GOALS FOR BASIC RESEARCH

IN CONSTRUCTION

A Report on a Workshop

Sponsored by

THE STANFORD CONSTRUCTION INSTITUTE

and Funded by

THE NATIONAL SCIENCE FQUNDATION

Grant ENG 74-23lll

Boyd C, Paulson, Jr.

July, 1975

PREFACE

In the years ahead, construction will be challenged by increasingly difficult and complex problems in both engineering and management. This report and the workshop upon which it is based offers the industry a challenge of another sort: to establish and develop basic research in construction, and particularly in the management of construction, as one way to overcome what otherwise might become insurmountable obstacles to the industry's continued prosperity.

The author's role in this report was merely to write down the findings and conclusions of the participants in a workshop held at Stanford University in April, l975, Although he was very proud to be associated with this group, he can lay no claim to the thinking and ideas herein. He does accept responsibility, however, for any biases, misrepresentations or distortions that may have inadvertently crept into the writing.

The ideas that are reported here reflect the collective thinking of a uniquely distinguished and exceptionally capable group of leaders in and associated with the construction industry. Specific research topics identified in Chapters III and IV should therefore be carefully scrutinized by anyone interested in doing basic research in construction. The recommendations in Chapter VI deserve careful consideration by any individual or organization with responsibility for leadership in helping to solve the industry's problems.

The sponsors of the workshop and the author of this report gratefully acknowledge the U. S. National Science Foundation, Grant No. ENG 74-23lll, for providing funds that made this venture possible. The author as principal investigator under this grant expresses sincere appreciation to his colleagues at Stanford and to the members of the Steering Committee for their generous help in preparing for the workshop. We are especially grateful to the many leaders in industry, government and education who contributed their own time and personal expenses to participate.

Boyd C Paulson, Jr.

Stanford, California

July, 1975

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CHAPTER I

BASIC RESEARCH AND THE CONSTRUCTION INDUSTRY

This report summarizes results of a policy-level workshop attended by a distinguished group of construction people representing owners, designers, contractors, government agencies, and educators. These industry leaders spent two full days in frank, far-reaching discussions in an attempt to define basic problems that the industry will face in the years ahead. The April, l975 workshop was funded by the National Science Foundation and was sponsored by the Construction Institute at Stanford University.

More specifically, the workshop was designed to (I) identify basic research needs in the management of construction, and (2) define and formulate goals for basic research in this area. The participants' efforts were concentrated in four general subject areas, including (I) manpower and organizational development, (2) management methodologies, (3) innovations in construction methods, and (4) construction industry dynamics.

This chapter describes the nature of basic research and discusses its relationship to construction. It then qualifies the scope and objectives of the workshop, and gives an overview of the remainder of the report.

Basic Research in Construction

The meaning of "basic research" is subject to continuing debate. And to link the terms "construction" and "basic research" would appear to invite a paradox. "Construction" implies designing and building facilities to meet specific needs. Most of the industry’s research advances come from solving specific problems when encountered on new projects; often this involves applied scientific and engineering research of a very high order.

On the other hand, "basic research" implies investigation of fundamental concepts or principles, but with no conscious intent that it lead to tools which are expected, much less guaranteed, to solve problems. For example, Einstein’s now famous but once obscure basic research led to a statement of the equation relating mass and energy. 8ui it took a long evolution through further basic research and then applied research and development to the eventual engineering, design and production that we now see in nuclear power plants, atomic submarines, and machines that cure cancer.

In defining "basic research" in construction, one could argue that since this is a very applied field even within engineering, then research that might not be viewed as basic research in the context of more theoretical fields such as physics, chemistry, or even engineering mechanics might still legitimately be called "basic research" in construction. It is worth noting that the other fields mentioned have been distinct disciplines for at least half a century. Nevertheless, certain characteristics of basic research should still apply to construction.

There are many ways to describe basic research. Some characterize it as "long-range" and "theoretical", as contrasted to short-term applied problem solving. Others say that it means the problem itself has not been defined yet. Perhaps more relevant than a general definition of basic research would be an assessment of its role. Dr. Vannevar Bush, head of the World War II Office of Scientific Research and Development, made such a statement in his 1945 report to President Harry S Truman entitled, Science: The Endless Frontier (2)* In explaining the need for Congress to establish an agency to support basic research, he said:

> Such an agency, moreover, should be an independent agency devoted to the support of scientific research and advanced scientific education alone. Industry learned many years ago that basic research cannot often be fruitfully conducted as an adjunct to or a sub-division of an operating agency or department. Operating agencies have immediate operating goals and are under constant pressure to produce in a tangible way, for that is the test of their value. None of these conditions is favorable to basic research. Research is the exploration of the unknown and is necessarily speculative. It is inhibited by conventional approaches, traditions, and standards. It cannot be satisfactorily conducted in an atmosphere where it is gauged and tested by operating or production standards. Basic scientific research should not, therefore, be placed under an operating agency whose paramount concern is anything other than research. Research will always suffer when put in competition with operations.

Bush’s statement predated by five years the establishment of the National Science Foundation. As overseer of much of the World War II research effort, including the atomic energy research that led to the Army’s Manhattan Project, he was intimately familiar with the role of basic research in breaking new ground in which to plant seeds of applied research and development. With a few changes of words, most of what he said would apply directly to construction.

Many would still object that the construction industry simply cannot afford the "luxury” of basic research while clear and urgent problems go begging for answers. To some, basic research conjures up images of impractical, "blue sky", "ivory tower" theoreticians whose seeming unconcern for potential

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*Numbers in parentheses refer to the list of references at the end of this report economic returns borders on being irresponsible, And yet, this intolerance for risk and delay is ironic in an industry which itself has its share of gamblers.

Others, however, argue that construction must invest in basic research if it is to cope with increasingly large and complex projects in the future and reverse its declining productivity compared to other industries. Taking this view, the workshop sought to define the role of basic research in construction and to outline some promising areas of investigation.

The Construction Industry

The construction industry itself meets another meaning of paradox, that of "a state of affairs with seemingly contradictory qualities". In its share of the nation’s gross national product it is the largest industry, but the vast majority of its hundreds of thousands of participants are small businesses. Its firms are intensely competitive among themselves in the best traditions of the classical free enterprise system, yet compared to other industries its technological advances sometimes appear trivial.

Construction is highly fragmented and sometimes divisive, yet in response to pressing national needs such as a major war effort, few industries can mobilize resources more quickly, Each of its elements -- designers, constructors, regulators, consumers, suppliers, crafts -- can be highly skilled in its own area, yet there is little general perspective on how all the pieces fit together. There really is no central focus.

Indeed, there is no clear definition as to just what is the construction industry. Certainly it must include the hundreds of thousands of general and specialty construction contractors. But to really understand the industry, one must extend its scope to include designers of facilities, materials suppliers, and equipment manufacturers. Labor organizations add still another dimension, as do public and private consumers of construction services, many of whom have considerable construction expertise of their own. Government regulatory agencies in such areas as safety, health, employment practices and fair trade also play an increasingly important role.

The construction industry is very custom-oriented; there is a strong feeling that if something is unique, it is better. Yet this also means that the industry has been slow to respond to the benefits of mass production. Its structure is highly specialized and layered, with complex interlocking interests and traditions. Its character makes it highly effective on practical or project matters, yet often ineffective on general or program matters.

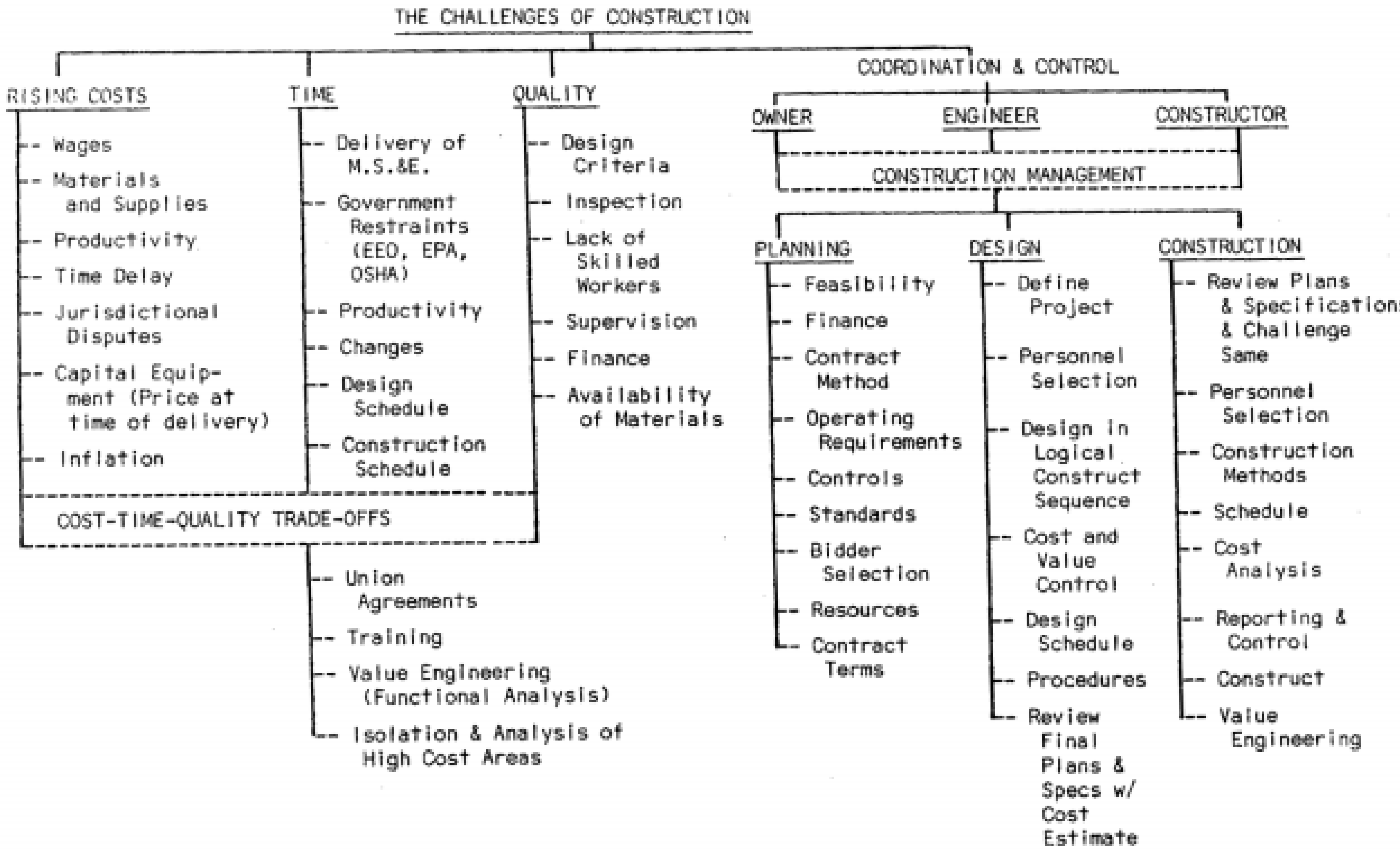
Needless to say, basic research falls in the latter category of the less practical and more general and speculative. Accurate data are not available, but it is generally assumed that only a fraction of one percent of the industry’s gross revenues are invested even in applied research let alone basic research. This is in strong contrast to industries such as electronics, where an estimated 20% of revenues go into research and development. This, in turn, at least partially accounts for the quantum leaps that industry has taken in recent years.

It has been observed that the construction industry is almost completely incentive-oriented. If there is little research and almost no basic research, it is likely that there is little incentive for investing in it. This probably results in part because advances in construction tend to result from innovations -- or "better ideas". Most of these cannot be protected either by secrecy or patents and thus disseminate rapidly through the industry. Thus there is little incentive for one firm to invest heavily in research that can soon be expected to equally benefit its competitors. If there is to be an increased research effort in construction, and particularly a deliberate move into basic research, incentives will most likely be provided through non-traditional means. This subject will be examined further in Chapter V.

Challenges in Construction’s Future

The most profound recent developments in construction are seen as the increasing size of many of its projects and organizations, the increasing technological complexity of such projects, more complex interdependencies and variations in the relationships between its organizations and institutions, and proliferating regulations and demands from government. At the project level, management has just begun to integrate design, procurement and construction into one total process. There are now and will continue to be shortages of resources, including materials, equipment, skilled workers, and technical and supervisory staff. There will be more and more governmental regulation of (I) the safety of the design and of field construction methods; (2) the environmental consequences of projects; and (3) personnel policies at all levels. Management must also cope with the new economic and cultural realities resulting from inflation, the energy crisis, changing world develop-ment patterns, and new societal standards. These trends have been accelerating and will most probably continue into the future, Figure I summarizes some of the elements that are involved.

Clearly economic difficulties and increasing shortages of materials and other resources play a major role in the problems now facing the engineering and construction of today’s projects. But this is not to say that engineers and managers must sit hopelessly by while urgently needed projects run out



Developed by
Boyd C. Paulson
Vice President, Construction
Utah International, Inc.

FIGURE 1

of control or are abandoned altogether, On the contrary, it is all the more critical that the skills of project engineers and managers improve and that they have better tools with which to work, so that they can optimize the planning and control of resources that are available, and better cope with the challenging realities imposed by new economic constraints. In spite of continuing economic problems, there is an ongoing need for the construction industry to expand and improve its capabilities and its scope of operation to meet changing and, in the long run, growing demands for its services.

The potential benefits from improved methods of accomplishing the management of future projects are worth seeking. For example, knowledgeable sources have estimated that the costs of delay on a major two-unit nuclear power plant exceed $200,000 per day. Consider this in view of current 10-to-11-year design-and-construction times for such projects, and multiply it by the 50-plus powerplants in the active concept, design or construction phases at any one time. The potential savings thus derived are for just one segment of the industry. Similar conclusions may be drawn when looking at urban rapid transit systems, refinery and chemical plants, pipelines, mineral resource developments, and the design and construction of projects to implement the advanced technologies that will be required if the United States is to achieve energy independence.

Time; money; equipment; technology; people; materials, These are resources. Organize them into activities, perform the activities in a logical sequence, and one has a project. Whether it is to construct a cottage at the beach, or design and construct a billion-dollar rapid transit system, the sequence is the same. Practice has been to assign total responsibility for all of this to one person: a project manager. Over the years, this has proven to be a good system. Intelligent, competent, experienced project managers have succeeded in "putting it all together". Can they continue? Why the past decade’s failures? Now, more than ever, planning and control of the resources required to successfully accomplish today's increasingly complex projects remain among the most difficult and perplexing management responsibilities.

Scope and Objectives

Before proceeding to discuss the findings of the workshop, it is important to recognize the qualifications and limitations that were assumed in its scope and objectives, and consequently in this report. First, the focus is primarily on basic research as defined in the context of construction. This differs from but is complementary to earlier efforts (I, 3, 4, 6, 7, 8, 9, IO, II). The workshop's purpose was not to assess general and applied research and development in construction. The latter, of course, does account for the vast majority of research carried out in this field. Second, within construction engineering and management in general, emphasis was primarily upon management, assuming that it is indeed possible to separate the two. Finally, the basic research topics identified in Chapter III are drawn primarily from the above-mentioned workshop. For example, it was well beyond the scope of this effort to attempt a comprehensive survey of construction organizations.

Since the participants were deliberately selected for their stature and experience, it *is* believed that a reasonably accurate and balanced understanding of the industry's main problems did evolve. Nevertheless, one can by no means guarantee that the findings of the workshop precisely reflect the needs of construction as a whole. Indeed, since there was deliberately no attempt to reach consensus within the workshop, the reader must not assume that this report will necessarily represent the individual position of any one of the workshop's participants.

There will be many who will criticize both the overall content and the specific research topics in this report for being incomplete. It is readily admitted that this is so, and indeed this fact should be emphasized, Even it were possible to produce exhaustive lists of needs, it was felt that the effort would rapidly reach a point of diminishing returns as increasingly marginal additions were made. In fact, past efforts of this type have been criticized for producing long "shopping fists" of topics where reams of minor items distracted from those that were really critical. The topics listed in Chapter III are the ones that, at least to some workshop participants, were important enough that they came readily to mind. In a sense, then, the topics that will be given are as remarkable for what they do not include as for what they do. In any case, they *are* presented at face value. Again, it is recognized that only a small, select, and possibly non-representative sample of viewpoints was present at the workshop.

Overview of Report

The remainder of this report is divided into five main parts. Chapter II deals with the objectives, structure and content of the workshop upon which this report is based, Specific problem sources and basic research areas that the workshop's participants thought to be important *are* identified in Chapter III. On the basis of the topics in Chapter III, Chapter IV attempts to evaluate priority guidelines for basic research in construction, and from this sets priorities for those topics thought to be most important. Chapter V discusses implementation, both in terms of where and how such research could be conducted, and in terms of needs and potential sources of funding. General conclusions and policy recommendations are given in Chapter VI.

CHAPTER II

THE WORKSHOP ON BASIC RESEARCH IN CONSTRUCTION

This chapter has two main functions. First it provides an overview of the objectives, organization, structure, and content of the workshop on basic research into the management of construction that was held at Stanford University on April 3 and 4, l975. Second, it outlines the rationale used in the remaining chapters for distilling areas appropriate for basic research from the general problem areas considered in the workshop.

Purpose

The workshop was designed to bring together a select group of knowledge-able, experienced and well respected leaders from the construction industry, from on-going users of construction services, from government agencies involved in construction, and from universities. Its purpose was to define and formulate goals and priorities for basic research In construction in areas that have potential for significantly contributing to the future development of the industry. The focus was on manpower and organizational development, management methodologies, innovations in construction methods, and construction industry dynamics, but the format was designed to encourage a full spectrum of input from each participant.

Organization

The workshop was sponsored by the Construction Institute at Stanford University. Stanford coordinators were Professors John W. Fondahl, Clarkson H. Oglesby, Henry W. Parker, and Boyd C. Paulson, Jr. A substantial portion of the organizational effort was attributable to the workshop Steering Committee, including Mr. Chandra K. Jha, Vice President of Tishman Construction Company, Mr. Alden P. Yates, Vice President of Bechtel Power Corporation, and Professors Keith C. Crandall of the University of California at Berkeley, Daniel W. Halpin of the Georgia Institute of Technology, and William A. Litle of the Massachusetts Institute of Technology. The Steering Committee met at Stanford in December, l974 for initial planning, gave valuable input as plans were further refined, and held a follow-up meeting soon after the workshop.

Participants

Because this was a policy-level workshop, participants were drawn from the upper levels of their respective organizations. They were experienced and competent in both technical *and* managerial aspects of their fields, and were respected for their accomplishments. Appendix A lists the participants by name, position, and organization. Representatives from the following sectors participated in the workshop;

1) The construction industry itself, with a cross section from progressive firms involved in design and/or construction in the heavy, building, and industrial branches. This group also included top officials from four important construction industry associations.
2) Users, primarily from industry, that have developed their own high level of expertise in the on-going procurement of construction services.

3) Government agencies, including those involved in design, building, funding or procurement in construction.

4) Faculty members from university programs in construction engineering and management that not only are active in construction education, but also have a demonstrated or potential capability in construction research.

In addition to representatives from these areas, other individuals were involved who could lend a special perspective on some of the problems under discussion. These included two representatives from the construction press who each have had broad exposure to construction projects.

It is recognized that two important sectors of the construction industry were not directly represented. These included, first, suppliers of materials, equipment and services that support construction operations; and second, representatives from construction labor organizations. These omissions were made to keep the number of attendees to a manageable workshop size, and to somewhat narrow the focus of the workshop. Although these are important sectors that certainly could have made valuable contributions, it was felt that a more limited workshop would have a greater chance of successfully formulating some initial basic research goals. Another important sector, designers, was represented through the dual roles of several participants.

Structure

The workshop was subdivided into four half-day sessions, each focusing on a separate subject area. Rather than try to second guess the areas in the management of construction that the participants might think would have the highest priorities, the planners deliberately tried to provide a structure in which many ideas could come out in the two days available, The limited structure that was given to both format and subject matter was intended to make sure that a wide variety of areas could be examined and that each participant would have ample opportunity to inject his thinking. Clearly there was not much time for detailed discussions of the state of the art or for trying to obtain consensus. Rather, the thrust was on defining concepts, ideas, goals and priorities that reflect critical needs for basic research in the management of construction in the decades ahead. Details of this structure are reflected in the agenda reproduced in Appendix B.

Each half-day session began with the whole group meeting for brief keynote statements from two or three individuals who in turn led a discussion involving all participants. Apart from the keynote openers, there were no prepared papers or speeches. The keynote openers were primarily intended to stimulate thinking and get a spectrum of ideas before the participants for the small group sessions described next.

Four chairman were appointed for the subgroup meetings in each half-day session. The duties of the chairman fell into two main areas. First, during the keynote discussion preceding subgroup meetings, the four chairmen had to be particularly attentive to note key ideas and problem areas that were identified. They could also supplement these with ideas that they thought of in preparing for the workshop. Then, in the break between the keynote discussion and the subgroup meetings, the four chairmen met for about IO minutes to briefly compare notes and make a logical allocation among the areas so that each subgroup meeting would not concentrate on exactly the same set of topics. This clearly was a crucial step, and it was a lot to ask in such a short period of time. Nevertheless, although the process was not expected to be perfect, it was much better than having the planners try to anticipate and "preprogram" what the participants would think to be most important.

The second duty of each chairman was chairing his subgroup’s meeting. In this it was important to try to keep the group on the subject and to try to draw out discussion on several of the points that were identified rather than try to reach consensus or any one of them. In keeping with the purpose of the workshop, the groups were trying to identify problems rather than solve them, to generate ideas, and get some feeling for priorities. Insofar as the subgroup meetings yielded good, wide-ranging discussions focusing on several specific points, the purpose was well served.

Most of the time in each half-day session was allocated to these small subgroup meetings. *Each* subgroup focused on separate sets of topics within the broad subject area of the overall session. Assignments of individuals to subgroups were designed to achieve the following objectives: (1) Provide a balance between participants from the construction industry and related associations, industry users of construction services, government agencies, and universities. 2) Remix the subgroups for each of the four sessions to periodically recatalyze the discussion process, 3) Keep the subgroups approximately equal in size.

In each of the subgroup meetings a summarizer was assigned to critically abstract, evaluate and document the ideas and concepts that were discussed. One or two non-participating post-master’s degree students were also present to more thoroughly record the full content of each subgroup meeting. At the end of the subgroup meetings for each half-day session, all participants reconvened to hear the summarizers briefly review the major problems, ideas and priorities their subgroups discussed and found most important, and to enable the group as a whole to compare and evaluate the subgroups’ conclusions.

Planned Content

The overall content planned for the workshop was subdivided into four general subject areas. These were deliberately defined in broad terms in order to encourage a full spectrum of input from the participants. It was left to the participants themselves to identify specific topics most in need of research and development.

Before outlining the general areas, it is important to again emphasize that the workshop was to focus on identifying and defining problems, not on solving them. Also, each subject area was to recognize the interplay of design and construction in the overall process of engineering and management from concept to completion. Where appropriate, each was also to consider both project and higher levels of organization.

With this background, the proposed subject areas were as follows:

1) Manpower and Organizational Development

Two major categories were to be included here. First was training, development and evaluation of skilled technical and managerial talent for construction. Second was understanding and improvement of organizational structures and team building for construction projects.

2) Management Methodologies

This area included improving analytical and administrative tools for cost engineering, planning and scheduling, quality assurance, materials procurement, estimating, etc., and more effective utilization of computer-based information systems.

3) Innovations in Construction Methods

Both design and field construction were to be considered here for improving actual technology and procedures, Examples include application of standardization, prefabrication, and automation.

Also to be considered were human and organizational factors in encouraging innovation.

4) Construction Industry Dynamics

The last session was to be devoted to the construction industry as a whole, including its interrelationships with the economy, government, labor and the public, Included were possibilities for modeling and analyzing the pr1mary interactions between these forces.

The subjects that were suggested were not intended to set bounds on the discussions. Rather, they were intended to give a loose structure that would serve as a point of departure for wide-ranging creative input and criticism aimed at identifying construction’s most critical long-term research needs. Chapter III gives details on the findings and thus more specifically defines the subject areas themselves.

Distilling Research Topics From Workshop Discussions

As would be expected, discussions within the workshop ranged widely. Sometimes they digressed from what might be considered directly related to basic research. For example, because of its dominance in the management of construction, labor relations was deliberately not explicitly included in the planned subject areas so that other subjects could be given more exposure. Labor is an emotional issue that could easily have excluded all other discussion. Nevertheless, this important subject was strongly interwoven into each of the four main subject areas. This, of course, was inevitable because of the strong relationship of labor to almost all aspects of construction. But many aspects of labor relations are more amenable to political or institutional changes, such as legislation or collective bargaining, than to basic research, or even applied research, Even here, ii is recognized that politics and institutions themselves may at times be appropriate subjects for research. Nevertheless, for purposes of this report, judgment distinctions had to be made between what appeared related to research and what was more political or institutional in nature.

Other discussions ranged into problems with anti-trust laws, and to government regulation in employment, environmental impact, and safety. Here, also, some aspects of these issues are relevant for research, and some are more appropriate for political or institutional consideration. Again judgment was applied to extract topics for research.

Although the participants did occasionally digress into problem areas that were important but not directly related to basic research, by and large they did consciously pursue the research objectives of the workshop. The quality and thoroughness of discussions was excellent. This is evident in the fact that almost all topics identified in Chapter III are drawn from notes taken while the workshop was in progress.

CHAPTER III

BASIC RESEARCH NEEDS IN CONSTRUCTION

This chapter summarizes potential areas in need of basic research in construction. The research topics identified by the participants are organized into four tables corresponding to the four main sessions in the workshop: 1) manpower and organizational development; 2) management methodologies; 3) innovations in construction methods; and 4) construction industry dynamics. Each table is organized into categories; within these there are "problem sources" and related "research areas”. A short narrative introducing each table amplifies Chapter II's broad descriptions of the four main sessions. Chapter IV will consider priorities for the topics given in the four tables.

To some it will appear that several topics as stated are more "applied" than "basic" research, In a sense this is inevitable in an objective-oriented field like construction, Others will quite correctly point out that much work has already been done or is in progress in many of these areas. Nevertheless, it is felt that new aspects of basic research can be found in almost any of the areas described here.

Manpower and Organizational Development

This present economy not withstanding, it appears certain that some of the critical problems in many sectors of construction are, first, a future shortage of skilled technical and managerial talent, and second, effective employment of the human resources that are available. Especially on large projects, many companies are finding that existing organizational structures cannot adequately cope with growing needs. Increasing governmental requirements are further complicating this situation. One full session was therefore devoted to topics within this field. General areas examined included means for accelerated and continuing education and training, human and organizational development, administration and contracts, the interplay of design and construction, the evaluation of management productivity, and the special management characteristics needed on "super projects". Specific research needs that were identified or implied within the context of the workshop are summarized in Table l.

Management Methodologies

Much of the academic research in construction to date has been devoted to new and improved analytical tools and administrative aids for management, but the results have often been subject to question and controversy. Subjects of interest here include cost engineering, planning and scheduling, quality assurance, resource analysis, management information systems, productivity analysis, simulation, estimating, etc. Also important is the effective utilization of computers in many of these applications.

The workshop’s session in this area served to identify fundamental problems in need of work and to suggest ways in which the related research could be made more meaningful. Some of the major basic research needs that were either explicitly or implicitly stated in the workshop are summarized in Table II.

Innovations in Construction Methods

Most new construction methods have been developed to solve immediate and pressing problems. This session in the workshop explored whether it would be appropriate to carry out basic research in anticipation of problems that may still be well into the future. A possible example might be prefabrication and standardization to accelerate construction of projects designed to implement new energy technologies. The session focused not so much on the identification of all the myriad technical problems that need solving, as on identifying broad areas and on exploring the relationship of universities and industry in carrying out such research. The results are summarized in Table III.

Construction Industry Dynamics

The final session was devoted to examining the construction industry from a national perspective. Questions here included: What are the underlying relationships of construction to the U. S. economy? What are the primary interactions? What secondary impacts do major construction policy decisions - or individual project decisions – have on other areas of the economy? How can the resources of construction best be used? Is there a need for a coordinated national construction policy?

It has been *said* that the construction industry, as a whole, cannot significantly influence the demand for its services, or control the supply. In contrast to industries such as automobiles and railroads, construction is not in a position to accumulate capital. It is largely a service industry. How, then, could the industry be more effective in controlling, or it least influencing, its own supply and demand?

As an example, in early 1974 there seemed to be an insatiable need for more nuclear projects, and he industry was hard-pressed to fill it. Six month later, largely as a result of short-run financial problems in the utilities industries, there were postponements and cancellations of projects, and pending layoffs of the skilled people the industry was so recently struggling to find. What are the long-run consequences of these decisions for the construction industry and for the U. S. economy?

Topics discussed in this session may lead to research in economic modeling, long-range forecasting, environmental impact policies, long-term goal definition, development of an industry profile, etc. Table IV gives an overview of some of the long-term research needs in these areas.

TABLE I: RESEARCH NEEDS IN MANPOWER AND ORGANIZATIONAL DEVELOPMENT

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
A. Management Personnel	1. Super-Projects Super-projects, often lasting a decade and costing over $1 billion have stretched managers too far. They "burn out", suffer "combat fatigue", and boggle at the enormity of decisions. Managers with outstanding reputations on smaller projects do indeed seem to reach their level of incompetence. 2. Long Project Durations Owing to the duration of large projects, potential managers will only fit four or five into a working career. It is thus difficult to obtain well-rounded experience. 3. Transition to Employment There is an unrealistic transition between management training in school and responsibility in industry.	1. Selection Identify qualities that determine which managers can be stretched to the limit and endure on large projects, and which can make sound decisions under pressure and with incomplete information. 2. Training What basic management skills are most important? What special training can develop the desired abilities? How can managers be better equipped to cope with super-projects? How can the training and development of well-rounded managers be accelerated? What is the potential for simulation with management games and case studies? What is "management development"? Define the problem and create better criteria for development efforts. What is needed for decision-making under uncertainty? 3. Analysis Comparative studies of management styles, characteristics and effectiveness on successful and unsuccessful projects. Study cause-effect relationships: What is and is not relevant in enabling managers to accomplish objectives? To what extent does the person make the difference? Or the techniques he uses? 4. Evaluation Determine how to objectively evaluate and compare productivity and efficiency of managers and alternative management approaches.

TABLE I (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
B. Sub-Manager Personnel	1. Productivity Productivity of technical and professional staff is difficult to evaluate. Also, it appears that productivity decreases in larger projects.	1. Productivity Factors Analyze basic attitudes, styles and characteristics that affect productivity. Determine how to evaluate productivity. Why, if at all, does it decrease on larger projects?
	2. Incentives How can project assignments be made more attractive? Human and family problems, moving, spouse careers, etc. are making this more difficult. Motivation on the job also causes problems.	2. Motivation Develop methods to provide incentives and rewards for superior performance on the job. (For example, effective incentives for inspectors are generally lacking, yet these are key people in quality control and field contract administration.) Study effects of employees' off-the-job relationships and responsibilities.
C. Organizational Development	1. Project Cycle A project involves a temporary organization with rapid growth, intense activity, limited resources, and phase-out. Special problems have been encountered with teams for preparing environmental impact statements.	1. Building Project Teams How can behavioral science concepts be applied to improving communications and motivation in a project environment? Consider this in the context of temporary team building. Study working relationships within interdisciplinary project teams.
	2. Structure Construction generally has a project-type organization with typical matrix organization problems. There is need for a better understanding of how project structures should change for different kinds of projects.	2. Structure vs. Project Size Analyze necessary changes in characteristics and requirements of organizational structure with changes in size of company or of project. When is it sufficient to simply add another layer of management for a larger project: and under what circumstances should the whole structure be reorganized? Why do traditional organizational structures that function well on smaller projects tend to break down when the size increases to

TABLE 1 (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
C. Organizational Development (Cont'd)	3. Repetition and Duplication Lack of effective transfer of knowledge and experience from one project organization to another inhibits progress. This causes considerable reinvention, duplication and lost improvements.	2. Structure vs. Project Size (Cont'd) the billion-dollar range? What is the most efficient way to run multiple small projects? 3. Documentation and Transfer of Knowledge Develop more effective means to document knowledge, experience, methods, successes and failures from previous projects so that they can be effectively transferred to new projects to minimize reinvention of procedures and repetition of mistakes. What can be learned from the organizational approaches taken by other countries to construction project management?
	4. External Constraints Project organizations have difficulty responding to outside groups -- environmental regulatory agencies, etc. -- that affect construction.	4. External Interaction Determine how construction project organizations could be better structured to interact effectively with external organizations.
	5. Joint Ventures There are special problems in organizations involving (a) joint-venture owners, and (b) joint-venture contractors.	5. Joint Ventures Make comparative studies and analyses to develop improved joint-venture procedures.
	6. Safety Regulation and "hardware" approaches to safety have produced disappointing results. It is widely recognized that people are both the problem and the answer, but little is known about how to apply this fact.	6. Improving Safety Performance Study relationships of attitudes, behavior, and performance of construction personnel - from workers to managers - to identify and understand factors that contribute to safe and unsafe projects. Apply findings to improve safety in construction

TABLE I (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
D. Interplay of Design and Construction	1. Communications Regardless of contractural approach, there continue to be communication barriers between engineering design and field construction.	1. New Training Requirements Improve the breadth of specialized training to enable engineers, technicians and non-technical personnel to function effectively at the design-construction interface.
	2. Objectives There are different time-cost trade-offs for the owner, A/E, contractor, etc., that produce different goals for each. Often there seems to be basic disagreement on what is the product: blueprints? a structure? a function? At one extreme designers may spend too little effort on design optimization that will save much more time and money in construction and operation. At the other extreme, time spent designing to save a few more pounds of steel on a minor structural element might delay the whole project at high cost.	2. Interplay of Owner, Designer and Constructor Study the owner-designer-constructor interplay to determine means to improve communications and understanding. Determine methods for establishing and achieving common goals rather than sub-optimal goals for company and project sub-groups and functional areas. Develop analytical tools for evaluating decisions in view of their impact on the whole project rather than just on its components.

TABLE II: RESEARCH NEEDS IN MANAGEMENT METHODOLOGIES

[illegible]	PROBLEM SOURCES	RESEARCH AREAS
A. Utilizing Methods and Information	1. Demands on Users At present, most analytical models and management information systems are operator-oriented rather than user-oriented. That is, sophisticated systems designed by technically-oriented people often seem to be designed for such people as well. In reality, there is often a large "temperament gap" between model-builders and managers. The technology needs to be adapted to fit the managers rather than hoping for the reverse to happen.	1. Communication Barriers Break down communication barriers between managers and analytical systems Study the interface between them; develop means for more direct and effective interaction; permit interactive query, sensitivity analysis, and insertion of managerial judgment. In electronic forms this means computers must be used in more innovative ways to communicate directly with non-technical human beings. 2. Temperament Gap Identify characteristics of "analytical" and "managerial" people. This understanding could help bridge the so-called "temperament gap" between the two and help build teams capitalizing on the real strengths of each.
	2. Data Inundation In both volume and content managers often have difficulty absorbing let alone applying information provided to them, sometimes are overwhelmed by it, and frequently must manage in spite of analytical models and systems.	3. Problem Solving By applying "management by exception", good information systems have overcome many problems of the "paper flood", or data inundation. Identification of problems, however, is only a relatively passive first step. Research must progress to dynamic manager-system interaction for solutions to problems once identified.

TABLE II (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
B. System Development	1. Operational Workability Existing analytical models and information systems require excessive "care and feeding" relative to benefits obtained. Data required for maintenance and updating is often voluminous and cumbersome. It is claimed that some methodologies have become ends in themselves, with whole departments dedicated to their service. This can severely impede their effectiveness as control tools.	1. Dispensing with Data More innovative use of computers could make existing systems more workable. Integrated systems combining scheduling, cost control, payroll accounting, materials procurement, etc. can reduce duplication of data entry. Beyond data-base concepts, where emphasis is on storing information in an organized and efficiently accessible manner, it is possible in many cases to dispense with data altogether and instead derive it on demand through proven models and known operators. For example, tables of logarithmic and trigonometric functions are no longer necessary since electronically programmed algorithms can provide the information directly. Similar thinking could be applied to other types of "data banks" by defining areas where automated logic can be more helpful.
	2. Oversimplification of Reality Most existing models only examine limited subsets of the design and construction process. Such oversimplification often limits them to relatively artificial situations and thus discredits them in broader applications. More of the richness of real life is needed in the model-building process.	2. Realistic Modeling Integration of analytical models and information systems could better recognize complex interdependencies in projects. Further research would provide systems that vary in complexity and sophistication depending on the size and complexity of projects.
	3. Duplication and Repetition The development and implementation of methods and procedures for scheduling, cost control, estimating, etc., have been subject to considerable reinvention from one organization to another. There is little standardization. Although this may give individual companies certain short-run proprietary advantages, the industry suffers in the long-run.	3. Coordinated Development Efforts The type of research at the Massachusetts Institute of Technology that led to standard engineering programs such as STRESS, STRUDL, and COGO, could benefit construction also in areas such as project planning and scheduling, cost control, estimating, materials procurement, and quality assurance. Industry-wide efforts could reduce the duplication and repetition

TABLE II (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
B. System Development (Cont'd)	4. Quality Assurance Quality assurance on large projects requires tremendous amounts of field and office labor. Another problem is providing mutually acceptable incentives for contractors to provide owners with quality products at reasonable cost. Special needs include Q/A safeguards on nuclear power plants.	4. Research in Quality Assurance How can quality assurance procedures such as statistical sampling become more standardized and reliable? To what extent can such procedures be programmed and handled by computer? What new types of non-destructive testing can be developed to provide timely answers to such matters as concrete quality? There is especially a need for simplified and more accurate testing and inspection appropriate to "performance specifications". Also important are the human problems in the professions, in inspection and in the crafts. More efficient procedures for quality assurance safeguards are needed, especially on nuclear plants.
C. Forecasting and Decision-Making	1. Problem Forecasting Many systems merely point out problems after the fact, or make linear projections of trends. Information is needed to enable managers to take corrective action in time to influence results. 2. Functional Integration With the introduction of data bases and integrated management information systems, diverse and formerly isolated specialties are communicating more and are becoming much more closely interwoven. This has created some problems, but also has tremendous potential advantages for large-scale team work.	1. Forecasting Investigate improved methods for projecting costs, cash flows, inflation, manpower productivity, resource demands, schedules, and quality results. This could include the analysis of risk and uncertainty mentioned below. 2. Influence of Technology on Organization Behavioral and management science research could determine how data bases and integrated management information systems affect the ways people work together. This in turn could lead to ways to restructure organizations to take best advantage of the new technology.

TABLE II (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
C. Forecasting and Decision-Making (Cont'd)	3. Risk and Uncertainty Contingency is often included in cost estimates, but there is insufficient evaluation of actual hazards, or of risk analyses of steps that might be taken to minimize the probability of occurance. This area is of special concern on: 1) projects constructed in hostile environments; and 2) projects starting construction without detailed plans and specifications.	3. Analysis of Risk and Uncertainty Investigate improved methods to analyze risk, quantify uncertainty, consider alternative strategies, and make decisions. This in turn could improve forecasting techniques for methods decisions and cost estimating.
D. Communications	1. Owner Interface The owner often puts in one-to-two years of pre-planning, but often there is limited carry-over from this to the design and construction phases.	1. Improving the Owner Interface How can the owner's preplanning be better integrated into the design and construction phases?
	2. Design-Construction Interface As construction becomes more complex, traditional orthographic drawings become less adequate. Problems occur both in communicating designers' intentions to constructors and in designers' understanding of field construction. Similarly, written specifications are continuously subject to ambiguity and misinterpretation. Example consequences are pipes and ducts with impossible penetrations, etc.	2. Improved Design-Construction Communication Investigate new technology and alternative media for communicating between design and construction. Some projects already make extensive use of physical models; this could be expanded. Computer graphics and other manipulable visual displays could add another dimension. Computers could also assist more in presenting technical specifications.
	3. On-Site Communications On complex projects it is especially difficult for management to monitor all operations in progress. A manager thus may lose perspective on the relative importance of problems on the job. Better on-site communications could alleviate this situation.	3. Improving On-Site Communications Visual communications give management a better feel for the project and more confidence in decision-making than written forms. Possibilities in this area could include broader and more innovative use of closed-circuit TV and time-lapse cameras as management tools.

TABLE II (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
Communications (Cont'd)	4. Documentation and Transfer of Information There is too little transfer of information, experience and methods from one project to another. Improved means of documentation and transfer are needed. There are numerous studies and records made of methods on particular jobs, but even here there is very little in the way of comparative analysis and evaluation of results.	4. Improved Information Transfer Research involving case studies not only of methods and procedures, but also of the results could both help evaluate the effectiveness of methods and procedures and also provide a vehicle for transferring this knowledge and experience to others. Included in this might be "What if?" considerations, such as "What if we did (or did not) use CPM on this particular project?".

TABLE III: RESEARCH FOR INNOVATIONS IN CONSTRUCTION METHODS

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
A. Design-Construction Interplay	1. Uncoordinated, Suboptimized Components Today components and materials for structures, including framing members, HVAC, plumbing, electrical, etc., are produced by many separate industries, but with little overall coordination. There are relatively few multiple-purpose components, such as pipe to both supply water and serve as a structural component. Heating ducts often cross "double T's" rather than utilize the natural shape of the structure. There is need for fewer total components and especially fewer on-site-assembled components. Other problems in materials design and selection come from ignoring facility life-cycle operation costs.	1. Integrated Design Integrated design could make increased use of multi-purpose components and subsystems. This would require closer inter-industry cooperation and cross-production, but could greatly reduce the number of physical elements in structures, reduce costly on-site labor, and hence reduce costs. Injecting construction knowledge into design helps, but more can be done. Perhaps even more important are evaluations of the overall life-cycle costs of facilities.
	2. Inefficient Standards Many existing standards are suboptimized by system and are often set by the industries that manufacture the components. Also, specifications by A/E's are sometimes unnecessarily high for the actual requirements. A perennial example is concrete cleanup.	2. Rational Standards and Industrialization Impartial research is needed for lighting standards, optimum room temperature, desired fire resistance, etc. There is need for new ways to express precise yet realistic specifications that communicate to designers, owners, contractors, craftsmen, users, and vendors.
	3. Energy Factors Energy shortages cause problems in diverse situations like designing for improved HVAC efficiency, minimizing fuel needs in earthmoving, and analyzing total energy requirements, from raw material through life of facility, in comparing such things as concrete vs. steel in a structural frame. There is insufficient information for making decisions like this.	3. Energy Research Create new ways of looking at construction from an energy point of view. Develop principles and guidelines for design of systems, selection of materials and components, and construction methods to assist designers and constructors in this area. More fundamentally, how should changing energy economics affect traditional approaches towards design and construction?
		4. Miniaturization Determine ways of reducing the size of support service facilities such as utilities, HVAC, etc. Study how much space is really needed by users and determine ways to utilize space more efficiently while not detracting from its function.

TABLE III (CONT'D)

TABLE 1 (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
A. Design-Construction Interplay (Cont'd)	4. Space Restrictions In conventional structures, land costs and other factors put space at a premium. These problems are even more acute for structures in hostile environments, portable structures, etc.	5. Adaptation Determine how research can be incorporated into new situations to accelerate the evolution of efficient solutions. An example is the design of large-scale undersea facilities as alternatives to platforms.
	5. New Situations There is need for more rapidly adapting design and construction to new environments and new technologies, such as ocean construction.	
B. Materials and Components	1. Testing There is need for accelerated test methods for long-life but failure-prone materials such as paint, joint sealers, roofing systems, etc. This also applies to obtaining shorter feedback on production-critical items such as concrete strength, welding and weld testing.	1. Automated Testing Develop methods to accelerate testing and make results more reliable. For example, means for reliably testing concrete in the plastic state could provide quick feedback. Computerized weld-testing needs investigation. Reliable predictions are needed for long-term performance on the basis of short-term changes under accelerated lab testing.
	2. Better Solutions Lighter, stronger, more durable materials are needed as design capabilities advance. Also needed are improved field capabilities for handling, and for obtaining and verifying specified quality.	2. New Research in Materials Considerable work is now underway in composites of concrete, fibers and polymers for producing durable, high-strength concrete. More can be done on this and similar approaches could be taken to other elements used in construction.
	3. Approval of New Materials There are problems in getting new techniques and materials approved with respect to safety, building codes, etc.	3. Accelerated Approvals Research could investigate both organizational and testing aspects of accelerating the approval of new materials and components for construction.

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TABLE III (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
B. Materials and Components (Cont'd)	4. Excessive Field Labor Many methods and materials are developed with little regard for the amount of labor required for on-site fabrication and installation. This applies to old methods too. As one participant pointed out, "We still lay bricks one at a time."	4. Automation and Mass Production Develop ways to apply automation and mass production in the more labor-intensive aspects of construction, such as installing electric wiring. Examine prefabrication, both on-site and off-site.
	5. Waterproofing Common failures occur in making structures waterproof. Examples include basements, roofs, etc.	5. Improved Waterproofing Investigate both improved materials and construction procedures for waterproofing.
C. Equipment and Technologies	1. New Tools There is continuing need for improved equipment for applications such as open-sea dredges capable of performing structural excavation with wider tolerance for swells; excavation and materials disposal underground; welding high-strength steels; laying large-diameter pipe in the open sea; concrete handling; excavation; and laser measurement.	1. New and Improved Equipment Investigate equipment for operations in hostile environments, such as the arctic, under sea, and near the equator. Others could explore new applications of technologies such as compressed air for production (erecting structures, transport, excavation, etc.) mobile factories for field manufacture of items like plastic pipe, water cannons for excavation, etc.
	2. Productivity and Efficiency Even the best equipment has wide variations in productivity depending on the operator's skill and working environment.	2. Automation The rapidly-developing semi-conductor technology has produced miniaturized computers with tremendous potential for controlling anything from fuel-metering and gear-shifting to providing an equipment-control interface for on-line field implementation of simulation analysis. Automated equipment could remain productive in bad weather or even in areas hazardous to human life.

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
D. Construction Procedures	1. Investigation and Exploration Better means are needed for predicting material to be excavated and supported in tunnels, shafts, chambers and deep foundations.	1. Improved Geologic Investigation Improve means of determining properties of materials to be excavated; evaluate their implications for construction.
	2. Productivity Evaluation Better ways are needed to measure and evaluate productivity and delays in work methods in the field. Possibly there could be nation-wide standards.	2. Productivity Evaluation Possibilities for further investigation in productivity evaluation include time-lapse photography and closed-circuit TV for data gathering, and simulation modeling for analysis.
	3. Seasonality Considerably more could be done to economically reduce fluctuations and losses of work due to bad weather.	3. Reducing Seasonality Develop economic means for reducing seasonality in construction. This may involve providing incentives for overcoming suboptimization.
	4. Start-up Improved techniques are needed for starting projects in remote locations - bootstrap operations.	4. Start-up Study successful methods for establishing construction projects in remote locations, identify the elements of success, then document these in a form useful for other projects.
	5. Lack of Innovation on Projects Often people doing work know of better ways it could be done, but are reluctant so suggest their ideas.	5. Motivating Innovation How can management create an "innovative atmosphere" on projects and within the industry? How can people with knowledge for improving the tasks become involved in improvements as well as performance? What are the characteristics and key elements on projects where innovation is prevalent?

TABLE IV. CONSTRUCTION INDUSTRY DYNAMICS

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
A. Construction, the Public, and Government	1. Industry Credibility Many problems in construction's credibility with the public stem from much-publicized cost overruns and schedule delays on projects such as rapid transit systems, and to the disruptions that occur while work is in progress.	1. Relationship to Society Assess how construction affects our way of life. This may enable the industry to more effectively cope with forces adverse to it. Determine how construction expertise can enter more into the evaluation of what and where services to the public should be developed.
	2. Mutual Perception Problems with government, including perceived overregulation by EEO, OSHA, EPA, etc., largely stem from a lack of government understanding of construction. For example, regulatory agencies may not realize their cumulative effects on the industry.	2. Interactions Investigate the relationship of construction to government, study the interaction between the industry and government agencies, and develop good information with which to educate all parties concerned for their decision-making and action.
	3. Use of Construction in Fiscal & Social Policy Construction is often placed on the forefront of government fiscal and social policy. Examples include the money supply for the housing industry, using contractors to increase minorities in unions, etc.	3. Interrelationships Study interrelationships of politics, legislation, industry, owners, and the public. Determine more direct ways to meet industry and national objectives.

CATEGORY	PROBLEM SOURCES	[illegible]
B. Construction and the Economy	1. Demand Instability Instability of demand dominates everything in construction. Seasonality is chronic. Construction has an amplified reaction to basic business and economic cycles. Many economic problems in construction relate to the lack of mobility of resources, especially labor. Often there is too much work in some regions at the same time that others are suffering localized recessions. There is a need for a more continuous workload, for market forecasting, and for improved projections of future trends by type, area and volume. 2. Finance Problems recur in funding both large and small projects. Government competition for finite funds exaggerates these problems. Related problems are in predicting escalation, and incorporating it into equitable contracts.	1. Economic Modeling What factors in the economy have the greatest impact on construction, and vice versa? Identify the predicators, then model, then try to influence. Coordinate existing models. What are the industry's capacities for production today? Assess its adaptability to short-run and long-run demand changes. Determine how to forecast resource capacity vs. backlog. What is the post-industrial economy going to require in the way of construction services? 2. Evaluating Costs Determine procedures for identifying the elements in cost overruns, i.e. the portions attributable to inflation vs. change of scope vs. inefficiences. Develop ways to internalize and quantify external costs, such as OSHA, EPA, etc.
C. Construction Industry Organization	1. Structure In general, there is a perceived need for a complete restructuring of the industry to reduce "layering", permit an integrated approach to objectives, and permit more standardization. 2. Contractual Relationships Some fear that non-competitive contracts may reduce incentives for efficiences in construction, slow innovation, cause more inflation, etc.	1. Restructuring If the industry were to be restructured what objectives ought to guide this effort? What new relationships would be needed? What new institutions and procedures? Would the benefits outweigh the costs? 2. Contractual Relationships What are the long-run influences of different forms of contracts on efficiency, innovation, inflation, etc.

TABLE IV (CONT'D)

CATEGORY	PROBLEM SOURCES	RESEARCH AREAS
C. Construction Industry Organization (Cont'd)	3. Research Cooperation There is a lack of desire to share research with competitors. Therefore an impartial means for sharing is needed. Similarly, there is a need for closer cooperation between university and industry people working in construction.	3. Improved Cooperation in Research Explore possibilities for a "clearinghouse" organization for disseminating construction research. Study the close relationships between universities and industry in Northern Europe to find ideas that might promote closer cooperation in the United States.

CHAPTER IV

FORMULATION AND ASSESSMENT OF PRIORITIES

This chapter suggests guidelines for formulating priorities for basic research in construction, discusses funding, then makes a preliminary assessment of priorities for topics given in Chapter III. Inevitably it will the most speculative and perhaps the most controversial part of this report. In a sense, even the attempt to assign priorities is contrary to the nature of basic research as described in Chapter I. The process implies that there are clear problems to be solved and that one can therefore make a comparative analysis to determine which should rank highest. Nevertheless, certain topics did seem more important than others in the workshop, and this report would be remiss if it did not emphasize them.

Guideline

The topics discussed in Chapter III indicate the types of things that are being done or that are inadequately being done. Those areas that are identified, either explicitly or by implication, focus attention in the kinds of research on which decisions for funding should be made.

The actual formulation of specific proposals and the development of research programs will be an ongoing process. Evaluation and budgeting should consider what types of things will be needed in the years ahead, and what is feasible in view of the resources of money, people and equipment available, in setting priorities within the overall spectrum of research and development, it will be important to keep the long-run need for basic research in perspective, and not let it be lost among urgent calls for applied research and development to solve what are only the current most critical problems. Research must look to the future as well as the present.

In an industry as diverse as construction, opinions on priorities will depend largely on perspective, Money-short homebuilders will probably not be greatly concerned about the massive logistics problems on the Alaska Pipeline. Pipeliners, in turn, pay little attention to the glut of high-rise office buildings in New York City. Priorities for labor organizations are often diametrically opposed to those of construction contractors. Perhaps the most important question that construction in all its parts must address is therefore the following: Given the finite limits on funds and resources that may become available for basic research in construction, what criteria should determine their most effective allocation?

Clearly economic criteria, such as those derived through benefit/cost or rate-of-return analyses, are one possibility. But to whom should benefits accrue? Contractors? Owners? Labor? Government? The public? How does one measure the benefits or costs in something as nebulous as basic research? Other criteria could relate to probabilities for successful utilization of research results. Would it be better to concentrate research efforts toward large, high-visibility, billion-dollar-plus projects? Advantages here are 1) even small improvements could add up to large sums, and

2) a single organization offers more control for implementation, On a cumulative basis, however, benefits might be even greater if research were aimed more at the hundreds of thousands of small projects and organizations. The corollaries, however, are I) benefits might be harder to identify, and 2) implementation is far more difficult to control.

Resources available to conduct research should figure into the priority mix. These include people, institutions and equipment with the necessary capabilities and experience. Currently there are only a handful of small, graduate-research-level university programs aimed specifically at construction. Independent contract research institutions are equally scarce, Even government laboratories operated by agencies such as the Army Corps of Engineers are small compared to areas of endeavor like military hardware, Assuming large sums of money did become available for basic research in construction, could the resources now available efficiently absorb and effectively apply those funds? Or would it simply be a great "boondoggle"? Chapter V will examine this subject further.

Other important criteria include the actual need for basic research in construction as compared to other industries, Compared to electronics, for example, construction is considered a fairly mature industry. Sources of funding will determine still other criteria. For example, priorities attached to funds provided by government would most likely differ from priorities for research funded by industry or by labor organizations.

It is well beyond the scope of this report to provide anything approaching a priority-assessment formula. The qualitative review of priority guidelines given above will have to suffice for purposes here. A group, organization or institution qualified to act on behalf of the industry in all its components, and on behalf of the public, will have to develop specific policies for actual allocation of funds and resources.

Funding

What levels of funding are needed or potentially available in construction? The most recent U. S. Department of Commerce "Census of Construction Industries" reports that in 1972, construction receipts were over $150 billion (5) That year the industry also employed over 4 million workers. Typically, construction's 12-to-15 percent accounts for the largest share of the nation's gross national product.

Assume, for a round number, that 1% of the 1972 annual receipts could go into research and development as a whole. This would be $1,5 billion. Of this, assume that 10%, or $150 million per year, might be allocated specifically to basic research. These numbers are not intended as recommended figures. but simply as order-of-magnitude reference points for further discussion, Potential sources of funds will be discussed in Chapter V.

Priorities

The priorities given below apply solely to the topics given in the tables in Chapter ill, They are based on intuition and judgment regarding the perceived importance of, and emphasis placed upon, topics discussed by the participants in the workshop, There have been no comparative economic analyses, nor were there carefully-constructed and pre-tested surveys. Certainly these assessments are subject to dispute.

The priorities given here are grouped in the same four categories used in Tables I through IV. No particular significance should be attached to the numerical order within categories, or to the sequence of the four categories themselves, Few enough items are given that the reader can quickly draw his own conclusions.

Manpower and Organizational Development. Of the topics shown in Table I, there was a general impression that some of the most difficult problems are:

1. Improve selection and development of managers who can be both comfortable and capable in running "super-projects".
2. Develop organizational structures that can more effectively cope with such projects.

These views, of course, were somewhat influenced by the large-project backgrounds of several participants. Nevertheless, in terms of both needs and potential impact, this area deserves high priority for basic research efforts. Eventual applications might include large pipelines, nuclear powerplants, urban rapid transit systems, mineral resource developments, and many others.

Management Methodologies. Topics in Table II that might be considered for highest priority include;

1. Bring analytical methods, information systems and control tools closer to managers who need them for decision-making, That is, adapt technology to fit management, not the other way around.
2. Reduce the ”care and feeding” required to implement and operate such systems, while making the models themselves more realistic and adaptable to actual project conditions.
3. Develop better methods for "problem forecasting", with provisions for analyzing risk and uncertainty.
4. Improve means for communications at the design-construction interface.

Although the need for research in these topic is especially acute on larger, more complex projects, smaller project and organizations would also benefit if effective means for dissemination and implementation of results could be found.

Innovations in Construction Methods. Subjects within Table III viewed as having higher priority include the following;

1. Develop more integrated approaches to design and construction, with increased use of multi-purpose components and subsystems, reduced incompatibility, and less field labor.
2. Develop rational, efficient, function-oriented standards that will aid automation, mass production and instrialization in construction.
3. Reduce seasonality via improved methods and less on-site work.

Research of this type could contribute to long-range changes in the structure and operation of the construction industry that would be required to receive full benefits from the results. Numerous short-run returns could come as well.

Construction Industry Dynamics. Table IV broadly examined the construction industry as a whole. Of its topics, the following may be viewed as having higher priority:

1. Develop a better understanding of the relationships of construction to society, to government and to the economy.
2. Explore ways to moderate instability of demand for construction services, and temper the consequent adverse effects on the industry and its workers.
3. Improve cooperation for research within the industry, and between the industry, government and universities.

Regardless of their importance, and whether or not there is general agreement, assessment of priorities is a hollow exercise if there is no means for implementation, Chapter V will now examine this subject.

CHAPTER V

DEVELOPMENT OF BASIC RESEARCH IN CONSTRUCTION

Two major requirements for development and implementation of basic research efforts in the management of construction are: (1) individuals and institutions with the resources, experience, interest and capabilities to carry out such research; and (2) incentives and means to provide funding. This chapter will discuss each of these in turn.

Resources for Basic Research

In the broad sense, research is an everyday activity in construction. Contractors are renowned for their ingenuity in developinq solutions to specific problems. They modify or build new equipment, develop new exploratory methods, think up new construction procedures, and try out new applications for existing technology. The sophistication of this analysis, design and development is frequently very high. In such innovation they often work closely with specialized consultants. designers, equipment manufacturers and materials suppliers. Indeed, in contrast to many industries, there is a remarkably free interchange of ideas and information between all these parties when problems arise. Very seldom, however, could these efforts be classified as basic research. Reasons for this were described in Chapter I.

Traditionally, basic research is conducted in universities and in private and government research laboratories operated primarily for this purpose. It is generally assumed that because these institutions are several steps removed from the "firing-line", they are in a better position to deal with long-term research. However, many people misinterpret this to mean that basic research conducted by such organizations is therefore less relevant. Once again it should be emphasized that the nature and purpose of basic research is quite different from applied research and development. Each is important and each has its appropriate role.

Where, then, should basic research *be* conducted? As mentioned, universities are one important source. Owing to their special significance in this report, they will be discussed in a separate section below. For many reasons that have been given, construction contractors generally are neither motivated nor in a position to carry out basic research. Nor are most architectural and engineering design firms. Nevertheless, these organizations should be deeply involved in advising and evaluating basic research efforts conducted elsewhere, Some larger manufacturers of materials and equipment have excellent laboratories that already do basic research related to construction, The Caterpillar Tractor Company’s facility in Mossville, Illinois is one example, Such laboratories, of course, are oriented primarily to the manufacturers’ products, but they have broader potential. Government research laboratories include those operated by the National Bureau of Standards near Washington, D.C., the Navy Civil Engineering Corps at Port Hueneme, California, and the Army Corps of Engineers’ Construction Engineering Research Laboratory in Champaign, Illinois, The latter, in particular, has placed considerable emphasis upon research in the management of construction. Independent private sources include organizations such as the Battelle Memorial Institute, the Midwest Research Institute, and the Stanford Research Institute. All have capabilities for basic research in construction.

The determination of where particular research topics should be investigated depends on, the nature of the research and on the capabilities of the organizations proposed to conduct it. Some research and some organizations are hardware-oriented and depend upon large sophisticated testing laboratories. Other research requires advanced computer facilities. Some may need the expertise of particular individuals in economics, the behavioral sciences, engineering, mathematics, business management and so forth. It is beyond the scope of this report, however, to attempt to classify which types of research should be done where. One important source, however, does need further consideration. Its role goes well beyond the actual quality and applications of its research output.

University Education and Research in Construction

Since World War II, and especially in the last decade, numerous college and university programs have evolved that are aimed primarily at the construction industry. Suddenly, the construction process and its management -- the logical culmination of the conceptual and design phases -- has been recognized for what it is: an integral part of the total engineering and management process required to provide new facilities. There are now dozens of four-year undergraduate programs; many are divisions within architecture, civil engineering or architectural engineering, There are also a handful of graduate education and research programs; most are small, having anywhere from one to five full-time faculty. Of these, most are identified with engineering departments in some of the most distinguished universities in the United States and abroad.

Research in graduate-level construction engineering and management programs is worth at least a brief review since this in turn may become an important source of basic research to construction. Initially such programs met considerable resistance from the traditional academic community in the engineering disciplines • Construction somehow did not fit into the well-defined classical specialties into which engineering had evolved. Indeed, it is true that at one time or another construction cuts across almost all fields of engineering and science, Others dismissed construction as having little or nothing to do with "real” engineering. To them, the engineering process left off once the designer completed his plans and specifications. Some professed that constructors should not only have nothing to say about design, but be considered untrustworthy and be strictly monitored and inspected to keep them from short-changing the owner in quality and performance.

In view of this situation, it is worth noting that several of the oldest and most distinguished graduate construction engineering and management programs were established in the most prestigious engineering departments. But since these departments maintain their positions through leadership and innovation, perhaps this is not so surprising after all. For example, each of the four top-rated civil engineering departments in the United States now have well-established graduate programs in this field. With the ground thus broken, many other schools have been or are attempting to follow suit. In the academic community, one of the major problems now is an acute shortage of qualified faculty to fill the rapidly proliferating positions in construction education.

Although most are still fairly new, established graduate programs have already made significant progress in both research and education, Until a few decades ago there was very little university research and no coherent body of college-level coursework aimed specifically at construction. Many innovations that increasingly are taken for granted In the industry today either originated in or were considerably advanced through research efforts of these programs, Examples include time-lapse photography for operations analysis, computer simulation of field operations, behavioral science research into the workings of project management teams, computer based information systems, studies of labor and industrial relations, and new methods *and* techniques for the planning, scheduling and control of resources on projects. In the latter category, for example, one research report funded by an unconstrained grant from the U, S. Navy Bureau of Yards and Docks has since sold over 20,000 copies and is widely recognized as a pioneering effort in its field.

On the education side, there are now many widely accepted courses that make up the core curricula of today’s graduate and undergraduate programs. New courses continue to *be* introduced, and many of these will become standard subject matter In the future. There have by now been literally thousands of graduates from the established construction programs. Many have gone on to become managers on some of today’s most challenging and successful projects. Others have advanced to top executive ranks in some of the largest and most reputable companies, and in many smaller but innovative companies as well. Still others are found in government construction agencies, large private consumers of construction services, and as faculty in construction programs in other universities.

It is especially important to recognize the indirect impact that university research has by its close relationship to the educational process. Of course, it is good when a given university research effort directly contributes to solving an existing problem, But in the long run, university research can have a greater impact through two influences it has on students.

First, while research is in progress, student assistants have the opportunity to sharpen their minds and immediately apply their learning in doing research, Second, results of successful research efforts often find their way into courses that will be taken by other students, perhaps a decade or more in the future, who in turn will apply this new body of knowledge in their own careers, Universities are thus not only charged with developing new knowledge through research, but of passing that knowledge on to succeeding generations through education, It is in this interplay between research and education that universities can have their greatest impact. This should apply equally well to basic research in construction.

Incentives for Funding

As mentioned earlier, the fragmented, intensely-competitive nature of construction makes it difficult to undertake industry-wide programmatic efforts such as a significant venture into basic research. Furthermore, construction is primarily a service industry and thus does not accumulate significant amounts of capital when compared to industries such as steel, transportation, and minerals. One sees this in comparative financial surveys such as the "Fortune 500", where, although several of construction’s largest firms are listed each year on the basis of sales (cumulative annual contract awards or revenues in construction), and sometimes on the basis of profits, few if any are anywhere near the "Top 500" on the basis of assets. Hence if a firm cannot preserve the fruits of its research innovations in the form of new processes or more efficient capital facilities, it has less incentive to invest in research. For these and other reasons, it is unlikely that the construction industry itself, whether as individual firms or in its trade associations, could invest in basic research on the scale found in capital-and-technology-intensive industries. A possible, but as yet largely untapped exception in this picture, is the wage-based industry advancement funds available in some areas.

Nevertheless, there are major financial incentives for investing not only in applied research in construction, but in basic research, These days one too often hears of large projects with cost escalations measured not just in millions of dollars, but in billions. The cumulative effect of cost escalations on smaller projects is undoubtedly even greater.
American ingenuity and know-how is still effectively coping with most technological problems in construction, but management and administration is too frequently inadequate in the face of larger, more complex projects, and growing demands for accountability to external organizations. If investments in research could overcome some of these difficulties and begin to pare down these billion-dollar cost increases, someone ought to benefit. In the workshop, the participants from the consumers of construction services, in both government and private industry, were generally the first to point out that it is their organizations that ultimately should be willing to make such investments, since they and their customers will be the primary beneficiaries, Once recognized, however, there is still a quantum leap to be taken to develop effective institutions to support such research in a coordinated and productive fashion.

When thinking of government funding, it is interesting to note similarities between construction and agriculture, Both account for a very large segment of the gross national product, and both are composed primarily of small businesses, Given free rein, the competitors in each are inclined to drive one another down to a marginal subsistence level, Each has also become increasingly subject to direct and indirect governmental intervention, whether through fiscal policy, regulatory agencies , special-purpose legislation, or whatever. In agriculture, however, it is worth recognizing the far-reaching effects of one aspect of governmental influence, the Land Grant College Act of l852. This, of course, is the legislation behind the numerous university-based state agricultural experiment stations. These have admirably served the cause of doing research on a very high level, yet have remained conscious of the main purpose of their research: transfer to and application by farmers in their respective states and communities. For better or worse, the so-called "green revolution" is in a very great way the product of the legislation that led to agricultural experiment stations in the United States. Although times have changed and the industries certainly do have fundamental differences, similar approaches might provide corresponding advances in construction.

Given that construction is often considered the "backbone" of the American free-enterprise system, it would seem appropriate that it avoid overdependence on and control by government, even in the support of basic research, In the private sector, several participants suggested that an organization such as the Business Roundtable could provide leadership in establishing a coordinated program for funding basic research in construction. Already this organization and its predecessor, the Construction Users Anti-Inflation Roundtable, are believed to have performed *a* highly visible and beneficial role in construction, It was pointed out, however, that efforts involving mutual cooperation of American businesses must carefully heed restrictions imposed by anti-trust legislation. Nevertheless, there is considerable potential for basic construction research in private industry if it can seize the initiative for its establishment and guidance. Since little exists at present, specific efforts must be made to develop both the sources of funds and the organizations for evaluating proposals and administering basic research in construction. This report, however, must stop short at simply suggesting general possibilities such as those given above. It would be worthwhile for organizations such as the Business Roundtable, the National Construction Industry Council, the National Institute of Building Sciences, the Associated General Contractors of America, the National Constructors Association, and others to pursue this subject further.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This report and the workshop upon which it was based were designed to identify, set priorities for, and focus high-level attention on the need for basic research in construction engineering and management. There is now and will increasingly be *a* need to bring research talents and capabilities both within and beyond the academic community to bear on performing basic research leading to means to solve problems in construction.

A second important purpose of the workshop was to bring about closer working relationships between the construction industry, private and government consumers of construction services, and university programs in construction engineering and management. This was perhaps the workshop’s most evident immediate success. Most participants seemed to feel that their time was well spent and that they learned a great deal about each others’ problems.

Specific topical recommendations can be read or inferred from the tables in Chapter III. They reflect the collective thinking of a distinguished and exceptionally capable group of leaders in and associated with the construction industry. These topics should be scrutinized carefully by anyone interested in doing basic research in construction and especially in the management of construction. Again, they are significant for what they do not include as well as for what they do.

Chapter IV extracted from Chapter III those topics that were felt to have highest priority. These should be considered not only by those interested in doing research, but by any person or organization thinking of himself or itself as being able or responsible to provide leadership to help solve problems in the construction industry.

Chapter V began by examining potential resources for carrying out basic research in construction. Institutions and organizations named therein were for example purposes only, Inclusion or omission of any particular organization was not intended to reflect on its qualifications. The chapter then discussed the special role of universities. The purpose was not to be self-serving, but to emphasize the importance of the interplay between research and education. Finally, Chapter V examined potential sources of funding. Tremendous leadership will be needed in this area if basic research in construction is to become more than a discontinuous series of small, unique, haphazard, and often accidental happenings.

This report began by examining challenging problems facing construction in the years ahead. It wilt conclude with recommendations designed to further challenge the industry and its constituents to take action.

1. Universities and related research institutions should recognize construction and the management of construction projects as important areas of endeavor in which basic research can make major contributions. Researchers should seek to understand construction and its problems, and look for opportunities for advice and cooperation from this industry.
2. The construction industry should focus attention upon the importance of basic research for its own long-run well-being and that of its clients. It should thus support and encourage the establishment of organized research programs, and play an active role in such programs once established.
3. As the primary economic beneficiaries of improved methods and management in construction, and as the organizations with the necessary capital and resources, both public and private consumers of construction services should actively encourage the development of basic research programs in construct/on, and should provide the major funding to enable such efforts to grow.
4. As a point of departure for discussion purposes, within five years annual investments for basic research in construction should approach 0.1% of the industry’s annual gross receipts, In l972, this would have been about $I50 million, It is recommended that this amount be built up over a five-year span since resources available now for basic research most probably could not efficiently utilize such a sum.

5. Any group or organization that is in a position for leadership in construction should schedule the subject of "basic research" on its agenda for a meeting within the coming year. Several such organizations were named at the end of Chapter V. Government agencies involved in construction should also recognize themselves here.

   The purpose of such meetings should not at first be to support basic research, but to understand it, It is recommended that one or more individuals be invited who are respected for their know-ledge of the subject. A person with the stature of Dr. Vannevar Bush would be an excellent choice, Contemporary experts can be found on the National Science Board, the overseer of the National Science Foundation.

It is inevitable that many readers will take issue with both major and minor points in this report. Indeed, the report will have failed if it does not bring forth other points of view. Its underlying purpose has been to provide "raw material" that can serve as a focal point for analysis, criticism and suggestions that, in turn, will provide a useful background for discussion and decision-making.

APPENDIX A – PARTICIPANTS AND CONTRIBUTORS

Participants

Mr. Donald S. Barrie, Manager
Construction Management Dept.
Kaiser Engineers

Prof. Neal B. H. Benjamin
Dept. of Civil Engineering University of Missouri at Columbia

Prof. Edwin Bidwell
Dept. of Civil Engineering
Univ. of Illinois at Urbana-Champagne

Mr. W. F. Brusher
Chief Engineer, General Engr. Dept.
Standard Oil Company of California

Mr. James A. Bruton
Vice President
Union Carbide Corporation

Mr. William F. Burkart
Technical Director
U. S. Navy Civil Engineering Lab.

Mr. Robert Byrne
Executive Editor
WESTERN CONSTRUCTION

*Prof. Keith C. Crandall
Dept. of Civil Engineering
Univ. of California at Berkeley

Mr. A. R. Crosby
Engineering Advisor
Exxon Research and Engineering Company

Mr. Joseph Debro
Executive Director
National Association of Minority Contractors

Prof. James Douglas
Dept. of Civil Engineering
Stanford University

Mr. David G. Ellingson
Regional Editor
ENGINEERING NEWS-RECORD

Mr. Paul A. Elsner
Executive Vice President
Swinerton & Walberg Co,

Mr. Donald Giampaoli
Assistant Commissioner, Resource Development
U. S. Bureau of Reclamation

Mr. Lyman R, Gillis
Assistant Director for Operations
California Dept. of Transportation

*Prof. Daniel W. Halpin
Dept. of Civil Engineering
Georgia Institute of Technology

Mr. Edward E, Hershberger
Project Manager/Dworshak Dam
Dravo Corporation

*Mr. Chandra K. Jha
Vice President
Tishman Construction Company

*Prof. Wiiliam A. Litle, Head
Construction Facilities Division
Dept. of Civil Engineering
Massachusetts institute of Technology

Mr. Robert Lyness
Vice President & Division Manager
Retail Engineering Division
Safeway Stores, Inc.

Prof. George E. Mason
Dept. of Civil Engineering
The Ohio State University

Mr. George T. McCoy, Jr.
Vice President
Guy F. Atkinson Company

* Indicates Steering Committee Member.

Mr. William I. McKay
Sr. Vice President and
General Manager
Los Angeles Division
Fluor Engineers and Constructors, Inc.

Mr. Robert W. Medearis, President
Hurd-Medearis and Associates

Mr. Walter A. Meisen
Acting Commissioner
Public Building Service
General Services Administration

Prof. John Melin
Dept. of Civil Engineering
University of Illinois at Urbana-Champaign

Mr. Boyd C. Paulson
Vice President, Construction
Utah International, Inc.

Mr. Al Scolnik
Director of Education and Research
Associated General Contractors of America

Mr. C. H. Sedam
Vice President, General Construction
Pacific Gas and Electric Company

Dr. L. R. Shaffer
Deputy Director
Construction Engineering Research Laboratory
U. S. Army Corps of Engineers

Col. William K. Stockdale
Dept. of Engineering
U. S. Military Academy

Dr. Paul Teicholz, Manager
Electronic Data Processing and Systems Guy F. Atkinson Company

Dr, Richard Tucker
Vice President
Luther Hill *K* Associates, Inc.

Mr. H. J. Weaks, Director
Engineering Division
The Procter 4 Gamble Company

*Mr. Alden P. Yates
Vice President and Deputy Division Manager
San Francisco Power Division
Bechtel Power Corporation

Mr. Charles W. Yoder, Principal
Charles W. Yoder and Associates, and Chairman, National Construction Industry Council

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Contributors

The following individuals made substantial written contributions, but were unable to participate in the workshop itself.

Prof. Ben C. Gerwick, Jr.
Dept. of Civil Engineering
Univ. of California, Berkeley

Mr. David L. Narver, Jr.
President
Homes and Narver, Inc.

Stanford Coordinators

*Prof, John W. Fondahl
Dept, of Civil Engineering
Stanford University

*Prof. Clarkson H. Oglesby
Dept. of Civil Engineering
Stanford University

*Prof. Henry W. Parker
Dept. of Civil Engineering
Stanford University

*Prof. Boyd C. Paulson, Jr.
Dept. of Civil Engineering
Stanford University

* Indicates Steering Committee Member.

APPENDIX B

FORMULATION OF GOALS FOR BASIC RESEARCH INTO
THE MANAGEMENT OF ENGINEERED CONSTRUCTION

Stanford University
April 3 and 4, 1975

AGENDA

Thursday, April 3, 1975

8:00 - 8:30 A.M. - Registration

8:30 - 9:00 A.M. - Welcome and Introduction

Dean William M. Kays
Professor Soyd C. Paulson, Jr.

Session 1: Manpower and Organizational Development

9:00 – 9:45 A.M. - Keynote Introduction to Session (Room 450)

- Mr. William McKay
- Mr. Robert Lyness

10:00 - 11:4 - Group Discussions (See assignment sheet)

Group	Chairman	Room
A	Mr. Don Barrie	450
B	Mr. Robert Medearis	301
C	Mr. Robert Lyness	260
D	Mr. Alden Yates	153

11:50 - 12:20 - Summaries of Group Discuss1ons (Room 450)

Group	Summarizer
A	Prof. Ed Bidwell
B	Prof. Dan Halpin
C	Mr. Al Scoln1k
D	Mr. David Ellingson

12:30 - 1:30 P.M. Lunch at Stanford Faculty Club

Session 2: Management Methodologies

1:30 - 2:15 P.M. - Keynote Introduction to Session (Room 450)

- Mr. Chandra K. Jha
- Dr. Paul Teicholz
- Mr. H. J. Weaks

2:30 – 4:15 - Group Discussions (See assignment sheet)

Group	Chairman	Room
E	Mr. James Bruton	450
F	Mr. Al Crosby	301
G	Mr. Paul Elsner	260
H	Mr. Boyd Paulson	153

AGENDA

4:30 - 5:00 P.M. – Summaries of Group Discuss1ons (Room 450)

Group	Summarizer
E	Prof. William Litle
F	Prof. John Melin
G	Prof. Neal Benjamin
H	Prof. Keith Crandall

6:30 P. M. + Cocktail Hour and Dinner . . . .

will be held at the home of

Professor & Mrs. Henry W. Parker
430 Kingsley Avenue
Palo Alto, California

Informal ... Please see map for directions.

* * * * *

Friday, April 4, 1975

Session 3: Innovations in Construction Methods

8:30 - 9:15 A.M. - Keynote Introduction to Session (Room 450)

- Mr. Ed Hershberger
- Dr. L. R. Shaffer

9:30 - 11:00 - Group Discussions (See assignment sheet)

Group	Chairman
I	Mr. W. F. Brusher
J	Mr. William Burkart
K	Mr. George McCoy, Jr.
L	Dr, Richard Tucker

11:10 – ll:40 - Summaries of Group Discussions (Room

Group	Summarizer
I	Col. William Stockdale
J	Mr. Robert Byrne
K	Prof. George Mason
L	Nr. Don Giampao11

11:45 - 1:30 P. M. Lunch at Stanford Faculty Club

AGENDA

Session 4: Construction Industry Dynamics

1:30 - 2:15 P.M. - Keynote Introduction to Session (Room 450)

- Mr. Joseph Debro
- Mr. Walter Meisen

2:30 - 4:15 - Group Discussions (See assignment sheet)

Group	Chairman	Room
M	Mr. Lyman Gillis	450
N	Mr. Robert Medearis	301
0	Mr. C. H. Sedam	260
P	Mr. Charles Yoder	153

4:30 – 5:00 - Summaries of Group Discussions (Room 450)

Group	Summarizer
M	Prof. Keith Crandall
N	Prof. Neal Benjamin
0	Prof. Dan Halpin
P	Prof. Ed Bidwell

5:00 - Closure

* * * * *

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