Culture of Using Mobile Cranes for Building Construction

By Aviad Shapira,[1] Member, ASCE, and Jay D. Glascock[2]

Abstract: While tower cranes traditionally are identified with high-rise, congested urban building construction, and mobile cranes primarily are associated with heavy civil and infrastructure construction, there exists a vast population of building projects where both are feasible. The question, then, is: why are different crane types used under similar project conditions in different geographic areas (e.g., tower cranes in Europe, mobile cranes in the United States)? This paper examines the culture of using mobile cranes for building construction, as observed in the southwestern United States. Project-specific and environmental characteristics are identified, classified, and described, while comparatively relating to tower crane practice. The role of non-project-specific factors (such as planning culture, operating style, employment patterns, and market organization) is emphasized in shaping the mobile crane culture. A rather homogeneous population of projects with distinct features, such as short construction duration, spacious sites, and supportive terrain, creates the grounds for this culture's evolution. Understanding the relationships between and within project and environmental characteristics is vital for a construction market that is becoming global and for a fresh examination of traditional equipment selection practices.

INTRODUCTION

For years now cranes of numerous types have been dominating the construction-site scene as the central lifting equipment. Their division as to different site conditions, though, is not haphazard: The tower crane, "a city child" (Shapiro et al. 1991), traditionally is identified with high-rise, congested urban building construction; mobile cranes, "born in open spaces," primarily are associated with heavy civil and infrastructure construction, where they often are used—in addition to lifting—for various other tasks (e.g., excavating, pile driving, concrete demolition). However, in between these two classes of construction, there exists a vast population of construction projects, and mainly buildings—public, commercial, industrial, and residential—where both tower and mobile cranes constitute feasible and practical solutions. It might have been expected that under similar project conditions, and pending cost comparison in each particular case, the solution would be the same (i.e., either tower or mobile cranes). Yet, observers of the European scene, where tower cranes are also seen next to low-rise buildings on spacious sites, may wonder why in the United States, under very similar conditions, mobile cranes are the rule. The opposite is also true: The American practitioner, normally using mobile cranes to solve lifting issues even for midrise buildings on constricted sites, may be astonished to see in rural Europe tower cranes next to small one-story houses, and even on road construction, landscape development, and utility projects.

Thus, it could be maintained that indeed there is a culture of using this or that type of crane, a culture whose roots probably exceed purely rational boundaries, and whose effect apparently is stronger than that of plain feasibility and cost analyses. Furthermore, this culture most likely provides the basis for any economical considerations involved in equipment selection and operation.

The objective of the current study was to examine the culture of using mobile cranes for building construction, while concentrating exclusively on projects suitable—as to structure and site conditions—for using both tower and mobile cranes. First, the present paper examines the characteristics of the projects themselves, not so much to discover unknown territory as to identify the degree of project homogeneity, a fertile soil for the evolution of any culture. But the paper's main focus is the environmental rather than project characteristics, that is, those that allow an understanding of the growth of a mobile crane culture under the given set of building project characteristics.

The projects and their environment were studied while comparatively relating to the "counter" culture, that of tower crane practice. In a way, characterizing the mobile crane practice using a given typical population of projects also provides an explanation as to why mobile cranes were selected over tower cranes in the first place as these projects' main lifting equipment. At the same time, it must be understood that identifying the reasons for each selection does not imply that the writers judge it a "good" (i.e., rational) selection. Quite often the opposite is true: Beyond providing a better understanding of the interrelationships between practical decision making (on equipment selection and operation) and culture-based factors, identifying the mobile crane culture's characteristics makes it possible to isolate likely changes in the way equipment selection and operation should be addressed. This has become increasingly important in recent years, as more construction companies cross more geographic—and cultural—borders, and as the traditionally local construction markets become more global.

Mobile and Tower Cranes

Crane terminology, in the technical and engineering literature, commercial publications, and practitioners' language, is not always uniform. For example, what is always referred to as a "tower crane" in Europe might be called a "European-type tower crane" in the United States to distinguish it from a mobile crane's tower assembly. Within the large mobile and tower crane families, different names are often used interchangeably for the same crane configuration. To avoid confusion, Fig. 1 presents silhouettes of the main construction crane types, along with the terms used in the present study and paper.

Mobile cranes service building construction sites in one of two capacities: either as the main (or even sole) lifting equipment, staying on site for as long as their services are needed throughout the full construction duration; or as auxiliary equipment. In the latter capacity they are normally seen on sites serviced primarily by tower cranes, where the (usually large) mobile crane provides short-term lifting services that

[1]Sr. Lect., Dept. of Civ. Engrg., Technion, Haifa 32000, Israel; formerly, Visiting Assoc. Prof., Dept. of Civ. Engrg., Univ. of New Mexico, Albuquerque, NM.

[2]Chief, Maint. Engrg. Element, USAF, Kirtland AFB, NM 87117; formerly, Grad. Student, Dept. of Civ. Engrg., Univ. of New Mexico, Albuquerque, NM.

Note. Discussion open until May 1, 1997. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on July 13, 1995. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 122, No. 4, December, 1996. ©ASCE, ISSN 0733-9364/96/0004-0298–0307/$4.00 + $.50 per page. Paper No. 11166.

J. Constr. Eng. Manage., 1996, 122(4): 298-307

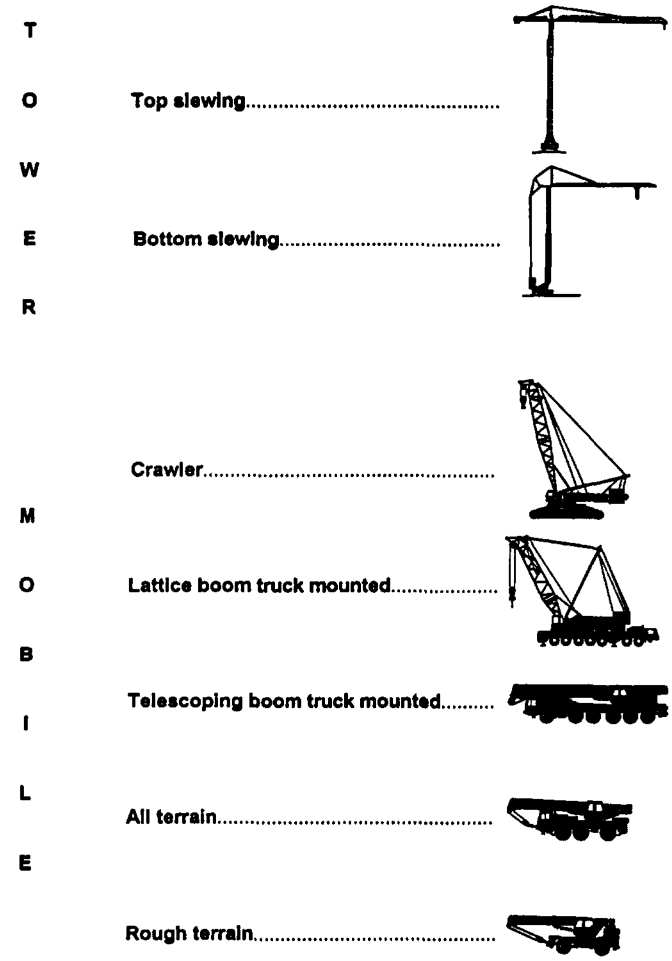

FIG. 1. Tower and Mobile Cranes

cannot be handled by the tower crane due to schedule or lifting-capacity limitations. Also, small rough-terrain models often are seen on sites where they complement the big mobile or tower cranes as general-purpose machines. The current research addressed mobile cranes essentially in their capacity as the main lifting-service providers.

METHODOLOGY

Data were collected through site visits and personal interviews conducted on 36 projects in the southwestern United States during spring and summer of 1994. Selection criteria included (1) building projects, that is, not road construction, infrastructure, utilities, and the like; (2) mobile crane(s) used as the central lifting equipment on site; (3) project cost of not less than $1 million; and (4) project duration not less than three months. The projects were carried out by 29 construction companies. As a rule, reflecting the desire for as representative a sample as possible, selected projects were limited to two per company. The southwestern United States was selected, among other reasons, because it is a wide geographic area that typically exhibits a developed mobile crane practice. Within this large area, projects were selected for their convenient location, mostly in and around the metro areas of Albuquerque, Denver, and Phoenix. A balance was maintained between the three states, as follows: New Mexico—11 projects, 8 construction companies; Colorado—12 projects, 10 companies; and Arizona—13 projects, 11 companies. These 36 projects, in fact, constituted the majority of the projects under construction in those areas at the time of the study, that met the selection criteria. Table 1 presents the profile of the participating projects.

TABLE 1. Characteristics of Projects

Size of project (1)	Project Cost (millions of dollars): Range (2)	Project Cost (millions of dollars): Median (3)	Construction Duration (months): Range (4)	Construction Duration (months): Median (5)	Number of Projects, By Type of Facility: Commercial and public (6)	Number of Projects, By Type of Facility: Industrial and R&D (7)	Number of Projects: Total (8)
Small	1–7	3.75	3–15	7.5	20	2	22
Medium	11–30	16	10–28	18	7	2	9
Large	50–200	50	7–24	8	3	2	5
(Total)	1–200	5.5	3–28	8	30	6	36

The in-depth interviews, conducted on site, lasted about three hours each. Specific questions, supported by a written questionnaire, focused on the particular project visited; open discussions also pertained to local building construction projects in general. In selecting their own representative interviewees, participating companies were asked to choose experienced, competent functionaries who were intimately involved in equipment planning and operation. Of these, 10 were project managers, 24 were project superintendents, and two were project engineers. Follow-up interviews were conducted with subcontractors and managers of crane rental service companies when recommended by the principal interviewees. On most sites, crane operators contributed to discussions relevant to their areas of responsibility.

The structured guide on which the interviews were based was developed from pertinent literature and from extensive consultations with leading project managers and crane rental service managers from the Albuquerque and Denver areas. It was then further tested and refined through pilot interviews on five medium-to-large building projects in Albuquerque. Excerpts from the final interview guide appear in Appendix I.

A total of 55 mobile cranes of various types and sizes were observed on site at the time of the interviews. Their profile, presented in Table 2, reflects the selection of cranes typically found on building construction sites in the southwestern United States. Crawler, truck-mounted (telescoping- or lattice-boomed), and rough-terrain cranes appeared in comparable numbers. All-terrain cranes apparently are not prevalent in this region (only one unit was seen) a few years after Shapiro (1991) observed an increase in sales of these machines in the U.S.

Albuquerque, N.M. illustrates the frequency of tower crane use in the area studied: At the time of the study only two tower cranes were on site in this metro area, which was then in the midst of a construction boom. One of these cranes was brought from out-of-state; the other had been, in fact, the only tower crane owned by a local general contracting company (Eggleston, personal communication, 1993).

Culture Measures and Research Variables

The interviews focused on three principal measures by which the culture of using mobile cranes was examined: (1) the project's physical features; (2) the project's operational features; and (3) non–project-specific and external factors. Information related to these measures was obtained from the interviewees through multiple variables, either by recording facts or by soliciting interviewees' evaluations (whether concerning their specific projects or pertaining to their wider experience). Answers were analyzed both individually and correlatively with regard to the different variables.

Major research variables were as follows:

- Physical features—structure dimensions, site spaciousness, site restrictions, site terrain, construction method, project cost, and construction duration
- Operational features—number of cranes used throughout

J. Constr. Eng. Manage., 1996, 122(4): 298-307

TABLE 2. Profile of Mobile Cranes

Size of crane (1)	CRAWLER: Lifting Capacity (tons[b]) Range (2)	CRAWLER: Lifting Capacity (tons[b]) Median (3)	CRAWLER: Number of cranes (4)	HYDRAULIC/TELESCOPING-BOOM TRUCK-MOUNTED: Lifting Capacity (tons[b]) Range (5)	HYDRAULIC/TELESCOPING-BOOM TRUCK-MOUNTED: Lifting Capacity (tons[b]) Median (6)	HYDRAULIC/TELESCOPING-BOOM TRUCK-MOUNTED: Number of cranes (7)	LATTICE-BOOM TRUCK-MOUNTED: Lifting Capacity (tons[b]) Range (8)	LATTICE-BOOM TRUCK-MOUNTED: Lifting Capacity (tons[b]) Median (9)	LATTICE-BOOM TRUCK-MOUNTED: Number of cranes (10)	ROUGH TERRAIN[a]: Lifting Capacity (tons[b]) Range (11)	ROUGH TERRAIN[a]: Lifting Capacity (tons[b]) Median (12)	ROUGH TERRAIN[a]: Number of cranes (13)	Total number of cranes (14)
Small	50	50	1	20–30	25	2	25–50	50	5	15–27.5	20	12[a]	20
Medium	65–82	73.5	2	50–60	55	2	75–90	82.5	4	35–40	40	9	17
Large	100–230	230	12	70–155	90	3	120–160	125	3	—	—	—	18
(Total)	50–230	150	15	20–155	60	7	25–160	75	12	15–40	27.5	21[a]	55

[a]Including one all-terrain crane.
[b]Lifting capacities are given in English units, as is common in U.S. practice and in all commercial and technical publications. To convert to metric ton (t), multiply by 0.9072.

construction, specifications of cranes on site, distance of crane transport to site, other lifting/conveying equipment, main lifting assignments, nature of equipment planning, plan issuance and format, contractual agreements, and crane operator responsibilities

- External factors—company's own/rent policy, equipment availability, experience with tower crane practice, reasons for not considering tower cranes, and local construction industry's current state

FINDINGS

The characteristics that shape the mobile crane culture in building construction are identified as project or environmental. It should be noted that, as is typical in discussing a culture, the separations between project and environment were not always distinct.

Project Characteristics

Project-specific characteristics are presented (1) as the physical framework that drives and supports mobile crane practice; (2) to demonstrate the homogeneity (in certain aspects) of otherwise different projects; (3) to characterize projects in a large and representative segment of the U.S. construction industry; and (4) to show how project characteristics synchronize as regards crane selection and employment—bearing in mind, though, that similar project conditions in a different environment may support a different solution.

Short Construction Duration

Construction duration of the 36 sampled projects was in the range of 3–28 months, with a mean value of 10.7 months and a median of eight months. On 22 of the projects (61%), total construction time was scheduled as eight months or less. Indeed, 29 out of 36 interviewees said it was the short construction duration of their projects that made using a tower crane uneconomical. Tower cranes were viewed as associated with long, costly assembly and dismantling processes, which would not correspond with short construction durations. Mobile cranes, on the other hand, can be transported easily and rapidly between sites; the need for this mobility is, again, one result of short construction durations.

Interviewees identified construction duration as important not only on their specific projects, but also generally; the existing competitive atmosphere and resulting compressed time schedules created great pressure for rapid mobilization. Under such conditions, tower cranes are likely to be used only where there is no alternative (e.g., high-rise construction).

When considered along with project cost, construction duration may have an additional effect. If we define ''construction rate'' as the ratio of cost (in millions of dollars) to duration (in months), then we find that 75% of the sampled projects had construction rates of 0.5 (i.e., $500,000 per month) or more. For example, three of the large projects (Table 1), with costs of $50 million each, had construction durations of 7–8 months (hence the median construction duration of the large projects in Table 1 is much smaller than that of the medium projects) and construction rates of 6.25–7.14. These three projects were defined by the interviewees as being ''fast track,'' where maintaining flexibility was perceived to be the key to coping with high uncertainty levels. Combined with short construction time, it accentuates the merits of using mobile rather than tower cranes.

Low-Rise Construction

Of the 36 projects surveyed, 33 structures were at or under 23 m (70 ft) high, and 27 (75%) were lower than 15 m (the equivalent of five residential stories). The median height was 11 m. Considering that the sample of surveyed projects not only reliably represented the local building population in and around urban areas but also included most structures under construction at the time of the study, this is clearly a picture of low-rise construction. All interviewees noted that structure height was a governing factor in using mobile cranes, albeit in a negative manner, that is, high-rise structures eliminated the consideration of mobile cranes and required the use of tower cranes. This observation referred both to the specific projects visited and to local construction in general.

On the only three projects in the sample that were higher than 23 m (the tallest structure, a baseball park, stood 55 m high), the use of mobile cranes was made possible by (1) working from the inside of the structure; (2) using more than one crane; (3) a very spacious and unrestricted site; or (4) a combination of any of these. Another possible solution, a crawler-mounted tower attachment, was not among the machines found on any of the sites visited.

Spacious Sites

The majority of sites visited were spacious, according to both site data and interviewees' evaluations. On 28 projects (78%), the site area was 16,000 m^2 (4 acres) and larger, with a median of 32,000 m^2 (8 acres) for all 36 projects. What is more indicative of site spaciousness is the ratio of building footprint to site area. On 29 sites (81% of the projects) this ratio was smaller than 50%, and the median footprint-to-site ratio for the whole sample was 20%. All seven sites where the

J. Constr. Eng. Manage., 1996, 122(4): 298-307

ratio was greater than 50% were evaluated by the interviewees as ''congested.'' Four other sites, with ratios of 10–41%, were similarly evaluated based on existing overhead utilities and adjacent buildings and roadways. Use of mobile cranes on congested sites was made possible by working from the inside of the building. That, in turn, was made possible by the construction method (discussed later).

All interviewees stated that easy maneuverability was a major deciding factor for using mobile cranes on their projects. Likewise, they characterized most local construction sites as being ''spacious.'' Other types of obstacles or restrictions that may also limit on-site crane movement were power and communication lines, found only on four projects. Thus, in terms of crane mobility with regard to geometric constraints (i.e., crane versus building versus site), the majority of the sites observed definitely supported the use of mobile cranes.

The equipment planning factor is discussed later. Yet it is interesting even at this stage to note the high correlation between site congestion and equipment planning. Of the small number of projects (nine of 36) for which an equipment plan was actually issued, five were in the group of seven congested sites with footprint-to-site ratios greater than 50%. On only four of the remaining 29 spacious sites (14%) was an equipment plan issued as well.

Supportive Terrain

Due mainly to their configuration and relatively short horizontal reach, and unlike tower cranes, mobile crane operation on site involves a great deal of movement; hence the importance of site spaciousness. But crane maneuverability is determined not only by the geometric relationships between crane configuration, building, and site; it is also affected by the site terrain, namely, topography and soil conditions. Flat terrain allows the use of mobile cranes, while mountainous sites may necessitate the use of (usually static-mounted) tower cranes; the same is largely true with stable versus soft ground (unless a crawler crane is employed). The Southwest sites visited are typical examples of terrains that agreeably accommodate mobile cranes. Interviewees were requested to rate site topography (flat, moderate, steep) and surface condition (supportive, nonsupportive). Six sites were described as moderate and the rest as flat; on only four sites was the surface termed nonsupportive (albeit not to the level of excluding the use of a mobile crane). That supportive terrain can become a prerequisite for mobile crane employment is exemplified by the typical use of tower cranes on the steep slopes of some mountainous Colorado sites—in the very same Southwest.

Construction Method

The construction method on all participating projects except one was essentially steel construction. In terms of crane employment, this had several implications.

Steel erection, as the major lifting assignment, governs the crane work. More than anything else, and with most buildings being low-rise, it allows a good portion of the crane work to be carried out from inside the building. This, in turn, helps the mobile crane overcome an inherent configuration-related difficulty, that is, handling from the building's interior those lifts that are geometrically obstructed by the building's exterior parts. Working from the inside is further facilitated if the building not only is low-rise, but also comprises just one floor. Of the 36 projects examined, half were one-floor structures.

Other major lifting assignments identified by the interviewees, in addition to steel erection, were installation of mechanical units (on 42% of the projects), precast elements and tilt-up (19%), and forms for concrete works (17%). Along with steel erection, these are for the most part typical lift works, for which—unlike duty-cycle work—mobile cranes generally are best suited (Peurifoy et al. 1996).

All projects but one included partial concrete works. However, concreting—the classical duty-cycle crane work—was carried out solely by the cranes on only three projects. Both concrete pumps and cranes were used on eight projects; concreting on the majority of projects, however, was carried out mostly by concrete pumps, and occasionally by telescopic hydraulic forklifts equipped with concrete buckets. Thus we are always likely to see concrete pumps on sites served by mobile cranes. It is interesting to note that, in comparison, sites served by tower cranes normally use concrete pumps only if the cranes are overscheduled with other lifting assignments.

Compared with conventional concrete construction, steel construction is an industrialized method, that is, the building is erected mostly by assembly work and not by in-situ production. Among other things, it induces relatively long work cycles and low lifting frequency, suitable for mobile crane use. (Under the opposite conditions, however, a tower crane might be favored.) This is true not only for the steel skeleton; the steel construction method also facilitates a higher industrialization level on the building exterior closure, interior construction, and finish works. Consequently, there is a relatively low volume of material handling per se; most craning is of elements. Since most sites visited did have conventional works to a certain extent (e.g., masonry walls in 72% of the buildings), it was interesting to observe the handling of materials for those works. The present findings show that this was seldom done by the cranes on site. For example, on only four sites (11%) were the mobile cranes used for conveying blocks (or bricks) for masonry walls. The better part of material handling was done by hydraulic forklifts, found on all 36 sites in quite impressive numbers (a total of 164 units, or mean value of 4.6 units per site).

In addition to its direct impact, the construction method—steel structures and high industrialization levels—also indirectly affects crane selection and utilization mode, mainly through short construction and crane service durations.

Subcontracting

The proportion of subcontracted work may have a major effect on the convenience of operating the equipment on site. Working with a tower crane means rigorous daily schedules and a high degree of time sharing, which inherently are not compatible with subcontracting large portions of the work. Conversely, use of mobile cranes is facilitated by splitting the work into subcontracted packages; thus a high subcontracting level can be expected in a mobile-crane–oriented culture.

The findings correspond to these expectations:

- On 81% of the projects, all crane work was subcontracted.
- On 67% of these, the subcontractors were also responsible for the daily crane schedule and for establishing priorities.
- When asked to evaluate why the tower crane versus mobile crane issue was not even raised with regard to their reported projects, 47% of the interviewees gave ''we are not concerned with equipment since we subcontract'' as a reason.
- Referring to the company's policy in general, only 19% of the interviewees estimated it was exclusively to purchase rather than rent equipment. Both owning and renting were reported by 17%, and the rest (64%) evaluated their companies' policy toward obtaining equipment as distinctly one of renting.

Environmental Characteristics

The environmental characteristics presented in the following are essentially non–project-specific, originating in the com-

J. Constr. Eng. Manage., 1996, 122(4): 298-307

pany, the local market, the construction industry in general, the physical and organizational infrastructure, and also in social and behavioral patterns. These are the very features without which the project-specific characteristics discussed earlier might have produced a different equipment culture.

Planning Culture

The planning culture of the participating projects was studied and evaluated through several measures. The findings were as follows.

All interviewees but one had not the slightest doubt that mobile cranes would be the right equipment on site, hence they had not even considered the option of tower cranes for their projects. This may not come as a surprise. More telling is that half of the respondents attributed this attitude to tradition or culture, rather than to analysis.

On a scale of fully rigorous to fully intuitive (left-to-right, see Appendix I) most interviewees (75%) placed the depth of their equipment planning somewhere within the right half of the scale, that is, equipment planning took place predominantly in an intuitive and informal mode. This apparently works with mobile cranes; all interviewees stated unequivocally that they were satisfied with the equipment they had on site. With tower cranes, on the other hand, this is not the case, as their utilization requires considerable planning and their selection involves a rigorous engineering decision-making process (Peurifoy et al. 1996).

Only nine (25%) of the projects had an equipment plan actually issued in the form of a document (and, as mentioned earlier, five of these projects were in the small group of seven congested sites). In six of these nine, the document was not an independent equipment plan but the project schedule (CPM, Gantt) with equipment tied to it. High correlation (seven of nine projects) was found between conducting rigorous equipment planning and actually issuing a plan, namely, on the majority of projects neither was done.

Doing without a formal equipment plan, or inserting equipment onto the project schedule, might be suitable for a typical mobile crane employment pattern, as described above. With tower cranes, however, a plan would not only be issued, but it would also be in a drawing format, often accompanied by a tabular daily schedule. The observation that the infrequent use of drawings for equipment planning is typical to a mobile crane practice environment is even further validated when seen in construction companies particularly selected on the basis of their proven progressive planning culture. A sample of such companies in the western United States was studied for various planning measures (Laufer et al. 1993). While the percentage of projects for which an equipment plan was actually issued was found to be much higher than in the current study (63% and 72% in the prebid and preconstruction planning stages, respectively), the findings as to formats used for equipment plans were very much the same (17% and 13%, respectively).

In open discussions, interviewees admitted to not having been too concerned about equipment planning. There appeared to be a consensus that in light of the prevailing basic conditions (extensive subcontracting, broad crane availability, easy crane mobility between sites) equipment planning was actually unnecessary. To some extent, it might even have been a limiting factor, mainly in terms of impairing flexibility.

This planning (or even a de facto lack-of-planning) culture and the use of mobile cranes are connected by a cause-and-effect relationship. On the one hand, employing mobile cranes supports and augments this planning culture, in a way makes it at all possible. On the other, this culture is what drives the use of mobile rather than tower cranes: adhering to independence, decentralization, self containment, and unbinding reality, while shunning long-term commitments, resource sharing, and a need for coordination. In the words of one interviewee, "I would feel threatened by the loss of scheduling control and flexibility if employing a tower crane" (Noland, personal communication, 1994). Using a metaphor suggested by another interviewee (Bosiljevac, personal communication, 1994b), the culture that drives the selection of mobile over tower cranes is the very same one in which a large number of daily commuters between Albuquerque and Santa Fe use the 100 km (60 mi) long highway. A mass transit system would save money, time, and lives, and would be better for the environment. Yet people would rather drive their own cars; it releases them from having to check and follow a mass-transit schedule, it relieves them from binding coordinations of all sorts (e.g., getting to a central departure point and then getting around their destination), and it gives them a sense of freedom and flexibility to change their plans.

Note that "planning culture" as addressed previously does not relate to the evident technical aspects of equipment planning; it is taken for granted that job requirements (e.g., lift capacity and reach) are closely considered when selecting the crane.

Operator Role

The apparently inherent correlation between the American spirit and mobile (rather than tower) cranes is noted by Howard Shapiro, an acclaimed authority on construction cranes. He writes (Shapiro et al. 1991):

> Some Danish friends who are tower crane engineers seem to think that American cowboys have laid down their guns and now use mobile cranes to kill each other instead. They are biased, to be sure, but that attitude stems in part from the stark differences in philosophy and history that separate the two crane concepts. . . . Mobile cranes rely on the individual, the operator, who can easily destroy his machine and surroundings by failure to exercise due care; in the frontier spirit, destiny is in the operator's hands. Tower cranes, on the contrary, reflect the discipline and limitations on the individual that are required for successful city living; the cranes are automatically controlled and limited so that the operator does little more than "aim."

In the current study, the crane operator's role was addressed through examining operator responsibilities. The findings evidently support Shapiro's observations, as they strongly reflect the operator's independence and autonomy. While operators' general responsibilities were unanimously reported as lifting assignments and safety, their responsibility was found to cover almost all aspects of crane operation on most projects. In the words of one interviewee, the crane operator is the "captain of the ship" (Bosiljevac, personal communication, 1994a). Of the list of 16 responsibility items (Appendix I), adopted from Dickie (1991), 12—from load chart, rigging, and moving, to inspection, maintenance and shutting down—were checked on 29–35 of the 36 sites visited. Schedule and training were found to be the least of operator-responsibility items, but still were included on 15 and 18 sites, respectively. Half of the respondents stated that the operator reported to the foreman or superintendent, yet the other half maintained that the operator reported to nobody. Even if this is not quite the case, it is still a strong evidence of the mobile crane operator's unique status on site.

Operation-induced safety issues, although in principle no less important, are not placed so highly on the tower crane agenda; unlike with mobile cranes, safety awareness would not be counted as a tower crane culture characteristic. As noted earlier, this is mainly due to the high automation level of tower crane control; it can also be partly attributed to the position

J. Constr. Eng. Manage., 1996, 122(4): 298-307

of the operator cabin high above building and site, with increased operator visibility. Further, tower cranes can be remotely controlled, offering a man-machine separation not available with mobile cranes.

Availability and Technical Support

Interviewees generally observed that equipment (i.e., mobile cranes) type and availability have not been a limiting factor in any way. Although the current (1994) state of the construction industry was evaluated by most respondents in all three states as highly active (only one interviewee out of 36 thought it was slow, and three more assessed it as average), there appeared to be abundant equipment available. A check of transport distances revealed that cranes were driven or hauled to most sites (86%) from locations not farther than 48 km (30 mi); in about half the cases (53%) the transport distance was shorter than 32 km (20 mi). Of course, the mobile cranes' high transit capability and ease of setup make them even more effective, as they can be available in different locations on relatively short notice.

Along with availability come technical and professional support, attachments and spare parts, timely service and repairs, and skilled operators. And if a crane breaks down, quite often, as observed by the interviewees, another one is immediately brought to the site, causing only minimal work interruption. This clearly is a distinct feature of mobile crane practice and an obvious advantage mobile cranes have over tower cranes, even in a tower crane practice environment.

Equipment Rental Market Organization

The tendency of construction companies to rent rather than own mobile cranes is reflected in the well-developed rental market for these machines. This tendency was also clearly demonstrated in the current study: Of the 29 participating companies, only six had a policy of owning their cranes. The main factor that drives this trend is the high equipment utilization it allows vis-à-vis relatively short on-site service periods and a planning culture that gives high priority to maintaining flexibility. Interviewees (both project managers and steel erectors) specifically noted the advantage provided by operating in a rental-market environment, which allows them to meet unexpected or changing lift requirements by promptly replacing cranes or bringing in more units.

Harris (1989) observes also a close link between the emergence of a strong mobile-crane rental market and the development of mobile cranes as specialized equipment.

Examining the parallel parameters with regard to tower cranes—largely versatile machines, operated in long-term and rigorous preplanning modes, and staying for long service durations on a single jobsite—clearly shows the reasons why they are used primarily on a purchase and owning basis.

Influence of Civil Engineering Projects

Unlike building construction, projects categorized as civil engineering (e.g., roads, bridges, utilities)—usually with large and open sites, and without height as a limiting factor—inherently make the use of mobile cranes favorable. Indeed, mobile cranes are seen working on most such projects, regardless of any environmental, non–project-specific factors, whether in Europe, America, or elsewhere. In the United States, where civil engineering projects traditionally comprise a relatively high percentage of overall construction, the resulting extensive and continuous use of mobile cranes has contributed to the evolution of a mobile crane culture (Shapiro and Shapiro 1988). More tangibly, this construction volume has made mobile equipment highly available and intimately familiar, while creating no grounds for seeking other solutions. Thus we identify this influence of civil engineering projects on building construction as one of the characteristics of the mobile crane culture.

The magnitude of the effect of one project type on another in terms of construction equipment is not given to direct sampling or measurement and perhaps can be best estimated by comparing different cultures; hence it was not addressed in the site interviews and data collection for this study. However if the mere existence of such effect needs further evidence, it can be found, for example, in what are perhaps the two best-known and most widely used American textbooks on construction methods and equipment (Peurifoy and Ledbetter 1985; Nunnally 1993). Cranes, the ultimate lifting machines in building construction, are briefly covered in both books, and then only within the chapters "Excavating Equipment" or "Excavating and Lifting"; other machines, typically identified with heavy civil works, take up the larger part of the equipment chapters, and are thoroughly and comprehensively addressed.

Unfamiliarity with Tower Cranes

The extent of the interviewees' knowledge of tower cranes was not directly examined within the current study; not only was there an objective difficulty in assessing abstract or even technical knowledge levels within the site interviews conducted, but also respondents' admitting to a lack of knowledge is problematic. However, since it might have been expected that one ingredient of a mobile crane culture would be a certain knowledge gap and unfamiliarity with tower cranes, the issue was only partly and indirectly addressed rather than ignored. The findings were as follows:

1. Only seven of the 29 participating companies owned tower cranes at the time of the study and/or have used tower cranes before (four companies, one crane each; three companies, two each).
2. Few of the 36 interviewees have ever worked with tower cranes.
3. When providing possible explanations as to why a tower crane had not even been considered for a given project, 67% of the interviewees said it was partly because their company did not own one.
4. Open discussions left a strong impression that the tower cranes respondents generally had in mind were the large, top-slewing machines usually seen next to high-rise buildings. Only one interviewee indicated familiarity with the smaller, bottom-slewing fast- and self-erecting machines that are particularly suitable for servicing on mid- and low-rise projects that also require a large number of on-site relocations.

No definite conclusions can be drawn as to the participants' knowledge of tower cranes. Yet there is firm ground for believing that a significant lack of knowledge (of tower cranes) was the case with most interviewees—a representative sample of project managers and general superintendents; unfamiliarity due to inexperience with tower crane practice is undeniable.

Employment Pattern

Employment pattern (or employment mode) of cranes, as defined in this study, is the variation picture of the on-site number of cranes throughout construction. If one crane is on service throughout construction, then its employment pattern can be graphically depicted as shown in Fig. 2(b). The graphic description of a changing number of cranes on site would typically look like Fig. 2(a).

As implied by the caption of Fig. 2, the findings of this

J. Constr. Eng. Manage., 1996, 122(4): 298-307

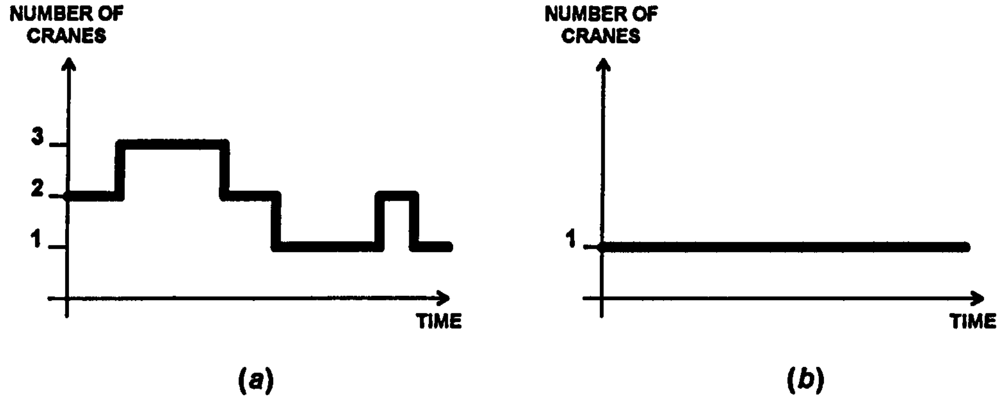

FIG. 2. Typical Employment Patterns: (a) Mobile Crane; (b) Tower Crane

study support the description of a typical mobile crane employment pattern as shown in Fig. 2(a). On 72% of the participating projects, two or more (up to six) cranes were on site during various construction stages. Moreover, as stated by the interviewees, cranes were in and out of the site as dictated by lifting tasks and by other projects' needs, namely, the number of cranes on site occasionally changed. This employment pattern can be viewed as the essence of the culture of using mobile cranes. It is clearly a picture of maintaining flexibility and independence, fitting well with other characteristics discussed here. It also shows a distinct difference from tower cranes, where the very same cranes (one or more) are usually present on site throughout most of construction, as shown in Fig. 2(b).

Working Mode

While requested to state the number of mobile cranes used throughout construction, the interviewees were expected to say how many cranes they had (and will have) on site. In reality, the information was disclosed in a different mode: For each crane a specific assignment was added; for example, crane 1—steel erection, crane 2—concrete forms. Except for one project, on which the cranes were numbered by construction stages (three cranes—project start; six cranes—superstructure), this pattern repeated itself on all 36 sites, whether with one crane or more.

This clearly is a different picture than the one commonly portrayed for tower cranes, and hence can be regarded as another characteristic of mobile crane use. Fig. 3 schematically illustrates two simplified working modes, for mobile and tower cranes, in which crane assignments and work stations are combined. Tower cranes [two are depicted in Fig. 3(a)] are assigned specific building zones they are to service, most likely (but not necessarily) from fixed locations; thus, in terms of lifting assignments, each crane carries out the various craning tasks within its working envelope. Mobile cranes, on the other hand [Fig. 3(b)], are primarily assigned specific tasks rather than building zones, and thus in principle each covers, from changing locations, the whole building (or part of it, if more than one crane is assigned a given task). This latter working mode is primarily driven by a high subcontracting degree on the one hand, and by the suitability of different mobile crane configurations (unlike with tower cranes) for different tasks on the other. It is further supported by other characteristics observed, such as the prevalent construction method and the spacious sites.

It should be stressed that, as indicated above, the models depicted in Fig. 3 are simplified; in reality this categorization of working modes is not always that clear-cut. When a tower crane is the equipment providing the main conveying services on site, often there is still a need to assign a mobile crane to the special lifting tasks that cannot be handled by the tower

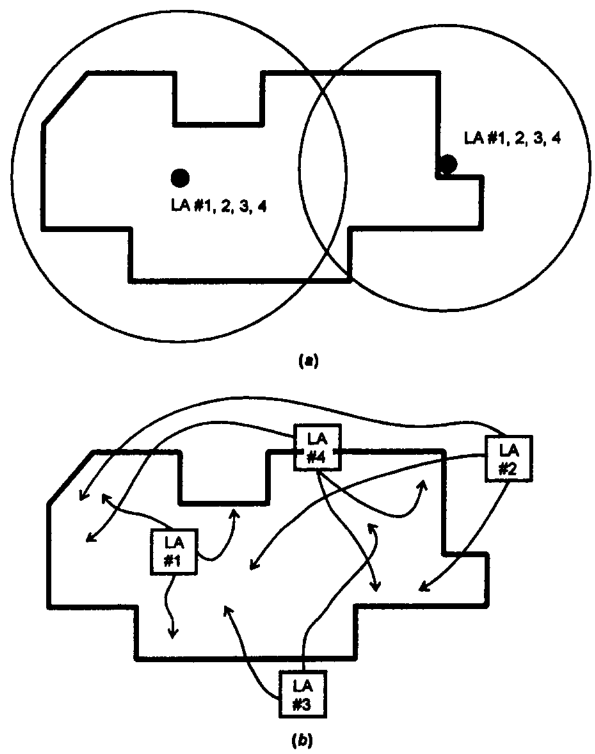

FIG. 3. Lift Assignments and Work Stations: (a) Tower Cranes; (b) Mobile Cranes (LA = Lift Assignment)

crane. With a mobile crane, occasional lifting tasks can be added to its main designated assignment, or even two main lifting responsibilities can be assigned.

OVERALL PICTURE

Construction projects do not exist in a void, and decisions made on a particular project cannot be isolated from those made on other projects. Thus the selection of cranes for a project is affected not only by project-specific considerations but also by the prevailing external conditions that often are the cumulative effect of the characteristics of a whole project population. In reality, this cumulative effect is realized through equipment availability. In other words, a mobile crane would be selected for a particular project not only because this project supports its use (e.g., it is low-rise, has a spacious site and supportive terrain, and needs a crane for a total of five months), but also because most other projects nearby possess similar characteristics, resulting in a developed mobile crane market, namely, high availability. Naturally, typical non-project-specific factors also affect crane selection through equipment availability.

TABLE 3. Characteristics of Mobile Crane Culture

Characteristic (1)	Project/environment (2)	Influence channel (3)	Prerequisite/supportive/outcome (4)
Short construction duration	Project	Both direct and through availability	Supportive
Low-rise construction	Project	Both direct and through availability	Prerequisite
Spacious sites	Project	Both direct and through availability	Supportive/prerequisite
Spread-out construction[a]	Project	Both direct and through availability	Supportive
Supportive terrain	Project	Both direct and through availability	Prerequisite
Construction method	Project	Both direct and through availability	Supportive
Low building repetitiveness[a]	Project	Both direct and through availability	Supportive
Subcontracting	Project/environment	Both direct and through availability	Supportive
Planning culture	Environment	Mainly through availability	Supportive
Operator role	Environment	Mainly through availability	Supportive
Availability and technical support	Environment	Through availability	Supportive
Equipment rental market organization	Environment	Through availability	Supportive
Influence of civil engineering projects	Environment	Through availability	Supportive
Unfamiliarity with tower cranes	Environment	Both direct and through availability	Supportive
Roadway infrastructure[a]	Environment	Both direct and through availability	Supportive
Employment pattern	Environment/project	[Not applicable]	Outcome
Working mode	Environment/project	[Not applicable]	Outcome

[a]Not discussed in text.

Thus, in addition to being classified as project- or environment-related, the characteristics of the mobile crane culture should also be examined as to their influence on crane selection; that is, is selection a direct effect of the particular project, or of factors, both internal and external to the project, affecting through equipment availability? We have found, based on interviewees responses, that most project-specific characteristics affect crane selection *both* directly and through availability. The influence of most environmental characteristics, however, is solely or mainly through availability. Table 3 provides the overall picture. Characteristics are listed in column 1. Next is the classification by which the findings are described in this paper (column 2), followed by the influence channel (column 3). To complete the picture, another classification is offered (column 4), which distinguishes between prerequisites, supportive factors, and characteristics that are essentially outcomes more than causes. Some characteristics not discussed in this text also appear in Table 3, for example: roadway infrastructure, which supports mobile crane practice if well developed; narrow roads—rural and urban—make it difficult to accommodate the frequent crane transports associated with mobile cranes and thus agree more with tower cranes. Building repetitiveness, as another example, affects crane use mainly in that high repetitiveness (such as in apartment, hotel, or office buildings) facilitates thorough and longer-term planning, which in turn creates more supportive grounds for using a tower crane.

The picture would not be complete without reemphasizing the relationships between and within project and environmental characteristics, as already implied here. Although the characteristics were presented under separate headings, what indeed makes them a culture is their integration—project, management, infrastructure, market, environment. Interrelationships such as those mentioned previously can be formalized, yielding a set of schematic representations as exemplified in Fig. 4. When done comparatively, these diagrams provide better understanding of how a given factor (e.g., type of contractual organization of the project) favors—through integration with other factors (e.g., planning and service mode)—the use of tower [Fig. 4(a)] or mobile [Fig. 4(b)] cranes. The two-headed arrows in Fig. 4 indicate the cause-and-effect type of relationships that exist among most factors considered. For example, decentralized service mode and flexibility in planning promote the use of mobile cranes; however, the use of mobile cranes by itself, in a way, impels flexible planning and decentralized service. Adding other factors to the picture (with one- or two-headed arrows) might make it complicated and harder to comprehend, but indeed may even better reflect reality.

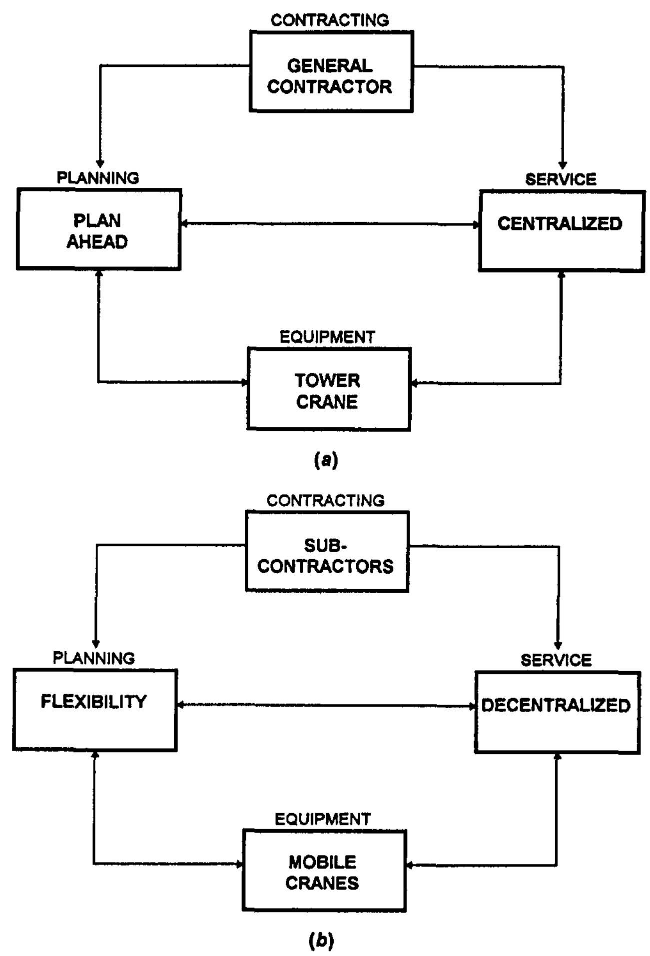

FIG. 4. Contracting/Equipment Interrelationships: (a) Tower Crane; (b) Mobile Crane

CONCLUSION

The familiar trade-off that exists between assembly, dismantling, and transport costs of tower cranes on the one hand, and cost per rated lift capability of mobile cranes on the other, sets the basic rules for comparing the two crane types and selecting the favored alternative. It is also commonly known

J. Constr. Eng. Manage., 1996, 122(4): 298-307

that high-rise buildings, extremely congested sites, and nonsupportive terrains necessitate in most cases the use of tower cranes, and inverse conditions are best fitted for mobile cranes. Yet, there clearly is an aggregate of factors that may strongly affect the implementation of these conventions, often to the effect of overruling it.

This study identified, analyzed, and described such factors that characterize mobile crane practice in building construction. Planning culture, operating style, contracting policy, and market organization, as well as the wide common denominator of a whole project population, are inseparable from the physical and organizational features of each particular project. At times when construction companies increasingly operate overseas, often in a scene different than at home, environmental factors such as these should be considered to assure harmony between performance intent and machine, and to increase the project's prospect for success.

At the same time, there are lessons to be learned and implemented at home too, mainly as the result of comparing the culture of using mobile cranes with tower crane practice. Indeed, this study demonstrated the power of tradition and culture, even with regard to an engineering/technical matter such as construction equipment selection and operation. One also cannot ignore the economical benefits of external factors such as equipment availability, technical support, and experienced and competent manpower. Nonetheless, even while these factors may promote the use of mobile rather than tower cranes, practitioners will serve themselves and their projects by learning and understanding the concept of using tower cranes; they can then explore ways to adopt those components from which their mobile crane practice may benefit as well (e.g., longer-term planning and higher sharing level for more efficient equipment utilization). A further step, requiring an intimate acquaintance with tower cranes and the release of conceptual fixation, may be to consider the potential gains of employing tower instead of mobile cranes on a particular project. Such consideration must be accompanied by situational and cost-benefit analyses with as little regard for tradition as possible; indirect gains expected from the different approach (i.e., to the whole planning process) entailed by using a tower crane must be taken into account as well. Indeed, companies pioneering in the use of tower cranes on projects that otherwise would employ mobile cranes may attain a significant edge in the current tight, competitive construction market. The handful of such cases encountered while conducting this study can only reinforce this conclusion.

ACKNOWLEDGMENTS

The writers wish to acknowledge the kind and constructive cooperation of the companies and individuals who were interviewed or consulted throughout this study. Special thanks are extended to George and Steven Bosiljevac of Structural Services Co., New Mexico, Will Webb of Webb Crane Service Inc., Colorado, Prof. Greg Howell of the Civil Engineering Department, University of New Mexico (UNM), and Roxy Flanders of UNM, for their active and continuous contribution. This study was conducted while the first writer spent his sabbatical leave at UNM's Department of Civil Engineering on a grant from the New Mexico branch of the Associated General Contractors of America (AGC). The support of the AGC endowment and the hospitality of UNM's civil engineering faculty and staff are gratefully acknowledged.

APPENDIX I. INTERVIEW GUIDE

Introduction

The following questions focus on characteristics of building construction in the southwestern United States and on factors affecting crane selection. They address both project-specific information and broader environmental issues relating to equipment planning and operation. You are requested to refer, throughout the interview, to one particular project with which you are currently involved, unless specifically asked otherwise.

Questions

General Project Data

Provide the following information:

- Building height and number of floors
- Footprint dimensions and area
- Project cost
- Construction duration
- Construction method and material (e.g., cast-in-place concrete, precast, steel, wood, brick) of the main building components (e.g., floors, walls, columns, beams, roof)

Site Layout and Conditions

1. Provide the site plan (or data needed to draw it), including crane location at main construction stages.
2. What is the site area?
3. What is the site topography? (flat/moderate/steep)
4. What is the surface condition? (supportive/nonsupportive)
5. What are the obstacles for crane movement on site?
6. Rate the site spaciousness (spacious/congested)

Equipment Operation

1. How many cranes were used throughout construction?
2. What are the specifications of the cranes now on site? Refer to undercarriage and boom configuration, make and model, lifting capacity, and boom length.
3. How were the cranes brought to site, and what was the transport distance?
4. What are the cranes' main lifting assignments?
5. How are materials/elements (e.g., steel, concrete, rebar, forms, precasts) for the main building works (e.g., substructure, superstructure, exterior closure, finishes, mechanical/electrical) handled?
6. What portion of the crane work is subcontracted?
7. Who is responsible for the daily crane schedule and for establishing priorities? (subcontractor/general contractor)
8. What other lifting/conveying equipment is on site in addition to cranes?
9. Overall, do you have the right equipment on site?

Crane Selection

1. Was a tower crane considered for the project? (yes/no)
2. If no, why was a tower crane not considered? Check one or more of the following, and indicate if there was one main reason:
   - Company does not have
   - Never used in the company
   - Lack of experience with tower crane practice
   - Not economical (specify why)
   - Not concerned with equipment since we subcontract
   - Mobile crane is the right equipment for this project (specify why)
   - Other (specify)
3. Was not considering a tower crane a result of analysis, or more a matter of tradition/culture?
4. What project features would make you consider a tower crane?
5. In your opinion, why are tower cranes not more widely used in the Southwest?

J. Constr. Eng. Manage., 1996, 122(4): 298-307

6. What are the main reasons for using mobile cranes in the Southwest?

Equipment Planning

1. Rate the depth of equipment planning. Place an "x" on the following scale (Fig. 5).
2. Was an equipment plan actually issued? (yes/no).
3. If yes, what was the format of the plan issued? Check one or more of the following. Add other formats, or indicate any combination of formats, as you see fit (Textual: lists, checklists, meeting protocols, verbal instruction; Technical: diagrams, drawings; Time charts: Gantt, C.P.M.; Tables: standard forms, tables).

Crane Operator Responsibilities

1. What is the crane operator's general responsibility on this project?
2. Check the following items for operator responsibility on this project (operation, limitations, load chart, maintenance, schedule, rigging, assembly, shutting down, functions, operating manual, inspection, log book, safety, configuration, moving, training).
3. Who does the operator report to?

Company and Industry

1. What is the company's policy toward obtaining equipment? (purchase/rent).

FIG. 5. Depth of Equipment Planning

2. Characterize local construction projects.
3. Describe the local crane rental market and availability.
4. Evaluate the current state of the local construction industry.

APPENDIX II. REFERENCES

Dickie, D. E. (1991). "Who's responsible? Guidelines for mobile crane operations." *Lift Equipment*, Feb.-March, 27–29.

Harris, F. (1989). *Modern construction equipment and methods*. Longman Scientific and Technical, Harlow, Essex, U.K.

Laufer, A., Shapira, A., Cohenca-Zall, D., and Howell, G. A. (1993). "Prebid and preconstruction planning process." *J. Constr. Engrg. Mgmt.*, ASCE, 119(3), 426–444.

Nunnally, S. W. (1993). *Construction methods and management*, 3rd Ed., Regents/Prentice Hall, Englewood Cliffs, N.J.

Peurifoy, R. L., and Ledbetter, W. B. (1985). *Construction planning, equipment and methods*, 4th Ed., McGraw-Hill, New York, N.Y.

Peurifoy, R. L., Ledbetter, W. B., and Schexnayder, C. J. (1996). *Construction planning, equipment and methods*, 5th Ed., McGraw-Hill, New York, N.Y.

Shapiro, L. K., and Shapiro, H. I. (1988). "Construction cranes." *Sci. Am.*, 258(3), 54–61.

Shapiro, H. I., Shapiro, J. P., and Shapiro, L. K. (1991). *Cranes and derricks*, 2nd Ed., McGraw-Hill, New York, N.Y.

J. Constr. Eng. Manage., 1996, 122(4): 298-307