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AHP BASED APPROACH FOR CRANE SELECTION OF BUILDING CONSTRUCTION IN SAUDI ARABIA: A CASE STUDY

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Abstract: Cranes are essential equipment used in the construction industry to hoist and place loads. The selection of the proper type of crane is challenging task to project management team. The challenge arises due to the involvement of many factors in the selection process. This paper presents a case study of the selection of the suitable crane in the construction of precast apartment buildings compound in Jubail City in KSA. The approach applied in the selection process is based on Analytic Hierarchy Process (AHP) technique which is capable of solving multi-criteria decision making (MCDM) problem. AHP is utilized to assess the significant influence of the identified main and sub criteria on the selection process. Both quantitative and qualitative criteria are considered in this study through a pairwise comparison. The identified crane alternatives in this study are tower crane, crawler mobile crane, and wheeled mobile cranes. Based on reviewing previous studies and meetings with local experts, 8 criteria of selection were identified which are load lifting frequency and capacity, structure height, project duration, purchase/renting cost, delivery, installation and disassembly, productivity, ground condition, and safety. The safety criteria has a sub-criterion including operator proficiency, wind, and visibility. The results obtained from the AHP showed that the best crane alternative of is the wheel mobile crane.

1 INTRODUCTION

The selection of the proper type of crane is a challenging task to the project management team. It involves many factors which can lead to inaccurate decisions resulting in delays, financial losses for the company or individual's investors or also unsafe job conditions. The development of commercial and industrial regions increases the need of using construction equipment including cranes. Many criteria are taken into consideration in order to select the proper type of cranes. In such case, it is essential to apply a proper method that is capable of solving the multi-criteria decision making (MCDM). This paper aims to present a case study of the selection of the suitable crane in the construction of precast apartment buildings compound in Jubail City in KSA. The approach applied in the selection process is based on Analytic Hierarchy Process (AHP) (Saaty and Vargas 1994) technique. AHP is utilized to assess the significant influence of the identified main and sub criteria on the selection process. Both quantitative and qualitative criteria are considered in this study through a pairwise comparison. In this study a limited number of experts are to be interviewed since this study is related to one unique precast project. In order to accomplish the objective of this paper include identifying the alternatives of cranes to be evaluated, identifying the criteria and sub-criteria affecting the selection process of cranes, evaluating the criteria and sub-criteria and alternatives based on AHP techniques, and analyzing and selecting the best crane alternative. Table 1 provides the main characteristics of the case project to fully understand the project and the case study.

Table 1: Project Characteristics

Item	Description
Project name	Fadhli Bachelor Camp(FBC)
Function	Residential compound buildings
Location	Jubail – Fadhli
Sub-structure type	Concrete raft foundation
Super-structure type	Concrete precast wall panels and hollow core slabs
No. of residential buildings	13 buildings
No. of floors	3 floors
Building height	11 m
Site area	840,000 m^2
One floor area	3850 m^2
Gross area	11550 m^2
Contraction price	SR 1,050,000,000

2 PREVIOUS STUDIES

The Analytic Hierarchy Process (AHP) is used for facilitating the selection process of the most appropriate alternative when multi-criteria are considered to select an alternative. The literature indicated that many research have applied the AHP in the construction industry. (Erdogan, Šaparauskas, and Turskis 2017) applied the AHP for the selection of the proper contractor for the construction of a swimming pool of a hotel. (Darko et al. 2018) conducted a review study of AHP application in construction management to improve understanding of the decision areas and decision problems that AHP could efficiently resolve. The study was conducted by reviewing 77 AHP-based papers published in eight selected peer-reviewed construction management journals from 2004 to 2014 to identify the popular AHP application areas and problems; and provide directions for future AHP application. The findings of the study revealed that risk management and sustainable construction were the most popular AHP application areas in construction. In addition, it was identified that reasons behind the wide adoption of AHP are that (1) it does not require large sample size, (2) it can achieve a high level of consistency and (3) it is easy to implement. The study indicated that some construction management areas have insufficient studies of applying AHP not limited to, quality management, knowledge management, planning and scheduling, pricing and bidding of construction operations.

As for equipment selection, (Temiz and Calis 2017) studied the proper selection of excavation machine by taking into account qualitative and quantitative criteria which included "*purchasing cost*", "*operating weight*", "*engine power*", "*hydraulic pump flow rate*", "*fuel consumption*", "*service conditions*", "*secondary market*", "*spare part conditions*" and "*comfort of operator*". Two methods were applied in the problem which are the AHP and the Preference Ranking Organization Method for Enrichment of Evaluation (PROMETHEE). The results indicated that both methods resulted in the same ranking for the selection of the excavation machine.

With regarding for the selection of cranes, the literature reveals that there are different factors affect the selection of the type of crane for a construction project. Many researches were conducted in order to optimize and visualize the selection of different types of cranes. (Shapira and Schexnayder 1999) performed a study on the decision making about the selection of the type and the model of cranes. A list of factors that affect the process of selection of mobile cranes was established based on previous studies. The interviewees were then carried out to assess the degree of influence on mobiles cranes selection for each factor. The results show that the top five factors affecting the selection of mobile crane as follow: lifting assignment, hook coverage, safety, structure height and project schedule. (Al-Hussein et al. 2006) proposed a selection model that integrates 3D visualization and simulation for the operations of the tower crane. Building and testing an integrated system for a new academic building at a Canadian University was considered by using the 3-D Studio MAX environment. A system database, consisting of three databases for tower crane specifications, site geometry data, and work packages data.

(Chen 2016) also conducted a study that offers an integrated crane planning system for construction, crane selection optimization and crane location optimization. The study developed models and algorithms which are consistent to integrate, interpret, and analyze the requirements for crane selection and crane placement in which affected by the primary factors. The primary factors affecting crane planning are captured and formulated into mathematical expressions. These factors include: crane coverage, work balance, material supply region connection, project time, site boundary, crane assembling and dismantling, crane rental cost, and relocation expenses. (Shapira and Simcha 2009) studied the factors influencing safety on construction sites resulting from tower cranes operations. The weights of safety factors were evaluated by using (AHP). The results of this study concluded that the top five factors influencing safety resulting from tower cranes operations are "*site-level safety management*", "*operator proficiency*", "*wind*", "*superintendent character*" and "*maintenance management crane*" and "*accessories*". (Dalalah, Al-Oqla, and Hayajneh 2010) studied the selection of cranes for the determination of the most suitable crane during construction by applying the AHP. The considered alternatives are derrick, mobile, and tower cranes. The criteria items that were considered are "*building design*", "*capability*", "*economy*", "*safety*", and "*sit condition*". The criteria were broken into further sub-criteria.

(SangHyeok Han et al. 2013) utilized an innovative selection matrix for cranes for establishing an optimization process for crane selection in construction. Three main categories were used in the matrix which are "*equipment and cost*", "*location and site*", and "*environmental impact*". The "*cost*", "*installation and disassembly*", "*maintenance and depreciation*", and "*additional safety features or technology*" are factors related to the equipment and cost category. The weather, availability, space, support system, and transportation were the considered factors associated with location and sit category. Energy, health, CO_2 emission, and neighbor impact are factors related to the environmental impact category. Moreover, there were sub-factors associated with the mentioned factors. More than 40 factors were considered for the purpose of reducing time and improving safety. The categories and factors were according to a questionnaire feedback.

(Marzouk and Abubakr 2016) developed a framework utilizing building information modeling (BIM) to plan for tower cranes in the construction industry. The analytical hierarchy process (AHP) was used to develop a model which is related to the decision making for the selection of the type of tower crane. The identified alternatives were the flat top tower crane, hammer head tower crane, luffing jib tower crane, and self-erecting tower crane. For the identification of the criteria having major impacts on the selection of tower cranes, a list of factors has been collected from literature and from experts. The classification of the criteria was based on two levels. The first level includes four criteria which are "*the specifications of tower cranes*", "*site conditions*", "*project characteristics*", and "*operating cost for cranes*". The criteria were broken down into another level forming the second level. The specifications of tower cranes were broken into maximum fee standing height, tower crane capacity, tower crane jib length. The site conditions were broken into assembly and dismantling, site obstructions, site topography, and site location. The project characteristics were broken into high rise, administrative, and industrial buildings. The operating costs were broken into cost of delivery assembly and dismantling, renting cost, and productivity. (Sanghyeok Han et al. 2018) proposed an integrated model which can help decision makers to design, simulate, and also evaluate potential crane operations according to a feasible type of crane. This model considers the equipment, cost, site and environmental aspects. A matrix for selecting cranes was an element of the methodology and was used to evaluate cranes and give scores by considering different factors of each feasible crane with respect the project criteria and constraints. The considered criteria included "*crane availability*", "*site accessibility*", "*installation and disassembly*", and "*project condition*". Factors considered in the selection matrix were "*cost*", "*installation and disassembly*", "*maintenance and depreciations*", "*additional safety features and technology*", "*weather*", "*availability*", "*space*", "*ground preparations*", "*transportation", "energy*", "*health*", "CO_2 *emissions*" and "*neighbour impact*" and there are sub-factors for every factor.

According to the reviewed studies, the application of AHP was an efficient tool to solve the equipment selection in the construction industry. The objective of this paper is to apply the AHP for the section of cranes for a construction of the precast apartment buildings compound in Jubail City in the Eastern region of Saudi Arabia.

3 PROPOSED APPROACH

A set of sequential phases were considered as an approach in order to achieve the objectives of this study which included the following:

- Conducting meetings with local experts working in the field of the construction of precast buildings in order to identify the most common crane alternatives used in precast construction in Saudi Arabia.
- Conducting a comprehensive review of the previous studies in order to identify the criteria that affect the selection of cranes in construction projects.
- Conducting interviews with experts working in the area of the construction of precast apartment buildings in the Eastern Province of Saudi Arabia in order to identify the criteria and sub-criteria of crane selection that are applicable to their field.
- Establishing the structural hierarchy containing the identified alternatives of cranes and also containing the criteria and sub-criteria affecting the selection of cranes. Accordingly, the pairwise comparison matrices can be established according to the AHP techniques.
- Evaluating the importance of the criteria, sub-criteria and alternatives by decision makers according to AHP techniques.
- Calculating the total scores and selecting the best alternative based on AHP analysis.
- Drawing conclusion and recommendations according to the obtained scores of the alternatives.

4 DATA COLLECTION AND ANALYSIS

4.1 Identification of criteria and sub-criadera affecting crane selection

Based on reviewing previous studies, conducting personal interviews with local experts and the project characteristics, eight of criteria of selection were identified which are the following:

- Load lifting frequency and capacity: This criterion affects the selection process since it is related to the maximum load to be lifted by the crane and how many times this load will be repeated. Therefore, if the maximum load to be lifted is relatively low, the selected crane alternative should not have an extremely high capacity.
- Structure height: This criterion affects the selection process since medium to high structures require tower cranes whereas the use of other crane alternatives is limited in such projects.
- Project duration: This criterion affect the selection process since relatively short project duration and activities require the use of mobile cranes.
- Purchase/renting cost: This criterion affects the selection process since it is related to the aforementioned criterion, project duration. Decision makers may consider renting the crane instead of purchasing it for short project durations.
- Delivery, installation, and disassembly: This criterion affects the selection process since some types of mobile cranes are delivered to the site as a one unit without the need for transportation and erection arrangements for such alternative.
- Productivity: This criterion affects the selection process since it is related to the aforementioned criterion, project duration. The selection of a crane alternative having a relatively low a production rate may result in a schedule overrun for the project.
- Ground condition: This criterion affects the selection process since it is related to soil condition. The soils condition has an effect of whether to select the wheeled mobile crane or crawler mobile crane.

- Safety: The safety criterion has a sub-criteria including operator proficiency, wind, and visibility

According to the identified criteria and sub-criteria, the structural hierarchy of the decision-making problem was developed as shown in Figure 1.

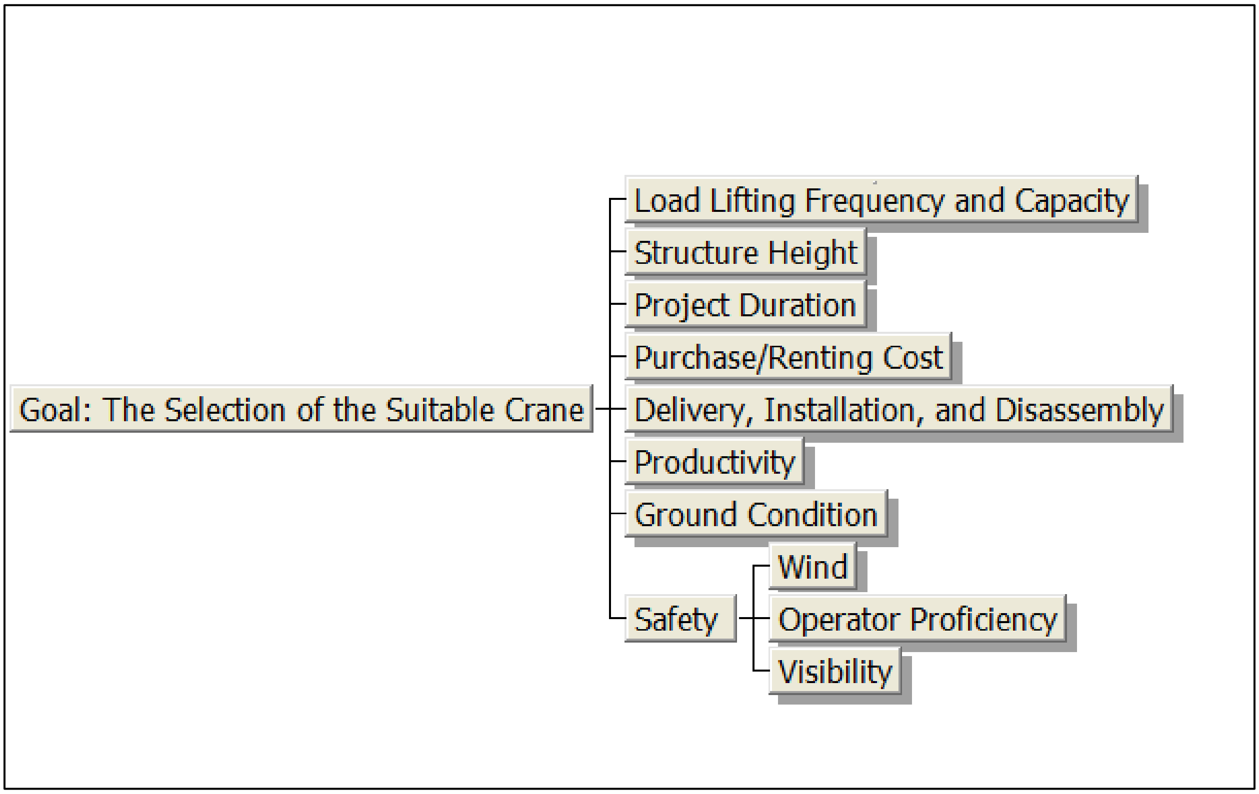

Figure 1: Structural Hierarchy

4.2 Identification of crane alternatives

Meetings with the representatives of local crane companies and local project managers were carried out to determine the most crane alternatives used for precast building construction in Saudi Arabia. Accordingly, the identified crane alternatives in this study are the tower crane, crawler mobile crane, and wheeled mobile cranes.

4.3 Evaluation of pairwise comparison matrices

The pairwise comparison matrices were developed according to the AHP method and then the matrix distributed to four different experts working in the construction firm. The four experts were asked to conduct the evaluation according to the AHP techniques. After the evaluation of the pairwise comparison matrices was collected from the experts, the AHP approach was applied to determine the weight of each alternative with respect to each respondent using Expert Choice software. Tables 2 through 4 show an example of the pairwise comparison matrices for the first respondent. All of the pairwise comparison matrices were consistent since they have a consistency ratio (CR) that is less than 0.1.

Table 2: Evaluation of the pairwise comparison matrix between different criteria (respondent No.1)

Criteria	Load Lifting Frequency and Capacity	Structure Height	Project Duration	Purchase/Renting Cost	Delivery, Installation and disassembly	Productivity	Ground Condition	Safety
Load Lifting Frequency and Capacity	1	5	3	1	1\2	2	4	1
Structure Height	1\5	1	1\5	1\6	1\4	1\5	1\2	1\5
Project Duration	1\3	5	1	1\2	2	1	3	1\2
Purchase/Renting Cost	1	6	2	1	2	1	5	1\2
Delivery, Installation and disassembly	2	4	1\2	1\2	1	1\3	4	1\2
Productivity	1\2	5	1	1	3	1	5	1
Ground Condition	1\4	2	1\3	5	1\4	1\5	1	1\4
Safety	1	5	2	2	2	1	4	1
CR=0.06								

Table 3: Evaluation of the pairwise comparison matrix between different sub-criteria of safety (respondent No.1)

Sub-criteria	Operator Proficiency	Wind	Operator Visibility
Operator Proficiency	1	1\2	2
Wind	2	1	2
Operator Visibility	1\2	1\2	1
CR=0.05			

Table 4: Evaluation of the pairwise comparison matrices between different crane alternatives in accordance to all criteria and sub-criteria (respondent No.1)

Load Lifting Frequency and Capacity	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**	**Delivery, Installation and disassembly**	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**
Tower Crane	1	1\5	1\4	**Tower Crane**	1	1\8	1\4
Wheel Mobile Crane	5	1	3	**Wheel Mobile Crane**	8	1	3
Crawler Mobile Crane	4	1\3	1	**Crawler Mobile Crane**	4	1\3	1
	CR=0.08				**CR=0.02**		
Structure Height	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**	**Productivity**	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**
Tower Crane	1	1\5	1\3	**Tower Crane**	1	4	3
Wheel Mobile Crane	5	1	2	**Wheel Mobile Crane**	1\4	1	1\2
Crawler Mobile Crane	3	2	1	**Crawler Mobile Crane**	1\3	2	1
	CR=0.00				**CR=0.02**		
Project Duration	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**	**Ground Condition**	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**
Tower Crane	1	3	2	**Tower Crane**	1	3	2
Wheel Mobile Crane	1\3	1	1	**Wheel Mobile Crane**	1\3	1	1\3
Crawler Mobile Crane	1\2	1	1	**Crawler Mobile Crane**	1\2	3	1
	CR=0.02				**CR = 0.05**		
Purchase/Renting Cost	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**	**Operator Proficiency**	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**
Tower Crane	1	1\3	1\2	**Tower Crane**	1	1\2	1\3
Wheel Mobile Crane	3	1	3	**Wheel Mobile Crane**	2	1	1\3
Crawler Mobile Crane	2	1\3	1	**Crawler Mobile Crane**	3	3	1
	CR=0.05				CR=0.05		
Operator Visibility	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**	**Wind**	**Tower Crane**	**Wheel Mobile Crane**	**Crawler Mobile Crane**

Tower Crane	1	2	2	**Tower Crane**	1	1\2	1\3
Wheel Mobile Crane	1\2	1	1	**Wheel Mobile Crane**	2	1	1\3
Crawler Mobile Crane	1\2	1	1	**Crawler Mobile Crane**	3	3	1
CR=0.00				**CR=0.05**			

5 RESULTS AND DISCUSSION

As presented in Figures 2, the score of each alternative according to the first respondent.

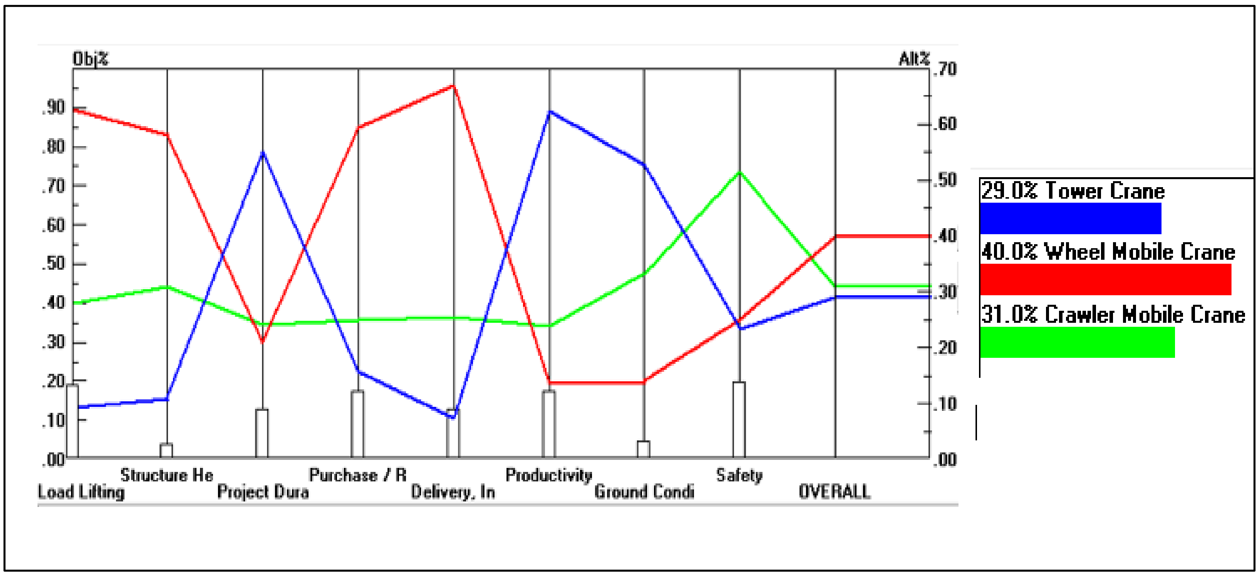

Figure 2: Weight of alternatives according to respondent No.1

In order to rank the alternatives and select the best alternative, the average respondents' score of each alternative was calculated using two different scenarios. The first scenario is calculating the weight of the alternatives without considering the years of experience of respondents. The second scenario is considering the experience of the respondents. To study the effect of years of experience on scoring the alternatives, a weighting for each respondent experience was given. Five points were given for 20 years of experience, four points for 16 years of experience, three points for 12 years of experience, two points for 8 years of experience, and one point for 4 years of experience. Table 5 shows the results obtained from the first scenario that is related to ranking alternatives without considering years of experience. Table 6 provides the results obtained after considering the years of experience.

Table 5: Results without considering the experience of the respondents

Respondent No.	Tower Crane (Score)	Wheel Mobile Crane (Score)	Crawler Mobile Crane (Score)
1	29.00	40.00	31.00
2	17.60	47.20	35.20
3	15.00	53.20	31.80
4	21.70	47.90	30.40
Average	20.83	47.08	32.10

Percentage %			
Ranking	3	1	2

Table 6: Results with considering the experience of the respondents

Respondent No.	Years of experience	Weighting of respondent experience	Tower Crane (Score)	Wheel Mobile Crane (Score)	Crawler Mobile Crane (Score)
1	16	4.00	116.00	160.00	124.00
2	14	3.50	61.60	165.20	123.20
3	14	3.50	52.50	186.20	111.30
4	4	1.00	21.70	47.90	30.40
Average Percentage %			62.95	139.83	97.23
Ranking			3	1	2

According to the previous results, it is clear that the best crane alternative to be selected is the wheel mobile crane. Interviews were conducted with experts in order to justify the reasons behind the selection of wheel mobile crane. The clarification was based on each criterion as follow:

- Load lifting frequency and capacity: the wheel mobile crane was selected since the construction of the precast building does not require extremely heavy structural elements (not more than 11 ton). Moreover, the maximum distance to be covered by the mobile crane in the building is 20 m.
- Structure height: according to the structure height, either a wheel mobile crane or a crawler mobile crane can be selected since the height of the building does not exceed 11 m height. Tower cranes are usually used for medium to high-rise buildings.
- Project duration: the wheel mobile crane was selected since the project requires relatively short durations, 6 to 9 months, for activities that require cranes.
- Purchase/renting cost: the experts considered the renting cost instead of the purchase cost in this project due the nature of project duration. The experts indicated that even the renting cost of tower cranes is lower than wheeled mobile cranes, the total cost of using tower crane will increase dramatically due to different aspects that should be considered when using tower crane. These aspects include the concrete foundation costs, hiring a mobile crane for installation and disassembly of the tower crane, and the installation and disassembly duration for the tower crane that consumes 1 to 2 weeks which will have a total delay of 3 months for the 13 buildings and that result in additional costs to the project.
- Delivery, installation, and disassembly: the delivery of a wheel mobile crane to the site is usually a one unit which is considered to be simpler compared to the tower crane. Moreover, as mentioned previously, the disassembly of tower cranes requires the assistant of a wheel mobile crane.
- Productivity: the experts could not differentiate the productivity accurately between the tower crane and mobile crane. The mobile crane was selected by experts due to its ability to change its position for maneuvering and reaching points that tower cranes could not reach due to their fixed position.
- Ground condition: the experts indicated that the wheeled mobile crane can be easily considered in this project due to the proper preparation of ground by compacting it to sustain crane loads.
- Safety: the safety had almost the same effect on the process of selection for the three alternatives.

6 CONCLUSION

This study aims to present a case study of the selection of the suitable crane in the construction of precast apartment buildings compound in Jubail City in KSA. The approach applied in the selection process is based on Analytic Hierarchy Process (AHP) technique which is capable of solving multi-criteria decision making (MCDM) problem. AHP is utilized to assess the significant influence of the identified main and sub criteria on the selection process. The identified crane alternatives in this study are tower crane, crawler mobile crane, and wheeled mobile cranes. Based on reviewing previous studies and meetings with local experts, 8 criteria of selection were identified which are load lifting frequency and capacity, structure height, project duration, purchase/renting cost, delivery, installation and disassembly, productivity, ground condition, and safety. The safety has a sub-criterion including operator proficiency, wind, and visibility. The results obtained from the AHP showed that the best crane alternative of crane to be selected was the wheel mobile crane. The evaluation of the three alternatives by respondents is considered to be specific for the project considered in the study. The application of AHP in crane selection can provide project management team with powerful and yet easy to use technique in the selection process that involves quantitative and qualitative criteria.

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