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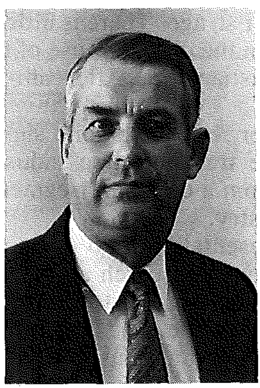

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Perfection of the Buggy Whip

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The First Annual Robert L. Peurifoy Award

Abstract: The buggy whip is a symbol of one of the world's oldest and largest industries—transportation. Little has changed in the buggy whip itself, yet the transportation industry has undergone significant changes. From the evolution of the wheel to man's landing on the moon, several quantum leaps have been achieved. Is the construction industry making the same quantum leaps? Despite significant events, we are executing construction projects in much the same manner as was done in the thirteenth century. If American industry is to compete on a global scale, it must increase its research and development activities manyfold.

Introduction

The buggy whip is a symbol of one of the world's oldest and largest industries—transportation. It is still in use today, although in smaller quantities than a century or so ago. There is little indication that significant changes have been made in the design or use of the buggy whip itself from the days of the pre-Christian era. After all, why try to improve on perfection?

Transportation, however, has undergone significant changes over history. That portion of the transportation industry characterized by the buggy whip has shrunk from a dominant segment to a relatively insignificant influence in the industry.

The purpose of this presentation is to compare the transportation and construction industries from a research and development (r and d) viewpoint. As part of that comparison, a historical reflection of the evolution of transportation may be worthwhile. The latter pages attempt to explore the current status of the construction industry and its needs for research.

History of the Carriage

Some major steps in the evolution of transportation are outlined in Fig. 1. Once man invented the wheel, he had to decide what to do with it. The first major innovation was apparently the principle of the fixed axle-tree, whereby the wheels revolved upon their own center. These early pioneers discovered that the axle fit best in a conical round hole, rather than a square one. The next process in the evolution of the wheel was the necessity of economizing materials that led to a wheel made of three portions: (1) A center (the nave); (2) an outside piece (the rim); and (3) a joining part (the spokes). A double set of rims was finally applied as they would wear more rapidly than the other parts (Straus 1912).

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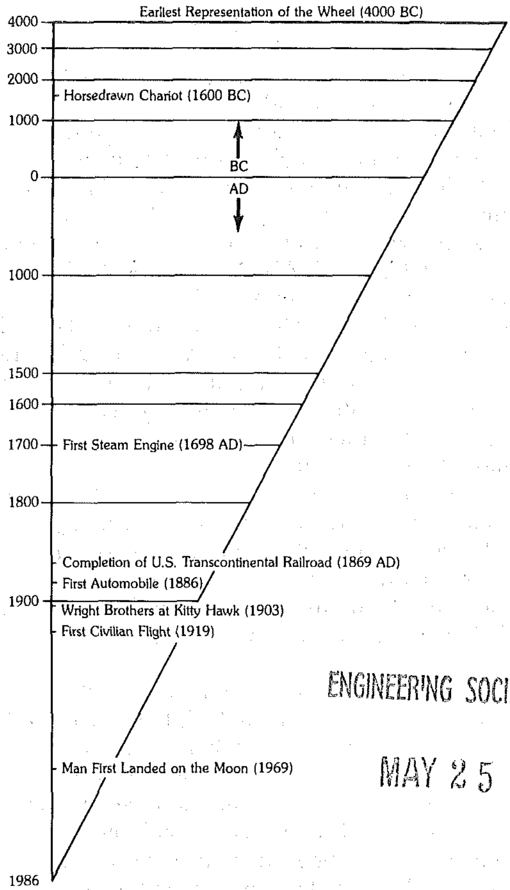

FIG. 1. History of Transportation

The first carriages for which there is documented information were those of the Egyptians and their neighbors, around 1500 to 1600 B.C. Enormous numbers of chariots were mentioned in the Old Testament of the Bible and in historical texts documenting battles where chariots were used. Indeed, after several hundreds of years of evolution from the primitive cart to the chariot, the only difference was in the delicacy and ornamentation of the chariot body (Straus 1912).

Since the inventors of the chariot seemingly were unable to improve on their design, they went about improving the roads. The chariot was to remain basically unchanged for several hundred years while the Romans built great roads, some of which still exist today.

For a time between about 1300 to 1500 A.D., the carriage-building industry was retarded by the fact that the Roman roads in western Europe had fallen into a sad state of disrepair. Added to this fact was the widespread attitude that any "hardy horseman caught lolling in the modern comfort of a carriage was bordering on the effeminate." Laws were passed, as was the case in 1294 under Philip the Fair of France, forbidding people to ride in coaches (Straus 1912).

This, however, did not stop the development of the coach from 1450 to 1600 A.D. The coach of this era had made great improvements since the Egyptian and Roman chariots. It had protection against the weather (i.e., a permanent roof), and certain rude attempts had been made at suspension improvement, which was combined with soft cushions to help minimize unpleasant joltings.

Further carriage innovations were made during the seventeenth century when steel springs first appeared. Also, revolutionary features were added, such as full-length doors with glass windows.

It became obvious during the eighteenth century that only limited further improvements could be made to the carriage body itself, so that legal warfare began over the wording of bills regarding wheel sizes. While coaches were becoming lighter, carts and wagons were becoming much heavier. It was argued that these heavier vehicles, in order to preserve the roads, should have "wheels bound with streaks or tire of the breadth of eight inches at least when worn and not set on with rose-headed nails." Others argued that the way to preserve roads was by using very broad wheels, some of which approached the size of rollers. Legally, it was settled that "the follies of the wheels shall be nine inches from side to side." Arguments were then put forward regarding the correct height for wheels, which became any wheel between two and eight feet high (Straus 1912).

The art of coach building had a dramatic transition during the early nineteenth century when Mr. Obediah Elliott produced his patented elliptic springs that rendered the old heavy perch obsolete. The old, cumbersome machines disappeared, making way for lighter, more comfortable carriages. The question of roads also received more attention. Up until 1810, gravel had formed the basis of road material. James McAdam developed granite and other allied substances, producing surfaces that had not been seen since the Romans had constructed their vast highway system hundreds of years earlier. A new variety of the coach, called the barouche, came on the scene at this time. The barouche was roofless, but had a hood attached to the back, if required, making it "convertible." Coach builders also began to lower the bodies of the coaches so that they could be "entered by a moderate double step instead of the three-fold ladder previously in use" (Fahre 1963).

In spite of all the innovations that brought the primitive cart from its origins of 4000 B.C. to its nineteenth century counterpart, the modern coach, it was inevitable that the "quantum leap" required to literally rocket transportation into space was the invention of the self-propelled carriage. Earlier models were powered by steam, but then in 1886 Carl Benz invented the first gasoline automobile that guaranteed the obsolescence of the horse as a necessary part of transportation.

The second "quantum leap" required in transportation occurred shortly thereafter in 1903 at Kitty Hawk, North Carolina, where the Wright brothers made the first successful flight. The rest of the story we all know. Those two single events occurring in less than 100 years enabled mankind to walk on the moon (Kelly 1943).

These last 100 years in the history of transportation make the previous

5,000 to 6,000 years seem so trivial, as shown in Fig. 1 (Straus 1912; Fahre 1963; Kelly 1943; Randers-Pehrson 1944). It was not all the small innovations to the carriage that moved transportation, but the quantum leaps.

Construction Industry Parallel

Do these same quantum leaps occur in construction? As can be seen in Fig. 2 (Nashert 1975) construction has had significant events. Indeed, many significant events are not included in Fig. 2. Are these events, however, the quantum leaps necessary to revolutionize the industry? Are we still executing construction projects in the same manner as King Henry III in the thirteenth century? Table 1 indicates that not much has changed in the way we execute our construction projects from the days of King Henry III (Colvin 1971). At that time, there was a recording system for labor and materials. Are our systems truly control systems or merely advanced versions of documentation?

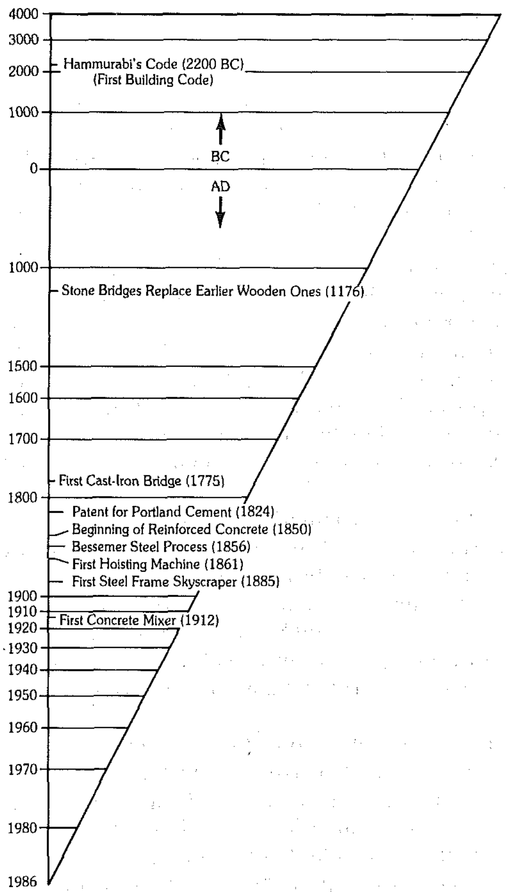

FIG. 2. History of Construction

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TABLE 1. King Henry III Castle Construction, 13th Century

Building materials (1)	Manpower loading, week of June 30–July 6, 1227		Material Cost (4)	Labor Cost	
	Occupation (2)	Number (3)		Salaries or expenses (5)	Amount (6)
Stone	White cutters	56	For 100 loads of lime from Richard Portefer, 40 shillings.	Master Adam, the mason	3 shillings/day
Lime	Marblers	49		Ralph of Popes Hall, master ditch digger	3 shillings/day
Flint	Layers	28			
Chalk	Carpenters	23	For portage of that lime from Dover to the work, 3 shillings.	Clothes for ditch digger	13 shillings, 4 pence
Sand					
Marble	Polishers	15		Thomas, the clerk	3 shillings/day
Timber	Smiths	17		Hugh, the smith	3 shillings/day
Tile	Glaziers	14	For 100 loads of lime from Bartholomew the lime-burner, 37 shillings, 6 pence.	Master William, the carpenter	4 pence/day
Stone Slates	Plumbers	4		Hogge Pollard, labor supervision	4 shillings/8 pence
Shingles	Laborers	220			
Thatch					
Iron					
Lead					
Glass					

Do we have a problem in construction? Apparently, we do. The Business Roundtable, a collection of the nation's largest owners, considers the problem to be one of major importance. The Roundtable has spent millions of dollars in direct funding and manpower in its construction industry cost effectiveness (CICE) project (*More construction for the money* 1982).

International competition in construction markets has intensified greatly over the past 10 years. The recession of the 1980s has led to a severe reduction in the foreign demand for construction at the same time that domestic markets in key exporting countries have declined. The phenomenal growth of projects in the Middle East has come to an end, and no other area has appeared to take up the slack. Bidding for contracts in a smaller international market has intensified and the U.S. share in total construction awards has fallen from over half in the mid-1970s to less than one-third in 1983.

Developing countries, particularly the newly industrialized countries, i.e., Korea, Brazil, and India, have developed significant construction capabilities. National construction capability was initially developed to meet domestic needs and to generate domestic employment. Firms from these countries are now becoming competition in other third country markets. These new competitors have sufficient technical capabilities for conventional construction projects and benefit from substantial personnel cost advantages.

The continuing expansion of this low-cost capability means that the labor-intensive conventional construction market may be permanently lost to the U.S. construction industry. The future prospects of the U.S. industry are clearly tied to superior technology and the ability to deliver services and products not available elsewhere.

The transfer of construction technology to developing countries has influenced international construction markets. A high percentage of graduate research degrees granted by U.S. universities go to students from developing countries. Many construction contracts in the third world now include significant training and technology transfer components. Technology itself has now become a major element of trade in the construction industry. This means that continued advancement and technological leadership are essential to success in international construction.

The competitive advantages of low-cost unskilled and skilled labor resources tend to shift over time. Firms from South Korea have benefited from a relatively inexpensive but highly productive labor force. These firms, however, are now losing ground to Philipine, Turkish, Indian, and other third-world countries' firms that can underbid Korean labor costs on international projects (*Proposal* 1986).

This development has also caused Korean firms to increase attention to higher labor cost markets as in the United States. Six Korean construction firms have set up U.S. corporations, and the Samwham Corporation has won international contracts for construction in Alaska. If the U.S. construction industry is to be faced with cheap labor competition in domestic markets, it will become imperative to maintain international technological leadership in order to hold on to markets at home (*Proposal* 1986).

Perhaps the most ominous competition of all is that of the position of construction in the economic marketplace. As shown by the Business Roundtable's CICE project, the construction percentage of the gross national product has fallen to slightly over one-half of its former value in recent years. One argument given by owners for the decline is that costs are now too high. As a result, owners are simply building less.

Robert H. Miller, Chairman of the Construction Industry Institute and Director of Projects for DuPont, issued the 12 challenges listed here to reflect some needed advancements from an owner's viewpoint (Miller 1986):

> First, how can we see to it that owners do only what's best for them? That they do not exercise their prerogative to change things in the middle of design, or worse, construction . . . and that they make decisions on time and that they actually help with the expeditious completion of their work.
>
> Second, how can we make the quantum leaps so necessary in our industry? Can we design specifically for construction and still get the building or plant we want? That is, can we get more standardization yet with the variety and the custom features that distinguish one design from another?
>
> Third, simplify what we do now, and that means installing, erecting, interconnecting, finishing. Does this mean the use of robotics, because after all that's what robots do best? And can we remove the potential penalty that comes with innovation? There may be more incentive to stay with the tried and true, than to take a chance on the unproven.
>
> Fourth, how can we make sure that the academic world meets our highest priority needs first? We need graduates who are strong in the real world of construction, and we also want them to become strong leaders. We also want to reeducate our managers when technology changes, as it will, and not at just the universities, but all around the country.

Fifth, how can we hold onto a proven project team when the project is over? What a penalty our industry pays, when we have to disassemble what has taken hard experience to develop. What's more, can we have industry standard practices, systems, communications, controls to ease the learning curve when we set up a new project team?

Sixth, how can we get organized labor into the picture as a full partner? What will it take for them to make their organization subordinate to the project organizations? How can we get them to consolidate their crafts and jurisdictions from more than 20 to just one? When can we count on them to share our goals in common?

Seventh, is there a better way in fact for owners to arrange for construction? Can we do better than a multitude of contracts and contract claims? Can we spread the risks and share the rewards better than we do now? I hope so.

Eighth, how can we make sure that government becomes and stays an asset to the industry? Adversarial government may be necessary to correct abuses, but it does not promote much and that's what's needed.

Ninth, can we streamline and simplify all the documents that we use? This means paperwork from agreements to specifications to purchase orders. Every one is clad in boiler plate. I would like to seen an industry-approved body of procedures, just as we have some industry-wide building codes, which by the way also need some attention.

Tenth, can we strengthen project management? How can we make sure that everyone in a project is dedicated to the schedule, budget, and the logistics in general? Can we get quality without having QA people?

Eleventh, how can we make sure our people become skilled and stay skilled? What can we do about substance abuse and other such problems?

And, finally, how can we make sure we in the industry have all the information we need, such as a data base on materials, tools, equipment, and their characteristics and costs? How about standardizing on all kinds of terminology, even to the point of sharing systems and data? All these challenges are long overdue.

Role of Research and Development

The basic problem in the lack of construction research and development (r and d) is, very simply, one of no effort. Regardless of the excuses, there has been virtually no organized r and d activity devoted to improving the erection process of construction projects. The numbers tell a rather revealing story.

To place the construction industry into perspective, it is appropriate to examine other industries and their research efforts. Table 2 is taken from the July 8, 1985 issue of *Business Week*, and shows some r and d expenditures for various industries. It is obvious that construction is inconsistent with other U.S. industries. The simple fact is that other industries invest a great deal more of their resources into r and d. Indeed,

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TABLE 2. 1984 Research and Development Expenditures

Industry (1)	Sales (Billions $) (2)	R&D (Billions $) (3)	% (4)
Aerospace	61.8	2.9	4.8
Automotive	169.2	5.7	3.4
Chemical	119.3	3.6	3.1
Drugs	53.6	3.8	7.1
Defense	—	40.0	—
U.S. Construction	350.0	—	—

construction research is funded at a level much less than 1% of gross sales, whereas other industries' funding levels are in the range of 3% or more.

The question then arises: Where does construction fit as a level of funded effort? The numbers in Table 3 provide an appropriate point of departure. Despite the establishment of the Construction Industry Institute (CII) and the National Science Foundation's recent commitment to construction research funding, it is doubtful that we could identify as much as $10,000,000 in research efforts dedicated to the construction erection process. In comparison with other industries, such efforts appear to be severely limited in size. Therefore, with limited resources it is necessary to maximize effectiveness in order to develop better information and techniques. Perhaps by examining the uniqueness of the construction industry, research programs can be designed that are compatible with those characteristics.

Some of construction's unique characteristics are listed in Table 4. The industry is fragmented. As shown in Fig. 3, a construction project involves many parties, although none has dominant control over its success. The industry has a transient nature, both in the projects and the personnel assigned to a given project. The system, whereby particular activities such as design and construction are separated among the participants shown in Fig. 3, hampers the development of a coordinated research effort. Project activities also have a nonrepetitive feature, so that benefits from the learning curve are diminished. Moreover, there is an abysmal lack of data in published literature and even in many company files. Construction cannot be easily modeled in a laboratory. Appropriate information is needed from the projects themselves. Above all, communication is difficult. It is rare that innovations and successes from a project are shared with others in the industry or even among members of the same company. Thus, even with creative and capable people in the industry, there is a

TABLE 3. Approximate Construction Research and Development Funding

Source (1)	Amount (millions $) (2)
National Science Foundation	1
Other miscellaneous funding	2
CII direct support	1
CII indirect support	5

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TABLE 4. Construction Research and Development Factors

Factor (1)
Fragmentation
Transient nature
The system
Nonrepetitive lack of data
Communications

dearth of information available to build a research base to develop advancements from past experiences.

These characteristics are perhaps overstated. There are some sophisticated companies. Nonetheless, the characteristics described probably are representative of the industry as a whole.

Recently, Clarence J. Brown, the deputy secretary of commerce, was recommending that the National Bureau of Standards terminate their fire and building research. He said, and I quote, "While these programs have been carrying out good research and providing useful services, the technology is not changing as rapidly as it is in many other fields. Nor are these areas subject to intense foreign competition . . ." (*Hearings* 1985).

Obviously there is much disagreement with Deputy Secretary Brown's statement. Foreign competition is definitely a threat. Above all, the reason that the technology has not changed is that virtually no resources have been committed to cause it to change as has occurred in other industries. For example, a typical r and d budget for many U.S. industries approaches 3% of gross sales. In poor economic times, the r and d budget increases because, in the words of one executive, "The thing that's driving us is very simply that we want to survive" ("R&D scoreboard" 1985). The total construction r and d expenditures in the United States are negligible. Ironically, it is reported that many Japanese companies have r and d budgets around the 3% level. We know of their developments in tunneling and other heavy equipment. We also know that they are aggressively

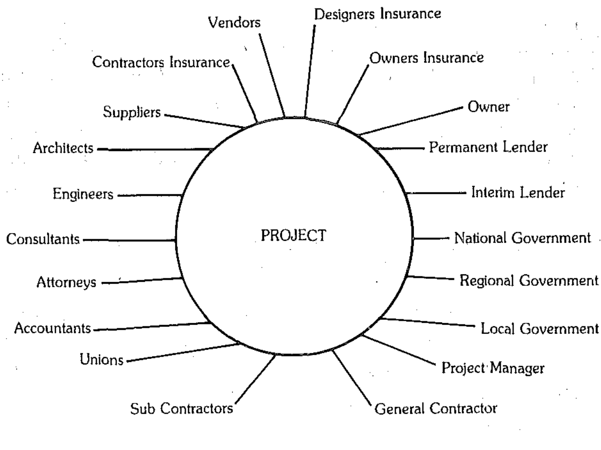

FIG. 3. Parties to a Project

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pursuing development of computer-controlled and automated machines to lay rebar and to place and finish concrete, as well as many other construction activities. If American construction is to compete, the industry must increase its r and d activities manyfold.

What Type of Research and Development?

If increased research and development is at least a partial answer, it is reasonable to assume that a directed effort will be more effective than random activities. Thus, it may be worthwhile to look at possible r and d directions.

One stated area of concern is labor productivity. There are many indicators that productivity has declined. The problems are worldwide in nature. No country has been immune. The United States has been impacted perhaps more than other countries.

There is little doubt that the relative influence of labor costs on total project expenditures has increased. Historically (certainly in the days of the Egyptian pyramids), labor has been a relatively inexpensive commodity, and the simple solution to quality or schedule problems was to increase the size of the work force. The major focus of cost control in both design and construction was in minimization and utilization of materials. Mass production and technological advances in materials supply have combined with increased wage rates so that labor is now the most expensive and the most volatile resource affecting a project's success (Tucker 1986).

To consider increases in labor productivity, it is perhaps useful to speculate on the utilization of worker time. Table 5 illustrates percentages of worker effort. As a point of departure, it is estimated that 40% of the average worker's time is actually spent in productive ways. Antiquated methods account for 20%, another 20% is lost to administrative delays, and work restrictions make up another 15%. Perhaps 5% or so of the total workday is spent on personal business.

Research and development programs need to be funded to reduce the amount of productive time lost to the antiquated methods and the administrative delays. These and other areas of r and d potential could be divided into two areas: (1) Efficiency improvements; and (2) new methods for current operations. A third area also holds potential new designs and new materials to radically change the construction process. Thus, there appear to be three distinct areas of needed r and d: (1) Efficiency improvements; (2) methods improvement; and (3) radical changes.

In the area of efficiency improvements, the U.S. construction industry is already addressing many of the concerns. Motivation programs and the

TABLE 5. Typical Craftsman's Time

Activity (1)	Amount of time (%) (2)
Productive	40
Unproductive	
Administrative delays	20
Inefficient methods	20
Work restrictions jurisdictions	15
Personal	5

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creation of quality circles are two notable areas that have drawn attention. Improved communications with computers have also helped to improve efficiency.

Of significant impact has been the construction industry cost effectiveness (CICE) project, a five-year study under the direction of the Business Roundtable. The project generated over 200 recommendations for owners and contractors that could be implemented and save the industry possibly $10 billion annually. Surprisingly enough, the majority of the recommendations involve ways to manage construction projects better—more careful planning, improved communications, more effective supervision, more thoughtful personnel and manpower policies. More than half the time wasted during construction, the study shows, is attributable to poor management practices. A great many of the recommendations are aimed at executives of companies that commission the building of industrial facilities, commercial structures, and power plants, in other words, the owners. The CICE project concludes that only if owners who pay the bills are willing to take extra pains and pay the often small extra cost of more sensible methods will they reap the benefit of more construction for their money (*More construction* 1982).

An important outgrowth of the CICE project is the Construction Industry Institute (CII), a national organization of owners, contractors, and academicians who have joined forces to conduct r and d activities in the construction industry. The CII has as its sole purpose to improve the cost effectiveness of the U.S. construction industry. In the area of efficiency improvements, the CII has established task forces in the following related areas: (1) Constructability; (2) cost/schedule controls; (3) design effectiveness; (4) education and training; (5) employee effectiveness; (6) materials management; (7) quality management; and (8) safety (*Annual report* 1985).

A second area of r and d emphasis can be found in the need for new methods of construction for current operations. The CICE study noted that many needs exist for significant improvements in construction technology (*Construction technology* 1982). In particular, dramatic economic gains might flow from research and technological improvement in several areas: (1) Piping; (2) installation of mechanical equipment; (3) electrical; (4) structure; (5) vessels; (6) heating, ventilating, and air conditioning (HVAC); (7) installation of special equipment; and (8) instrumentation.

New methods also include the areas of robotics and automated construction equipment, computer applications, modular design and construction, and materials development. In the 1980s, a new generation of robots and automated systems has entered the market that are able to accept and process input from vision, force, and other sensors. Research labs are now turning to the problem of vehicle mobility. Some machines already used on construction projects have sensors and processing abilities that approach robotics, such as automated rebar replacement and paving machines, tunnel-boring machines, automated forklifts, and ditching and grading machines guided by lasers with computerized controls. Automated pipe fabrication systems include automatic pipe bending and welding. In Japan, construction robots are being used for tasks such as spraying fireproofing on structural steel, lifting and positioning steel beams, and finishing concrete (Evans 1986).

The construction industry has seen recently the introduction of computer-aided design (CAD) and computer-aided drafting in engineering. The use of computers is more commonplace now in project management and purchasing. What is needed is total integration of these systems, including the fabrication shops and construction sites by the use of a data base approach.

The ability of expert (or knowledge-based) systems to perform diagnosis of problems, historically requiring human expertise, has opened an entire field of computerized problem solving that could be applied to the construction industry. Knowledge-based design systems could give engineers creative perspectives on design variables such as soil, traffic, or seismic loads on bridges. Knowledge-based systems could also make schedules easier to maintain and monitor by predicting how jobs are likely to fall behind.

Modular design and construction is a concept that is impacting the construction industry, with applications extending from industrial piping systems all the way to assembly-line house construction.

Materials development has long received significant attention. Polymers have been used in concrete now for some 20 years, but current research on microadditives has proven successful in reducing costs by reducing the amount and size of additives required in the cement. Radiation from a laser can be used to melt shallow layers of materials on road surfaces for crack repair. Researchers have been learning how to blend and bake ceramics into materials that are "strong as steel, hard as diamonds, and tough enough to withstand a blast furnace" (Moavenzadeh 1985). The Japanese are developing a ceramic known as precastable autoclaved lightweight ceramic (PALC), which is used in the home building industry. Japanese houses built of PALC are several times stronger than their U.S. counterparts (Moavenzadeh 1985). Cathodic protection technology is important for the preservation of materials in existing structures. The Norwegians are developing a totally automated welding process that can fuse two 8-in. pieces of pipe together in 30 to 40 seconds. The Norwegians also are working on a process that can improve the interior surface of pipe fittings by 1,000 times the life by means of using tungsten carbide as an internal surface agent (*Proceedings* 1986).

The final category of needed research is perhaps the most important. This category relates to new designs and materials to radically change the construction process. This is the area where the greatest contributions of quantum leaps will occur.

New ideas can come from current concepts such as inflatable air structures. What if the building of the future did not require a structure, but was supported by cables and positive air pressure? What if the cables doubled as the insulated electric wiring and the air pressure was temperature controlled? There would be no need then for all of the space taken up by cable trays and HVAC. This could be accomplished in conventional structures by routing utilities through beams and columns. Even though structural shapes have some efficiencies, pipes or tubes might serve dual purposes. Remote instrumentation might do away with some wiring. New ceramic materials would do away with corrosion.

There are certain new processes already impacting the construction industry, such as precast concrete, segmental bridge construction, and roller-compacted concrete dam construction. Radar surveying has done away with the old laborious transit, rod, and chain. Fiber optics have changed electrical and instrumentation systems.

The construction industry, however, has a need for more dreamers. Construction research demands more quantum leaps similar to transportation. Wilbur Wright once said, "To try to build one (horseless carriage) that would be any account, you'd be tackling the impossible. Why, it would be easier to build a flying machine" (Kelly 1943). We need more people in construction research who dream that way.

Causes and Solutions

Obviously, there are plenty of challenges and dreams for those with the pioneering spirit necessary to achieve hoped-for quantum leaps. However, the problems we face today in construction are extremely complex. Some causes of our problems are listed, along with possible solutions in Table 6. The very nature of projects has grown to be complex. The industry, with its fragmented nature, has a difficult problem in communications. For years, the academic community paid little attention to construction methods, designs, or materials. The lack of r and d funding has been a major stumbling block. In short, both the academic and research communities have ignored the increasing construction process complexities until recent years.

The solutions to these problems are finally being addressed today, although the level of effort is still insufficient. The Business Roundtable's landmark construction industry cost effectiveness project greatly increased the awareness of both owners and contractors. The CICE recommendations to the industry, if implemented to only a small degree, could save billions of dollars. The Construction Industry Institute is a logical outgrowth of the CICE project, and promises to change not only the r and d efforts of the industry, but to change the approach to projects in all aspects, from contracting methods and design to constructability and safety and even to education and training and employee effectiveness. The trade associations are an important group for the implementation activities of both CICE and CII.

Along with the implementation efforts, communications have improved. The academic community has greatly expanded its efforts by starting new educational and research programs. The new programs and enthusiastic interest of the faculty in the nation's colleges and universities have

TABLE 6. Causes and Solutions

Causes (1)	Solutions (2)
More complex projects	Increased communications
Fragmented industry	Increased academic attention
Academic ignorance	Increased research and development
Lack of research and development funding	

attracted more students into graduate engineering programs in project management and other related fields.

The third solution to the industry's problem is also under way with the development of funding for r and d in construction. The National Science Foundation, the Construction Engineering Research Laboratory, and the CII research projects are the spearhead of increased awareness and attention to construction. Although the effort is small, by at least an order of magnitude, it is nonetheless a positive step.

As a closure, the following thought is offered. The nation has the perfect buggy whip. It was perfected many years ago. But to be honest, even the horses look askance at those who would prefer to use it. The construction industry must keep its nose to the grindstone, but must also remind itself to look up—those blue skies are full of dreams and challenges not yet met. After all, even with the perfect buggy whip, man would still prefer to fly.

Appendix. References

Annual report 1985. (1985). Construction Industry Institute, Austin, Tex.

Colvin, H. M. (1971). *Building accounts of King Henry III*. Clarendon Press, Oxford, England, 472 pp.

"Construction technology needs and priorities." (1982). *Construction industry cost-effectiveness project report B-3*, The Business Roundtable, New York, N.Y.

Evans, J. M. (1986). "Automation in construction." *Robotics*, 2(2), 85–86.

Fahre, M. (1963). *A history of land transportation*. Hawthorne Books, New York, N.Y., 105 pp.

Hearings on the mission and future of the National Bureau of Standards. (1985). House Subcommittee on Sci. Res. and Tech., Testimony of Clarence J. Brown, held October 1, 1985.

Kelly, F. C. (1943). *The Wright brothers*. Harcourt, Brace and Co., New York, N.Y., 340 pp.

Miller, R. H. (1986). "Perspectives of the Chairman." Address to the Construction Industry Institute, *Proc. 2nd CII Annual Conf., Asheville, North Carolina*, Construction Industry Institute, Austin, Tex.

Moavenzadeh, F. (1985). "Construction's high-technology revolution." *Tech. Review*, 88(7), 32–41.

"More construction for the money." (1982). *Construction industry cost-effectiveness project report*, The Business Roundtable, New York, N.Y.

Nashert, W. (1975). *America's builders*. Southland Press, Los Angeles, Calif., 262 pp.

Proceedings of the sixth annual convention. (1986). Society of Piping Engineers and Designers, Houston, Tex.

Proposal to establish a committee of the Building Research Board on research and development to meet the challenge of international competition in the construction industry. (1986). Natl. Acad. of Sci., Natl. Res. Council Commission on Engrg. and Tech. Systems, Washington, D.C.

"R&D scoreboard." (1985). *Business week*, 2909, 86–96.

Randers-Pehrson, N. H. (1944). *History of aviation*. National Aeronautics Council, New York, N.Y., 132 pp.

Straus, R. (1912). *Carriages and coaches: Their history and their revolution*. J. B. Lippincott Co., London, England, 309 pp.

Tucker, R. L. (1986). "Management of construction productivity." *J. Mgmt. Engrg.*, ASCE, 2(3), 148–156.

J. Constr. Eng. Manage., 1988, 114(2): 157-171