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Evaluating modelling methods for mobile crane lifting operations in South Africa

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ABSTRACT

The successful completion of construction projects is dependent on safe and efficient crane operations. As modularized (off-site) construction is increasingly replacing traditional on-site activities, the evaluation of mobile crane lifting modelling should be evaluated. This paper investigates current modelling practices adopted and utilised by South African firms for the planning and/or designing of mobile crane lifting operations, the influencing factors affecting the choice of modelling methods by firms, and the impact they have on project performance. Quantitative data gathered revealed that firms who are actively adopting virtual modelling as a planning tool for mobile crane lifting operations, have higher success rates with regards to achieving targeted project performance measures such as scheduling-, safety-, and achieving customer satisfaction goals. The research revealed that the two most significant factors influencing the choice of firms to adopt virtual modelling as a planning tool, was found to be Awareness and Perceived usefulness. Findings from the research suggest that failure to adopt innovation in this field could have long term negative consequences to the market share of firms operating within this industry. It is therefore suggested that South African firms within the lifting industry improve their competitiveness by ensuring they invest in the adoption of virtual modelling as a planning tool for mobile crane lifting operations.

Keywords: Virtual modelling, Lift planning, Crane optimization, Construction project performance, 2D modelling, Mathematical modelling.

1. INTRODUCTION

During the planning of lifting operations, lift planners needs to consider dynamic, iterative processes to enable the optimization of operations that are safe, efficient, and effective (Lei et al., 2016). Initial investigations found that the majority of current lift planning practices still involves the use of outdated static 2-Dimensional (2D) modelling techniques for the design and evaluation lifting operation feasibility. These outdated and static approaches cause inferior crane operations leading to crane relocations and/or collision errors which can be costly and time-consuming (Chi et al., 2010). Furthermore, applying static 2D modelling techniques for dynamic activities such as lifting activities, are some of the root causes of misunderstandings and/or miscommunication errors among project team members (Han et al., 2015).

Several studies have been conducted on the topic of crane lift planning with the purpose of overcoming the limitations of traditional static modelling. Researchers such as Han et al.,(2015) proposed the use of 3D visualization software to aid designers in developing collision-free lift plans. By reconstructing a construction site and using 3D simulation software to simulate crane operations, virtual modelling methods are able to assist project teams to identify collision risks, optimize operational efficiency, enhance decision making, and improve communication among team members.

At the time of this study, no local standard industry practice for the planning of lifting operations in South Africa could be identified. Therefore, the primary objective of this study to investigate current practices for planning/modelling of mobile crane lifting operations in South Africa.

By identifying current practices for modelling in South Africa, insight can be gained into what modelling practices have been adopted and the reason for adoption. The study also aimed to identify the linkage between influential factors affecting technology adoption in the construction industry and the choice of modelling method. By understanding what is being adopted as well as why it is being adopted, the research aims to provide insight into the needs and concerns of firms in the local lifting industry regarding the adoption of modern modelling practices for lift planning.

The research also investigated the relationship between modelling practices and key project performance indicators. The results highlight best practices for planning of mobile crane lifting operations in South Africa.

These objectives were achieved by answering the following research questions:

- What modelling methods, relating to designing and/or planning of mobile crane lifting operations, are currently being applied in South Africa?
- Which factors correlate with the choice of modelling method utilized by firms for planning and/or designing of mobile crane lifting operations in South Africa?
- How does the choice of modelling method affect project performance within the context of mobile crane lifting operations in South Africa

2. LITERATURE REVIEW

2.1 Lift planning

In construction projects, planning of crane-related lifting operations has an impact on project success (Zhang and Pan, 2020). To be able to successfully execute a mobile crane lifting operation, an optimal lift plan needs to be developed by competent lift planners having the required skills, knowledge and experience to be able to solve a complex combinatorial optimization problem (García de Soto et al., 2020).

Traditionally, lift planning involved operations using 2D drawings or, in more complex lifts, static 3D drawings. Using these techniques, lift planners focused primarily on evaluating crane lifting operations only at the pick and set points of the load to be lifted, rather than evaluating the entire lifting operation. This approach often resulted in costly errors in crane lifting operations such as collision errors, miscommunications and/or crane relocations (Zhang and Pan, 2019).

Significant research and development have been done in recent years to help address these problems. Some notable research include, decision-making based on multiple criteria in crane selection (Jalali et al., 2018), visualizations for lifting collision analysis (Chi and Kang, 2010), heuristic searching for lift path planning (Wu et al., 2018), and AI-based algorithms for location optimization (Lien and Cheng, 2014).

2.2 Lift planning optimization

Crane-related lifting operations can be regarded as a system containing different entities that interact with each other in order to complete a lifting task. Various methods exist that can be used to experiment with this system. Figure 1(Law et al., 2000) shows a diagram of the different methods that can be used to study a crane lifting operation. It is generally not economically feasible to experiment with the on-site actual crane operations as a system. A better alternative is to construct a representative model of the crane lifting operation. This model can be either physical, mathematical, or virtual (see Figure 2).

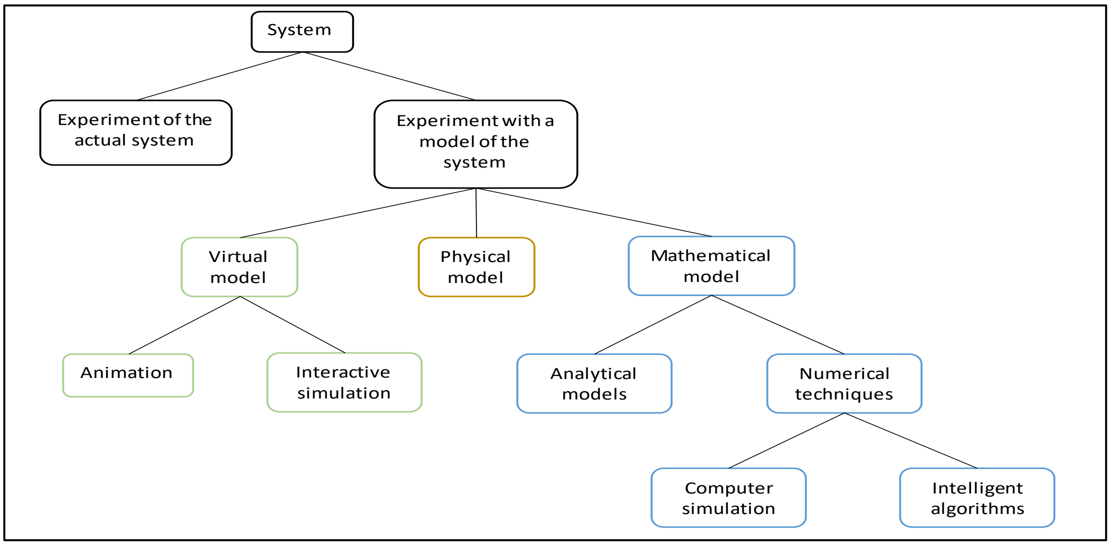

Figure 1: Methods of experimenting with crane lifting operations (Law et al., 2000)

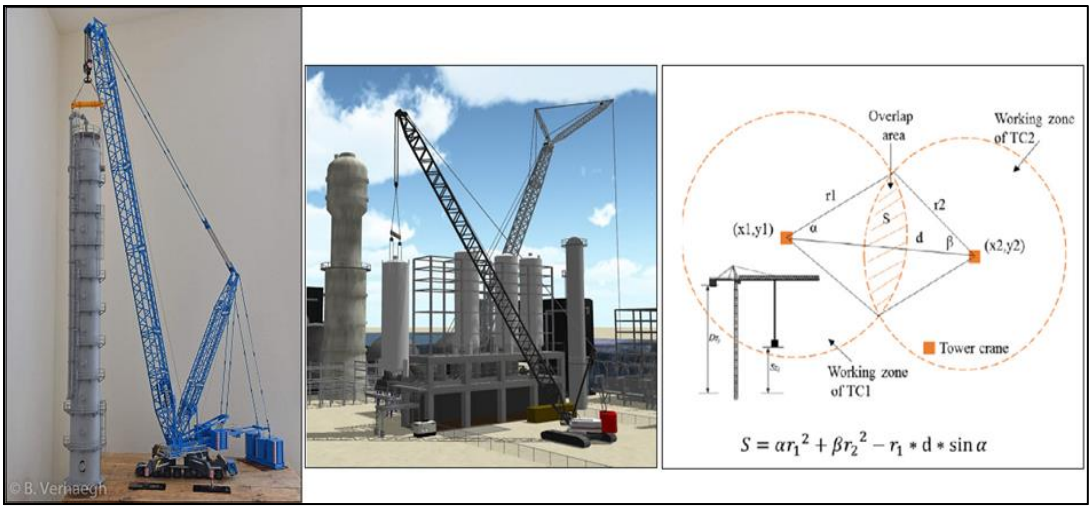

Figure 2: Types of models for a crane lift-system. Physical (left), virtual (middle), and mathematical (right)

2.2.1 Experimenting using mathematical modelling

In a mathematical model, a defined set of constraints can be created in which input variables can be minimized or maximized with respect to a clear objective function (Marzouk and Abubakr, 2016). Mathematical models are commonly examined using analytical and/or numerical techniques such as intelligent algorithms or computer simulations. Analytical methods are recommended when the mathematical model is not complex as these methods provide an exact solution for the model. Complex models are examined using numerical techniques which provide approximate solutions and involves a trial-and-error approach to obtain the approximate solution. Lifting operations are often modelled using numerical approaches since optimum lift planning of lifting operations involve complex planning and decision-making processes.

Numerical methods (using computer simulations) make it possible to reproduce a system's behavior by simulating the outcomes of a mathematical model using computer software. This simulation can then be used evaluate the performance of complex systems (Cantot and Luzeaux, 2013). As computer technology is advancing, the use of simulations in construction planning is increasingly aiding in developing better project plans, improving material handling systems, optimizing decision making process, and improving project productivity in terms of project costs and durations (Song and AbouRizk, 2006). Simulation methods in lifting operations have also been explored in recent years such as discrete-event simulation as a modeling method for movement of mobile cranes (ElNimr, Fagiar et al. 2016) and layout planning for tower cranes using an agent-based simulation (Younes and Marzouk, 2018).

Intelligent algorithms (as a numerical solution to mathematical modelling) have gained traction in recent years as faster heuristics and big data analyzing capabilities have made intelligent algorithms superior to numerical simulation methods in many ways. In recent decades, Intelligent algorithm methods, such as artificial intelligence (AI), have been introduced into the construction industry with the aim of making machines perform in a smart way by solving complex decision-making/optimization problems (Negnevitsky, 2005). Intelligent algorithms are capable of numerically solving complex mathematical problems by mimicking human intelligence and/or behaviors, such as decision-making learning and perception.

Artificial neural networks (ANN's) are one of the most popular approaches to machine learning and have become a common intelligent algorithm modeling technique in the field of lifting operations. Applications of ANN's and other AI-based models for lifting operations have yielded significant results in improved accuracy, productivity, and reliability of lift planning. Furthermore, AI-based numerical models have made it possible to simultaneously evaluate multiple planning components (Hornaday, Haas et al., 1993).

2.2.2 Experimenting using virtual modelling

A 3D virtual model can be described as a digital reconstruction/representation of a physical object, which can be built using relevant computer software. Animations using Building Information Management (BIM) software combined with Augmented Reality (AR) or Virtual Reality (VR) using interactive simulations, are the most commonly used methods for virtually experimenting with crane lifting operations (Bouchlaghem et al., 2005).

The construction industry has adapted well to the use of BIM software in correlation with computer animation software for generating construction sequencing animations. The combined use of these technologies has been successful in enhancing communication between various project stakeholders (Zhang and Pan, 2020). Han et al (Han et al., 2015) noted the following benefits of utilizing animating software for lifting operations:

- Increased productivity – Potential spatial conflicts are easily identified and eliminated.
- Improved communication, understanding and collaboration between project stakeholders prior to lifting operations.
- Improved confidence and morale of the project lifting team - By providing a visual pre-lecture of the lifting operation, team members gain a better understanding of the lifting task to be executed.

3D virtual modeling identifies the working radii and clearances during crane operations concurrently in order to validate and confirm the feasibility of each possible scenario, including crane locations, selected crane types, and crane lifting path. If spatial errors are identified in the 3D model, the selected crane model, crane location, or crane lift path is deemed to be unacceptable, and the relevant analysis is restarted.

The lack of descriptiveness and information in 2D drawings can lead to misunderstanding and miscommunication among project participants, resulting in poor decision making and the delivery of lower quality projects to clients (Han et al., 2015). Project participants may select an inefficient scenario because of the lack of information, such as uncertain clearances during crane operation when more than one feasible scenario exists. These uncertainties can lead to a faulty decision, which in turn increases operation time and cost for transportation and installation of the crane while necessitating an additional support system, even though a more efficient scenario utilizing an economical crane model with less operation time is available.

3D virtual modeling provides sequences of all lifts, complete with all the required information to facilitate better and faster communication, understanding and collaboration among participants so that effective and efficient decision making can be implemented resulting in productivity improvement. Furthermore, 3D virtual modeling assist project teams to identify potential high-risk areas and to design efficient and effective crane operations, so that productivity can be increased by reducing site errors, cost, and time (Han et al., 2015).

2.3 Technology Adoption in Construction

Research done by Akbarnezhad et al. (2016) proposed that, based on the benefits and risks of Building Information Modelling (BIM) adoption, and theories of implementing innovations in the construction industry, influential factors for innovation adoption can be categorised into the following three groups: adoption motivation, organizational competency, and ease of implementation.

Adoption motivation relates to the initial stages of implementing innovative processes and involves developing an awareness of the innovation as well as perceiving the need for utilizing/adopting the innovation (Sebastian et al., 2009). Existing literature on technology adoption in the field information technology have categorised perceived usefulness of BIM implementation, organizational innovativeness, subjective norms, and awareness as major motivations for BIM adoption (Lee et al., 2013).

According to Akbarnezhad et al. (2016), organizational competency can be measured in the following areas: organizational support, expertise, and organizational intention. Technical issues with software technology have been highlighted by previous studies as the main barrier for information technology adoption in the construction industry (Gledson et al., 2012). The primary factors contributing to ease of implementation are (Akbarnezhad, 2016): Ease of operation, ease of maintenance and, down time.

2.4 Research review

The process of lift planning optimization can be facilitated by a reconstructed model of the actual lifting operation. Different modelling methods include physical modelling, mathematical modelling, and virtual/3D modelling. Virtual modelling (through the integration of BIM and computer animation software) has been recognized as an effective method for crane location optimization and lift path planning. The literature review identified influential factors affecting technology adoption in the construction industry. These factors were used as independent variables in the integrated framework developed for this research in order the evaluate current modelling practices for mobile crane operations in South Africa.

3. CONCEPTUAL METHOD

The aim of this research was to identify the factors and their impact on the choice of modelling methods for planning of mobile crane lifting operations, and secondly, to develop and investigate the linkage between the choice of modelling method and project performance. The integrated framework developed for this research is shown in Figure 2.

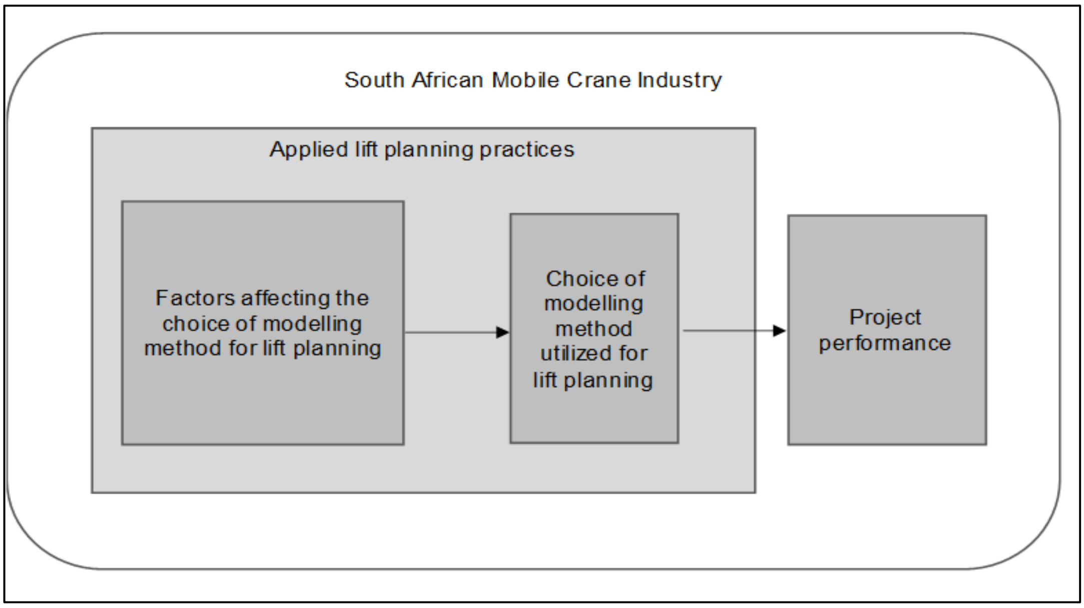

Figure 2: Integrated framework for investigating lift planning practices in South Africa for modelling of mobile crane lifting operations

In developing the integrated framework shown in Figure 2, a hypothesis of each influencing factor's relationship with the choice of modelling method was formulated as follows:

H1-1: Perceived usefulness has a positive effect on the choice of adopting advanced modelling methods (i.e., virtual modelling and mathematical modelling).

H1-2: The more innovative a firm, the more advanced the applied modelling method will be.

H1-3: Client preferences will influence the type of modelling method that a firm uses.

H1-4: The more knowledgeable a firm is regarding the applications and benefits of a specific technology type, the more likely they are to utilize that technology.

H1-5: A firm that executes larger, more complex lifting projects will most likely utilize more advanced modelling methods.

Hypotheses of the impact that virtual modelling has on project performance was formulated as follows:

H2-1: Utilization of virtual modelling methods for planning of lifting operations increase the percentage of projects that meet their schedule goals.

H2-2: Utilization of virtual modelling methods for planning of lifting operations increase the percentage of projects that meet their safety goals.

H2-3: Utilization of virtual modelling methods for planning of lifting operations increase the percentage of projects that meet their customers' requirements.

The analytical framework for the study is shown in Figure 3 below and was composed from the integrated framework shown in Figure 2.

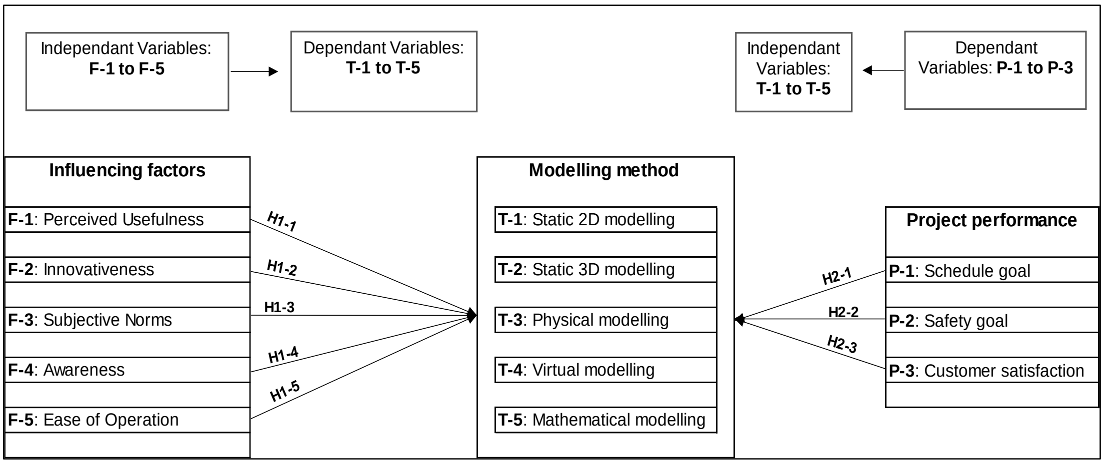

Figure 3: Analytical framework for hypotheses testing.

4. RESEARCH DESIGN AND METHODOLOGY

A quantitative research approach was used to employ a self-administered online questionnaire survey to investigate the linkage between influencing factors affecting the choice of modelling method utilized by lift planners in South Africa, and the impact the preferred modelling method has on project performance.

The survey questions were composed from the integrated framework shown in Figure 2. The unit of analysis for the study was the mobile crane industry of South Africa with the technical design and planning staff of the firms within this industry, comprising the unit of analysis. The questionnaire was organized into the following four sections:

General information: This section was used to establish the individual profiles of the respondents in terms of current role in the company, experience and technical skills, qualifications.

Choice of modelling method: This section was used to indicate what type of lift planning support tools are used by the respondent and was measured as a percentage of projects in the past 5 years.

Factors affecting the choice of modelling method: This section was used to identify the factors affecting the choice modelling method.

Project Performance: This section relates to the impact the type of lift planning tool/technique/software has on project performance.

The sample population consisted of individuals who are actively working at firms with a core business relating to lifting equipment and/or the transportation/installation of heavy machinery. The Lifting Equipment Engineering Association of South Africa (LEEASA) lists approximately 110 mobile crane-related firms in South Africa who are registered at LEEASA. However, not all service providers registered with LEEASA are involved with actual mobile crane lifting operations, as the LEEASA covers a diverse set of load handling service providers. A conservative assumption was therefore made to use a sample size greater than a 100 to accurately represent the mobile crane lifting industry of South Africa.

Choice of modelling method was measured by asking the respondents if they have used any of the modelling methods in Table 1 by indicating the percentage of projects over the last 5 years which have used that specific modelling method for design and/or analysis of mobile crane lifting operations.

Table 1: Modelling methods for lift planning

Modelling method for lift planning	
T-1	Static 2D modelling (drawings and/or sketches)
T-2	Static 3D modelling (drawings and/or sketches)
T-3	Physical modelling (solid 3D model)
T-4	Virtual modelling (animations and/or interactive simulation)
T-5	Mathematical modelling (analytical techniques and/or numerical techniques)

The factors affecting the choice of modelling method are ordinal discrete variables. A summary of the quantitative input factors and their definitions used for this research is shown in Table 2. The measuring method comprised of a five-point Likert-type scale ranging from "strongly disagree" (score 1) to "strongly agree" (score 5).

Table 2: Factors affecting the choice of modelling method

Factors		Definition
F-1	*Perceived Usefulness*	The degree to which person believes that utilizing a system would enhance the performance of his or her portfolio of work tasks.
F-2	*Innovativeness*	A measure of the processes in place for organizations to introduce new ideas, workflows, methodologies, services, and/or products.
F-3	*Subjective Norms*	An individual's perception that most people, who are important to him/her, think that he/she should or should not perform the behaviour.
F-4	*Awareness*	The degree to which an organization is familiar and knowledgeable on the existence, applications, and capabilities of the innovative technology.
F-5	*Ease of operation*	The degree to which the technology can assist a user in his/her portfolio of work tasks.

The key project performance indicators that were measured by this study were schedule targets, safety goals, and customer satisfaction. These performance indicators were measured as ordinal discrete variables, indicating the percentage of projects executed in the past 5 years that met the relevant performance targets for each of these indicators. The respondents were asked to indicate their answer by selecting a percentage range, ranging from 0% to 100% in increments of 10%. These variables were coded using the coding method presented in Table 3.

Table 3: Coding method

T -1, T -2, T -3, T -4, T -5, P -1, P -2, P -3		
0% - 10%	=	1
11% - 20%	=	2
21% - 30%	=	3
31% - 40%	=	4
41% - 50%	=	5
51% - 60%	=	6
61% - 70%	=	7
71% - 80%	=	8
81% - 90%	=	9
91% - 100%	=	10

The survey questionnaire was developed and published on the internet for respondents to easily complete. The survey questionnaire was comprised of the following sections:

Section 1: General information - This section was used to establish the individual profiles of the respondents in terms of current role in the company, experience and technical skills, qualifications.
Section 2: Choice of modelling method - This section was used to indicate the type and frequency of modelling methods utilized by respondents.
Section 3: Factors affecting the choice of modelling method - This section was used to identify the factors affecting the choice modelling method.
Section 4: Project Performance - This section relates to the impact the choice of modelling method has on project performance.

Data entered for section 1 was used to establish the individual profiles of the respondents in terms of current role in the company, experience and technical skills, qualifications. An ordinal five-point Likert-type scale was used for section 3. Data entered for section 2 and 4 of the survey was ordinal discrete variables, indicating a percentage ranging from 0% to 100% in increments of 10%. These variables were coded using the coding method presented in Table 3.

Descriptive statistics are used to form the basis of quantitative analysis of the research and are used to describe the features of the collected data by providing measures of spread, centre and association about the data sample. The Three descriptive measures of a variable that will be evaluated by this research are:
Distribution: The summary of frequency of individual variable shall be analysed and depicted on graphs.
Central tendency: The mean, median and mode shall be calculated to describe the central tendency of the sample data.
Dispersion: Standard deviation shall be used to estimate the dispersion of data.

5. RESULTS

5.1 Descriptive Analysis

A primary objective of the research was to identify current modelling practices in South Africa for planning/designing of mobile crane lifting operations. In section 2 of the questionnaire survey, respondents were asked to indicate their percentage of utilization for planning of mobile crane lifting operations over the past 5 years for each of the listed modelling methods. The results are shown in Figure 4 and indicate that all modelling methods discussed in the literature are adopted, albeit at different extents in South Africa.

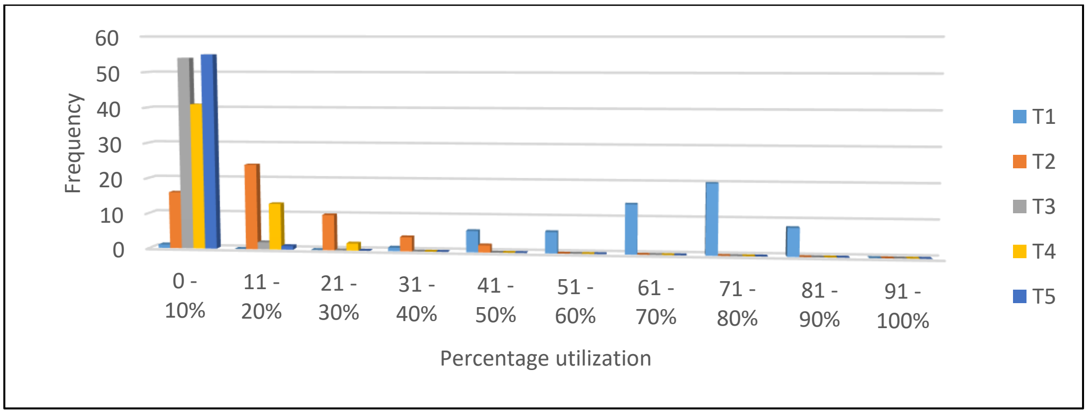

Figure 4: Column diagram of the frequency distribution of choice of modelling method

Descriptive features of the data collected from section 2 of the questionnaire survey are presented in Table 4 below. The maximum mean of 7.16 indicates that the majority of respondents utilize static 2D modelling for planning and/or designing mobile crane lifting operations. The low mean values of 1.03, 1.3, and 1.01 for T3, T4, and T5 respectively, indicated a very low utilization rate for these modelling methods among respondents.

Table 4: Descriptive statistics for choice of modelling method

Variable	Description	Mean	Mode	Median	Std Dev
T-1	Static 2D Modelling	7.16	8	7.5	1.51
T-2	Static 3D Modelling	2.14	2	2.0	1.03
T-3	Physical Modelling	1.03	1	1.0	0.18
T-4	Virtual Modelling	1.30	1	1.0	0.53
T-5	Mathematical Modelling	1.01	1	1.0	0.13

5.2 Hypotheses Testing

The hypotheses were investigated using the statistical techniques; correlation and multiple regression analysis.

5.2.1 *Influencing Factors and Choice of Modelling Method*

In order to ascertain the impact of influencing factors on the choice of modelling methods, linear multiple regression analysis was used on the data. The model results are presented in Table 5 below.

Table 5: Regression Analysis results captured from Microsoft Excel

		Dependent Variable: Static 2D modelling					
		Regression Analysis Data					
Independent Variable		Correlation	R²	Slope Coefficient	Slope P-value	t-test	F-test
F1	Perceived Usefulness	0.493	0.243	0.170	0.000	4.171	17.400
F2	Innovativeness	0.185	0.034	0.163	0.170	1.388	1.929
F3	Subjective Norm	0.186	0.034	-0.122	0.169	-1.392	1.939
F4	Awareness	0.460	0.212	0.145	0.000	3.814	14.547
F5	Ease of Operation	0.050	0.002	0.049	0.712	0.370	0.137
		Dependent Variable: Static 3D modelling					
F1	Perceived Usefulness	0.499	0.249	0.468	0.000	4.239	17.976
F2	Innovativeness	0.484	0.234	0.623	0.000	4.070	16.566
F3	Subjective Norm	0.005	0.000	-0.004	0.970	-0.037	0.001
F4	Awareness	0.512	0.262	0.483	0.000	4.389	19.267
F5	Ease of Operation	0.482	0.233	0.696	0.000	4.051	16.417
		Dependent Variable: Physical modelling					
F1	Perceived Usefulness	0.343	0.117	1.907	0.009	2.685	7.211
F2	Innovativeness	0.195	0.038	1.388	0.149	1.463	2.14
F3	Subjective Norm	0.203	0.041	-1.074	0.133	-1.524	2.323
F4	Awareness	0.16	0.025	0.759	0.236	1.197	1.433
F5	Ease of Operation	0.162	0.026	1.296	0.231	1.211	1.467
		Dependent Variable: Virtual modelling					
F1	Perceived Usefulness	0.76	0.57	1.55	0.00	8.53	72.82
F2	Innovativeness	0.64	0.41	1.60	0.00	6.17	38.02
F3	Subjective Norm	0.22	0.05	0.40	0.11	1.65	2.71
F4	Awareness	0.80	0.64	2.24	0.00	9.78	95.69
F5	Ease of Operation	0.71	0.50	1.97	0.00	7.40	54.72

		Dependent Variable: Mathematical modelling					
F1	Perceived Usefulness	0.404	0.163	2.418	0.002	3.248	10.555
F2	Innovativeness	0.187	0.035	1.872	0.165	1.405	1.976
F3	Subjective Norm	0.407	0.165	3.018	0.001	3.277	10.740
F4	Awareness	0.479	0.229	2.436	0.000	4.015	16.121
F5	Ease of Operation	0.205	0.042	2.290	0.129	1.540	2.372

The correlation results showed acceptable levels of correlation between certain influencing factors (independent variables) and choice of modelling method (dependant variables). The results indicated a moderately positive correlation (0.34 – 0.499) between perceived usefulness and choice of modelling method for all methods except virtual modelling, where a strong positive correlation (0.76) was observed. Hypothesis H1-1 is therefore supported (t-test > 2.01, F-test > 4.02. P-value < 0.05).

A moderately positive correlation was observed between innovativeness and the utilization of static 3D modelling and virtual modelling. Hypothesis H1-2 is supported for the choice of static 3D modelling and virtual modelling (t-test > 2.01, F-test > 4.02. P-value < 0.05). A weak positive correlation was observed between subjective norm and the choices of modelling, except for mathematical modelling where a moderately positive correlation was observed (0.407). Hypothesis H1-3 is therefore supported for the choice of mathematical modelling (t-test > 2.01, F-test > 4.02. P-value < 0.05).

A moderately positive correlation was observed between awareness and the choice of modelling methods with a very strong positive correlation (0.8) observed for virtual modelling. Hypothesis H1-4 is therefore supported (t-test > 2.01, F-test > 4.02. P-value < 0.05). Ease of operation indicated a moderately positive correlation to static 3D modelling as well as virtual modelling. A moderately positive correlation was observed between Ease of operation and the choice of modelling methods, with a very strong positive correlation (0.7) observed between ease of operation and virtual modelling. Hypothesis H1-5 is therefore supported (t-test > 2.01, F-test > 4.02. P-value < 0.05).

5.2.2 *Project Performance and Choice of Modelling Method*

In order to ascertain the impact of choice of modelling method on project performance, linear multiple regression analysis was also used on the gathered data. The model results are presented in Table 6 below.

Table 6: Regression Analysis captured in Excel

		Dependant Variable: Project Schedule Targets					
		Regression Analysis Data					
Independent Variable		Correlation	R²	Slope Coefficient	Slope P-value	t-test	F-test
T1	Static 2D Modelling	0.398	0.158	0.434	0.002	3.189	10.170
T2	Static 3D Modelling	0.508	0.258	0.810	0.000	4.340	18.839
T3	Physical Modelling	0.157	0.024	1.388	0.245	1.173	1.377
T4	Virtual Modelling	0.642	0.412	1.974	0.000	6.160	37.950
T5	Mathematical Modelling	0.151	0.023	1.872	0.264	1.128	1.273
		Dependant Variable: Project Safety Targets					
T1	Static 2D Modelling	0.458	0.210	0.451	0.000	3.795	14.408
T2	Static 3D Modelling	0.464	0.215	0.667	0.000	3.854	14.853
T3	Physical Modelling	0.118	0.014	0.944	0.382	0.880	0.775
T4	Virtual Modelling	0.523	0.274	1.450	0.000	4.518	20.414
T5	Mathematical Modelling	0.129	0.016	1.436	0.342	0.956	0.915
		Dependant Variable: Project Customer Satisfaction Targets					
T1	Static 2D Modelling	0.364	0.132	0.363	0.005	2.871	8.248
T2	Static 3D Modelling	0.489	0.239	0.713	0.000	4.124	17.008
T3	Physical Modelling	0.209	0.043	1.685	0.121	1.572	2.471
T4	Virtual Modelling	0.575	0.331	1.617	0.000	5.172	26.756
T5	Mathematical Modelling	0.146	0.021	1.654	0.281	1.088	1.185

A moderately positive correlation was observed between the independent variables (static 2D modelling, static 3D modelling, and virtual modelling) and the dependant variables (project performance targets). Results from the regression analysis revealed that the utilization of virtual modelling methods for planning of lifting operations, increased the percentage of projects that met their schedule goals, safety goals, and customer satisfaction goals. Hypotheses H2-1, H2-2, and H2-3 is therefore supported.

6 DISCUSSION

The following subsections present summaries of the findings and substantiates the proposed hypotheses which apply only to firms operating in the mobile crane lifting industry in South Africa.

6.1 Influencing factors affecting the choice of modelling method

Findings from the research revealed that, a firm's choice of modelling method is strongly influenced by their perceived usefulness towards a specific modelling method. This finding was most applicable to virtual modelling, where a strong positive correlation (0.76) was observed between perceived usefulness and the adoption of virtual modelling. These findings are consistent with Sebastian et al. (2009)'s suggestions that implementing innovative processes involve developing an awareness of the innovation as well as perceiving the need for utilizing/adopting the innovation.

From the literature it is stated that innovativeness of an organisation to have processes in place for introducing new ideas, workflows, methodologies, services, and/or products, is a critical factor for technology adoption (Newton and Chileshe, 2012). Results from the research are consistent with the findings of Newton and Chileshe, (2012). It can therefore be concluded that South African firms holding a competitive advantage in terms of developing and/or implementing new ideas and/or processes in the field of mobile crane operations, have a higher adoption rate for innovative technologies (such as virtual modelling), compared to firms who are not considered market leaders.

The investigation revealed that, except for mathematical modelling, client preference had no noticeable effect on the choice of modelling method. This finding is not consistent with existing literature (Lee et al., 2013). It should be noted that existing literature on client preference as an influencing factor in technology adoption in the construction industry are primarily done in industrialized countries. As the survey was conducted in South Africa, the local environment could potentially influence the results compared to other industrialized countries. This finding suggests that for client preference to have a significant impact, the entire industry value chain needs to collectively adopt and promote modern lift planning practices.

Ease of operation has a positive effect on the adoption of virtual modelling as a modelling method. Further to this, the research revealed that firms who execute more complex lifting operations are more likely to utilize more innovative modelling methods such as virtual modelling. The literature has shown how utilizing innovative modelling methods to simulate mobile crane lifting operations (Han et al., 2015), are improving the performance of complex lifting projects by optimizing crane selection, improving communication among project participants and reducing the turnaround time of project execution. Table 7 below provides a summary the significance of each influencing factor in relation to each modelling method.

6.2 Project performance and the choice of modelling method

The second part of this research was aimed at investigating the linkage between the choice of modelling methods and its impact on project performance. Findings from the research revealed that firms utilizing virtual modelling as a planning tool, had a higher success rate with projects achieving their scheduling goals, safety goals, and customer satisfaction goals compared to firms using other methods. These findings are consistent with Han et al., (2015)'s suggestions that virtual modelling improves the turnaround time of lifting projects, helps identify collision risks, and assists with decision making and communication among project participants.

Table 7: Influencing factors ranked from most significant to least

Ranking	Modelling Method				
	Static 2D Modelling	Static 3D Modelling	Physical Modelling	Virtual Modelling	Mathematical Modelling
1	F1 - Perceived Usefulness	F4 - Awareness	F1 - Perceived Usefulness	F4 - Awareness	F4 - Awareness
2	F4 - Awareness	F1 - Perceived Usefulness		F1 - Perceived Usefulness	F3 - Subjective Norm
3	F6 - Ease of Maintenance	F2 - Innovativeness		F5 - Ease of Operation	F1 - Perceived Usefulness
4		F5 - Ease of Operation		F2 - Innovativeness	

7 CONCLUSIONS AND RECOMMENDATIONS

This research proposed a conceptual framework to evaluate current modelling practices applied in South Africa for mobile crane lifting operations. The framework was used to:

- Investigate current adoption levels for the different types of modelling methods in South Africa.
- Identify the influencing factors affecting the choice of modelling methods used by firms in South Africa for planning and/or designing of mobile crane lifting operations.
- To investigate the linkage between the choice of modelling methods and the impact it has on the performance of mobile crane lifting projects in South Africa.

The results concluded that existing literature and theories do indeed apply to some of the hypotheses and propositions put forward by this investigation which applies to mobile crane lifting related projects in South Africa.

Previous studies have shown how the utilization of advanced modelling technologies for lift planning activities offer advantages to mobile crane lifting operations as project key performance indicators such as safety, production, and customer satisfaction can be optimized, thereby offer customers a significant leap in value and user a competitive advantage. The research revealed that most of the mobile crane operations executed in South Africa are still being planned/designed using outdated static 2D modelling methods.

Findings from the research revealed that, a firm's choice of modelling method is strongly influenced by their perceived usefulness towards a specific modelling method as well as the awareness of a firm regarding the applications and benefits of a specific technology type. This finding was most applicable to virtual modelling, where a strong positive correlation was observed between perceived usefulness (0.76) and awareness (0.8) to the adoption of virtual modelling.

Findings from the research revealed that firms utilizing advanced modelling methods such as virtual modelling, had a higher success rate with projects achieving their scheduling goals, safety goals, and customer satisfaction goals.

7.1 Research implications

This research helped to identify which factors affect the choice of modelling methods for lift planning and how these chosen methods affect the performance of projects executed by firms operating in the mobile crane lifting industry in South Africa. Adoption of innovation in mobile crane lift planning (i.e., virtual modelling) was identified as a key driver for project success and ultimately business competitiveness. From Table 7, the two most significant factors influencing firms in adopting virtual modelling was found to be Awareness and Perceived usefulness. It is therefore imperative that firms operating in the mobile crane lifting industry ensure that they invest in the adoption of innovative modelling methods for planning of mobile crane lifting operations.

Failure to adopt innovation in this field could have long term negative consequences which could negatively impact a firm's market share. As global trends are set to continue to shift to modularization, increased performance of optimized crane operations on site will become critical to both project and company success. Given these trends, firms who are resistant/slow to adopt innovations in lifting operations, will likely face reduced market share, or even extinction (as history has shown with many other industries such as for example, newspaper printing industries) in a rapidly occurring 4th industrial revolution.

7.2 Limitations and assumptions of this study

The assumptions of this study were:

Financial factors: It was assumed that local firms in the mobile crane industry would be reluctant to supply information regarding the financial aspects of current practices in lift planning as well as potential financial implications of the proposed methodologies for this research. Thus, the economic implications were not covered in this research.

Response: An assumption was made that responses to the questionnaires would be truthful and accurate to give an accurate view on current practices and challenges associated with planning of lifting operations within the local South African industry.

The limitations of this study were:

Sample size: The research was limited to the mobile crane-related industry in South Africa. Furthermore, it was limited to a population group comprising of predominantly designers and planners of lifting operations within this industry, which limited the study group.

Time frame: The study was limited by the fourteen-month time frame that was allocated to it, which limited the scope of study that could be covered.

Method of data collection: It was not practical for the researcher to physically access all relevant industry companies and personnel. Due to this limitation, data had to be collected using a survey-questionnaire method. This method of data collection also adds limitations on the research as factors such as low response rate can affect the validity of the research findings.

7.3 Recommendations

It is recommended that futures studies should focus on identifying the constraints within the South African mobile crane industry that hinders the upskilling and training of relevant staff members in firms, as internal skills and capabilities of a firm are critical factors for successful adoption of innovative modelling techniques. Furthermore, future research should investigate the factors preventing South African firms from adopting innovative modelling practices and how the findings from this research could be used by key decision makers to adopt their business strategies to benefit from the global emerging trends of off-site construction methods.

There is a further need to link this modelling method selection to a project management process, such as the phase-gate process. For projects where a significant amount of material handling and lifting activities will occur, a lifting specialist should ideally form part of the project team during the pre-construction phase of a project. During this phase, the lifting specialist must do proper pre-construction engineering activities to be able to assess the material handling and lifting requirements, to optimize the trade-offs between design, construction, and lifting activities.

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