TECHNICAL TRENDS IN THE E&C BUSINESS: THE NEXT 10 YEARS

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ABSTRACT: This paper examines broad trends in the tools and techniques affecting the engineering/construction business over a 10-year time horizon. As a synthesis of various public and private assessments, it is divided into three sections: trends in design and information handling; trends in the construction process; and trends in the modularization of materials handling. Each section includes a description of basic trends and also their overall implications for the industry at large. Conclusions include the need for more data to properly assess the real impact of the noted trends; the relevance of low-tech as well as high-tech trends; and some observations concerning the necessity of adapting corporate culture to emphasize innovation and rapid exploitation of emerging technologies. More aggressive leadership in the R&D (research and development) aspects of engineering/construction is required if our industry is to capitalize on the value perceived from incorporating technical trends into current practice.

SCOPE

The time has come to take a broad look at the most important technical trends affecting the worldwide E&C (engineering and construction) industry over the coming decade. This paper focuses on the tools and techniques that are changing the nature of the design/build process, and thus excludes discussion of innovative design concepts in any specific engineering discipline. Changing international markets for E&C business, labor relations, new competitive players, and traditionally decentralized sectors such as residential housing are not considered. The issues raised herein are based upon recent public and private forecasts, personal experience, and the shared observations of experts in various organizations working on E&C technology. My aim is to describe what I see as most likely trends and thus invite comments and discussion in order to improve everyone's perception of where we are headed.

Like ancient Gaul, this paper is divided in *partes tres:* technical trends in the design process (including trends in how information is handled); technical trends in the construction process; and the modularization of equipment fabrication as a special and distinct set of trends. Each part is further subdivided into first a description of the basic trends, and then a discussion of their implications for E&C on an industrywide basis. A final section offers some overall conclusions and observations.

TECHNICAL TRENDS IN DESIGN AND INFORMATION HANDLING

Basic Trends

The growth in dedicated engineering workstations for all design work will continue indefinitely, with more powerful features becoming available, al-

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though the cost/unit curves will probably flatten out. Standard design details will be available on all CAD (computer aided design) systems—all typical civil, structural, piping, and electrical schematics and cable tray layouts have been on CAD sytems in larger engineering firms for some time. Further, computer-based "expert systems" will come into use as part of many aspects of CAD development. Applications range from more mundane topics such as automatic pipe support design systems to programs that use CAD-based data to optimize the entire plant construction and operating cost cycle.

Many more design depictions will be via 3-D computer models with sophisticated, standardized design symbols and aids—some design work is already being done this way. Most, but not all, observers feel that there will be a reduced need for conventional orthographic and isometric drawings when 3-D models are available, and some feel that holographic techniques may advance quickly in the next 10 years and have an impact on model representations. Also, common communications protocols will become more sophisticated, allowing easier linkage of remotely located CAD terminals. Linkage of design models/documents to computerized simulation of the built facility will become common, so as to optimize design from an operational viewpoint. This trend will benefit the owner, who will push hard to include it as a standard part of the design process.

Common CAD languages and interfaces among various CAD vendors, particularly in hardware, will be much closer than is possible now although compatibility will still be a problem in most cases. Also, those E&C firms who are decentralizing their engineering staffs will still have to wrestle with the issue of centralized versus stand-alone CAD systems, although the growing acceptance of centralized but "distributed" systems may provide a new and effective alternative.

Improvements will occur in standard discipline interface checking (e.g., mechanical/structural and electrical/plumbing) including the use of some expert systems in limited ways. Closer interface coordination will reduce the risk of construction cost overruns and increase reliability of the process of construction. Also, the trend will continue for earlier review of all designs from a "constructibility" viewpoint. Engineering services will have to include the use of the best available software for analysis of design alternatives with regard to life-cycle costing, reliability, and operations/maintenance (i.e., all activity throughout the lifetime of the client's facility).

Electronic interchange of both conventional and graphics-based data between the engineer and the vendor/fabricator on a same-day basis will become common. Use of bar-code technology will play a major role in assisting jobsite staff in tracking/locating materials and equipment, and identification codes will be linked directly to CAD systems. Bar-code technology is already used in some design offices for drawing and component identification.

Incorporation of an automated "construction cycle" process including the management of change orders has already been demonstrated in the aerospace industry, by some A/E (architect and engineering) firms, and also via a test sponsored by the National Academy of Sciences at their annual summer workshop on integrated data base development at Woods Hole, Massachusetts—Bechtel has played the role of the "contractor" during the test process. The academy work is part of a larger exercise in the development of an integrated project data base, and the automation of change orders is only one of several features of their project.

In the prerobotic, preautomation era, the process of code setting included establishing safety factors based on the large uncertainty inherent in many design calculations. Despite all the traditional factors that act to retard the changing of codes, it is quite likely that various automated construction technologies will enhance productivity considerably, simply by reducing the overprotective limits in some of today's codes. In fact, the availability of better computer simulation methods, such as those for floor pressurization in a high-rise office building during a fire/smoke event, will combine with better technology to accelerate the rationalization of the code process.

Some overseas firms have hinted at plans to leapfrog CAD advances by using improved CAD/CAM (computer aided design/computer aided manufacturing) techniques, including explicit linkage to on-site modularization of construction, within the next few years. Wherever these firms are part of a corporate vertical integration structure, that structure will lend itself to such a comprehensive linkage. For example, it has been reported that at least one firm already provides "same-day" total construction estimates to clients of commercial projects where materials to be used are fabricated by captive subsidiaries.

Implications for the E&C Industry

If all information-handling mechanisms from preconcept to job turnover are truly integrated, the key critical path item on many projects will become the unavoidable fabrication time for major equipment. Competitive advantages will be available for those firms who can demonstrate a capability to optimize information transfer in this fashion. Earlier identification of bulk component requirements, allowing earlier bulk staging of commodity materials at predescribed locations, will be a consequence of rapid design capability. Many observers feel that we are essentially moving toward an assembly-line-type process for even the most complex construction sequences. The implication for the E&C industry is that field productivity will be even more closely related to material delivery than it is now. Further, application of a suitable modified just-in-time method of supply to construction sites will lead to minimum warehouse and site lay-down areas, where only small items are inventoried. We will need to establish even closer links to equipment fabricators and "system vendors" who can provide the necessary logistic procedures to allow such "just-in-time" delivery systems. The efficient administrative control of field productivity, via the optimized orchestration of materials scheduling to the jobsite, is perhaps the most important implication of a start-to-finish fully integrated CAD system. Also, enhanced computer/communications networks linking jobsites worldwide will allow further innovations in solving unanticipated procurement problems.

One of the first activities at any large jobsite will be establishing the computer and communications links with the engineering office, the client, and selected major vendors/fabricators. E&C firms should add this task as a standard construction site policy, where appropriate, and subject to the availability of standard interface protocols. With the availability of electronic communication of data among all project participants (owner, designer, vendor, and builder/contractor), the contractor must prepare for project team members to have common networked workstations, to meet in "electronic" mode, and to share all necessary data bases.

Additional internal investment in both expert systems and simulation software packages as they relate to CAD is another management issue to consider. These enhanced capabilities are of special significance for owners of those process-oriented facilities such as factories and refineries that require extensive simulation of operations prior to construction, in order to optimize design layouts. Regarding simulation of the construction process itself, this capability will be available for facilities with simpler constructed components, and already has proven its value in certain civil works.

Managing the change order process during construction will become more efficient during the 1990s as software is gradually developed that will link design changes to cost and schedule impacts. It should be possible to measure the savings due to these improvements through a statistical sampling of jobsite change orders. The competitive advantage here is one of client perception that the E&C firm has full control and quick response capability whenever changes are suggested, and that all project team members are kept involved on a real-time basis.

With more techniques available for rapid and relatively cheaper analysis of alternative designs, design staff will need to be further trained in how to display options for the client. Each display of a change in a given trade or subsystem must carry with it the impacts on other trades as well as total project cost implications. The challenge here is to use our new tools wisely and train ourselves to exploit their complete potential for the benefit of the entire project. Further, if subjective "weighting factors" are combined by the designer into prepackaged computer software, these factors will need to be tested periodically to ensure that they are realistic and balanced. In a similar fashion, the built-in "logic trails" of computer-based expert systems will require continual retesting. Since they are not strictly deterministic but rather are based on "best available" judgements, reliability issues will be raised when these systems are used for design verification. As they gradually prove their worth, reliability concerns will lessen, but in the interim contractors must be prepared for a period of skepticism and perhaps greater contractual risk exposure.

As more hardware/software is required, the design process becomes more capital intensive. Along with the presumed enhanced capability to further integrate design options with their associated impacts on procurement requirements and constructibility, these trends imply a reconsideration of engineering pricing policy for design services.

With the flexibility of CAD allowing multiple custom designs, clients may feel less need to arbitrarily standardize their facilities. However, in special cases that often will be of interest to certain market areas (e.g., large public or semipublic facilities) regulatory requirements may force the use of "reference design" schemes. The capability to store such "reference designs" on a CAD system will be an important benefit to the engineer in such markets, and training of staff in this area will be an important need. In any event, improved record keeping for such items as historical estimate tracking and as-built referrals will be possible, as CAD systems come into use at the jobsite and supplant the need for paper-based working drawings.

The jobsite will eventually need to be equipped with terminals and graphic workstations for access to released design models and data bases. Battery-powered hand-held terminals are already becoming generally available for use on a walk-around basis at the jobsite. This point is an illustration of what is seen to be a major trend towards redefining the "designer" role versus the "contractor" role. It is conceivable that jobsite supervision over project documentation/models will become the responsibility of the designer, who will be permanently located at the jobsite, and thus the interface between the design office and the "field" will be dramatically shifted in favor of the designer. This is a serious implication for the industry relative to its traditional structure and division of work between engineering and construction departments.

Technical Trends in the Construction Process

Basic Trends

Improvements in conventional construction practices (e.g., advanced slipforming techniques) will continue on an incremental basis. Jobsite heavy equipment will continue to become more efficient, and some specific breakthroughs will occur, such as laser-guided excavation machinery with both vertical and horizontal alignment capability. Also, most observers see very steady progress in the application of so-called "smart instruments" such as concrete strength sensors being developed by the Bureau of Standards.

We will see greater use of advanced materials at the jobsite in many ways. Honeycomb structures and other lightweight cellular materials will provide greater strength. Materials will be more durable (e.g., the use of polyester fiber for sewage/water refitting pipes); repair will be more rapid with use of new fiberglass fabrics; and new materials will be developed for use in extreme (arid, arctic, undersea, radioactive, extraterrestial) environments. Fiber-reinforced plastics and ceramics are just two examples of new materials with increasing use in various applications. Progress in the development of sophisticated composite materials will be gradual, continuous, and usually applications driven, with construction-related applications often lagging behind those of the defense and manufacturing sectors.

The use of knowledge-based expert systems for construction applications is a growing trend. Current examples include systems for diagnosis of vibration problems in rotating machinery and for verification of welding procedure qualifications. Extensive research to develop construction-based expert systems is underway at both the National Bureau of Standards and the Corps of Engineers in such areas as evaluation of concrete durability and building air infiltration dynamics. Beyond 1995, the greater convergence of self-directed robots guided by expert system control may have enormous potential.

Technologies such as laser range finding and satellite-based position locating can be used to pinpoint exact facility locations and to set guide tracks for remotely operated moving vehicles. These technologies will gradually be integrated into a coherent system for automated control of certain jobsite activities.

As modular and prefabricated methods of construction develop, much of the unstructured environment at the construction site will disappear. This trend will hasten the use of robots, which will reduce cost and improve safety; increase productivity, which will shorten construction schedules; and allow for continuous inspection, which will result in a higher-quality product. Use of remote technology also will accelerate in areas where labor is performing repetitive tasks, or in a hazardous environment, or where quality

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can be improved by continuous inspection of the operation or product. In general, robots will be less prominent in the more complex process-oriented industries where less repetitive batch-type operations are required. Furthermore, during the next 10 years, partially automated systems that combine conventional equipment with sophisticated feedback control from high-quality sensors will become common as we move towards a fully automated environment.

The development and application of robotic systems in American industry is relatively new. According to various trade association estimates, only 6,000 robots were operating in the United States by the end of 1981, and most of those were installed in the preceding five years. The total number of robots installed in the U.S. had increased to over 20,000 at the end of 1985, and some predictions are that as many as 100,000 robots may be at work in this country by 1990. The robots referred to here, however, are robots in the classical sense (i.e., programmed repetitive machines used in production line operations). This technology is generally transferable to remotely controlled robotics, and it is expected that the development and application of remotely controlled robots will parallel the growth of production line robots. First-generation construction robots, those now on the jobsite, are really microprocessor controllers retrofitted to conventional construction equipment.

The contrast between a "true" robot with "embedded intelligence" versus a "teleoperated device" adapted for construction using a human operator is important to consider. The following list of current robotic-type devices is a further indication of the current range of robot applications. It is not intended to be comprehensive.

Table 1 was included in a recent paper by Kenneth F. Reinschmidt delivered to a symposium of the National Academy of Sciences' Building Research Board, in which he also noted that feedback of as-built conditions is the step that closes the design-construction loop and makes robotics feasible in construction. In this "adaptive control" concept, erection data with exact locations are fed back in real time and compared with the design data. Installations outside of tolerances can then be corrected.

Relative to all the above trends, the useful lifetimes for advanced equipment on the jobsite will become shorter as advances in equipment are accelerated. This, however, will be partially offset by the introduction of "modular" robotic equipment (i.e., equipment with standard base features but with interchangeable parts for different applications).

Implications for the E&C Industry

The reduction of skilled field labor at the jobsite will continue as technological changes occur. Absolute man-hours will decrease as machines learn more tasks, and fewer high-tech field workers will be needed when total installation time is shortened. For example, the installation of multiplexed wiring requires less electrical field staff by comparison to equivalent bundled single-wire systems. For those personnel still needed, training requirements to operate more complex devices usually start by being more intense, but growing application of "user-friendly" techniques often results in less total training effort.

The simple fact that certain automation equipment is available for use may change how we perform construction. For example, the tie off of rebar strands is a relatively costly and time-consuming step in much reinforced concrete

TABLE 1. Selected Examples of Construction Related Robotics Applications

Application (1)	Developer (2)
Excavation and grading laser controllers	Spectra-Physics
Utility connection excavation robot	Carnegie-Mellon
Bricklaying robot	Carnegie-Mellon
Surbot: surveillance teleoperator	Remote Technologies
Odex: six-legged walking device	Odetics
Terragator: mine-mapping teleoperator	Carnegie-Mellon
Structural steel paint-spraying robot	Taisei
Automated excavating machine	Kajima
Shotcrete-spraying robot	Kajima
Concrete-finishing robot	Kajima
Concrete-finishing robot	Hitachi
Rebar placement robot	Kajima
Tunnel-lining robot	Carnegie-Mellon
Painting robot	Normed (France)
Moose: concrete-scabbling teleoperator	Pentek
Autonomous road-following vehicle	Martin-Marietta
Six-legged rough terrain walker	Ohio State
Fred: hydrolasing teleoperator	Hodges Robotics
Jet-cutting tunneling robot	Kajima
Tile inspection robot	Kajima
Amphibious bulldozer	Komatsu
Eight-legged underwater walking robot	Komatsu
Ocean floor surveyor	Komatsu
Horizontal concrete distributor	Takenaka
Insulation-spraying robot	Shimizu

work. On a total systems basis, it may be cheaper and simpler to rethink this process, perhaps changing it to improve the quality of the rebar steel such that an automated device can spot-weld connections cheaply and quickly (one firm has already developed a robot for the rebar-placing process). We must find clever ways to adapt construction to automation, and not just try to adapt automation to construction.

Current methods to measure jobsite performance will have to change in order to properly measure jobsite productivity due to automation. Measures for comparing labor productivity versus machine productivity must be improved, and collaboration among many E&C firms to obtain a worldwide picture will be needed. One important analytical issue to study is whether the current reported decline in construction productivity indicators is partly due to an unintentional bias that neglects the transfer of certain higher-productivity functions away from the jobsite and into the fabrication process. Also, ordinary jobsite sampling methods may gradually become obsolete, given proper diagnostic programs imbedded within high-tech on-site equipment.

Implications for future QA/QC (quality assurance/quality control) also must be considered. With more accurate robotic-type machines, field QA will change dramatically in terms of both the reduced need to check certain construction devices that already have embedded high reliability and the availability of machines that improve the QA-checking process itself. The Bureau of Mines, for instance, is developing an optical-based QC method for grouting analysis.

Requirements for remotely operated construction equipment can evolve in a number of ways:

- The constructor may decide it needs a special piece of equipment to suit its needs and then asks a manufacturer to build the equipment.
- The manufacturer decides independently to market a new line of equipment because it foresees a need.
- The constructor makes the decision that it intends to change the way in which it constructs, which requires a new generation of automated equipment be developed.

All of the aforementioned implies that the technology requirements for new equipment will motivate us to collaborate more closely with equipment suppliers, and with the research staff that generates new designs and new applications. We will need to plan more opportunities for field trials of new procedures in some cases. We may also need to reconsider construction sequencing to accommodate automated methods (e.g., if access for automated material handlers requires clear pathways of transit at the site).

As further illustration of the positive interaction of various technical trends with each other, the increased use of robots at the jobsite, with their high capital costs and 24-hour availability for work, will demand improved just-in-time delivery systems for precise material scheduling. All construction work may become essentially "fast tracked" (even to the extent that some trade materials will be ordered prior to the final designs being completed for other trades), although we must modify existing factory-based just-in-time systems to reflect the realities of the construction jobsite.

Individual E&C firms need to consider whether technological trends in tools and equipment as described above are of such a unique nature as to demand the creation of new stand-alone business lines to exploit some of these developments. Further, an active R&D program is required to identify specific major tools and equipment which, while perhaps not worthy of pursuit as a full-fledged business line, could provide a distinct competitive advantage for certain types of jobs.

Modularization

Basic Trends

Off-site fabrication/assembly is a trend that is clearly established, even if exact evidence is unavailable and facts vary from project to project. Considerable past experience, including, for example, North Slope work and Bechtel's New Zealand gas-to-gasoline project, indicates future trends. Equipment modules on the order of 2,500 metric tons are no longer uncommon and 4,000 metric tons may be a current upper limit. While constraints such as lifting equipment capability and proximity to water transport do exist, the pattern of maximum off-site assembly and close coordination of delivery logistics has been clearly established.

Factory assembly of components has the following generic advantages over jobsite assembly:

- Time is saved since more assembly work can be done in parallel with on-site activity.
- All interfaces are tested earlier.
- "As-built" drawing documentation is minimized, thus reducing error/omission potential.
- Labor costs are usually lower due to the existence of a relatively stable labor force in a factory environment unhampered either by weather or physical jobsite constraints on assembly.
- A positive learning curve exists from experience on similar units, as well as from the supervision of available on-site QA/QC staff.
- Factory fabrication usually has greater potential for automation.
- Greater choice (implying cheaper cost) of fabricators is available, especially if offshore options exist, within a lump-sum bidding environment.

Modularization applications, to some extent, will follow the path from simpler to complex components. Assembly of the simplest structures, warehouses, and low-rise office buildings is now "fairly common" (statistics unavailable in detail). Common structural components and fixtures for more complex facilities such as hospitals and high-rise office buildings are also part of this trend. We now see large complete process units such as customized boilers and turbines manufactured and shipped almost in a commodity fashion.

Improvements in the characteristics of construction materials may accelerate the trend towards modularization in application areas such as mass-produced high-quality exterior skin materials for commercial structures, whether stone or metal.

Not all technological trends point toward factory fabrication and away from jobsite fabrication. For example, the automation of field welds via standardized robotic-type devices will provide reliability at the jobsite as high as that in the factory, and may even be more cost-effective for those materials that are limited by shipping constraints. We must be careful to balance our assessment, since advances are taking place on both sides of the "fabricator/jobsite" equation. Furthermore, the trend on larger jobs to locate some fabrication capability adjacent to the actual jobsite will blur this issue even more.

Implications for the E&C Industry

An emerging trend based on modularization is to use manufacturing capacity to build heavy industry components in standardized fashion, in anticipation of construction of a finished facility. Considerable savings in schedule and thus the carrying cost of money will result if fabrication is done in parallel with site-specific preparation. Designs are intended to be simple but proven, in order to maximize the value of the component. The implication for the E&C firm is to choose the project team with this trend in mind, and thereby pick the most efficient fabricators and subcontractors.

More owner input at the preconcept and concept phases can be expected for those jobs where the availability of modular fabrication will require "freezing" the design at an early date, thus changing the engineering sequence of activities very substantially.

The minimum response mode for the industry is to take a passive role on this issue. This response option assumes that within the next 10 years only incremental advances will have been made and no spectacular change will occur at most jobsites for our projects. Rather than initiate unnecessary and speculative studies of this trend, we should simply begin a well-managed program to maintain standard statistics of jobsite activity from the perspective of field versus nonfield assembly. An intermediate response mode is for E&C firms to collaborate more closely amongst themselves, perhaps via trade assocaitions or similar entities, to push harder for standardization of common equipment and procedures.

In contrast, the maximum response mode for an individual E&C firm would be to take a lead role and pioneer the introduction of techniques to maximize off-site fabrication/assembly, through the creation of sophisticated internal programs linking inventory management to jobsite scheduling. Performance would be optimized by drawing on a worldwide project base to provide the infrastructure for rapid response, going beyond existing procurement programs, and we may even wish to create "centers of excellence" for these activities throughout the industry. By taking a more active approach, we also assure ourselves of knowing who the best off-site partners will be for any project involving rapid fabrication. Major E&C firms must remain involved, if not take a leadership role, in any R&D effort to establish standardized/modularized heavy industry components for our biggest business lines (e.g., powerplants, refineries). As more complete process units are fabricated in modular form, firms will need to make major policy decisions about whether to directly intervene and form active partnerships in such efforts, or whether to avoid such involvement in lieu of the more traditional construction management role.

Conclusions and Observations

Five general conclusions can be drawn:

1. Due to a lack of data, we currently have no practical way to assess in detail the impact of all of the trends discussed in this paper—impacts that include competitive attractiveness, cost effectiveness, productivity enhancements, quality changes, and marketing potential. Therefore we need a technique for calculating on-site construction productivity that is readily understood within the industry as a way to measure the effect of changes such as robotics. We also need a parallel effort to actually measure the changes, systematically, on a quantifiable year-by-year basis. The development of this measuring process should be part of an industrywide R&D (research and development) effort, and may require the creation of a special initiative.

2. Several observers of these issues have stressed that it is often tempting to overfocus on "high-tech" trends in technology at the expense of cost-effective "low-tech" issues. Among these more prosaic activities are better jobsite training, careful material tracking using simple computer software packages, and specification standardization within E&C firms wherever possible. Improved E&C productivity is in reality composed of both "high-tech" and "low-tech" items, and often the "low-tech" improvements will stimulate further "high-tech" ideas.

3. R&D spending within E&C firms is usually evaluated in terms of estimated downstream competitive advantage. The most forward-looking E&C firms will

TABLE 2. Characteristic Attitudes of Winners and Losers when Facing Technology Change

Winners (1)	Losers (2)
(*a*) Perception of change	
Eagerness to understand	Resistance to orderly change
(*b*) Control of change	
Systems approach to management and budgeting	No central control for major policies, allowing inefficient reaction to change
(*c*) Criteria for new investment	
Competitive advantage	Not market focused
(*d*) Criteria for personal success	
Recognizing that mistakes do happen; rewarding sensible risk taking	Avoiding rocking the boat, and penalizing all mistakes
(*e*) Long-term increase in market share	
Providing clients with designs that consider ease of operations and maintenance	Giving the client the minimum effort to meet contractual obligations (i.e., treating client as adversary)

drive R&D spending as they demonstrate continual success in terms of contracts won due to enhanced R&D capability. Other benefits of an active R&D program include the improved education of the staff in the nuances of new tools and techniques, and the marketing appeal of being portrayed as at the "leading edge" of technological developments. The precise targeting of specific technological tools and techniques will lead to calculating the potential of specific competitive advantages in various E&C market sectors.

4. From the U.S. perspective, several major overseas companies can be identified that have active and comprehensive construction research programs, sometimes executed in company research laboratories, and who are competing in all overseas market areas. While some firms are quite liberal in promoting the more glamorous aspects of construction R&D as an advantage for the parent company, many have planned a fast track for serious improvements to their knowledge base. Some observers feel that the knowledge gained by this research has provided a competitive edge for major construction jobs, but I suspect that we are not likely to find much useful data from an analysis of whether R&D played a large role on past jobs. It would be more useful to establish a systematic industry program to identify the value of R&D factors on current major E&C jobs.

5. Finally, the issue of "corporate culture" attitude towards change must be addressed. Technology-driven transitions in other industries have created major winners and losers, whose attitudes generally can be characterized in Table 2.

Senior management of the "winner" firms will have to use various formal and informal means of communication to prepare all staff for the gradual changes implicit in all the trends discussed in this paper. Also, the industry should consider the explicit targeting of objectives regarding E&C productivity in specific areas. For example, an announced target of reducing ma-

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terials distribution costs by 25% over the next five years on an across-the-board basis would stimulate aggressive innovations by middle managers who would be responsible. Some overseas E&C firms seem to have a "cultural" inclination to use these announcements as the basis for motivating their staff, and perhaps others could borrow this technique. An alternative approach would be to take the lead in promoting a national effort on construction productivity improvement via perhaps a limited partnership R&D effort funded by major corporations with direct interests in E&C business. These are offered to suggest more aggressive technological leadership in matters related to E&C productivity, each of which will require modification of the current "cultural attitudes" with regard to the trends that continue to shape our business.

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