Building Better: Technical Support for Construction

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Abstract: Increasing complexity of many constructed facilities and escalating demands for project performance are driving significant changes in design and construction. Increased project integration and technical support of construction operations provide a promising response to these demands. This paper identifies and describes nine critical activities to increase technical support for construction: integrate early planning; plan for regulatory compliance; consider construction methods and sequences in design; tailor and time technical information to users' needs; provide materials to support effective construction; identify and provide construction-applied resources; create an environment for safe, productive, and high quality work; technically support efficient construction operations and completion; and transfer experience between projects. The paper's relevance to industry practitioners includes multiple benefits of completing these activities for firms, projects, and professionals, along with the necessary steps to develop this capability and gain these benefits. Educators and researchers can use the activities to structure course topics related to technical fundamentals of construction and integration with design, along with future investigations of construction process knowledge.

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Introduction

The increasing performance demands regarding all types of project objectives and the growing scope and complexity of many types of constructed facilities combine to create strong drivers for increased technical support of construction operations. Several other recent trends in design and construction, described below, increase the importance of these drivers. Viewed strategically, these changes create an opportunity for firms, projects, and design and construction professionals. The ability to deliver more complex facilities better can provide a strong competitive advantage.

Technical support of construction operations, as used in this paper, is the application of engineering fundamentals and knowledge from experience to integrate design and construction, foster innovation in both, plan and assist the completion of field operations, all to better achieve project objectives. This broad scope of representing and supporting construction activities includes all phases of project delivery and considers the full lifecycle of the facility. Technical support, which expands the traditional scope of construction engineering, is highly visible in heavy and industrial construction, but the need and potential benefits are important for all types of construction. For building projects, preconstruction services include early activities to provide technical support for construction and project engineering includes the support of field operations.

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Every construction project requires technical support, although the scope and visibility is much greater on some types of projects. The approaches to providing technical support range from centralized within the general contractor's organization on heavy civil projects to distributed between specialty contractors on building projects. Each of the activities described below is required, to some degree, for each type of construction. If no one has before, construction crafts must complete these activities as a part of field operations.

The purpose of this paper is to increase understanding of the scope of technical support for construction (the what), the benefits from providing this support (the why), and the steps to provide this support (the how). The scope of activities described focuses on those shared by all types of construction but also includes specialized activities required for specific construction operations, such as concrete work. The benefits described include three levels: the firm, the project, and the professional. The steps to provide support include strategies and actions at each of these three levels. Greater attention to technical support of construction in practice, education, and research can increase the success of projects in meeting owners' objectives and of careers for all types of professions involved with constructed facilities.

The background for this paper includes experience on industrial projects, research concerning design–construction integration and innovation in construction, and teaching construction engineering topics in a graduate construction program. Field experience on two power plant projects contributed background concerning: construction and resident engineering activities (Tatum and Harris 1981); design construction integration (Tatum and Teague 1981); and innovative design and construction methods for concrete work and heavy rigging (Tatum 1983a, b).

Research that contributed to increase understanding of technical support activities included investigations of integration and innovation in construction. The integration research included improving constructibility (Tatum 1987, 1989a), and construction knowledge to consider in design (Fischer and Tatum 1997; Tatum

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and Korman 2000). The product innovation research focused on new designs that also required changes in construction, such as high-strength concrete (Nam et al. 1991). The process innovation research described case studies of new construction technology or methods along with differences in innovative construction organizations (Stewart and Tatum 1988; Tatum 1989b; Tatum et al. 1989).

The paper also includes technical support activities identified in graduate construction courses concerning concrete construction operations, construction engineering, and mechanical and electrical systems for buildings. In over 20 years of classes, curious and insightful construction students contributed to understanding key activities through probing questions and innovative ideas about ways to improve technical support of field operations.

This paper first describes incentives to provide increased technical support for construction operations and illustrates their importance with examples from each major type of construction. The main section then identifies and describes nine shared activities to provide technical support and increase the effectiveness of all types of construction operations in meeting project objectives. The following section then adds specialized activities to support five different types of construction operations. The final sections of the paper then identify benefits for individuals, projects, and firms; describe relevance for industry practitioners, educators, and researchers; and highlights conclusions.

Drivers Requiring Increased Technical Support for Construction

Complex and uncertain, many construction activities require technical support. This includes "representing" construction throughout all phases of the project, especially during early planning and decision making that have the highest cost influence. Several current trends increase the need for this technical support. Owners require the design and construction of more complex facilities and insist that project teams complete these facilities "better, faster, cheaper, and always safer." These include extremely challenging facilities as different as monumental buildings and Intel's semiconductor fabs. Other significant trends include expanded use of integrated methods of project delivery such as design–build, decreased owner staff and involvement in design and construction, decreased duration and scope of design activities, fast track construction, and performance-based engineering for structural and mechanical systems. Increased integration of all technical activities on a project and increased technical support of construction are important elements for effective response to the challenges created by each of these trends.

Design and construction are extremely knowledge intensive businesses. Designers require extensive knowledge about their engineering discipline, the facilities they design, and the codes and standards that govern the performance of these facilities. They make frequent use of experience from similar prior projects. Likewise, providing technical support and successfully completing construction operations require extensive knowledge from experience. The increasing capability of information technology can help fill both of these needs. New software tools offer particular promise as a means of capturing, representing, and applying all types of knowledge required for more effective design and technical support of construction. The technical support activities described in this paper can help set priorities and provide knowledge for the most effective application of these new tools to improve project performance.

Examples of Technical Support for Different Construction Operations

The examples described in the following paragraphs illustrate the types of technical support activities required for construction operations representing several different types of work. Each is essential for successful completion. These examples illustrate the extensive requirements for support and the surprising number of organizations involved in providing it. The examples also illustrate types of support activities shared over all types of construction and other specialized activities for different construction operations. The main sections of the paper describe both of these.

Building Substructure

An equipment operator for a hydraulic excavator digs material and loads it into an articulated truck as a part of substructure work on a building. Activities required to technically support this construction operation include planning the construction method and selecting the equipment, designing the haul road, laying out and staking the excavation, designing the temporary ground support, and selecting the fill or disposal area for the material. Field engineers and superintendents working for the general contractor or excavation contractor typically provide this technical support.

Structural Steel

An ironworker raising crew sets steel columns as a part of erecting a building frame. Activities required to technically support this operation include detailing the structural shapes for fabrication and erection, planning the erection sequence, selecting the location and type of equipment required to erect the steel, providing fall protection equipment, and checking the location and plumbness of the erected steel. Steel detailers, field engineers, and foremen working for the fabricator and erector typically provide this technical support.

Cast-in-Place Concrete

A carpenter crew fabricates and sets formwork panels for a cast-in-place concrete wall. Activities required to technically support this operation include locating the construction joints in the structure, selecting the method and rate of concrete placement, selecting and obtaining the materials and hardware to build the forms, locating the penetrations and embedments in the placement, and planning the method of setting and securing these embedments. Field engineers and foremen working for the general contractor or formwork contractor typically provide this technical support.

High Pressure Piping

Pipefitters erect and weld a piece of fabricated pipe in a feedwater system for a boiler in a power plant. Activities required to technically support this operation include detailing the pipe spools to define piece size and field weld location, planning the sequence of pipe erection, selecting the methods of moving and hoisting the heavy pipe spools, defining the tolerances for fit-up, setting up the field welding program, and providing nondestructive examination. Pipe detailers working for the fabricator and field engineers and foremen working for the general contractor or piping contractor typically provide this technical support.

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Electrical Distribution in Buildings

Electricians pull a feeder cable through a conduit raceway and terminate it to electrical switchgear. Activities required to technically support this operation include detailing the conduit routing, setting up a shop for conduit bending, planning for precutting the cable, selecting the location of the cable pull points, selecting access routes for the cable spools to pull points, providing specialized equipment for cable pulling, preparing diagrams for cable termination, and defining requirements for testing. Field engineers and foremen working for the electrical contractor typically provide this technical support.

Heating, Ventilating, and Air Conditioning Ductwork

Sheetmetal workers erect and connect a piece of ductwork in a building heating, ventilating, and air conditioning system. Activities required to technically support this operation include detailing the ductwork in accordance with industry standards and shop fabrication capability, selecting piece sizes for shipment and handling, selecting the fabrication method and equipment, planning the sequence of erecting the ductwork, and defining requirements and methods for testing and balancing the systems. Field engineers working for the mechanical contractor, shop and field foremen, and testing and balancing consultants typically provide this technical support.

Importance and Responsibility

These examples illustrate two characteristics of technical support for diverse construction operations. Technical support activities, although often performed before construction, are either essential or very beneficial for efficient construction. As further described later, they have a major impact on the success of construction operations in meeting objectives for cost and schedule, quality, and safety. Though often not visible, these activities are critical. They are performed by many different types of design and construction professionals, along with suppliers of materials and equipment.

If no other discipline or function completes these activities prior to field construction, then construction field forces will have to complete them by default. Although construction craft persons develop extensive knowledge from their field experience, it focuses on their trade and they are typically not involved until field construction begins. Leaving these key activities to the field therefore fails to realize potential project advantages from performing them earlier in the project and integrating them with other activities for the best project solutions.

Key Shared Activities for Technical Support of Construction

Construction operations are highly diverse; they are performed under very different conditions, require many types of resources, and present a range of risks. Despite these significant differences, these operations share the need for many key types of technical support activities to better achieve project objectives. Identifying the scope of these activities at a fundamental level highlights the need to consider possible applications in firms and on projects. This broad level of activity definition is intended to pose questions and stimulate creative thinking regarding the appropriate scope and best approach for a project and possibly help transfer experience regarding these activities between different segments of the engineering and construction industries.

This section describes nine technical support activities shared between different types of construction operations. These are: integrate early planning, plan for regulatory compliance, consider construction methods and sequences in design, tailor and time technical information to users' needs, provide materials to support effective construction, identify and provide construction-applied resources, create a safe and productive work environment, technically support efficient construction operations and completion, and transfer experience between projects. The following section identifies specialized activities required to support different types of work, including civil and infrastructure work, concrete work, structural steel work, mechanical and piping work, and electrical and controls work. Later sections describe the major opportunities and benefits from successfully completing each type of activity and the actions required by owners, operations managers, project managers, and individuals.

Integrate Early Planning

Integrating construction planning with early project planning for engineering, procurement, commissioning, and operations is the first key step in providing the design and materials necessary for effective construction and in providing a facility that is fully ready for commissioning and operation. For many projects selecting the construction method and sequence is a key initial decision. Considering the technical aspects of construction methods and determinants of sequence is essential to select the most cost effective approach and to develop accurate estimates. Then integrated planning defines the scope, sequence, and schedules for packages of design and key procurement actions to support milestones for estimating, contracting, fabrication, construction, and commissioning (Tatum and Teague 1981). Integrated planning and estimating also share schedule and cost challenges over all phases of the project and provide essential benchmarks for monitoring performance throughout the project.

Plan for Regulatory Compliance

Careful attention to regulatory requirements and processes results in realistic commitments and reliable plans to assure compliance. Permits and other forms of entitlement, along with special requirements from lenders and insurers and others, can result in severe constraints for design, construction, commissioning, operations, and maintenance on many types of projects. Examples include limited construction working hours and staff, restricted access to the site, environmental monitoring, and additional inspection and testing requirements. Input from design and construction to permit applications and the resulting commitments can identify ways to satisfy the regulatory intent with less impact on design requirements and field operations (Tatum and Harris 1981). Establishing systems to assure that these requirements are fully implemented and monitored during design, procurement, construction, and testing is another key activity for technical support.

Consider Construction Methods and Sequences in Design

Planning to identify preferred construction methods and making input to preliminary and detailed design based on these plans results in designs that allow more effective construction. The

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Construction Industry Institute (CII) expresses this in a constructability concept stating that design approaches should consider major construction methods and identify different approaches for implementation (CII 1987, Gugel and Russell 1994). O'Connor and Tucker (1986) identified many different types of constructability benefits. Innovative solutions often result from joint efforts by engineering, procurement, and construction to investigate several possible construction methods (Tatum and Teague 1981). Examples include use of precast concrete structures, modular portions of industrial plants, or innovative methods for heavy rigging (Tatum 1983a, b, 1989). Other examples of integrated construction considerations into detailed design include multiple use of components from all systems, such as using portions of the permanent structure to support formwork or using parts of the permanent utilities during construction (Tatum and Harris 1981).

The detailed configuration of systems also results in significant implications for construction. The most effective installation sequence for systems in congested areas of plants or buildings is generally to build from the top down. This requires routing the systems to allow this sequence and still support priorities for completion and commissioning to comply with required dates for operation or occupancy. Integrated design also allows construction input concerning flexibility for field fitup and adjustment of components that require precise location tolerances.

Tailor and Time Technical Information to Users' Needs

Fabricators and installation crews need technical information in a form and on a schedule that allows them to operate effectively. Providing technical information this way is perhaps the most critical activity in effective technical support. It includes additional requirements or configuration details to fully define and implement the design intent along with information related to technical support of field operations. The following examples illustrate the types of information needed to fully define design requirements. Additional requirements for technical information are described under a later activity concerning support of field operations.

1. The plans and specifications for a facility define the technical scope and requirements that govern all construction operations, but frequently do not define the detailed configuration for fabrication or full requirements for installation. This requires interpretation and sometimes extension to fully define the design intent and scope. Integration and early definition of detailing responsibility lessens the need for additional design information from the field. When requests for information are necessary, integrated technical support allows proposing solutions based on understanding the design intent to greatly improve the process.
2. Detail drawings define the configuration for all types of engineered materials and systems in a building. Examples include reinforcing steel, structural steel, small and large diameter piping, pipe supports, and electrical raceway. These details must comply with all design and code requirements, but also need to consider construction methods and sequences. Examples of construction considerations include reinforcing steel details that correspond to concrete placements, sizes and weights of structural steel members that fit crane plans, and pipe spools that allow movement into confined spaces and adequate access for welding.
3. Composite or coordinated drawings (or computer-aided design models) integrate the work of several design disciplines and construction trades to avoid field problems. Examples include physical interferences such as ductwork clashing with fire sprinkler lines and functional interferences such as cable tray blocking lighting before operation (Tatum and Korman 2000). These drawings also facilitate detailed planning of installation sequence. Composite drawings include underground systems in the yard, lift drawings showing all embedded items in each concrete placement, coordination drawings for mechanical, electrical, and plumbing (MEP) systems, and penetration drawings for routing MEP systems through walls and floors.
4. Detailed instructions from suppliers of critical mechanical and electrical equipment and components define storage and installation requirements, piping and electrical connections, testing, and start up. This supplier information often contains specific requirements not included in other design documents. Technical support activities include identifying and obtaining needed information, along with coordinating technical representatives to assist with installation and start up of complex equipment.
5. Technical requirements and acceptance criteria for commissioning describe the scope of systems for testing, the required testing process, the acceptance criteria for results from testing, and required documentation of results. This information is also valuable for future operations and maintenance of the facility. Examples of the many types of possible testing on a project include load testing of pile foundations, balancing of heating, ventilating, and air conditioning systems, pressure testing of piping systems, continuity tests of electrical systems, and preoperational testing of subsystems. Effective performance of each type of testing requires planning to fully define requirements, frequency of performance, acceptance criteria, and documentation (Parsons 1972).

The timing of technical information is also critical for effective construction operations. The first need is often for materials fabrication. Fast track projects may require close design– construction coordination to assure that design requirements are frozen and released on a schedule that minimizes adverse impacts for construction. These projects may include a release system to assure that specific parts of the design, such as individual concrete placements, are complete and ready for construction in accordance with the schedule. Similarly, timely technical response to changed conditions and other field problems is an essential element of construction support.

Provide Materials to Support Effective Construction

Field crews need permanent equipment and materials on a schedule and in a specific condition to allow effective installation. This includes appropriate degree of shop completion, delivery in conformance with site need dates, clear and simplified field assembly and installation, and fully defined requirements and technical support for system completion, testing, and commissioning. Materials management systems encompass all aspects of providing materials for effective construction operations. Meeting this goal requires technical support to define requirements for materials, takeoff or verify quantities, prepare or review detailed drawings, inspect the materials, support installation, and solve problems.

Identify and Provide Construction-Applied Resources

Effective construction operations require many types of resources other than permanent materials and equipment. Construction-applied resources are used during the construction phase and do not remain a part of the completed facility. These include knowl-

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edge and skills based on construction experience, construction equipment, tools, and temporary materials that are consumed during construction operations. The plans and estimates mentioned in a prior activity identify the need for construction-applied resources. Examples of technical support include fully defining requirements ranging from the type and capacity of earthmoving or lifting equipment to the size and quantity of lumber and plywood for formwork. Technical adequacy and cost are key requirements. Innovative construction methods often involve using new construction-applied resources or existing resources in new ways.

Create Environment for Safe, Productive, and High Quality Work

Several characteristics of the work environment are essential for safe and effective construction operations. Facilities contributing to a safe working environment include safety and first aid, fire protection, temporary ventilation for enclosed spaces, and security systems. Portions of the construction plant that support productive and high quality construction operations include: sufficient areas for laydown and staging of construction materials; efficient access to the workface for crafts, equipment, and materials; means for efficient materials handling; and utility systems. An appropriate level of facilities and services shared by multiple contractors or trades on a project can increase construction productivity and high-quality workmanship. Examples of possible shared facilities include materials handling equipment, temporary heat and ventilation, electric power, construction lighting, compressed air, and welding systems and gasses. Possible shared services include hoisting, weather protection, inspection and testing, cleanup, trash removal, and materials recycling (Tatum and Harris 1981). Technical support activities related to shared facilities and services include input to decisions about the appropriate scope for the project, design, and fabrication of buildings and systems, contracting for services, and technical support of system operation and maintenance.

Technically Supported Efficient Construction Operations and Completion

Anticipating and avoiding field problems is a major goal of technical support. Field people term this "first building the job on paper in the office." Computer tools can now help analyze the design requirements, apply knowledge from experience, identify all essential resources, and prepare designs and detailed plans for field operations. A part of the product of these activities to prepare for effective field operations results in the composite drawings and testing instructions that are synthesized from separate design requirements, as described in a prior activity. The other products include construction drawings for temporary works and the construction plant and detailed instructions for high-risk operations, as described in the following examples.

1. Construction drawings for field layout define control points, benchmarks, and other references for horizontal and vertical control of field activities. Easy access to control points at all locations and stages of construction is essential for accurate layout and productive field operations.
2. Construction drawings and specifications for temporary buildings and utility systems define the scope and requirements for the construction plant. These documents technically define the elements of a safe and productive work environment described above.
3. Space planning drawings allocate laydown areas and short-term staging areas for materials of construction in the yard and inside buildings. They also define access routes for people, construction equipment, and materials to the workface.
4. Design drawing for temporary ground support, falsework, and formwork for concrete identify required materials and configurations. The critical safety aspects of these temporary structures may required design or review by licensed engineers.
5. Detailed procedures describe construction tasks, sequences, controls, and quality acceptance criteria for critical operations. The objective is to fully define technical requirements and identify at least one feasible method to satisfy these requirements. Examples of operations that may require procedures include welding, setting and aligning precise equipment, special coatings, and testing.

Each of these technical support activities and types of technical information provided to the field greatly increases the chance of avoiding field problems and allowing productive operations. When problems do occur, effectively solving them requires understanding the design intent, analyzing the consequences of the installed condition, and proposing solutions that comply with all design constraints. Direct technical support in the field is the most visible form but successful completion of the previously described activities helps to diminish the number and scope of field problems.

Transfer Experience between Projects

The project nature of design and construction requires activities to transfer experience to help repeat successes and avoid failures. Construction engineers document best practices and identify key resources and activities required to successfully complete specific types of work. They also identify problems and lessons learned about how to avoid them on future projects. Technical job reports provide a wealth of knowledge and major advantage in progressive firms. The major challenges in transferring experience are collecting the information as the project progresses and putting it in the form that is most accessible and useful to the next project team. This key learning activity for the firm requires commitment and clear responsibility assignment, focus on the highest priority contents based on the information needs of the user, and the cooperation of all disciplines and trades. Computer tools can help if these other elements are in place (Fischer and Froese 1996; Kartam 1997).

The nine activities described above provide technical support to assist in meeting project objectives for all types of constructed facilities. The scope and visibility of these activities differs for different projects, but they bring benefits for all types of construction operations. In contrast, the following section identifies and describes examples of specialized technical support activities for successful completion of five different types of construction work.

Technical Support Activities for Specific Types of Work

Specific types of facilities and construction operations require specialized activities to provide technical support. Differences in site conditions, facility designs, and materials of construction create the need for these specific activities. The examples described below highlight differences for the following basic types of con-

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struction work: civil, concrete, structural steel, mechanical, electrical, and controls.

Civil and Infrastructure Work

Sometimes referred to as engineered construction, projects to build civil works and infrastructure require many visible activities to provide technical support. Often built in remote locations, these projects can present special risks related to site conditions, weather, or resource availability. Examples of specialized activities for technical support on these projects include designing temporary structures and haul roads, developing custom infrastructure, designing cofferdams and river diversions, measuring installed quantities, coordinating inspection and testing services, and providing environmental protection and erosion control.

Concrete Work

The many possible applications of concrete and the potential to degrade its properties during construction operations required special technical support to assure specified quality. For example, field engineers and superintendents on projects involving extensive or specialized concrete work design concrete mixes; design and provide aggregate and concrete plants; locate construction joints and prepare lift (composite) drawings for each placement; release reinforcing steel for fabrication to support safe and efficient construction; design formwork, falsework, and shoring; and select methods and specialized equipment and materials for concrete transport, placing, finishing, and curing.

Structural Steel Work

Large steel members are often fabricated to precise tolerances; steel erection operations are potentially dangerous; and welding large connections in compliance with stringent quality requirements is challenging. These characteristics of steel work increase risks and needs for special technical support. Examples of important activities include detailing steel for fabrication, planning steel erection methods and operations, coordinating delivery to support efficient field operations, selecting and providing cranes or other lifting equipment, checking the location of steel compared with design requirements and tolerances, and completing nondestructive examinatiton and other quality control methods required for steel connections.

Mechanical and Piping Work

Major mechanical equipment and piping systems often involve large numbers of highly specialized components, fabricated and connected to precise tolerances. Acceptable installation of the correct components, including quality welding, requires extensive technical support. Examples of these activities include defining special requirements for equipment installation, detailing pipe pieces, providing specialized pipe supports, developing programs for acceptable quality welding, qualifying weld procedures and welders, performing and evaluating nondestructive examination of pipe welds, planning pressure testing, and coordinating technical support from suppliers for installation and startup.

Electrical and Controls Work

Electrical and control systems include sophisticated equipment and devices connected by large quantities of raceway and wiring, much of which is routed in the field. Efficient installation and safe and functional systems require extensive technical support. This includes providing the proper storage environment for electrical switchgear and other equipment, detailing electrical raceway systems, preparing loop schematic diagrams and termination lists, developing plans for cable pulling and termination, planning the calibration program, and planning testing and commissioning of the systems.

Technical Support: Providing Competitive Advantages for Firm

The general and the specific activities to provide technical support described above are extensive and can be expensive. Why provide this level of technical support? Clearly, the investments in people and technology must payback with value exceeding cost. This section and the two that follow describe this payback in terms of benefits for the design or construction firm, the project, and the professionals' careers. Each section also includes a description of strategies and actions to realize these benefits.

Effective technical support for construction provides a distinctive core competence for a design or a construction firm. It is also a key element of continuous improvement and an essential basis for integration and innovation. Firms with a highly developed capability for technical support of construction can add greater value to projects and therefore gain increased profitability. This capability also provides a solid basis for analyzing the risk of unusual project or site conditions and a vital foundation for developing needed new capabilities for a firm in times of major changes in the markets it serves.

Selecting and realizing these potential benefits for the design or construction firm requires defining competitive advantages sought, formulating technology strategy to gain those advantages, and implementing the selected strategies. Each of these actions is described below.

Competitive Advantage

How should managers select the scope and approach for providing technical support? Background in competitive strategy provides useful guidance. Porter (1980) identified cost, differentiation, and focus as the major types of competitive advantage for firms. Very difficult to develop or acquire, capability to provide technical support for construction is a key means of differentiation and a highly sustainable source of competitive advantage. This capability also brings cost advantages based on improved construction operations.

Several successful firms illustrate competitive advantages based on differentiation by increased capability for technical support of construction. Peter Kiewit Sons' applies expertise to design temporary works and complete the complex and high risk operations required for challenging infrastructure projects. Charles Pankow Builders combines the design–build delivery approach with expertise in special processes such as slipforming and onsite precasting to integrate design and construction and provide greater value for building owners. Chicago Bridge and Iron applies unusual capability in fabricating large plates, welding, and rigging to successfully complete complex industrial projects. Each of these firms has developed technical expertise and special capability to provide technical support for operations that their competitors lack.

Technology Strategy for Technical Support

Functional strategies for finance and human resources guide the development and allocation of resources in the firm to realize business objectives. Similar technology strategies guide decisions regarding technical resources. A firm's approach to technology is defined by decisions to select specific types of expertise for the firm and to determine the degree of decentralization for that expertise (Hampson and Tatum 1997). For example, a firm may design its own formwork for concrete and special shoring for specific types of structures, such as highway overpasses. Heavy civil firms may concentrate construction engineering capability at the home office, decentralize it to their own employees assigned to projects, or engage consultants.

Several architectural, engineering, and construction firms specializing in large industrial projects develop capability for technical support of construction and concentrate it in groups termed home office construction. These small teams of construction professionals with diverse experience provide the dual advantage of representing construction during early planning and design for a project and providing technical support by performing special studies such as transport and rigging for large vessels and equipment. Owners of large industrial plants, such as hydrocarbon processing and power, are often convinced that the benefits of providing this technical support exceed the costs. They require and pay for it.

Implementation

Several steps are necessary to select competitive advantages based on specific capabilities for technical support of construction and to formulate and implement a technology strategy to realize these benefits. The following provide a starting point:

1. Analyze markets, types of constructed facilities, desired competitive advantages, and technical support activities necessary to provide these advantages. The complexity and risk of the construction operations required are key considerations.
2. Select priority activities for technical support and define the capabilities required to perform these activities. A key consideration in these decisions is balancing fundamental technical capability with applications to fit the work the firm does. This strategy will also allow the firm to use the increasing capability of information technology to capture and apply knowledge from experience in the firm and to leverage activities to provide technical support.
3. Develop and implement a technology strategy or plan to obtain the expertise and resources necessary to perform the selected activities for technical support. This requires defining sources of required expertise and degree of centralization in the organization. Possible options include hiring, developing, or engaging from the outside. Effective implementation requires specific plans, resources, and periodic review.

Formulating and implementing a strategy for technical support of construction in a firm will provide a baseline level of capability appropriate for the markets and projects of the firm. This baseline should allow project managers to select the scope of this activity on a specific project based on the project objectives, special design requirements, experience of the owner, differences in the site, experience of the contractors and crafts involved, and other key project differences.

Technical Support: Better Meeting Project Objectives

The activities to provide technical support described above help satisfy all types of objectives for the project. These activities foster more productive, safer, and higher quality construction by providing all of the resources needed to complete construction operations with minimum rework. They also increase the level of design–construction integration on a project and the potential for innovation in design and construction. This builds effective teams. This section describes how technical support can help achieve each project objective and how to provide this capability as an important part of project teams.

Cost and Schedule

All of the technical support activities described above assist in achieving project cost and schedule objectives. The activities involving integration decrease project cost and schedule by allowing use of beneficial construction methods and providing design with increased constructibility. Product or process innovation can decrease the scope and difficulty of construction or provide new methods or resources that enhance construction productivity. Technical support activities provide favorable working conditions and all types of resources needed for productive operations and responsive resolution of field problems. This allows foremen and crews to focus their attention on building the work rather than obtaining the information and materials. Thus technical support provides major benefits for the most visible project objectives of cost and schedule, but not only for these objectives.

Quality

Technical support activities help achieve project quality objectives by contributing to defining realistic quality requirements and acceptance criteria, a key topic for design–construction integration. Innovative construction methods or equipment and tools may also decrease the risk of not conforming to quality requirements. Engineers providing technical support interpret the plans and specifications, highlight special requirements, and otherwise work with crews to help build it right the first time. They select appropriate quality control methods [inspection, testing, tracking, trending, and documenting (Parsons 1972)] that fit the type of work and technical requirements. Engineers providing technical support assist quality control personnel with fully implementing the selected quality methods and assuring compliance with quality requirements.

Safety

Technical support activities help achieve project safety objectives by providing input to design regarding requirements and configurations that allow safe construction, assessing the safety implications of specific design requirements, and designing temporary works to support safe construction. Technical input to construction plans also includes identifying potentially unsafe conditions and operations and recommending alternatives to avoid problems. Field engineers design and provide safety facilities, temporary structures, and a construction plant that creates a safe working environment. They also observe operations and help avoid problems.

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Environmental Protection

Permits and licenses for most types of construction projects include commitments regarding runoff control, storage of petroleum products and chemicals, dust and noise from construction, and many other environmental and health concerns. Technical support activities help assure compliance with these requirements by providing input to permit applications to assure realistic commitments are made, planning programs to implement and monitor compliance, and designing and providing required special facilities needed to assure compliance. As with safety, it is very important to consider environmental protection early and throughout the project to provide the plans and resources needed to assure compliance.

Providing Technical Support for Projects

Owners seeing to improve project performance through increased technical support can use this capability as one of the selection criteria for project team members and can encourage these activities throughout the project. As described above, decisions regarding the technology strategy of the firm establish a baseline of available resources and capabilities for providing technical support to projects. This gives the project manager choices regarding the most effective level for the project. Operations and project managers select the organization and staffing based on their experience on similar projects (Tatum 1984). This can create problems if the current project includes different types of challenges that required increased technical support.

Defining the project approach and plan for providing technical support should include identifying critical operations, selecting the most effective level of support, and setting the schedule for getting the required people involved. The level of technical challenge of the project guides these choices and includes site conditions, design complexity, risks of construction operations, cost and schedule demands, and other special conditions or requirements. The timing of technical support is significant. If the construction firm is involved early, then integration of planning and other technical support activities as described above can add substantial value to the project.

Technical Support: Gaining Career Advantages

Experience in providing technical support for construction provides many career advantages for construction professionals. These include getting off to a good start, advancing along the career path, pursuing other careers related to facilities, and learning throughout one's career. This section describes each of the advantages along with actions to realize.

Off to Good Start

Ted Kennedy of BE&K observed that engineers beginning careers in construction are first evaluated on their technical performance. A good start requires being able to do something quite well and this is often a technical activity. Examples include field engineering, surveying and layout, design of temporary facilities, interpreting the plans and specifications—all identified in the technical support activities described above. Individuals beginning careers in construction obtain increased responsibility based on the visibility and reputation resulting from doing something well. People and management skills then become more important. So, even if someone advances rapidly and requires new types of skills, their technical capability is critical for getting off to a good start and gaining recognition and increased responsibility.

Along Career Path

But the need for technical expertise is not limited to early career years. Increased responsibility involves delegation of key work activities to others and that requires judgment to assess the technical adequacy of their work. This calls for even more, not less, fundamental technical understanding and experience-based knowledge of design and construction. As responsibilities continue to increase, so do the risks and stakes of decisions. For example, operations and senior managers review estimates and bids for new work and must assess the appropriateness and risk of the planned methods along with the expected productivity rates and costs. Successful senior managers often display a surprising ability to identify and probe fundamental technical issues that are critical for risk and cost. By setting an example of the necessity for technical depth, effective senior managers also contribute to the technical development of the future leaders in their firms. This required the continued learning described below.

Diverse Careers Related to Facilities

Several other career paths relate to the technical aspects of facilities but do not involve direct responsibility for design or construction. Real estate development and property or facility management are two examples. Both require an understanding of the technical attributes of facilities and construction operations to make good decisions. At the front end of the project, real estate developers must consider the technical characteristics of potential sites to complete the pro forma analysis of project economics and to identify the major project risks before commitment. Examples include drainage and soil bearing capacity, utility availability, and access. They must also apply extensive technical knowledge of building systems to fully define the program and functionality of the facility. After the facility is built and ready for occupancy or production, property managers or facility managers and operations staff need to understand design criteria and construction activities for the major systems in the buildings they operate, maintain, and retrofit for different use. Early career experience in providing technical support for construction provides an excellent basis for these and other careers related to facilities.

Foundation for Lifelong Learning

Prior background, particularly at a fundamental level, greatly assists in new learning. Experience with the activities described above provides just the right kind of knowledge for this. The increased understanding of engineering fundamentals and experience-based knowledge gained from providing technical support provides an unmatched foundation for continued learning throughout a career in design, construction, or related fields. Professionals who ask many questions and think analytically about what they learn from experience in providing technical support gain major career advantages. A solid foundation from early career experience can greatly increase the rate of learning for all types of future responsibilities related to facilities.

Career Actions

The first critical career action to gain advantages from providing technical support is to select an initial position that will provide

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experience in performing the activities described above. Working in the field on an integrated project provides extremely valuable initial experience. Curiosity about how to design and build is essential to gain technical knowledge. The activities described above provide an excellent opportunity to ask, research prior projects, consider new approaches, and learn. After some experience in the field, a subsequent assignment that involves direct interaction with design is also very important.

An engineering degree provides a very useful background in the fundamentals to begin learning from construction experience. Graduate construction education can also assist in broadening perspectives regarding the technical and managerial aspects of design and construction. But providing technical support to construction at various levels is a lifelong learning experience. It requires further study of fundamentals, often from several different engineering disciplines, and applications for each new situation and discipline to keep growing technically. Iteration between learning from your own and others' field experience and learning more about engineering fundamentals continues to build the scaffold or framework for future learning and the basis for career progression. This requires commitment and effort, but offers big payback. Other activities that support continued learning and growth include creating specific requirements such as project reports to reflect on experience, taking courses that provide background for current responsibilities, taking courses that broaden perspective and help prepare for future responsibilities, participating in professional organizations, and teaching courses based on experience.

Relevance to Industry Practitioners, Educators, and Researchers

Benefits for Practitioners

If the potential benefits of increased technical support are so large, why isn't everyone doing it? A few progressive firms and managers are, quietly, and with admirable results. Others are fully committed to traditional approaches and the lowest possible cost for design and construction, including minimizing overhead. This contrast between strong drivers for change in some segments of the industry and strong traditions in others will create significant opportunities for firms and individuals that add technically based value to projects and better meet owners' objectives. Considering the activities identified in this paper will help realize this opportunity.

Performing the activities identified to provide effective technical support of construction results in clear advantages for design or construction firms, for projects, and for career paths by industry professionals. But realizing potential advantages at each of these levels requires actions. Design and construction firms gain competitive advantages by adding new kinds of value and getting paid well for it. Effectively performing the activities described in this paper is a key way to do this. Senior and operations managers need to develop the capability for technical support as a part of the technology strategy of the firm by deliberate choices and commitment of resources necessary to develop this competence. This requires viewing the capability and knowledge as major competitive advantages for the firm. Managers also need to monitor performance in technical support.

Project managers improve performance regarding all project objectives and decrease risks by selecting appropriate levels of technical support based on specific challenges and constraints. Considering the activities described in this paper assists in making these tough choices. This begins with the baseline capability for technical support established within the firm. The next step is analyzing project requirements and conditions and tailoring the level of technical support to best satisfy project objectives. A specific activity may provide high levels of payback for a project.

Design or construction professionals involved in providing technical support can use the activities identified in this paper to increase their rate of learning and advancement. They keep increasing their knowledge from experience and their understanding of engineering fundamentals in lifelong learning. Possible career advantages from this knowledge extend to all types of professions involved with facilities including planning, entitlement, financing, inspection, facility or property management, operations, maintenance, and retrofit.

Benefits for Educators

Identifying fundamental activities to provide technical support can assist educators in better preparing graduates for multiple career paths related to facilities. The activities emphasize the importance of understanding technical fundamentals for application to support work by multiple design disciplines and construction trades. Description and examples of each activity can help structure coverage of topics related to design and construction in a manner that helps students understand how they may apply what they learned in entry-level positions. Preparing to do something well quickly motivates increased understanding. The activities for technical support also provide a means to illustrate the essential technical basis for increased responsibility. The activities can also assist in structuring topics to provide a foundation for an increased rate of learning from experience. Many graduates now focus on applications of computer-based tools; the activities for technical support provide further content to increase the flexibility and benefits of these tools.

Benefits for Researchers

The activities for technical support of construction identified in this paper provide a starting point for further investigation to increase understanding of construction process knowledge. Investigations to further identify differences in these activities for different types of construction work and to add more detailed tasks would increase value and potential applications. Future researchers can also identify knowledge requirements for the activities, including technical fundamentals and knowledge from experience. Formalized and disseminated, this knowledge would provide a basis for representation and modeling to allow easy access and use by all team member at all stages of the project. It would also provide the understanding and content to help realize the potential advantages that rapidly advancing information technology offers for design and construction.

Increased understanding of technical support could also foster development of principles for effective integration on projects and ways to increase innovation. Each of these areas of possible future research would provide a basis for new alternatives for technology strategy in design and construction firms and for techniques to assess the costs and benefits of different levels of technical support. Increased need for technical support may prompt the development of a new integrating discipline in design and construction and provide knowledge that fosters improved performance on integrated projects, such as design–build or turnkey.

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Conclusions

The above description and analysis of technical support to build better identified key activities, benefits at three levels, and approaches to realize these benefits. These topics lead to the following conclusions.

Increasing facility complexity and demands regarding each project objective are increasing the need for technical support for construction operations. Although historically focused in heavy construction, this support is growing in importance for specific types of projects in all segments of construction. Technical support involves actions by designers, suppliers, field engineers, and others to provide all of the resources necessary for effective construction operations. Including integration and innovation in these activities along with emphasizing the preconstruction activities expands the traditional concept of construction engineering.

Examples of construction operations related to each design discipline and construction trade illustrate the essential role of activities to provide technical support. Many of these activities, such as providing information and materials, are shared by almost all construction operations. This paper identified nine key activities to provide technical support for all types of construction. These activities help to provide plans, site conditions, and resources that allow effective construction operations. Although clearly essential for effective construction, many of the technical support activities are performed by people in other parts of the project team or over the complex supply chain for materials of construction and other essential resources.

Providing technical support for construction operates in several ways to bring benefits for firms, projects, and individuals. The activities described in this paper provide structure for a systematic approach to considering how to build better as a part of activities during each project phase. This structure will prompt attention to activities that are not part of current practices, but could add significant value for firms, projects, or individuals. Considering the activities broadens thinking, increases integration, and fosters improvement and innovation. Capability for technical support of construction strengthens fundamental technical expertise and ability to handle changes in design or construction. Based on several types of construction, the activities for technical support encourage transfer of experience between design disciplines and also between different segments of construction.

The activities to provide technical support for construction emphasize the technical basics. They foster building with a better process, building a product that better meets the owners' needs, and developing professionals to improve overall performance. The opportunity to improve technical support by completing these activities challenges operations and project managers to consciously evaluate potential applications, deliberately select levels of capability and support, and willingly provide the resources and capabilities required. Then they build better.

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