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Examination of Job-site Layout Approaches and Their Impact on Construction Job-site Productivity

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Abstract

In all forms of construction project delivery, job-site layout is routinely developed and designed after bid award and prior to the contractors' receipt of the notice to proceed or letter of commencement. Job-site layout decisions are made to locate temporary offices, sanitary facilities, worker rest areas, crane locations, storage and workshop areas, access points and access roads, utilities and other critical features. These jobsite design decisions affect the operational capabilities of the site and have a direct influence on both the costs and schedule through productivity. This paper will examine the various approaches utilized in practice and proposed through research for jobsite layout design and site optimization. Factors and variables considered in the identified approaches are discussed and evaluated with respect to the impact on jobsite productivity and successful contract delivery. Important factors for job-site layout are further explored through a survey of working professionals within the United Arab Emirates (UAE). Survey results are summarized, examined and discussed in relation to the variables and critical parameters identified and their effect on job-site performance and contract success. The paper concludes with a discussion of future directions for job-site benefits.

Keywords: construction; jobsite; operations; productivity

1. Introduction

Construction is a unique project-oriented manufacturing industry where prototype facilities are delivered by general contractors according to owners' requirements. These requirements are articulated in the plans, specifications and other contract documents produced by design professionals, which form the basis for bidding and tendering. Project delivery commences after the tendering process is complete and the successful general contractor is charged with construction delivery at the prescribed quality within the contractual time and cost constraints. Delivery of the project must be undertaken within unpredictable environmental conditions while managing the incorporation and delivery of a wide diversity of materials and equipment and significant capital expenditures. Efforts are further compounded by diverse involvement and interests of stakeholders, which further complicates successful project delivery in the industry.

With significant risks and complexity, the industry has developed and instantiated well-defined processes and procedures to guide the process of construction project delivery for mutual benefit of all parties involved. The industry is truly driven by the well-known motto that 'failure is not an option,' and success stories abound throughout the world. Today, the construction industry has pressed through the challenges and complexities to become one of the most satisfying and rewarding environments for engineering practice and an essential metric for gauging economic vitality.

While the construction industry has and continues to be successful in the physical facilities to support societies, it has faltered when considering total and partial (i.e. labor or equipment) productivities. The construction industry, unlike all other comparable economic sectors, has stagnant or even negative productivity growth over the last

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several decades. This means that less output is being realized for every unit of input. Owners are getting less for their money even while technologic increases and material advances transform the industry. Contractor profit margins decrease, engineers experience less design opportunity, construction disputes increase, labor rates are pressured, and bankruptcies may result. The industry has a productivity problem and positive change is required to make a difference.

When examining productivity, there are numerous avenues that can be pursued and numerous parties that can be focused upon. This includes the owner's selection of project delivery systems, designer implementation of BIM tools to minimize errors and omissions, and regulators incentivizing innovation in project delivery. Contractors can ensure that their productivities are realized and profitability ensured through proactive site-planning, implementation of lean construction principles, and innumerable other areas of consideration which influence the on-site project delivery.

The purpose of this study is to focus on elements which are under direct control of the general contractor. The research performed by Naoum in the United Kingdom [1] identified well over 100 research journal articles covering construction labor productivity. Through this work, a survey of practitioners evaluated 46 factors covering "preconstruction, activities during construction, management-related factors, organization factors and motivational and social factors," which directly impact construction labor productivity. This included process flow variables, such as overcrowding on the site, ineffective site planning and inefficient site layouts, which are the focus of this examination.

Job-site layout and site layout planning is imperative and impacts almost all operations required to deliver the facility. The site layout design process must take into account the number of temporary facilities needed for construction, the size and shape of the site as well as the construction program [2]. Temporary facilities may include but are not limited to: temporary offices, sanitary facilities, crane locations, storage areas for materials and equipment, workshops, access roads, rest areas, safety and health facilities, and security features. When decisions are made regarding the site layout, they can be difficult or costly to change as the project progresses; therefore, developing an effective site layout plan is paramount for efficient construction and ensuring productivity. With a good and efficient job-site layout excess movement of material within the site is reduced, labor productivity increased, costs and durations reduced, worker safety improved and construction quality positively impacted.

There are various approaches can be employed to develop the job-site layout design and to enhance site optimization. Each approach has to take into consideration factors and variables that will lead to job site productivity as well as successful contract delivery. This paper provides a survey of approaches identified through the literature and explores important factors for job site layout design. The importance of the factors identified were further explored through a survey implemented in the United Arab Emirates (UAE) among working professionals. Survey results are contrasted with tasks and priorities identified in the literature where possible.

2. Laying out the job-site: Approaches for design of the site

Job-site layout, as discussed in the introduction, is paramount for construction project success. The site layout must effectively address many concurrent considerations, including:

- Space provided to function on the job site and constraints on space utilizations, such as set-backs.
- Access to the job site for vehicles and as access to work areas within the job site
- Temporary facilities required including temporary offices, storage facilities, sanitary facilities and utilities
- Material handling and movement and associated worker and public safety/security measures.

There are many techniques available for utilization in job site layout development and a literature review was performed to identify current state-of-the-art and state-of-the-practice. A wide diversity of practices were identified including heuristic, rule-of-thumb approaches, optimization, and artificial-intelligence approaches. A detailed overview of research performed in this area previously has been summarized by Sadeghpour and Andayesh [3], whom surveyed nearly 100 technical journal articles from 1987 through 2015. A wide variety of approaches were identified, including knowledge based approaches (inclusive of heuristics), mathematical programming approaches (including linear and non-linear optimization), and artificial intelligence approaches (including neural networks, genetic algorithms, ant or bee-colony and swarm approaches). The vast majority of approaches focused on static site-layout development and all approaches included productivity and spatial proximity goals and objectives.

Three different approaches were identified in terms of the site-space: predetermined, grid-system and continuous space models. Objects were assigned in the space models using either a dimensionless representation, approximate dimensions or actual dimensions. For the knowledge based, heuristic and mathematical optimization based approaches, the sites were, in general, considered as continual spaces with object dimensions most frequently based on approximate dimensions in lieu of actual dimensions. For the mathematical optimization approaches,

there will be an optimal solution and all other alternatives are sub-optimal in nature. The heuristic approaches produced sub-optimal solutions by definition, which are generally acceptable for implementation in practice.

Regardless of the approaches taken, Sadeghpour and Andayesh determined that decision variables could be categorized through definitions of six alternative constructs. These include: Site space approaches, How the objects were defined (boundaries, typologies and mobility), Time considerations (static, dynamic, phased), Goals and objectives, Approaches for planning/optimization, and Technique employed (genetic algorithm, neural net, etc.) Object typology included, in general and not prioritized order, are as follows:

- Temporary Facilities
- Construction Equipment
- Materials Storage Areas
- Workplaces
- Access Roads
- Site Objects

Heuristic approaches were examined in further detail by Ray and Raju [4] including three alternative approaches to assigning positions to objects on the job-site: a rule-of-thumb approach, an ad-hoc approach and a first-come/first-serve approach. The rule-of thumb approach was based entirely on judgment whereas the ad-hoc approach was rule based and incorporated more specific design criteria to suit specific needs of activities on a particular site. The third approach identified and placed objects on site based in the order in which the objects were scheduled and is termed as the first come - first served approach. Each of three approaches have advantages and disadvantages. Using a rule-of-thumb approach, cost-effective layouts could be rapidly produced while the ad-hoc and first-come approaches were useful in overcoming immediate task-related problems. However the approaches ultimately led to confusion and/or significant inefficiencies at some point during the construction. For each, additional considerations are required to finalize the layout for implementation and the approaches should thus be expanded, refined or replaced.

Alternative approaches discussed focus on the process and less on the procedure or algorithm. One such approach identified in the literature is termed as construction site utilization planning [5]. Through this approach, design decisions are facilitated through team-based decision making process and plans finalized collectively based on consensus. Proof-of-concept was articulated based on locating temporary facilities and considering when they would be required. An alternative philosophical approach identified [6] focused on a subcontracting where job site layouts decisions were based on the operational needs of independently operating subcontractors assigned to specific task. The job site layout is developed to meet the subcontractor requirements while minimizing subcontractor conflict due to space allocation, which could decrease productivity of job sites, introduce and exasperate delays and reduced employee morale in past projects [5]. Site layout approaches which take into account health and safety factors as the layout design is developed were also identified [7].

3. Evaluating current practices: a survey of working professionals

In evaluating the different approaches for job-site layout, there were many different variables and considerations employed. This included the location of entrances, requirements for temporary facilities, occupational safety and health measures, labor employed and other factors. All of these factors effect site operations and by default affect the productivity of the job-site. To clarify and to identify which factors are pertinent for productivity, a survey was developed and implemented among the construction and civil engineering community in the United Arab Emirates. Basic demographic information was collected and respondent were asked questions to evaluate whom should be responsible for developing a job-site layout. Importance of various factors in designing a productive job-site layout were evaluated using a 5-point Likert scale. The following variables were evaluated:

- Access Points: Entrance and exit locations for vehicles and personnel
- Cranes/Lifts/Support Equipment: Tower crane locations, personnel hoists/lifts, generators and temporary power
- Storage/Workshop Areas: Material storage locations, workshop areas, tool-sheds, equipment storage areas
- Worker Support Facilities: WC and toilet facilities, worker rest areas, food and food service locations
- Site Offices: General Contractor, subcontractors, owners/consultants

The survey was distributed electronically via e-mail and social media. A total of 55 responses were obtained with relatively equal participation from owners, engineers, consultants, contractors, regulators. Results were examined to identify any counter-intuitive patterns based on the ranking using average Likert response data.

4. Survey responses: Responsibility for site-planning and layout design

The survey asked participants whom had the responsibility for job-site layout: the owner, consultant, designer, general contractor, etc. This question was important to get a feel for the perspective of the respondent with respect to the clauses and provisions employed for construction. The majority of respondents felt that the task should be performed by the general contractor (39%), the consultant (30%) or the designer (26%). When considering the respondents' profession, there was little variation between engineers and construction professionals whose results generally reflected the overall numbers. Architects, however, unanimously, felt that the job-site layout should be performed by the general contractor.

Site design responsibility was also evaluated by employer type, which indicated differences between the perspectives of those working for owners versus those working for contractor or consulting engineers or designers. The majority of those employed by contractors or subcontractors (56%) felt that general contractors were responsible for the site design while 44% felt that the responsibility lied with the consultant or designer. A similar response was identified by respondents working for consultants and designers with 53% indicating that the general contractor was responsible for the job-site layout design. Those working for project owners felt that this was the responsibility of consultants (55% of respondents). This is a logical response since consultants act as the owner 'agents' and is the owner's principal point of contact for construction.

Determination of whom actually is responsible for job-site layout requires examination of the specific contract documents employed. Many of the provision in Dubai are based on FIDIC which states that, "the employer shall give the Contractor right of access to, *and possession of*, all parts of the Site," in a timely fashion without impeding or causing delay to the contractor. FIDIC further specifies that the contractor, "shall design (to the extent specified in the Contract), execute and complete the Works in accordance with the Contract," [8] and is responsible to provide, "all things and services, whether of a temporary or permanent nature, required," for completion. Furthermore, the contractor and "shall be responsible for the adequacy, stability and safety of all site operations and of all methods of construction, [e]xcept to the extent specified in the Contract." [8] Thus, FIDIC, as with most general conditions, assigns responsibility of the site to the Contractor. This further implies conveyance of the authority to design and structure the site for effective and efficient project delivery to the general contractor, which may be considered as the default position unless overridden by supplementary conditions or contractual provisions. Survey respondents did not reflect this default position so it may be presumed that contractual forms employed in practice override or, more likely, integrate the consultant and engineer into the site layout approval process.

5. Survey responses: Importance of variables in the site-planning and design process

Regarding variables considered and their relative importance for job-site layout design, results of the surveys are summarized in Tables 1 and 2. In Table 1, rankings are summarized by profession for engineers and construction professionals and whether the respondent had previous experience designing a job-site layout. In Table 2, results are summarized by the employer. Both tables compare results to the rankings developed from all respondents. Where ranks deviate by three or more positions, the rankings are shown in bold-italicized text in shaded cells to highlight differences in preferences. In general, priorities shown are reflective of element criticality with cranes, vehicular access points and material storage areas receiving the highest rankings. Owner/consultant and subcontractor site offices receive the lowest priorities when considering overall rankings.

Considering the results by the respondent's background and profession, those whom identified as engineers, irrespective of employers or direct involvement in construction, emphasized increased importance for food/food service facilities for the workers and toolsheds. Engineers de-emphasized the location of personnel hoists and lifts. Those whom identified as construction professionals increased emphasis on both the workshop areas and the equipment storage areas. Of interest is the differing opinions of those whom have previous experience. Here, respondents with previous experience significantly increased the importance of locating generators and temporary power facilities and general contractor work site offices. The location of power and generators was deemphasized by those without experience while equipment storage areas received increased priority.

Results are summarized in Table 2 by the employer. Employees of general contractors emphasize the equipment storage areas but de-emphasize the entrances and exits for personnel. Those working for owners, on the other hand, significantly increase the importance of the entrances and exits for personnel ranking this measure nearly of equal importance to the entrances and exits for vehicles, tower cranes and material storage locations. Regulators and consultants both deemphasize the importance of material storage areas and express differing opinions on worker rest-areas. Consultants ranked this as the lowest variable while regulators significantly emphasized its importance.

Table 5: Ranking of Variables by Profession and Experience with Site Layout Design

Variables	Ranking	By Profession		Previous Experience	
	All Respondents	Engineers	Construction	Yes	No
Tower crane locations	1	1	1	1	1
The entrance and exit locations for vehicles	2	2	2	2	2
Material storage locations	3	5	2	5	3
The entrance and exit locations for personnel	4	3	6	4	4
Personnel hoists and lifts	5	***9***	5	7	5
Generators and temporary power	6	4	8	***3***	***10***
Workshop areas	7	5	***4***	9	6
WC/Toilet Facilities	8	7	8	7	8
General contractor site offices	9	7	8	***5***	11
Worker rest areas	10	12	11	11	8
Equipment storage areas	11	13	***7***	***14***	***6***
Food and food service locations	12	***9***	14	13	12
Toolsheds	12	***9***	13	10	13
Owner/consultant site offices	14	15	12	12	15
Subcontractor site offices	15	14	15	15	13

Table 6: Ranking of Variables by Employer

Variables	Ranking	Employer			
	All Respondents	G/C or Sub	Owner	Consultants / Designers	Regulators
Tower crane locations	1	2	1	1	2
The entrance and exit locations for vehicles	2	3	3	2	1
Material storage locations	3	1	4	***6***	***11***
The entrance and exit locations for personnel	4	***9***	***1***	4	3
Personnel hoists and lifts	5	4	***10***	4	6
Generators and temporary power	6	5	4	7	7
Workshop areas	7	5	6	7	8
WC/Toilet Facilities	8	9	6	10	4
General contractor site offices	9	7	12	***3***	11
Worker rest areas	10	9	6	***15***	***4***
Equipment storage areas	11	***7***	***6***	12	9
Food and food service locations	12	14	12	11	9
Toolsheds	12	12	10	12	14
Owner/consultant site offices	14	15	12	***9***	14
Subcontractor site offices	15	13	15	14	13

With the results of this survey, generalizations can be made as to the importance of various elements. The general trends and rankings are logical and make sense and where there are deviations, logical explanations can be seen. Looking at the average importance and ranking of the categories (i.e. access points, cranes/lifts/support equip, storage/workshops, worker support and offices) is a useful way to generalize the data. This is shown in Table 3. In general, the trends are consistent. Those working for G/C's and subcontractors emphasize cranes/lifts/support equipment over access points, which has the second priority. Consultants and designers place increase emphasis on office locations, which directly affect their activities. Regulators have increased emphasis on worker support variables, which demonstrate care and concern for the welfare of the workforce, which is to be expected.

Table 7: Ranks by Categories

	Table 1			Table 2			
RANKS	All Respondents	Profession: Engineers & Constructors	Experienced & Non-experienced	G/C or Sub	Owner	Consultants / Designers	Regulators
Access Points	1	1	1	2	1	1	1
Cranes/Lifts/Support Equip	2	2	2	1	2	2	2
Offices	5	5	5	5	5	3	5
Storage/Workshops	3	3	3	3	3	4	4
Worker Support	4	4	4	4	4	5	3

6. Summary and conclusion

As discussed, the construction industry has a productivity problem and there are many different areas where significant contributions can be made to impact and drive significant change. For the general contractor, one area of paramount interest is the relationship between the job-site layout and construction productivity. There are many different techniques that have been developed and explored throughout the last several decades to provide decision support to facilitate efficient and effective job-site layout design. Approaches include heuristic and knowledge-based techniques, mathematical optimization and resource assignment techniques and artificial intelligence. Techniques for managing collaborative teams to drive job-site layouts through consensus decision making have also been proposed and were discussed herein. Most approaches demonstrated proof of concept and provide consideration of various constructs at different levels of detail. This includes consideration of temporary facilities, construction equipment, storage areas, workspaces, access roads and site objects. To determine which specific elements practitioners in the UAE prioritize in terms of site layout design, a survey was developed and implemented. Results allowed specific consideration of differences in variables based on profession, whether the respondent had previous experience in site layout design, and the respondents' employer. It was seen that the most important priorities are the tower-crane location, vehicular access points, and material storage locations. The priority of worker support variables, such as rest areas, versus office locations varied based on the perspective of the respondent. Results enable re-examination of prioritization of job-site element given the variety of alternative approaches proposed.

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