project Communication Management	
Project Risk Management	Machine learning

Technology Organization Environment Model

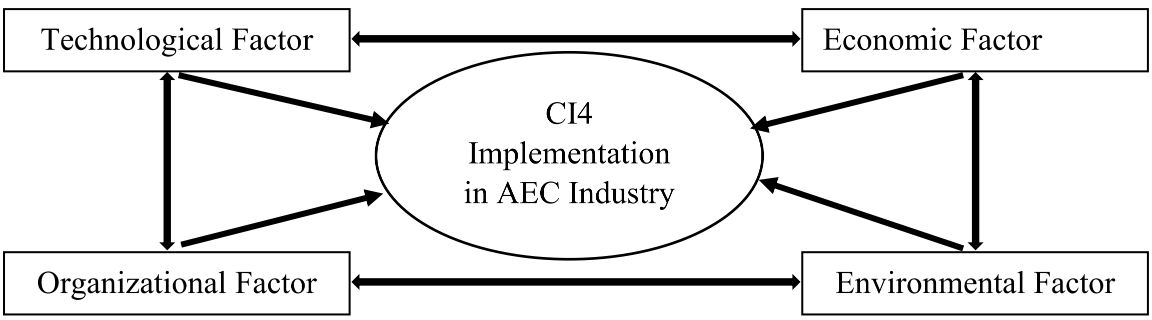

Figure 1: TOE Model for CI4 Implementation in AEC Industry (From Paper X.Qin., et.al., (2020))

X.Qin., et.al., (2020) used the TAM-TOE model in BIM Implementation. From his work it is understood that, The Technology-Organization-Environment model (TOE) was proposed by Tornatzky and Fleischer (1990) which models the influences of technological, the organizational and the environmental context in the process of adopting and implementing technological innovations by a firm (Drazin,1991). The technological context refers to internal (ERP System which an Organization is being used) and external technologies (CI4 technologies) that are currently applied by the organization and those available in the market but not yet used by the company. The organizational context refers to the company size, organizational structure and human resource and the environmental context covers factors outside the control of the organization such as competition, partners and the industry environment. Songer et al. (2001) suggested to introduce economic factors into the technology adoption framework, as the fourth dimension of factors for the TOE-based framework of BIM technology (Figure 1). The influencing factors were identified through literature was finally chalked down to 15 factors using Delphi technique and the same was tabulated in Table 3 below. These factors were again circulated to Industry experts and responses were collected to identify the relation among these factors. DEMATEL Technique was used for analyzing the responses received from the experts.

Table 2. Influence levels and respective interval numbers (From Paper X.Qin., et.al., (2020))

Influence Level	No Influence	Very Low	Low	High	Very High
Value	[0,0]	[0,1]	[1,2]	[2,3]	[3,4]

Data Analysis & Results, Discussions

The DEMATEL (Decision Making Trial and Evaluation) method quantifies the independent views of the helps respondents such that it can be measured and analysed. It can be used to describe the causal relationship model between the variables and the effects exerted by the factors. The benefit of this technique is that experts can communicate their views on the effects (direction and intensity of effects) between variables more fluently.

1:Direct relation matrix generation.

Direct relation matrix A is generated.

$$A = \begin{bmatrix} 0 & \cdots & a_{n1} \\ \vdots & \ddots & \vdots \\ a_{1n} & \cdots & 0 \end{bmatrix}$$

The table 4 shows the direct relation matrix, which is the same as pairwise comparison matrix of the experts.

2: Normalized direct-relation matrix computation

$$p = max\left\{max\sum_{j=1}^{n} a_{ij}, \sum_{i=1}^{n} a_{ij}\right\} \qquad N = \frac{1}{p} * A$$

3: Total relation matrix computation

"After calculating the normalized matrix, the fuzzy total-relation matrix can be computed as follows":

$$T = \lim_{k \to +\infty} (N^1 + N^2 + \cdots + N^k)$$

$\mathrm{T} = \mathrm{N} \times (I - N)^{-1}$"

4: Set the threshold value

In this study, the threshold value is equal to 0.646. All the values in matrix T which are smaller than 0.646 are set to zero, that is, the causal relation mentioned above is not considered. The model of significant relations is presented in the table 7.

5: Final output and create a causal diagram

"The next step is to find out the sum of each row and each column of T (in step 3). The sum of rows (D) and columns (R) can be calculated as follows:

$D = \sum_{j=1}^{n} T_{ij}$ $R = \sum_{i=1}^{n} T_{ij}$

Then, the values of D+R and D-R can be calculated by D and R, where D+R represent the degree of importance of factor i in the entire system and D-R represent net effects that factor *i* contributes to the system."

The table 8 below shows the final output.

Table 3. Influential Factors Identified through Literature and categorized into TOE Framework

Code	Category	Factor
Criteria 1	Technological	Non-physicality (without human physical presence)
Criteria 2	Environmental	First Mover Advantage / Implementation of technology by competitors
Criteria 3	Environmental	Demand for technology in market
Criteria 4	Economic	Technological Benefits (Reducing coordination problems / increased collaboration, increased productivity, etc.)
Criteria 5	Organizational	Top management support / Push by top management
Criteria 6	Technological	IT involvement in technology
Criteria 7	Organizational	Employees, stakeholders(subcontractors & vendors) adaptability and knowledge level to new technology, change management, skill gap assessment & re-skilling, Raising organizational challenges through implementation of new technologies in business operations
Criteria 8	Technological	Decision-support aiding tools in O&M
Criteria 9	Technological	Technology modifications through in-house capability enhancement / Support for technology provider, Timely discovery of potential problems through increased detail and information
Criteria 10	Environmental	Information management (Interoperability) between all stakeholders and single point of trust
Criteria 11	Economic	Effective in Life Cycle Cost incl. investment cost
Criteria 12	Economic	Better valuation / Brand Image with use of technology
Criteria 13	Environmental	Policy formulation towards industry academia collaboration for technological knowledge updates
Criteria 14	Environmental	Standardisation/ Regulatory laws
Criteria 15	Technological	Data Security, Protection & Fraud Resistance

*Note: For Ease, further we name Criteria 1 as C1, Criteria 2 as C2 and so on., Criteria15 as C15.

Table 4 Direct relation matrix

.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.0	1.2	3.2	3.2	2.8	4.0	2.8	2.8	2.6	3.0	3.0	3.2	2.6	2.6	2.8
C2	0.0	0.0	3.2	1.2	4.0	3.8	2.2	2.0	3.0	2.0	3.0	3.8	2.4	1.4	2.2
C3	2.2	2.8	0.0	2.4	3.0	3.6	2.4	3.0	3.0	3.0	2.8	3.0	2.4	2.4	3.0
C4	2.8	2.2	3.0	0.0	3.0	3.4	2.8	3.2	2.8	3.2	2.8	3.6	2.2	2.6	2.8
C5	2.8	3.2	2.6	3.0	0.0	3.2	3.0	2.6	2.4	2.2	2.4	3.2	2.2	2.4	2.4
C6	2.8	2.8	3.2	3.4	2.2	0.0	2.4	2.4	2.8	2.6	2.6	2.6	2.6	2.2	3.2
C7	1.2	1.6	2.0	3.2	3.2	2.8	0.0	3.0	2.2	2.6	2.4	2.6	1.8	2.6	2.4
C8	2.6	2.4	2.6	3.4	2.6	3.0	2.2	0.0	2.4	2.4	3.0	2.6	2.4	2.8	1.8
C9	1.6	2.6	2.8	3.6	2.6	3.0	2.4	2.2	0.0	2.4	2.4	2.6	2.8	2.6	2.8
C10	1.2	2.2	2.8	3.2	2.2	2.8	2.4	2.4	2.6	0.0	2.2	2.6	2.2	2.8	3.2
C11	1.0	2.8	2.8	3.0	2.4	3.0	2.4	2.6	3.0	2.2	0.0	3.0	2.0	2.2	2.6
C12	2.6	3.2	3.4	3.0	3.2	2.4	2.6	2.6	2.8	2.4	3.0	0.0	2.8	2.0	2.0
C13	2.6	2.6	3.2	2.6	2.4	2.6	2.2	2.0	3.0	2.6	2.0	3.0	0.0	3.0	2.2
C14	1.8	2.4	3.2	2.4	2.4	2.2	2.6	2.4	2.8	2.6	2.2	2.4	2.8	0.0	2.0
C15	2.0	2.8	3.0	2.8	2.4	2.6	2.6	2.6	2.8	2.8	2.2	2.6	2.0	2.4	0.0

Table 5 The normalized direct-relation matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0	0.030	0.079	0.079	0.069	0.099	0.069	0.069	0.064	0.074	0.074	0.079	0.064	0.064	0.069
C2	0	0	0.079	0.030	0.099	0.094	0.054	0.050	0.074	0.050	0.074	0.094	0.059	0.035	0.054
C3	0.054	0.069	0	0.059	0.074	0.089	0.059	0.074	0.074	0.074	0.069	0.074	0.059	0.059	0.074
C4	0.069	0.054	0.074	0	0.074	0.084	0.069	0.079	0.069	0.079	0.069	0.089	0.054	0.064	0.069
C5	0.069	0.079	0.064	0.074	0	0.079	0.074	0.064	0.059	0.054	0.059	0.079	0.054	0.059	0.059
C6	0.069	0.069	0.079	0.084	0.054	0	0.059	0.059	0.069	0.064	0.064	0.064	0.064	0.054	0.079
C7	0.030	0.040	0.050	0.079	0.079	0.069	0	0.074	0.054	0.064	0.059	0.064	0.045	0.064	0.059
C8	0.064	0.059	0.064	0.084	0.064	0.074	0.054	0	0.059	0.059	0.074	0.064	0.059	0.069	0.045
C9	0.040	0.064	0.069	0.089	0.064	0.074	0.059	0.054	0	0.059	0.059	0.064	0.069	0.064	0.069
C10	0.030	0.054	0.069	0.079	0.054	0.069	0.059	0.059	0.064	0	0.054	0.064	0.054	0.069	0.079
C11	0.025	0.069	0.069	0.074	0.059	0.074	0.059	0.064	0.074	0.054	0	0.074	0.050	0.054	0.064
C12	0.064	0.079	0.084	0.074	0.079	0.059	0.064	0.064	0.069	0.059	0.074	0	0.069	0.050	0.050
C13	0.064	0.064	0.079	0.064	0.059	0.064	0.054	0.050	0.074	0.064	0.050	0.074	0	0.074	0.054
C14	0.045	0.059	0.079	0.059	0.059	0.054	0.064	0.059	0.069	0.064	0.054	0.059	0.069	0	0.050
C15	0.050	0.069	0.074	0.069	0.059	0.064	0.064	0.064	0.069	0.069	0.054	0.064	0.050	0.059	0

Table 6 The total relation matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.491	0.647	0.785	0.778	0.733	0.823	0.678	0.693	0.727	0.699	0.700	0.781	0.644	0.656	0.688
C2	0.425	0.536	0.686	0.636	0.668	0.717	0.580	0.588	0.644	0.589	0.613	0.697	0.559	0.546	0.588
C3	0.529	0.668	0.695	0.743	0.722	0.797	0.655	0.682	0.720	0.683	0.681	0.760	0.626	0.636	0.677
C4	0.560	0.677	0.789	0.712	0.746	0.818	0.685	0.709	0.739	0.710	0.703	0.798	0.643	0.662	0.694
C5	0.527	0.657	0.733	0.733	0.634	0.766	0.649	0.654	0.686	0.647	0.653	0.743	0.604	0.618	0.644
C6	0.530	0.652	0.750	0.746	0.689	0.697	0.639	0.654	0.699	0.660	0.661	0.734	0.616	0.617	0.666
C7	0.446	0.564	0.651	0.671	0.642	0.686	0.521	0.603	0.618	0.595	0.592	0.661	0.539	0.566	0.584
C8	0.508	0.620	0.711	0.720	0.672	0.739	0.612	0.574	0.665	0.631	0.646	0.708	0.590	0.608	0.611
C9	0.487	0.627	0.717	0.726	0.674	0.740	0.618	0.627	0.611	0.633	0.634	0.710	0.600	0.606	0.635
C10	0.459	0.594	0.689	0.690	0.639	0.707	0.594	0.607	0.645	0.552	0.605	0.681	0.564	0.587	0.619
C11	0.456	0.611	0.692	0.689	0.647	0.715	0.597	0.614	0.657	0.607	0.556	0.694	0.562	0.576	0.609
C12	0.527	0.664	0.757	0.740	0.714	0.757	0.646	0.660	0.702	0.657	0.672	0.677	0.623	0.615	0.642
C13	0.504	0.621	0.720	0.698	0.664	0.725	0.608	0.617	0.675	0.632	0.620	0.712	0.531	0.609	0.617
C14	0.464	0.589	0.687	0.662	0.634	0.683	0.589	0.597	0.640	0.603	0.595	0.667	0.569	0.513	0.584
C15	0.485	0.619	0.707	0.695	0.656	0.717	0.610	0.623	0.662	0.629	0.617	0.695	0.571	0.589	0.558

Table 7 The total- relationships matrix by considering the threshold value

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0	0.647	0.785	0.778	0.733	0.823	0.678	0.693	0.727	0.699	0.700	0.781	0	0.656	0.688
C2	0	0	0.686	0	0.668	0.717	0	0	0	0	0	0.697	0	0	0
C3	0	0.668	0.695	0.743	0.722	0.797	0.655	0.682	0.720	0.683	0.681	0.760	0	0	0.677
C4	0	0.677	0.789	0.712	0.746	0.818	0.685	0.709	0.739	0.710	0.703	0.798	0	0.662	0.694
C5	0	0.657	0.733	0.733	0	0.766	0.649	0.654	0.686	0.647	0.653	0.743	0	0	0
C6	0	0.652	0.750	0.746	0.689	0.697	0	0.654	0.699	0.660	0.661	0.734	0	0	0.666
C7	0	0	0.651	0.671	0	0.686	0	0	0	0	0	0.661	0	0	0
C8	0	0	0.711	0.720	0.672	0.739	0	0	0.665	0	0	0.708	0	0	0
C9	0	0	0.717	0.726	0.674	0.740	0	0	0	0	0	0.710	0	0	0
C10	0	0	0.689	0.690	0	0.707	0	0	0	0	0	0.681	0	0	0
C11	0	0	0.692	0.689	0.647	0.715	0	0	0.657	0	0	0.694	0	0	0
C12	0	0.664	0.757	0.740	0.714	0.757	0.646	0.66	0.702	0.657	0.672	0.677	0	0	0
C13	0	0	0.720	0.698	0.664	0.725	0	0	0.675	0	0	0.712	0	0	0
C14	0	0	0.687	0.662	0	0.683	0	0	0	0	0	0.667	0	0	0
C15	0	0	0.707	0.695	0.656	0.717	0	0	0.662	0	0	0.695	0	0	0