"Soft" Considerations in Equipment Selection for Building Construction Projects

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Abstract: This paper raises the issue of "soft" considerations in the selection of equipment for building construction projects. The paper aims at increasing the awareness: (1) to the nature, variety, and richness of soft factors; (2) to their significant role and potential impact on the outcome of decision making; and (3) to the inherent difficulty of evaluating them and integrating them within a comprehensive selection process. Existing state-of-the-art equipment selection models were analyzed and found to be inadequate in terms of both considering soft factors and providing mechanisms for their systematic evaluation. Six cases of large-size, complex construction projects were investigated to obtain an extensive list of typical soft factors. This investigation revealed that the consideration of soft factors in current practices is essentially unstructured and is not integrated within the selection process in a systematic manner. A desirable selection process is outlined that generally responds to the needs identified in the study. The proposition of a specific method for the quantitative treatment of soft factors and their tradeoff with cost factors is the subject of another paper.

DOI: 10.1061/(ASCE)0733-9364(2007)133:10(749)

CE Database subject headings: Construction equipment; Construction management; Decision making; Cranes.

Introduction

Selection of equipment for construction projects generally involves two classes of factors or considerations. The first class comprises tangible, quantitative, formal considerations. Typical factors of this class include technical specifications of the equipment, physical dimensions of the site and constructed facility, and cost calculations; they are hereby termed "hard" factors/considerations. The second class covers a large array of "other" factors, which are mostly intangible, qualitative, and informal in nature. Random examples include safety considerations, company policies regarding purchase/rental, market fluctuations, and environmental constraints.

Factors that fall into this latter category—termed "soft" in this paper—are, by nature, much more difficult to deal with. They are often less defined than the hard factors, as their definition depends to a great extent on, and changes with, the users and their environment—the planning team, the construction company, local authorities, and regulations. Furthermore, it is unclear how, in practice, these factors—which express the culture and tradition, the intuition, the uncertainty, and the subjectivity that are rooted in construction decision making—are taken into consideration in terms of method/algorithms, modus operandi, and timing. It is clear, however, that these factors "frequently take on a disproportionate influence during the decision-making process" (Harris and McCaffer 2001) and therefore they are worthy of much more investigation.

This paper purports to explore the role of soft considerations in the selection of construction equipment, with a focus on building projects. More specifically, the paper seeks to answer the following questions:

1. What soft factors are acknowledged by models suggested in the technical literature, and how do these models process and consider them?
2. What soft factors are considered in current practices, and how are they treated, particularly vis-à-vis cost factors and other hard considerations?
3. What lessons should be drawn as to the centrality of soft factors and the integration of their evaluation within the overall selection process?

The predominance of cranes on building construction sites is reflected throughout the paper, as the paper focuses on equipment for *building* projects (rather than for heavy civil works, infrastructure, roads, etc.). Note, however, that the term "construction equipment" in this paper also refers to other major building construction equipment, such as concrete pumps and forming systems.

State-of-the-Art Models

The selection of construction equipment—for building projects, as is the interest of the current study, or for civil engineering projects in general—is covered at various levels in the technical literature. On the practical side, there are manuals and handbooks (and articles in trade magazines) listing factors and general—albeit usually unstructured—recommendations. Examples of these with respect to cranes are Dickie (1981), Selinger and Sha-

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Note. Discussion open until March 1, 2008. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on June 17, 2003; approved on December 19, 2006. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 133, No. 10, October 1, 2007. ©ASCE, ISSN 0733-9364/2007/10-749–760/$25.00.

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pira (1987), Proctor (1995), and Dieleman (2002). Providing structured guidance, including ways to deal with the various factors in a systematic manner, are selected construction management textbooks, which often give detailed examples as well as case studies. Illingworth (1993) and Harris amd McCaffer (2001) are noteworthy examples of such books. At the high end of research-based solutions are advanced models offered by papers published in professional journals. Quite predictably, these models focus on methods and algorithms, as they aim mainly at improving the process (and the resulting products) rather than the content (i.e., the theoretical base). Table 1 provides a listing and summary of applicable research.

A comprehensive literature review and a subsequent critical comparative analysis yielded the seven model families represented in Table 1 by 13 different models. The table provides the fundamental points and main features that distinguish the various models from each other, with a focus on each model's limitations as concluded by adopting an overall view of the selection process and its desirable output (i.e., equipment solutions). Table 1 presents a concise picture of a much broader and detailed body of findings, available in the complete report on the current study (Goldenberg 2002).

With respect to the issues explored by the current paper, the following conclusions should be noted, in relation to the models compared in Table 1:

1. All models simplify the problem to some extent, either by assuming simplified hypotheses (that may indeed hold true for various standard cases) or by directing and preadjusting the solution for specific (mostly standard) case types only. This is conceivably a reasonable way to overcome the difficulty inherent in predicting multiple possibilities, but real-life complex situations are thus left unresolved;
2. Most models base the solution solely on explicit economic factors, while intangible qualitative considerations are practically ignored. Admittedly, it is hard to take the latter into account. The few models that do offer an option for the incorporation of user-originated considerations have no structured mechanism for the systematic review of subjective factors;
3. The infusion of contextual considerations into the solution is allowed by only a few models, and then only in part. It is the aspiration to offer a universal solution that impairs the solution's flexibility and its potential suitability for the specific conditions that may prevail in any given project; and
4. A handful of models exhibit awareness to the concept of comprehensiveness and integration of all equipment selection factors. Selecting equipment without due attention to interrelated decisions (such as those pertaining to construction methods or other equipment systems in the same project) may lead to a solution that is far from optimal.

Thus it may be summarized, with reference to the question on models suggested in the technical literature, that: (1) soft (i.e., qualitative, subjective, contextual) factors, which reflect the complexity and uncertainty prevalent in construction decision making, are hardly acknowledged by state-of-the-art models suggested in the literature; and (2) these models provide no structured, comprehensive method that allows the systematic treatment of soft considerations.

Note that various other works were published that address specific equipment types and offer planning models for specialized assignments (e.g., Hornaday et al. 1993; Lin and Haas 1996a,b; Varghese et al. 1997). Being outside the immediate scope of the present study, such models were not addressed here; they provide, however, a source for the kind of considerations and solutions relevant for unique cases. Similarly, commercial software is available that offers solutions for the selection and location of a specific crane model and for lift planning (Meehan 2005). Examples are Compu-Crane and LPS (NCI 2006), Cranimation and Tower-Management (Cranimax 2006), LiftPlanner (LiftPlanner Software 2006), and MéthoCAD (Progistik 2006). These software packages, commonly used by engineering and construction firms, address mainly the technical aspects of crane location and lift planning; none of them accommodates the consideration of soft factors.

Current Practices

Methodology

Data were collected through case studies of six building construction projects in Israel. The projects varied in type and included construction of public, commercial, and residential complexes. In order to qualify as a rich source of equipment selection considerations, these projects were selected on the basis of their size, complexity, and varied equipment systems. All of the projects were located amidst busy urban environments and in proximity to congested road systems. They all had confined construction sites, with physical obstacles of various kinds. The six projects were constructed by seven different companies. All of these companies are known for their highly developed planning culture. Six of them were leading locally based contractors also active internationally (D&B 2003), and one was a foreign contractor. Only two of the six projects were constructed by the same company, while two of the projects were constructed by joint ventures of two companies each. Project profiles are given in Table 2. Two to four in-depth interviews were conducted with each of the six project managers. The interviews were supported by numerous site visits throughout construction of the projects.

Findings

Table 3 presents 27 soft equipment selection factors identified by the interviews and observations. Each factor is accompanied by a brief explanation and an example, where deemed necessary. By their nature, soft factors are hard to classify. An attempt was made through the interviews to map their areas of impact. This classification was of importance in the development of a systematic multicriteria decision-making method for the quantitative evaluation of these soft factors in the equipment selection process (Shapira and Goldenberg 2005). Specific example impacts of soft factors on the selection of equipment for the studied projects are given in Table 4.

Hence, this investigation of current practices yielded a rich knowledge body of soft factors while demonstrating that the consideration of soft factors in equipment selection for complex construction projects is not only unavoidable, but may also play a major role in the selection decision. At the same time, the study revealed that the extent to which these factors should be properly considered depends greatly on the project's planning team and mainly on its project manager. This part of the selection process—the consideration of soft factors—is essentially unstructured and is not integrated within the entire process in a systematic manner, even in companies that demonstrate a highly developed planning culture.

The flowchart in Fig. 1 represents from the case studies the

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Table 1. Existing Models for Selection and Positioning of Construction Equipment

Model family	Model and major references	Alternatives considered	Method/phases of solution	Intangible factors	Major limitations
Optimization models	Single crane location optimization Choi and Harris (1991)	Crane locations, as determined by user (by means of coordinates)	• Computation of hook travel time for each location • Selection of location with minimum hook travel time	• No intangible factors considered	• Restricted to location of crane • Deals with one crane type only (e.g., no option for tower crane on rails) • Assumes the shortest angular movement is performed • 2D only; height dimension ignored (albeit on purpose) • Assumes all-simultaneous movement: angular, radial, vertical • No reference to different assembly/disassembly costs at different locations • Temporary facilities assumed fixed, and referred to as points
	Location optimization for a group of tower cranes Zhang et al. (1999)	Crane locations, within permitted area determined by user (by means of coordinates)	• Generation of initial feasible location area • Reallocation of tasks to optimize workloads • Final optimization of location for each crane	• No intangible factors considered	• Restricted to location of crane • Deals with one crane type only (e.g., no option for tower crane on rails) • No reference to different assembly/disassembly costs at different locations • Temporary facilities assumed fixed, and referred to as points
Graphics models	"Cranes"—graphical assistant for selection of tower cranes Cooper (1987)	Crane models, from built-in database; crane locations, as specified by user (graphically)	• Examination of user-suggested locations to meet a number of technical requirements while considering available machines	• No intangible factors considered integrally • Such factors may, however, be incorporated manually by user	• Crane selection without systematic consideration of intangible factors • No cost estimation of alternatives • System provides guidance, but all decisions are left to user's discretion
	"Cranes"—graphical interface for mobile cranes Farrel and Hover (1989)	Combination of crane model and number, as examined (graphically) by user (models: from updateable database)	• Graphic visualization of work envelopes and obstacles, as well as display of several indicating parameters, to examine crane combinations	• No intangible factors considered integrally • All factors are incorporated manually by user	• Visualization tool only; system provides no guidance (other than a few technical calculations); examination of alternatives left to user • Crane selection without systematic consideration of intangible factors • No cost estimation of alternatives • No measurement of efficiency of crane utilization
Database-based models	"D-Crane"—MS-access database for mobile cranes selection Al-Hussein et al. (2000, 2001)	Crane models (48 models in five types of mobile cranes); models stored in updateable database	• Mathematical processing of data pertinent to numerous lift configurations and settings of cranes (stored in databases) to meet given lift and site constraints • Selection of least rental-cost available crane	• Nointangible factors considered	• Deals with single lifts only; no treatment of entire project lift requirements • Crane selection without consideration of intangible factors • Crane selection without consideration of productivity requirements • No consideration of the entire site plant (e.g., other equipment as a substitute for crane or used in conjunction with it)

Table 1. (*Continued.*)

Model family	Model and major references	Alternatives considered	Method/phases of solution	Intangible factors	Major limitations
Expert systems	"Cranes"—expert system for crane selection Gray and Little (1985); Gray (1987)	Cranes types (four types of tower cranes and three types of mobile cranes) and locations	• Implications of building shape (for each floor) by means of graphic routine • Generation of feasible crane alternatives (type and location) on the basis of a predetermined set of rules representing expert knowledge • Selection of least-cost alternative	• No intangible factors considered	• Crane selection without consideration of intangible factors • Rental-oriented only solution; no capacity for consideration of owned (or choosing between rented and owned) equipment • Local nature (pertaining to specific market) of rules and parameter values • Probability of missing good solutions, due to inability of expert system to take into account threshold situations
	"Locrane"—expert system for crane selection Warszawski and Peled (1987); Warszawski (1990)	Crane types (five types of tower cranes and two types of mobile cranes) and locations	• Selection of feasible crane types on the basis of building geometry • Feasible solutions are checked vis-à-vis rules representing expert knowledge • System-supported selection of best solution by user	• No intangible factors considered integrally • Such factors may, however, be incorporated manually by user	• Crane selection without systematic consideration of intangible factors • No consideration of the entire site plant (e.g., other equipment as substitute for crane or be used in conjunction with it) • Method of solution based on extensive use of assumptions and simplifications • Local nature (pertaining to specific market) of rules and parameter values • Probability of missing good solutions, due to inability of expert system to take into account threshold situations
	"ESACP"—computer-aided equipment selection for transporting and placing concrete Alkass et al. (1993)	Combinations of equipment types for concrete hauling (truck mixers, trucks, dumpers) and concrete pouring (cranes, pumps)	• Selection of feasible equipment combinations on the basis of decision rules representing expert knowledge • Selection of least-cost alternative	• Job conditions (represents: site conditions, type of structure, mixing method, weather, length of workday, accessibility, traffic flows, supervision)	• Restricted to projects in which concreting operations are the major activity • Advantages of multipurpose versus single-purpose equipment not examined • Rental-oriented solution; user-furnished unit costs required for consideration of owned equipment • Limited consideration of intangible factors (e.g., no option for comparison—other than cost—between rented and owned equipment) • No project-specific aggregation of all components of "job conditions" • Probability of missing good solutions, due to inability of expert system to take into account threshold situations
Dynamic programming	Crane selection on a construction site using mathematical techniques Furusaka and Gray (1984)	Combinations of crane type, model, number and location for each floor (built-in database contains 11 mobile crane and nine tower crane models)	• Generation of feasible crane combinations (for each floor) by means of dynamic programming (based on lifting capacity, working range, boom length, site width and service height) • Selection of least-cost combination	• No intangible factors considered	• Crane selection without consideration of intangible factors • Rental-oriented only solution; no capacity for consideration of owned (or choosing between rented and owned) equipment • Assumes that total transportation time not dependent on crane type • No consideration of the entire site plant (e.g., other equipment as substitute for crane or used in conjunction with it)

Table 1. (*Continued.*)

Model family	Model and major references	Alternatives considered	Method/phases of solution	Intangible factors	Major limitations
Multiattribute-decision-making-based models	Systematic plant selection Harris and McCaffer (2001)	User-generated alternatives of the entire plant (types, models, locations)	• Generation of feasible alternatives by user • Identification and ranking (0–10) of selection criteria • Computation of an overall rate for each alternative, used to compare them	• Intangible factors, as identified by user, are integrally considered	• Treatment of distinct cost factors as qualitative factors • Ranking of disparate factors in a single context (and by the same scale) may yield nonoptimal selection • Ranking of all factors in one batch creates a problem of consistency (no measurement of conflicting ranking) • Results are sensitive to formulation of selection factors • No facility for integration of economical and technical considerations
	Crane type selection based on fuzzy logic approach Hanna and Lotfallah (1999)	Crane types (tower, mobile, derrick)	• Calculation of solution efficiencies with respect to static/dynamic factors by fuzzy sets/rules, respectively • Aggregation of efficiencies to obtain efficiency center, used to find the best crane type	• Ground conditions • Accessibility • Crane productivity • Lift frequency • Operator visibility • Safety	• Restricted to the selection of general crane type only • No provision for the simultaneous selection of more than one crane type • No reference to factors relating to owned equipment • No provision for systematic assigning of weights of factors for the specific project • No consideration of the entire site plant (e.g., other equipment as substitute for crane or used in conjunction with it)
Artificial intelligence techniques	Single tower crane and supply locations optimization based on GAs[a] Tam et al. (2001)	Crane locations and supply positions, as determined by user (by means of 3D coordinates)	• Random generation of initial feasible locations (of crane and supply locations) • Repetitious improvement of solutions by means of GAs operators (until no further improvement is achieved)	• No intangible factors considered	• Restricted to location of crane • Deals with one crane type only (e.g., no option for tower crane on rails) • Assumes the shortest angular movement is performed • No reference to different assembly/disassembly costs at different locations • Temporary facilities assumed fixed, and referred to as points
	"IntelliCranes" —crane type and model selection based on ANNs[b] Sawhney and Mund (2001, 2002)	Eight crane types in first phase; crane models (from updateable database) in second phase	• Selection of crane type by means of ANNs-based matching process • Selection of crane models by screening of crane database (to meet limited number of physical criteria)	• Site spaciousness • Soil condition • Relocations on site • Site accessibility	• Tower crane selection without reference to crane location • Merely few intangible factors considered • "Binary" approach ("yes/no") problematic; in particular unsuitable for consideration of intangible factors • "Black-box" approach (ANNs cannot provide explanation as to how the solution was derived) • No provision for the simulataneous selection of more than one crane • No consideration of the entire site plant (e.g., other equipment as substitute for crane or used in conjunction with it)

[a]GAs=genetic algorithms—method based on the natural selection and genetics of a population, for solving optimization problems.

[b]ANNs=artificial neural networks—the data processing system also known as parallel distributed processing, connectionism, cognitive science, and pattern recognition. The system consists of a number of interconnected processing elements (neurons) in a manner that strives to emulate the cerebral cortex portion of the human brain (Edwards et al. 1998). Inputs and outputs obtained from historical data are used to train the network to solve the problem.

Table 2. Profiles of Case Study Construction Projects

Number	Title and location	Contractor	Cost ($M)	Main structure[c]	Major equipment[d,e]
1	"City Gate" (Ramat Gan, Israel)	Aviv & Co.	90	One 69-floor tower[b]	• Two tower cranes: full-height external crane for tower, free-standing crane for horizontal structure • Stationary concrete pump with climbing placing boom • Automatic climbing form system for all vertical concrete elements of tower (core and external walls)
2	"Azrieli Center" (Tel Aviv, Israel)	Cementcal + Magil (JV)[a]	105	Two towers, 50 and 46 floors[b]	• Three tower cranes: two internal-climbing cranes, one for each tower, one free-standing crane for horizontal structure • Stationary concrete pump with two climbing placing booms, one for each tower • Slabs: flying table forms for cast-in-place concrete in one tower, precast concrete elements in other tower
3	"City Tower" (Ramat Gan, Israel)	U. Dori	60	One 46-floor tower[b]	• Two tower cranes: internal-climbing crane for tower, free-standing crane for horizontal structure •Stationary concrete pump with climbing placing boom • Automatic climbing form system for concrete core of tower • External load-bearing precast concrete wall panels
4	"Government City" (Haifa, Israel)	Solel Boneh + Ashtrom (JV)[a]	35	One 35-floor tower	• Two full-height external tower cranes (one on each tower side) • Concrete placing by tower cranes • Flying table forms for cast-in-place slabs
5	"Toyota Towers" (Tel Aviv, Israel)	U. Dori	33	Two towers, 25 and ten floors[b]	• Four tower cranes: two full-height external cranes for high tower (one on each side), external crane for low tower, free-standing crane for horizontal structure • Concrete placing by tower cranes • High tower: automatic climbing form system for concrete core, external load-bearing precast concrete wall panels for two facades
6	"Rubinstein House" (Tel Aviv, Israel)	Ben Yakar–Gat	60	One 31-floor tower	• Two full-height external tower cranes (one on each tower side) • Concrete placing by tower cranes • Flying table forms for cast-in-place slabs

[a]JV=joint venture.
[b]Sitting on top of a 12–25-m-high podium.
[c]All concrete frames.
[d]Including craned and specialized forming systems (conventional slab/wall panel forms not mentioned).
[e]Including precast concrete elements for slabs and load-bearing walls (screen walls and other nonbearing wall elements not mentioned).

main steps taken in the selection of the equipment for these projects. In the figure, dark and light backgrounds denote soft factor strong and weak influence levels, respectively. The flowchart clearly shows that the consideration of soft factors, although evidently performed, was not structured into the selection process as a separate stage, nor was there any deliberate attempt at weighing soft factors vis-à-vis hard factors and cost considerations in a rational, systematic manner. That the equipment selection for each of the investigated projects was evaluated, at project completion, by the project managers as being satisfactory and a major contributor to the success of the projects may thus be attributed to a great extent to the high skills and rich experience of planning teams working in a highly developed planning environment, rather than to any structured and systematic selection process.

Proposed Selection Model

Once the central role of soft factors in equipment selection has been consolidated, attention should be drawn to four issues:

1. Content: The classes of soft factors considered, some are general (i.e., applicable in all or most projects) while others are contextual that relate to particular project circumstances;
2. Method: A model and algorithms by which to evaluate soft factors; a quantitative evaluation would be desirable, yet the inherent difficulty of converting qualitative, subjective assessments into numbers will have to be addressed;
3. Timing: Shaping a structured process with well-defined stages in terms of what soft factors to consider, to what extent, and at what stage; and
4. Integration: Integrating the new "soft part" with the classical "hard" one, to obtain a complete selection process.

The flowchart in Fig. 2 depicts a selection process that attempts to respond to the needs identified in this study. The flowchart uses the same nomenclature and graphics used in Fig. 1 so that the transition from the current-practice process to the desirable one is clearly visible. Note that the process depicted in Fig. 2 makes no detailed reference to either "content" or "method" as mentioned above. The content issue was covered in the previous section ("Findings" and Tables 3 and 4). The list of soft factors provided by Table 3, comprehensive as it purports to be, may still be augmented by unique circumstances that prevail in any particular project under discussion. Building on the experience of others may also be an option, but the contribution of the few

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Table 3. Equipment Selection Soft Factors

Number	Selection factor	Explanation/examples	Factor may have bearing on: Cost estimates	Managerial convenience	Operational efficiency	Schedule and progress delays	Work safety
1	Company policy toward own versus rent	"Own" policy may result in purchasing equipment that, with a view to future projects, exceeds the requirements of a particular project, wheras "rent" policy is likely to produce a solution catering to the project's exact needs only. Similarly, preference may be given to the use of owned, currently unemployed equipment (e.g., two small cranes) over rented equipment (e.g., one large crane), even if the latter would have otherwise been the optimal solution.	+				
2	Site ground conditions	While this is essentially an engineering factor, it mostly affects costs, as ground conditions dictate the cost of preliminary earth works and foundations (e.g., deep pile foundations for a large-size tower crane in clay soil, or soft ground requiring stabilization for vehicle mobility).	+				
3	Company project forecast	This factor influences current purchase/rent decisions, and thus may affect the equipment selected for a particular project under discussion. It has a bearing on costs through the value given to the predicted return period in economic calculations.	+			+	
4	Commercial considerations	The desire to start operating part of the constructed facility (cash-flow producing asset) earlier than the rest of it may affect equipment selection (e.g., refraining from locating tower crane in underground parking or tower of climbing placing boom inside elevator shaft).	+			+	
5	Procurement method and subcontracting	Quite often the clinet/owner dictates certain requirements that affect equipment selection (e.g., using the client's given equipment, providing craning services to other contractors on the same project, or forbidding the use of certain zones for locations of equipment).	+	+		+	
6	Company project specialization	A company may specialize in certain classes of construction (e.g., high-rise buildings, precast structures). This is reflected in the equipment it owns and operates, and can have direct implications on the equipment available for a new project. It also influences the type, experience, and size of the company's equipment maintenance department, which, in turn, affects cost estimates.	+	+			
7	Administration of day rentals	Extensive use of equipment (e.g., concrete pumps, truck loaders) rented for short durations, reflected in frequent ad-hoc coordination and rescheduling, impairs on-site managerial convenience and flexibility.		+			
8	Dependence on outsourcing	Outsourcing increases dependence on factors outside the site management control, chances of mishaps, and uncertainty in general. Avoiding it may lead, for example, to favoring on-site plant for precast elements over ordering them externally.		+			
9	Shifting responsibility to external party	Favoring ready-mixed concrete over on-site concrete production or favoring the ordering of precast elements over on-site fabrication has an advantage in terms of quality assurance of the product as well as contractual liability to this quality.		+			
10	Work night shifts	Night shifts commonly result from either a tight schedule or traffic-induced difficulties in transporting concrete/precast elements to the site during the daytime. It may affect site management and is always a cause for safety concerns.		+		+	+

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Table 3. (*Continued.*)

Number	Selection factor	Explanation/examples	Factor may have bearing on: Cost estimates	Managerial convenience	Operational efficiency	Schedule and progress delays	Work safety
11	Progress plan and timetable	The number and location of cranes and other equipment must take into account the project progress schedule. For example, a crane located inside the building, or adjacent to one of the facades from the outside, is bound to hold up nearby works.		+		+	
12	Interaction with other equipment	Selection and location of various equipment units must consider their uninterrupted interaction. A classical case is overlapping cranes; another example is locating the crane outside the elevator shaft so that it does not interfere with the forming system.		+	+		
13	Tradition, previous experience	The types of equipment selected for the project may be heavily affected by experience and by tradition, either on the market level (availability of technical support), company level (culture), or site management level (personal preferences).		+	+		
14	Pieces of equipment to manage	Essentially a tradeoff between operation flexibility and backup for contingencies versus wider control span and complex coordination.		+	+		+
15	Coverage of staging areas by crane(s)	Principally, and separating it from costs and other potential interfering factors, there should be a striving towards achieving a coverage as large as possible, thus maintaining optimal control, avoiding double handling, and shortening cycle times.			+		
16	Site congestion	Tight sites give preference to fixed over mobile equipment and to the location of equipment inside rather than outside the building.			+		+
17	Obstacles on site	Commonly power lines and adjacent structures, these affect productivity and safety. Fixed equipment may have an advantage; specialized operator aids may be required.			+		+
18	Labor availability	Manpower shortage increases the attractiveness of automated systems.				+	
19	Noise levels	Give preferences to electric over diesel powered equipment. May also exclude night work.				+	
20	Site accessibility	Narrow roads may limit the size of precast concrete elements or steel trusses transported to the site, which in turn may affect equipment size requirements.				+	
21	Heavy traffic	For projects located in urban areas near busy roads, heavy reliability on continuous external supply (e.g., ready-mixed concrete) may be abandoned in favor of on-site production. Night work is another solution.				+	
22	Owner/client satisfaction	The owner/client may have certain preferences—not necessarily corresponding to preferences of the construction company—that the company may wish to consider.				+	
23	Poor visibility due to weather conditions	Projects located in certain geographic areas may be given to long periods of limited on-site visibility (due to fog, haziness, etc.), which may affect equipment selection.				+	+
24	Strong winds	In areas given to strong winds, tower cranes may be preferred over mobile cranes. Also, the use of forming systems that climb automatically without crane assistance may be considered so as to avoid craning of large forms.				+	+
25	Equipment age and reliability	Technological advantages aside, newer equipment is likely to encounter less operational problems and downtime, and thus offers better service overall.				+	+

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Table 3. (*Continued.*)

Number	Selection factor	Explanation/examples	Factor may have bearing on: Cost estimates	Managerial convenience	Operational efficiency	Schedule and progress delays	Work safety
26	Overlapping of crane work envelopes	Overlapping tower cranes often are unavoidable, whether because of reach limits or daily schedule demands. Careful work and designation of forbidden zones help coping with safety hazards, but work may be slowed down.					+
27	Obstruction of crane operator view	Even with signal persons, this could become a major safety hazard (lower productivity is another result), and hence should be taken into account when equipment selection and location alternatives are considered. Operator vision aids (e.g., crane-mounted cameras) offer a partial solution.				+	+

existing sources (Proverbs et al. 1996; Shapira and Glascock 1996; Shapira and Schexnayder 1999; Shapiro et al. 2000; Peurifoy et al. 2006), in terms of additional soft factors, is limited, and essentially revolves around different definitions of factors listed in Table 3.

The proposition of a method for the quantitative treatment of soft, intangible factors, both on their own and vis-à-vis cost considerations, is the focus of another paper (Shapira and Goldenberg 2005).

The addition of two new stages marks the difference between the selection processes as depicted in Figs. 1 and 2. Our proposed first additional stage is the "evaluation of soft factors," which comes as a separate stage, equal to the "cost and economic considerations" stage. Our second additional stage, which precedes the "selection" stage, is where the overall evaluation of soft versus hard factors is conducted. Yet another difference, resulting from the above, is the redistribution of the extent to which various types of soft factors would be considered in, and would influence the outcome of, the various selection stages. Notably, the "selection" stage is now released of the consideration of soft factors, as this consideration has become the focus of the two new additional stages.

It should be stressed that by no means can the evaluation of soft factors—systematic and comprehensive as it may be—substitute cost calculations and economic comparisons, nor does it diminish the importance of the latter. It may, however, have a decisive role alongside economic considerations, certainly to the point that "if two alternative methods show near enough the same costs, decisions may depend entirely on an adequate assessment of intangible factors" (Illingworth 1993). Operatively, then, the evaluation of soft considerations may either consolidate a selection that would have been made on economic grounds only or, alternatively, point to a solution that otherwise appears to be more costly. An example of the latter case is presented in great detail by King and Schexnayder (2002).

Important as the understanding of the distinction between soft and hard factors is, this distinction is hardly clear cut. Some soft factors have a bearing on cost estimates or may even be converted into monetary terms, as also shown in Table 3. Likewise both soft and hard factors indiscriminately affect decisions made early in the selection process, as depicted by Fig. 2. In addition, intuition, experience, and subjective judgment—classically regarded as soft—would likely be in the background of many seemingly pure technical calculations. This all accentuates the problem, the essence of which may be illustrated as the tension between a set of often ill-defined, contending factors and arguments, which are anything but deterministic for the most part, and a final decision—a single selected equipment alternative—which is well defined, optimally reflects all constraints, and caters to all needs, and which is very quantitative and deterministic in nature. The general process shown in Fig. 2, accompanied by the systematic model handling the evaluation of soft factors and the overall evaluation of soft versus hard factors (Shapira and Goldenberg 2005), are believed to be capable of moderating, if not bridging, this tension.

Conclusion

This study has attempted to raise the issue of soft considerations in the selection of equipment for building construction projects: to increase awareness to their nature, variety, and richness; to their significant role and potential impact on the outcome of decision making; and to the inherent difficulty of evaluating them and integrating them within a comprehensive selection process.

Selecting the "right" equipment is usually crucial for the success of the project; hence the great importance of profound understanding and appreciation of the issue of soft considerations and the essentiality of their structured integration within the equipment selection process.

This paper demonstrated the inadequate treatment of soft factors by state-of-the-art equipment selection models. It also listed a variety of soft factors typical of present-day construction environments, and outlined a proposed selection process model. The introduction, validation, and demonstration of such a model that systematically evaluates soft factors and their tradeoff with cost factors is presented elsewhere (Shapira and Goldenberg 2005; Goldenberg and Shapira 2007).

As cranes are the predominant equipment on today's construction sites, they were also the focus of the current study as well as the major class of equipment addressed by most of the models reviewed within this study. However, the aforementioned analysis and the proposed model it has produced could be beneficial to the selection of other types of building construction equipment as well.

Acknowledgments

The writers gratefully acknowledge the support of the Technion V.P.R. Fund—M. and C. Papo Research Fund.

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Table 4. Example Impacts of Soft Factors on Selection of Equipment

Number	Project	Soft factor	Example impact
1	"City Gate" (Ramat Gan, Israel)	• Company project forecast • Company project specialization	For a building of this height (250 m), only rarely would a full-height external tower crane be used, due mainly to the cost of mast sections and the possible longer jib required as a result of crane position outside the structure. Yet this solution was favored in this case because this construction company specializes in high-rise buildings and thus possesses an exceptionally large number of tower crane mast sections. Dismantling of an external tower crane is less costly than that of an internal climbing crane, yet the difference in costs of mast sections between the two options is considerably higher than the difference in dismantling costs.
2	"Azrieli Center" (Tel Aviv, Israel)	• Site accessibility • Heavy traffic	Amount of concrete for this concrete-frame structure was 175,000 m^3, or an average daily pour of 500 m^3. To avoid projected delays due to congested access roads (building is in the heart of a major urbane center), an on-site concrete plant was favored over the common solution of truck-mixed concrete transported to the site from any of numerous ready-mixed concrete plants in the nearby vicinity. This is in spite of the restricted site and the resulting necessity for three costly relocations of the on-site plant during construction, which also required some temporary shoring of underground floors. Working night shifts, another solution to overcome traffic-induced delays, was used anyway for supply of precast elements to the site.
3	"City Tower" (Ramat Gan, Israel)	• Interaction with other equipment • Labor availability • Strong winds	An expensive automatic climbing forming system for the building core (elevators and stairwell shafts) was purchased and used, for the first time ever in the country (i.e., no previous experience) although there was no prediction for further use on other projects (no rental option was offered then by the system supplier). This was mainly because of: (1) severe manpower shortage nationwide; and (2) strong winds due to seaside location. Consequently, the climbing crane was taken out of its "natural" location inside the core and positioned elsewhere. The mast of the concrete placing boom was left in the core and climbed along the forms, slowing work progress to some extent.
4	"Government City" (Haifa, Israel)	• Procurement method	Initially a vertical transporation solution of one tower crane and a stationary concrete pump with climbing placing boom was worked out. The two construction companies for this joint venture project, however, decided to have each a tower crane of its own on the project so as to simplify accounting between them. Thus two almost identical, external tower cranes were used. The Project Manager, though, did not find this solution satisfactory, and when work reached the 25th floor, a pump with a climbing boom was brought to the site to help with concrete placing.
5	"Toyota Towers" (Tel Aviv, Israel)	• Own versus rent company policy • Previous experience with equipment	The construction company initially did not deem the use of a costly automatic climbing system to form the concrete core a viable solution, given the height of the building (25 floors, while these systems are commonly used for 30+ floor high structures). However, the company had acquired such system for an earlier project (see number 3 above), where the system was to complete its function upon the beginning of the current project; only moderate system customizing was required for the current project. The very same crew who had worked and acquired experience with the sophisticated system on the earlier project was to operate it on the current project.

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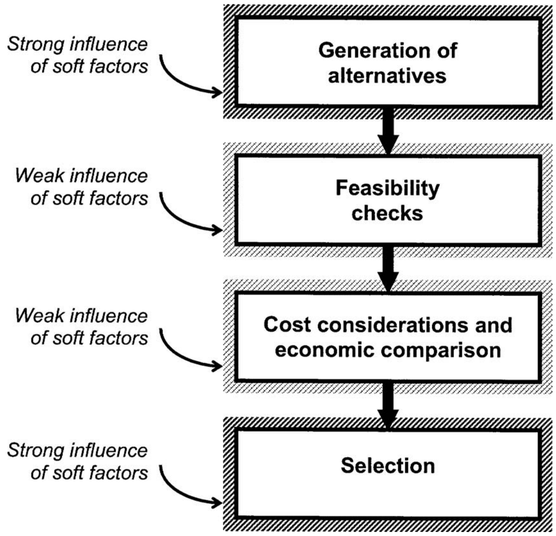

Fig. 1. State-of-practice equipment selection process

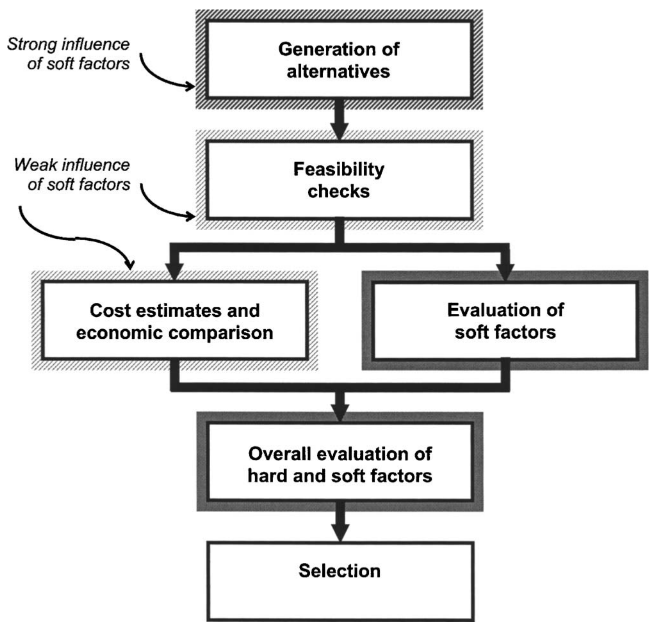

Fig. 2. Proposed equipment selection process

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