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Construction Technology Transfer Center

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The U.S. Army Corps of Engineers (USACE) is one of the world's largest engineering and construction organizations. As such, it must use new and existing technologies in the most effective and efficient manner possible. Also, as a Federally funded activity, USACE is mandated by the Federal Technology Transfer Act of 1986 to transfer commercially viable technologies into the public marketplace.

With this mandate in mind, a pilot project was initiated between the U.S. Army, Construction Engineering Research Laboratories (USACERL) and the Indiana State University (ISU). Under this project, USACERL worked with ISU's School of Technology to establish the Construction Technology Transfer Center (CTTC) and to develop mechanisms to transfer the results of Corps construction-related research to small- and medium-sized construction companies throughout the Wabash Valley Region. The goals of the effort have been defined by three phases: Phase 1, survey the needs of small- and medium-sized construction firms in the region in terms of both automation skills and technology opportunities; Phase 2, development of technology transfer activities based on the results of the survey findings and an analysis of Corps technologies; Phase 3, delivery of Corps technologies to the target contractor population.

Foreword

This study was conducted for the U.S. Army Corps of Engineers, Directorate of Research and Development (CERD) under Corps Of Engineers General Investigation 96 X 3121, LJ7, “Construction Technology Transfer Center” (CTTC). The technical monitor was David B. Mathis, CERD-C.

The work was performed by the Engineering Process Division (PL-E) of the Planning and Management Laboratory (PL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Jeffrey G. Kirby, and the CTTC principal investigator at Indiana State University, Terre Haute, was Dr. Bruce D. Dallman. E. William East (USACERL) was formerly a principal investigator on the project and designed the Site Safety Planner software. Dr. Michael P. Case is the Division Chief for PL, and L. Michael Golish is the Laboratory Operations Chief, PL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

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1 Introduction

Background

As one of the world's largest engineering and construction organizations, the U.S. Army Corps of Engineers (USACE) must effectively use new and existing technologies in the most efficient manner. Managing the design, construction, operations, and maintenance of billions of dollars of new or existing infrastructure offers the potential to exploit the benefits that may be attainable from the use of new technologies. Since design, construction, and operations and maintenance activities are typically fragmented within the United States and research is not centrally supported—only 0.4 percent of annual construction costs are spent on research (Laborde and Sanvido 1994)—innovation is both slow to occur and slow to be implemented. For this reason, the Corps supports and funds its own basic and applied research needs. USACE laboratories are also encouraged to solicit work from other Army and Department of Defense activities related to technical problems. These additional funds can complement and leverage the Corps basic and research applied programs. As a Federally funded activity, USACE is also mandated by the Stevenson/Wydler Act (Federal Technology Transfer Act of 1986 and amendments) to transfer commercially viable technologies into the public marketplace.

Corps research laboratories hence face a twofold task: first, to develop new and unique solutions to problems and, second, to effectively transfer the developed solution directly to the desired end user. The Corps laboratories' primary approach to delivering new technologies is through partnership arrangements with other governmental agencies and the private sector. Partnership agreements range from license agreements for government-held patents to cooperative development agreements that lead to joint ownership of the completed product.

Clearly, a key issue of interest to Congress in particular and to the Corps in general is how to improve innovativeness in the construction industry. One possible approach would be to improve the transfer of USACE-developed technologies to small- and medium-sized firms that constitute a majority of the firms within the industry. These firms typically have not benefited directly from the technology transfer activities identified above.

With this in mind, a pilot project was initiated between the U.S. Army Construction Engineering Research Laboratories (CERL) and the Indiana State University (ISU). Under this project, CERL has been working with ISU's School of Technology to establish the Construction Technology Transfer Center (CTTC) and to develop mechanisms to transfer the results of USACE construction-related research to small- and medium-sized construction companies throughout the Wabash Valley Region. Reaching the objectives of this effort means that the target firms would have improved access to new technologies and the Corps would gain an expanded pool of technologically enhanced firms to bid on Corps projects.

Objective

The objective of developing transfer activities was divided into three subgoals. Prior to initiation of transfer activities, however, the infrastructure to support these activities at ISU had to be established. Establishing the infrastructure included locating dedicated space at ISU, establishing telephone help-line operational protocols, and procuring and installing a computer-use training facility within the dedicated space.

The first of the transfer activities was to determine the capabilities and needs of the target population of small- to medium-sized contractors. Second, potentially transferable Corps technologies had to be identified. Finally, transfer activities had to be initiated.

Approach

Meeting the objectives of this effort was approached in three phases. These phases correspond with the subgoals discussed in the previous section.

Phase 1

The first step in the process was to survey the needs of small- and medium-sized construction firms in the region in terms of both automation skills and their perceptions of technology opportunities. This step was accomplished by the creation, mailing, and analysis of a questionnaire sent to approximately 1,900 contractors within the four-county Wabash Valley Region.

Phase 2

The findings of the survey were used to rank Corps laboratory-developed technologies in the order of transferability to the target population. Potential technologies were then evaluated in detail to select the most transferable with the widest impact.

Phase 3

Transfer activities included basic technology training, product commercial modification, public announcements, demonstrations, discussions with possible manufacturers, and steering committee formulation.

Mode of Technology Transfer

The CTTC was established as a recognized Center of Technical Expertise for the identified technologies. CERL will assist with technical issues related to the upgrading and improvement of the technologies as appropriate. The CTTC, however, will have primary responsibility for marketing and delivery of the technologies to the end users. This report is available on the CERL web page at http://www.cecer.army.mil

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 sq ft	=	0.093 m^2
1 lb	=	0.453 kg

2 Survey of Needs

Identification of Construction Productivity Factors

To determine those issues that small- to medium-sized construction firms in the Wabash Valley Region believe both detract from and enhance the attainable level of productivity, an initial literature search was performed to identify suitable measurement instruments. While Arditi's (1985) productivity improvement study did provide an example of an instrument similar to what was needed for this study, it was determined that a completely suitable current instrument was not available. Therefore, the Construction Productivity Study Questionnaire was developed. Development began with a thorough review of current construction-based literature to identify areas that had the potential to both negatively and positively affect construction productivity. Tables 1 and 2 list the factors that were identified to affect productivity from this review.

To measure the target population’s ranking of the relative importance of these positive and negative productivity factors, a questionnaire was created to measure responses based upon a 5-point Likert scale. In addition, items were generated to gather demographic data about the respondents' organizations and their preferences for potential CTTC services. To provide a sense of content validity and instrument reliability, a pretest was conducted on a random sample of the target population. After reviewing the pretest results, minor modifications were made to the Construction Productivity Study Questionnaire and cover letter in preparation for mailing them to the entire identified population.

Table 1. Negative productivity factors.

Claims for damages	Historic information retrieval
Duplication of paperwork	Data transfer from jobsite
Job costing	Cash flow
Regulatory issues	Workers compensation
Human resources	Job site safety
Quality control	Insurance
Company marketing	Financing
Relationships with subcontractors	Relationships with A/Es
Contract disputes	

Table 2. Positive productivity factors.

Word processing	Historic information retrieval
Computerized scheduling	Data transfer from job site
Job costing	Cash flow analysis
Computerized estimating	Workers compensation
Job site safety	Quality control / TQM
Insurance costs	Company marketing
Financing	Relationships with subcontractorss
Relationships with A/Es	Dispute resolution boards
Craft training	Litigation avoidance
Computer-based contract documents	Computer-aided drafting (CAD)
Increased company specialization	Employee ownership
Strategic planning	

Population Identification

The population used for the purposes of this study included construction organizations in a two-state area of west central/southern Indiana (25 counties) and east central/southern Illinois (37 counties), which were contiguous to the Wabash Valley Region. Contractors in the region were identified through the use of a purchased listing of contractors (Caldwell List Company) with validation and augmentation through the use of 16 construction-related professional organizations' listings of members (Association of General Contractors (AGC), Association of Builders and Contractors (ABC), National Association of Home Builders (NAHB), etc.). This process identified a total of more than 1,900 contractors in the region. Of the 1,900+ contractors who were contacted for inclusion in the study in 1995, 193 returned questionnaires, for a 10 percent response rate.

Population Demographics

Of those responding, 42.6 percent identified themselves as residential contractors while 41.6 percent fell into a more "commercial" category. Approximately 15.8 percent of the respondents fell into what could be categorized as "specialty contractors," who might work in residential as well as commercial construction.

The average age of companies responding to the questionnaire was 20.3 years, with the newest company at 1 year, and the oldest respondent at 99 years.

Approximately three-quarters of those completing the questionnaire were either the owner or president of the company.

Results indicated that the educational backgrounds of those responding included a high school education for almost all responding and 4-yr college degrees for almost half of all respondents (46.1 percent). Undergraduate majors were varied with the largest single major identified as business (5.2 percent) followed by civil engineering (4.7 percent), construction (3.1 percent), and education (2.6 percent). Very few of those responding had completed any graduate education. Craft training had been obtained by over 40 percent of those responding, with carpenter (16.8 percent) and electrician (3.7 percent) being the two largest identified crafts.

Company size varied with the average size of those responding at slightly over 17 employees. Company size ranged, however, from 1 to more than 300 employees.

Sales volume of those responding ranged from less than $1 million (42.9 percent) to over $20 million (3.7 percent). Other levels of sales volume were $1 to 2 million (25.7 percent), $3 to 4 million (11 percent), $5 to 6 million (6.8 percent), $7 to 10 million (4.2 percent), $11 to 15 million (3.1 percent) and $16 to 20 million (1.6 percent). Profit margins for the respondents for the past 4 years had remained relatively constant from the average level of 10.6 percent in 1990 to the average level of 10.4 percent in 1993.

Of those responding to the questionnaire, approximately 30 percent had been involved in litigation during the past 5 years. Of those involved, 67.3 percent had reached agreement on the resolution of the issues involved. The average time to reach resolution was approximately 22 months and, of those reaching resolution, 61.5 percent were satisfied with the results. Of those responding, only 28.1 percent had been involved in any type of dispute resolution or arbitration board.

Computer hardware and software were in use by the majority of those responding. The most used computer system was based on the 80486 Intel series followed, to a lesser degree, by engineering workstations, 80386, 80286, Macintosh, and Pentium. With over 130 separate software packages identified as being in use, the four software packages that were cited most often included WordPerfect®, Lotus 123®, cost estimation programs from Timberline, and book-keeping assistance by Quicken.

Analysis of Productivity Factors

During the development of the Construction Productivity Study Questionnaire, factors that had both negative and positive affects on productivity were identified. Respondents were asked to rate these factors in two ways: (1) how they felt the productivity factor affected the overall construction industry and (2) how they felt the productivity factor affected their individual company.

The initial analysis of productivity factors was completed through two techniques: (1) the use of ranked weighted responses of the overall population, commercial contractors, and residential contractors, and (2) a change score analysis based upon weighted responses. The first technique, a weighted response, was used to determine overall ranking of the productivity factors identified by the Construction Productivity Study Questionnaire. The second technique, a change score analysis, was used to remove the bias of the respondents on the reported level of their own company's performance on each of the identified productivity factors. In addition, results were analyzed based upon the overall population of respondents, as well as the individual groupings of commercial and residential contractors. Appendix A gives further details for the findings presented in the next section.

Overall Population of Respondents - Weighted Response

The top five Negative Productivity Factors for the construction industry as identified by respondents included: (1) regulatory issues, (2) cash flow, (3) workers compensation, (4) relationships with subcontractors, and (5) insurance. The majority of the identified issues were reported in the 17 areas identified in Figure 1.

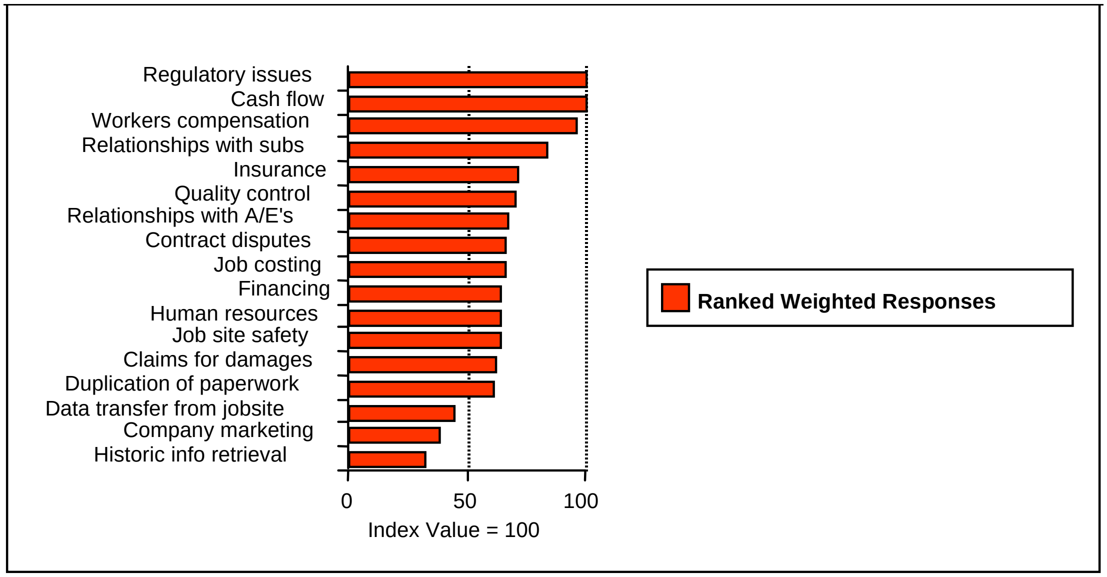

Figure 1. Construction industry – negative productivity factors.

The top five identified Negative Productivity Factors for the respondents' company included: (1) cash flow, (2) workers compensation, (3) regulatory issues, (4) insurance, and (5) human resources (see Figure 2).

To compare the identified effect of Negative Productivity Factors for the Construction Industry versus the Respondent's Company, a change score analysis was completed. This analysis compared the two weighted mean scores for each Negative Productivity Factor. The resulting data indicated that respondents had less success in reducing the effect of Negative Productivity Factors in the following areas: (1) insurance, (2) workers compensation, (3) human resources, (4) cash flow, and (5) company marketing (see Figure 3).

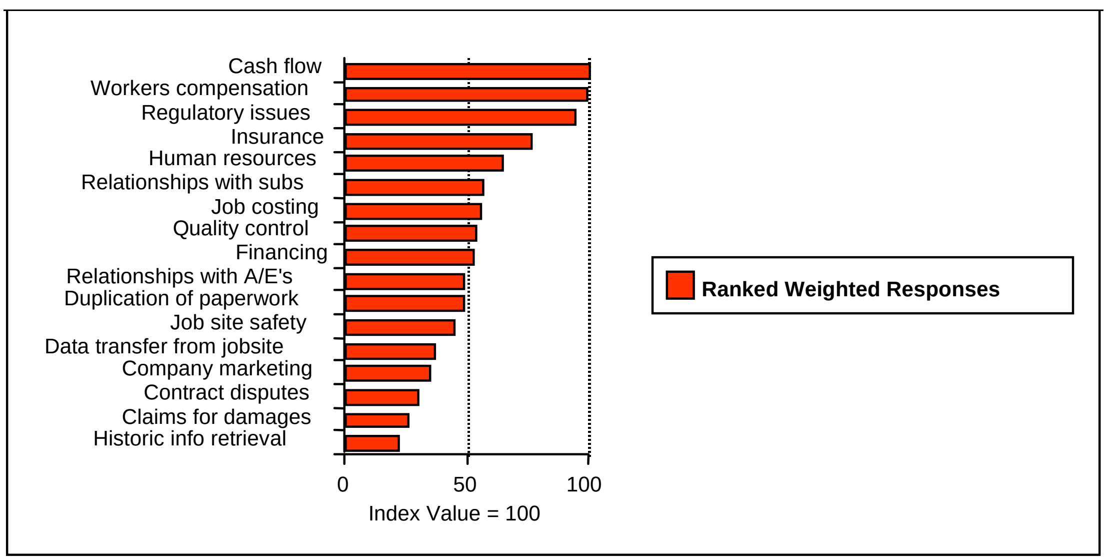

Figure 2. Respondent's company – negative productivity factors.

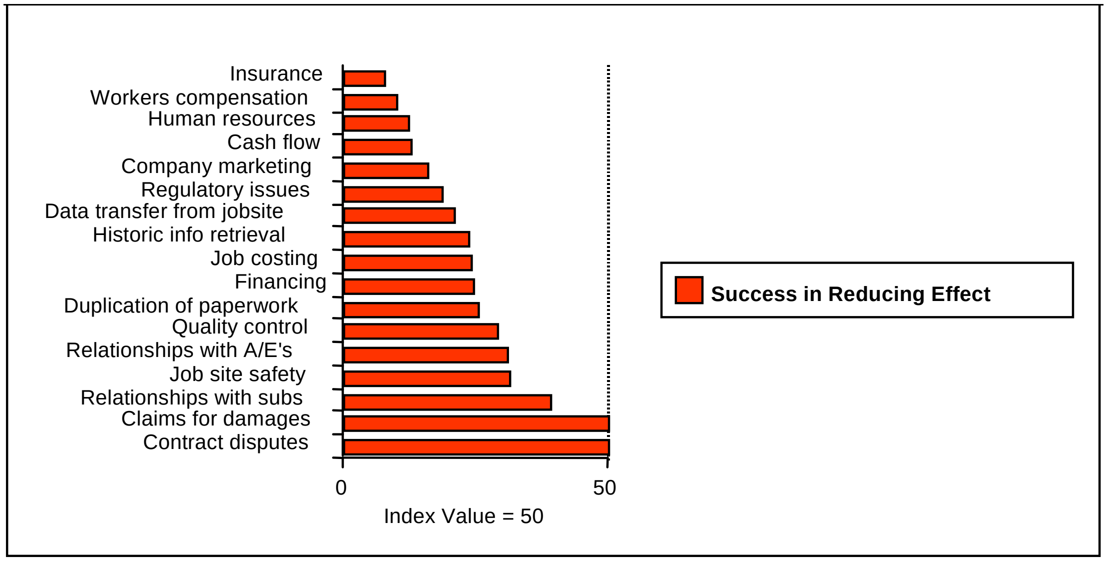

Figure 3. Change score analysis – negative productivity factors.

The top five Positive Productivity Factors for the construction industry as identified by respondents included: (1) job costing, (2) workers compensation, (3) computerized estimating, (4) relationships with subcontractors, and (5) craft training (see Figure 4).

The top five identified Positive Productivity Factors for the respondent's company included: (1) job costing, (2) relationships with subcontractors, (3) workers compensation, (4) cash flow analysis, and (5) insurance costs (see Figure 5).

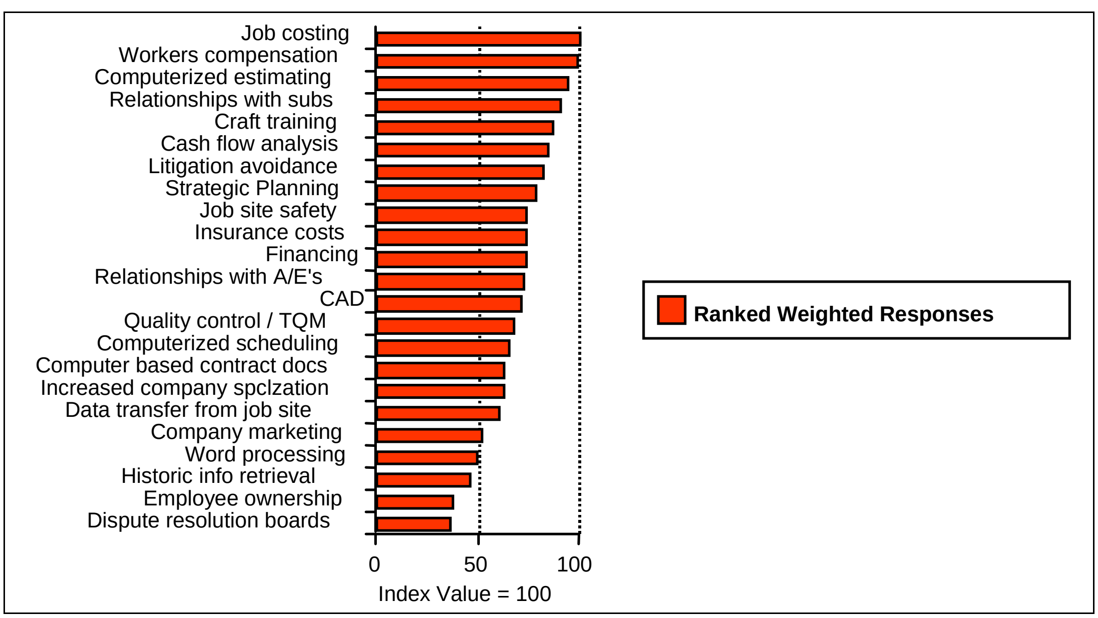

Figure 4. Construction industry – positive productivity factors.

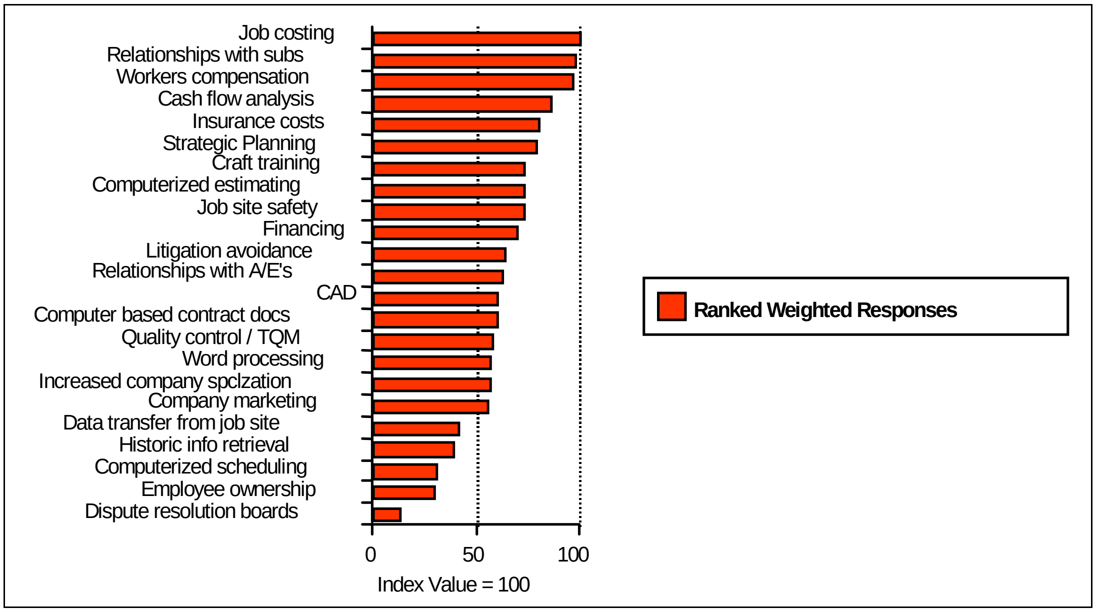

Figure 5. Respondent's company – positive productivity factors.

To compare the identified effect of Positive Productivity Factors for the Construction Industry versus the Respondent's Company, a change score analysis was also prepared. This analysis procedure compared the two weighted mean scores for each Positive Productivity Factor. The resulting data indicated that respondents had less success in incorporating the effects of Positive Productivity Factors in the following areas: (1) computerized scheduling, (2) dispute resolution boards, (3) computerized estimating, (4) data transfer from job site to office, (5) litigation avoidance.

Table 3 summarizes these findings, which were used as a basis for identifying outreach training that the CTTC could supply to the target population.

With the exception of safety issues that might affect worker's compensation and improved estimating that could affect cash flow, most of the negative productivity factors were viewed as outside the typical scope of CTTC domain. Positive productivity factors, however, offered several instructional opportunities for CTTC training.

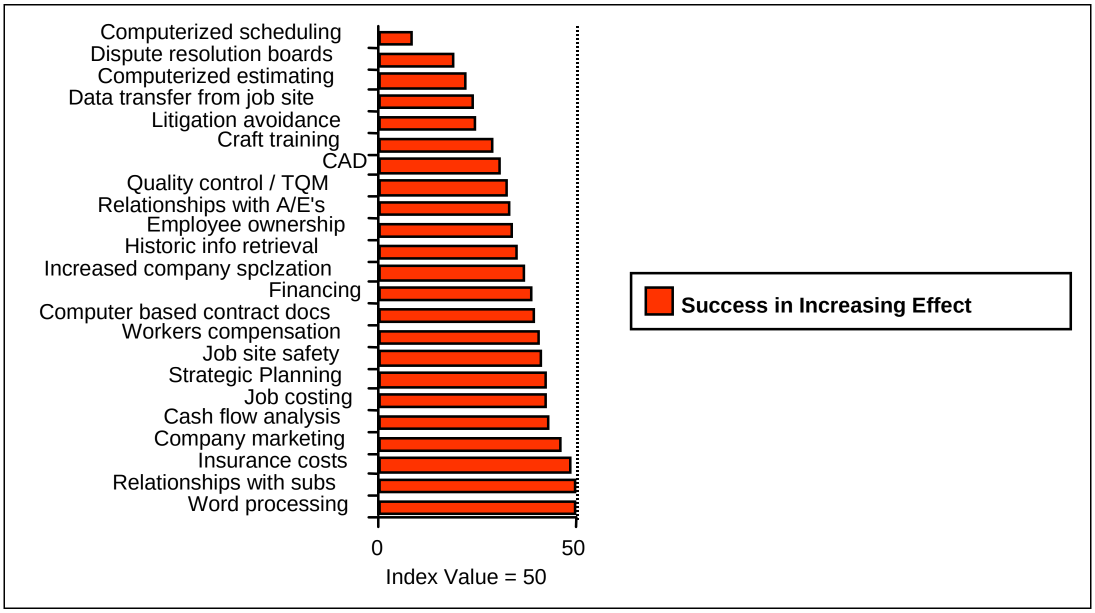

Figure 6. Change score analysis – positive productivity factors.

Table 3. Change score comparison.

Change Score Rank	Positive Productivity	Negative Productivity
1	Computer Scheduling	Insurance
2	Dispute Resolution	Workers Compensation
3	Computer Estimation	Human Resources
4	Jobsite/Office Data Transfer	Cash Flow
5	Litigation Avoidance	Company Marketing

Background Instructional Efforts

One basic finding from the survey was that a certain degree of basic background training in automation and construction issues should be made available to the clients of the CTTC. A predevelopment workshop was held at CTTC with two academic professionals to provided guidance on the appropriate approach to adult continuing education. Specific issues discussed were course content, choice, instructional design, and delivery methods. CTTC presented five courses: Construction Computing (May 1995), Fall Protection (December 1995), Hazardous Communication (March 1996), Construction Estimation (June and August 1996). To increase the effectiveness of a proposed course on project scheduling, an earlier version of a personal computer (PC)-based Critical Path Method (CPM) tutorial was updated to a Web-based training course. Converting this training to a Web base allowed the CTTC to use the revised training for both classroom training and remote delivery to clients. The new CPM Tutor (Figure

7) provides general information about the critical path method, and shows how to construct a precedence diagram.

The program also includes a guided practice session on how to do forward and backward passes through the diagram as well as how to do float calculations (Figure 8).

Figure 7. CPM Tutor Main Screen.

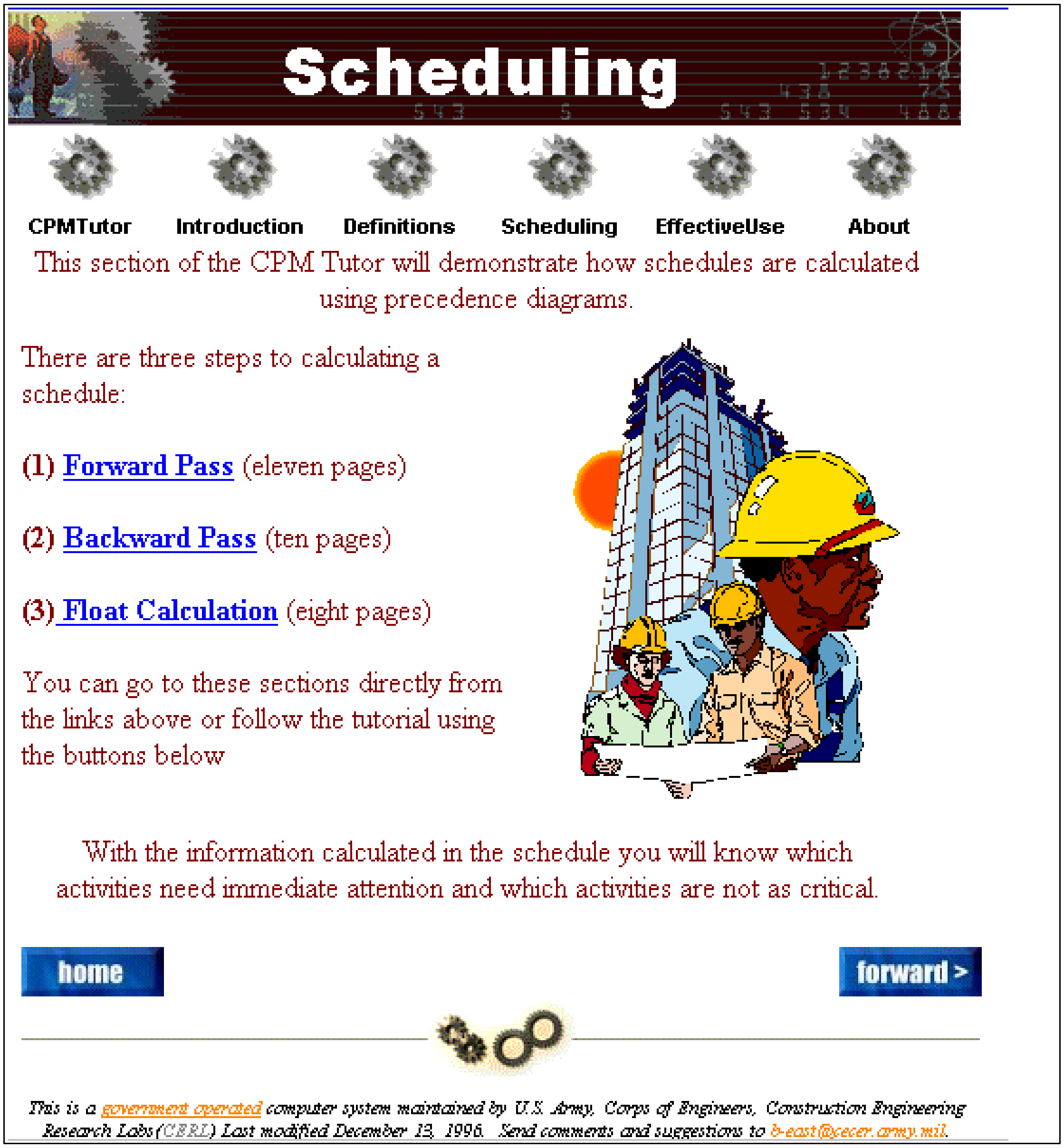

Figure 8. CPM Tutor Lesson Selection Page.

CTTC had prepared a Project Scheduling course, which featured use of CPM Tutor. Unfortunately, the course was cancelled because of low enrollment. CPM Tutor has been used by the CTTC to assist contractors with CPM questions, and the program has also been used by CERL and other COE personnel for CPM training.

3 Identification of Technologies

Candidate Technology Identification Process

A comprehensive list of 203 USACERL project-descriptive fact sheets were reviewed to identify those technologies at or near completion that might be applicable to the target population of small- and medium-sized contractors. The descriptive information for the initial 73 potential candidates was reviewed to confirm both the technology availability and appropriateness. This review identified 45 USACERL technologies with potential transfer capability. A similar process was conducted with other Corps laboratories' informational material. Four Waterways Experiment Station technologies were identified as having transfer capability for this effort and were included in the more detailed evaluation process.

Scoring Schema

A database program was written in Microsoft Access® that would allow the factor by factor scoring of each of the identified technologies against the change score positive productivity factors identified by the survey respondents. The program calculated the sum of the weighted scores for each of the selected technologies and rank ordered the totals. These numeric values provided a measure of the overall transfer potential of each technology (Table 4).

A data entry form was created for each of the 45 technologies. The form listed the 27 survey evaluation factors. Each factor was scored as either high impact (h), medium impact (m), low impact (l), or no impact (blank). Values were assigned to each of the rating factors ranging from 3 for high to 0 for no impact. The program calculated a weighted score for each technology by multiplying the impact rating value by the identified change score value and summed the total across all 27 factors. The resulting ranked list provided a structured method to conduct a detailed selection. Appendix B gives the complete results of this effort.

Table 4. Ranked candidate technologies.

Candidate Technology Description	Transfer Score
Data exchange for scheduling software	3.81
Construction Automation Support Center	2.20
High performance ultralight concrete masonry	2.05
Acceptance testing of HVAC systems	1.95
Paint test kits	1.83
Homeowners Assistance Program	1.83
Lead-based paint hazard mitigation	1.73
Building energy performance commissioning	1.67
Trenchless rehabilitation of sewer pipes	1.53
Teaching assistance for AutoCad	1.49
Antifreeze admixtures for winter concreting	1.40
Building assemblies systems (interior partitions)	1.34
Using exterior insulation and finish systems	1.19
Barcode technology for quality assurance inspections	1.13
Mechatronically Assisted Mason's Aide	1.12

Technologies Evaluated

The top 16 technologies with the most transfer potential were reviewed by USACERL and CTTC to determine which would be the most widely applicable for the target audience. Detailed discussions were held with the developers to identify the current status of the technologies, and if any known transfer issues existed. Some items were no longer manufactured (i.e., the Paint Test Kit or the Antifreeze Admixtures for Cold Weather Concreting). For others such as the High Performance UltraLight Concrete Masonry, transfer potential was uncertain because it was unknown when or even if it would ever receive code-compliant approval. This code approval would be necessary before the product could enter the retail market.

A detailed review and elimination was also conducted by the CTTC to consider the potential degree of use across the widest spectrum of the target population. Some of the technologies that included a training component were reviewed for possible inclusion into the onsite CTTC technology training effort. These specific technologies included: Data Exchange for Scheduling Software, Construction Automation Support Center, and Teaching Assistant for AutoCad.

Technologies Selected

As a result of this multi-step evaluation process, the Mechatronically Assisted Mason's Aide (MAMA) was identified as the most likely technology with transfer success within the CTTC target population. It was recognized that successful transfer would require several phases: repair of the existing prototype, field testing to validate performance and benefit, redesign and identification of a marketing partner. During the later stages of the MAMA transfer effort, an additional secondary technology transfer opportunity was also identified.

The growth of Web-based tools and USACERL-developed applications during the multi-year MAMA effort was dramatic. During this period, USACERL had developed two Web-based applications DrChecks (a construction lessons learned system) and the OK Data Bank (an organization knowledge base). It was determined that the design concepts of these efforts could relatively easily be modified to produce a Web-based system that could produce construction project-specific safety plans. These tailored safety plans are required by existing COE construction projects and also will be required by upcoming Occupational Health and Safety Administration (OSHA) regulations. Had this alternative been available during the initial scoring and selection process, it would have ranked very high, because the Safety Planner would be useful for most all of the CTTC audience. It also would have addressed four of thefive of the top issues the contractors viewed as difficult to impact: insurance, workman's compensation, human resources, and cash flow.

4 Mechatronically Assisted Mason's Aid

Development History

The masonry component of the construction industry represents a large portion of the annual business volume. In 1994 it represented $13 billion, of which 40 percent was direct labor, 40 percent was material, and the remaining 20 percent was overhead and profit (Marshall 1994). One common injury in this industry is to the worker's back from the repetitive lifting and twisting associated with the placement of concrete masonry unit blocks. This particular trade has had difficulty in attracting new entry-level workers. With an aging workforce, compensation claims have been growing.

To explore the possibility of developing a robotic lifting device to alleviate muscular strains and injuries associated with lifting heavy objects, USACERL and the International Masonry Institute (IMI) established a partnership in 1990 under the Construction Productivity Advancement Research (CPAR) Program and a Cooperative Research and Development Agreement (CRaDA).

The result of this partnership was the development of MAMA, an electro-mechanical device designed to lessen skeletal and muscular strains associated with the lifting and handling of heavy masonry units. MAMA is a computer controlled, mechanically assisted placement system consisting of scaffolding mounts, a transformer package, and assemblies for a trolley track, a trolley, a manipulator, a gripper, and a power control. Figure 9 shows how these components connect to form a suspended crane-like device that attaches to mast-type scaffolding. The operational prototype was designed to be mounted on a Morgen Scaffolding System. Power for MAMA is supplied by a 24 volt direct current power supply.

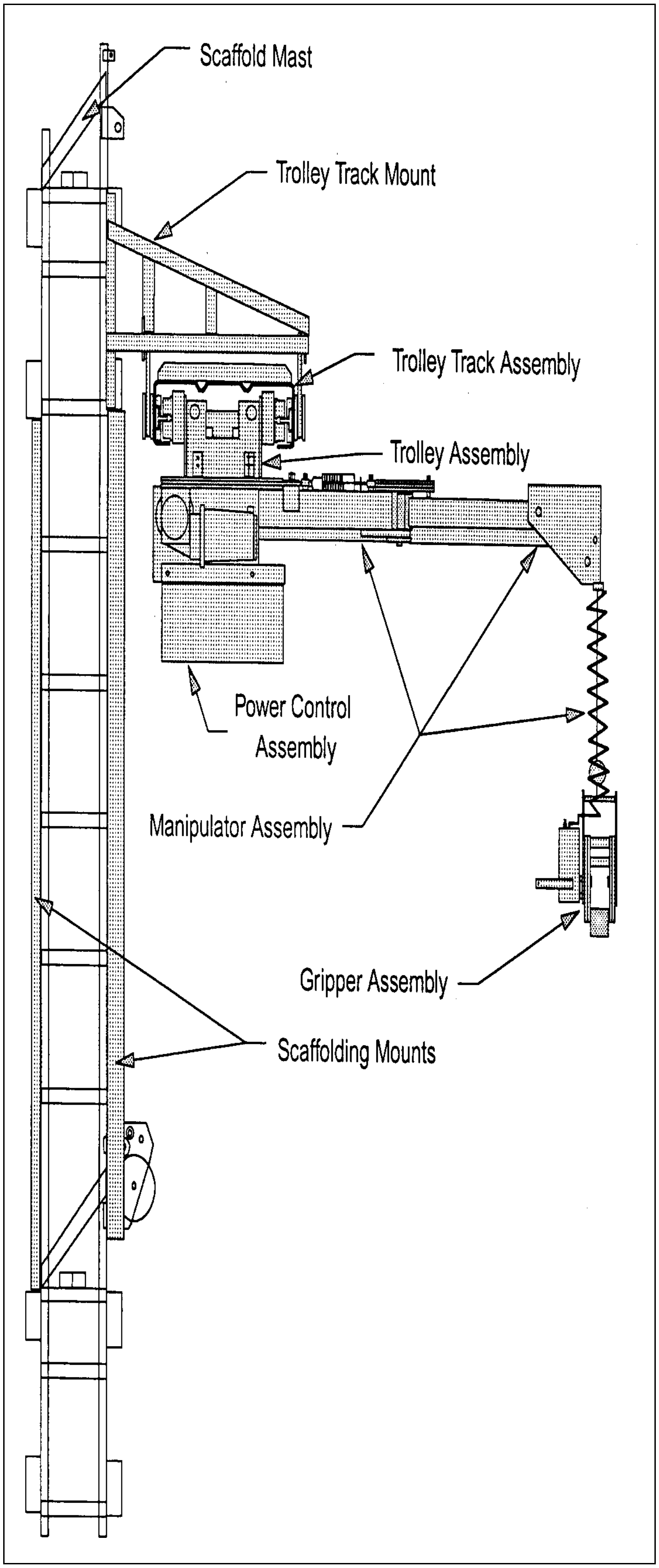

Figure 9. MAMA design.

The initial demonstration of MAMA was successfully conducted on 21 and 24 October 1994 at the IMI Apprentice Training Center near Harpers Ferry, WV. A follow-on demonstration was conducted at Bal Harbor, FL, for the 18 November 1994 annual business and training conference of IMI. Unfortunately, a week-long tropical storm struck during the conference, and the unit was damaged so badly that it could not operate. IMI removed the unit and placed it in storage at the completion of the conference.

Repairs and Improvements

The prototype MAMA was retrieved from storage and shipped to the CTTC in the spring of 1996. The internal electrical components of the power supply unit were corroded from the saltwater contained in the “sealed” power control unit since the winter of 1994. The MAMA prototype was assembled, made operational, and several recurring problems were identified and corrected.

Load Cell Failures

The weight of the load lifted by the gripper mechanism is determined by a load cell in the articulated arm suspended from the overhead mounted trolley. Although the load cell was rated for a much higher weight than anticipated, early testing resulted in the unit being crushed. Each replacement cell had to be individually manufactured and could not be made precalibrated to standard MAMA programmable logic controller (PLC) settings. Hence, the PLC had to be reset for each replacement load cell. This process was quite time consuming as the PLC had to be reconnected to a PC and all of the setpoints had to be revised to reflect the new parameters of the replacement load cell. A crushproof surround housing was fabricated to ensure that the cell would not be crushed. After this surround was added, no further failures occurred.

Relay Failures

During operations of MAMA, collapsing magnetic fields caused by switching on and off the power were found to introduce eddy currents that burned out one of the motor control relays within the power control assembly. The current carrying capacity of the relay was increased and surge protection was added. These changes resolved the problem.

Track Power Delivery Failure

The suspended track assembly was designed with an isolated power bar incorporated within it. The trolley was designed with a power pickup brush assembly. This arrangement did not work satisfactorily within track sections because the brush power pickup did not make consistent contact with the power bar. Power pickup at scaffolding joints seldom occurred, since the scaffold sections were often misaligned. During the scaffold raising process, individual sections were jacked separately, which further accentuated the differential elevations between sections. The CTTC substituted an electrical tether between the power supply and the power control assembly on the trolley Assembly. While this substitution was not an optimal solution, it did provide consistent power to the unit at all trolley locations.

Programmable Logic Controller Settings

The prototype had an extensive software-driven logic sequence that would offer the user a high degree of safety protection. The PLC provided selective locking and unlocking of the pivot arm sections, trolley track brakes, and opening and closing of the gripper jaws.

The logic sequence ran as follows: At the start of a lifting operation, the unloaded tare weight of the gripper assembly was recorded by the load cell. During lifting, the load cell would compare the lifted weight (tare weight plus load) against the allowable maximum load (tare plus 100 pounds). If the maximum was exceeded, the lifting sequence was not energized. When in the lifting mode, the load could not be released until the gripper and load weight reached tare. This prerequisite eliminated the possibility of the operator dropping a block when it was not either resting on a staging pallet or on a mortar bed. The single horizontal hand control unit had a deadman switch incorporated into the handle and a grip-and-release thumb-activated switch on both sides of the handle (for right- and left-handed operators). If the deadman switch was released, the PLC would deactivate the power and lock all brakes. Total vertical travel was also monitored so the unit could not “bottom out.”

Although the sequence was well thought out to provide a high degree of user protection, the sequencing was rigid and required the operator to follow the sequence step by step. Some beginning operators had difficulty in correcting out-of-phase operations. If the deadman switch was released prior to the block release sequence while in the down position, the gripper could not be released when re-energized because the PLC expected an open gripper reading, not a closed reading. The corrective solution was to raise and lower the block again and then release it. One operator continually tried to manually move the trolley unit in the track without the deadman switch activated. Since an inactivated deadman switch meant all the brakes were locked, the operator was consistently frustrated with the unit.

Gripper Jaw Wear

During extended testing, CTTC personnel noted the wear blocks on the gripper mechanism were abrading at a high a rate. A more durable material was substituted.

Design Improvement

Second handle. Observations of professional masons using the system identified an ergonomics problem. As originally designed, the gripper assembly was to be used by one hand only. In actual use, however, masons preferred to use a second hand to assist with precise placement of the block prior to release. CTTC staff designed and added an additional handle on each side of the gripper assembly to facilitate two-handed use of the unit (Figure 10). Release/grip buttons were incorporated in each handle so the operator could grip or release the block with either hand.

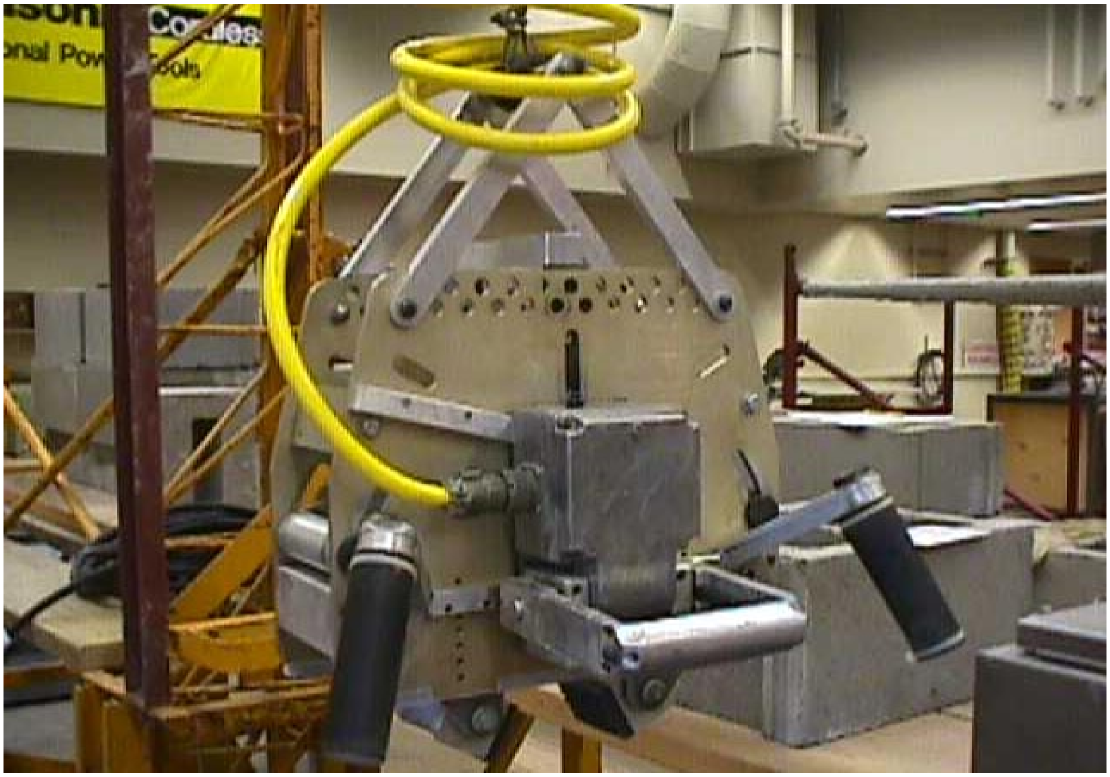

Figure 10. Additional handles on MAMA unit.

Improved rebar clearance. As originally designed, the actuator mechanism was located horizontally through the center of the gripper assembly. This placement made it impossible to place a block over a reinforcing rebar or other core penetration. CTTC staff redesigned and moved the actuator mechanism to the rear of the gripper assembly (Figure 11) so blocks could be placed over vertical rebar.

Figure 11. Gripper actuator moved to outside to allow for rebar clearance.

Interest Generated

Formal Demonstrations

After the unit was debugged, but before the improvements were added, technical transfer activities were initiated. CTTC hosted a formal demonstration in November 1996. Attendees included representatives from two bricklayers union locals, a scaffolding manufacturer, IMI, AGC of Indiana, and a number of constructors. Positive comments were obtained from the two locals, and they pledged to work toward identifying a project for field testing the unit under an actual job site environment. A consultant was hired to help preplan for a test by identifying the data collection and analysis procedures necessary for statistically valid findings. A second formal demonstration was held in the spring of 1997.

Informal Demonstations and Marketing Efforts

Follow-up activities were planned for each demonstration attendee. A three-phase marketing effort was pursued: underwriter endorsement, labor safety sponsorship, and developing manufacturing interest from both suppliers and users. Telephone and mail contacts were made with large construction causality insurance companies, construction labor protection organizations, potential manufacturers, and large masonry construction firms. Public announcements were made both in professional (*Engineering News Record*) and popular magazines (*Popular Mechanics*). Each of these articles was successful in generating initial contacts and follow-up conversations.

A national claims loss manager for a large insurance company viewed the system on 30 May 1997 and indicated he might be able to help fund a demonstration and locate a contractor for a field test of the unit. The loss manager viewed MAMA as an important device to reduce injury claims. A regional sales manager for a scaffolding manufacturer viewed MAMA on 3 June 1997 and felt his firm should consider offering the unit. He was unsuccessful in arranging for the president of the company to view the unit. Also during this time, a second potential manufacturer expressed interest in manufacturing the unit and one of the nation's larger masonry contractors expressed initial interest and possible desire to test the unit on an actual job. Contact with these individuals was maintained during the quest for a field demonstration.

Field Demonstration

Although numerous offers to identify a test project were received from organized labor, insurers, and constructors in early to mid-1997, it was not until November 1997 that an actual field test was arranged.

The field test was held in St. Louis, MO, the first 2 weeks of November to assist with the construction of a new middle school. No system failures were encountered, no blocks were dropped, and no operator injuries occurred. While the test productivity did not quite equal that of a two-man crew, it was very close. Furthermore, it would most likely have surpassed productivity with 12 in. or larger concrete block. Also, if the local had the typical 50-lb two-man block limit instead of the 35-lb block they were using, the test would have most likely surpassed manual production levels.

The test did, however, clearly identify some problems with the initial design in regard to assembly, use, and the effect of negative weather conditions.

1. The total system was too complicated and cumbersome to install.

More than 300 separate pieces are necessary to install the track assembly. This total includes associated mounting hardware such as nuts, bolts, washers, pins, spacers, clips, track, and track mounts. To expect a system as complex as this to make it through more than one set-up and removal by average tradesmen is unreasonable.

Redesign response: The second generation MAMA unit requires approximately 90 percent fewer individual parts than it took to assemble the original unit.

2. The track held water, which then leaked on the mason's back during the entire workday.

During the testing period, MAMA was exposed to 2 days of driving rain, a 3-in. snowfall, sleet on two occasions, and high winds. The track assembly, when relatively flat, has a horizontal surface area of approximately 2 sq ft per linear foot. In addition, each track has two formed areas that were designed to add strength and ensure correct placement of track sections. The entire track sections acted as reservoirs, especially when covered with snow.

Redesign response: The track cross section no longer has any area that can retain either water or snow. The redesigned track is an extruded, monorail design with a per foot weight of approximately 7.5 lb.

3. Gripper did not allow easy passage of conduit/rebar through the core.

Although modified to allow MAMA to be used with penetrations through the block cores, the scissors mechanism that grips the block has points to catch rebar or conduit. This design caused productivity to be reduced.

Redesign response: The gripper assembly has been redesigned with a "clean sheet" procedure. This procedure is a totally different response to the needs of a gripping device to incorporate no moving parts and provide absolutely no interference with penetrations through the masonry units.

4. Too slow – productivity was 80 to 90 percent of what a two-man crew could do without MAMA.

This productivity estimate must be considered with the existing 35-lb two-man block limit within the St. Louis bricklayers local.

Redesign response: Two main areas that caused excessive time in the cycle of picking a block and placing it in a bed of mortar were (1) travel of the carriage assembly and (2) the gripper mechanism of MAMA and its need for interlocks and serial logic within the PLC. Both of these issues were resolved through a completely redesigned gripper assembly and a redesigned track/carriage assembly.

5. Power supply chord got caught in block on scaffold.

While MAMA was originally developed with power provided by the track assembly, it was not an operational design. The onsite test, however, does indicate that a track mounted power delivery system is needed.

Redesign response: The second generation MAMA incorporates industry standard INSUL-8 Cluster-Bar™/collector assemblies. These assemblies are well-tested in industrial applications, and the extrusion profile for the track assembly has been designed to accept these power bars without modification.

6. Carriage did not travel across joints in track very well unless track was perfectly level.

It is probably unrealistic to expect the scaffolding to be perfectly level. With the minor variations in the height of each individual scaffolding tower carriage, MAMA did not travel over track connections easily. This is a function of the original design.

Redesign response: The first generation MAMA incorporated track assemblies formed from ¼-in. aluminum plate materials, which led to track that was not consistent from piece to piece. This inconsistency led to misalignment of the track assemblies. While some custom alignment of the track was possible, alignment necessary for smooth carriage movement was not possible. Redesign of the track to an extruded shape gives 100 percent alignment to all track sections. Further, with the weight of track sections significantly reduced, the number of track joints has been reduced by 80 percent.

7. Set up time was too long.

See problem #1. Approximately 3 man-days were required to assemble MAMA by three CTTC staff that had a thorough understanding of the MAMA system.

Redesign response: It is projected that the amount of time to assemble the second generation MAMA will be less than 1 man-day.

8. Take down time was too long.

See problem #1. Approximately 2-½ man-days were required to disassemble MAMA.

Redesign response: Time to remove MAMA will be virtually the same as installing MAMA to the scaffolding assembly.

9. MAMA was too heavy on scaffolding.

Laborers had a hard time lifting the scaffolding due to the added weight of MAMA. In addition, due to the upper carriage mounts and Morgen Scaffolding System, movement of the lifting cable was required on each scaffold section. This number is twice the normal number of cable movements.

Redesign response: It is projected that the second generation MAMA system will weigh less than 25 percent of the original MAMA system.

10. Scaffolding mounts made jacking difficult.

Spacing channels used to support the upper carriages, which in turn provided attachment points for the track mounting system, caused interference in the jacking system for the lifting process. A redesign of the spacing channels must be completed.

Redesign response: The second generation MAMA system mounts on the scaffolding manufacturer's weather canopy system. This system does not interfere with the jacking system whatsoever.

11. The mounting system on the scaffolding was too heavy.

In general, all components of the mounting system are over-designed. A ¼-in. wall thickness on support members adds unnecessary weight to the overall system.

Redesign response: Due to the overall redesign of the MAMA system, it was possible to design mounting brackets for the second generation MAMA system that were smaller and significantly lighter than in the original MAMA design.

12. The track acted as a walking platform for the laborers – and that brought up mud, gravel, etc. that then caused the track to not want to slide as the scaffold was lifted.

Laborers will exploit anything that they think makes their job easier. The track assembly became a convenient walking platform for moving from tower to tower in the jacking and cable moving process. Use of the track as a walking platform caused the deposit of the associated mud, gravel, sand, and general muck onto the top of the track. Melting snow caused this material and water to constantly drip on the masons below.

Redesign response: The second generation MAMA track, a monorail design, has a cross section width of only 5 in. In addition, it is set away from the scaffolding towers approximately 19 in. These factors combined make it highly unlikely that the track assembly will be used any longer as a worker walkway.

13. Carriage assembly was too heavy. Getting it to slide back and forth took too much effort.

This item is associated with over-design of components, uneven track elevations, and mud, gravel, and sand that came from laborers walking on the track.

Redesign response: The redesigned trolley was also a “clean sheet” design process. The second generation MAMA system incorporates a trolley that has been designed as a two-part assembly: (1) the trolley is the actual traveling mechanism on the extruded track assembly and (2) the lifting arm assembly that is attached to the trolley after the trolley has been placed on the track. Each of these assemblies have been designed (for both size and weight) to be placed by a single person on the track assembly.

14. Taking down MAMA without access to the end of the scaffolding was difficult.

With the weight of the MAMA unit and no perpendicular access to the scaffolding system, removal of the carriage unit was a problem. Redesign of MAMA should consider a two- or three-part system for the carriage that has an individual weight within the limits of worker placement on the track system without the use of a crane or mechanical lifting device.

Redesign response: The second generation MAMA system incorporates a two-part trolley assembly.

15. Carriages had to come off the top of the tower.

Carriage removal required the towers to be taken apart to remove MAMA. In many cases, towers would be left assembled, just moved back 4 in. to allow application of the brick veneer. Therefore, the upper carriage mounting system must be redesigned to allow attachment and removal without going over the top tower section.

Redesign response: The second generation MAMA mounting assemblies can all be placed on the scaffolding system from the scaffolding work platforms. Mounting brackets that attach back to the scaffolding towers have been designed to hinge and clamp around the tower instead of being lifted over the top of it.

Current Status

A comprehensive redesign was developed as a result of the field test. CTTC and a commercial vendor are partnering to seek a manufacturer to create a revised prototype and begin marketing efforts.

5 Safety Planner

During early 1997, an Indianapolis contractor approached CTTC to assist in developing the automation of their safety planning process. Since the goal of the USACERL/CTTC cooperative effort was to provide the CTTC with marketable products, this potentially marketable area was explored. A key driver in this decision was the 1995 survey of the CTTC target population that identified the top two most important areas they felt they could not control: insurance and worker's compensation. USACERL and CTTC developed a proposal for automating the safety process for the contractor based upon using the COE's *Safety and Health Requirements Manual* (EM-385-1-1) as a basis for pen-based and personal digital assistant recording systems. Although the proposal was not accepted, it pointed to a construction safety need for which the CTTC could provide support to its target clients.

Related COE Technologies

Corps Construction Safety

The COE has an outstanding construction safety record. *The Center to Protect Worker's Rights Chart Book 1997*, which is based on Bureau of Labor Statistics (BLS) figures, reports the rate of nonfatal injury cases resulting in days away from work (1991-1994) per 100 Full Time Equivalent (FTE) construction workers showed a slight decline from about 5.6 in 1991 to about 4.9 in 1994. During this same period, the COE maintained an injury record of only 1.1 per 100 FTE for each of these years. The Corps requires each contractor to submit and use a project-specific safety plan. Contractor compliance, with their submitted safety plan, is periodically reviewed by Corps quality assurance inspections. The Corps has also captured recommended safe practices within the Corps Safety Manual. This document is similar to OSHA standards but is written more in a "how to" mode than with strict standards to be met. Clearly, this commitment to effective use of a site-specific safety plan and aggressive enforcement have paid off for both the Corps and its constructors. OSHA plans to introduce the site-specific safety plan in the near future.

The Corps has also developed the Resident Management System (RMS), which is a comprehensive tool to assist a Corps project/field office manage local construction projects. RMS captures and records construction activities by 750 categories of work types.

Web Programs

USACERL has developed several Web-based applications that focus on the capture, evaluation, and retrieval of past experience to apply to current problems. The experience gained in developing concepts to capture lessons learned and good business practices was found to be directly transferable to the design of a system to assist safety professionals in developing a project-specific safety plan (Figure 12).

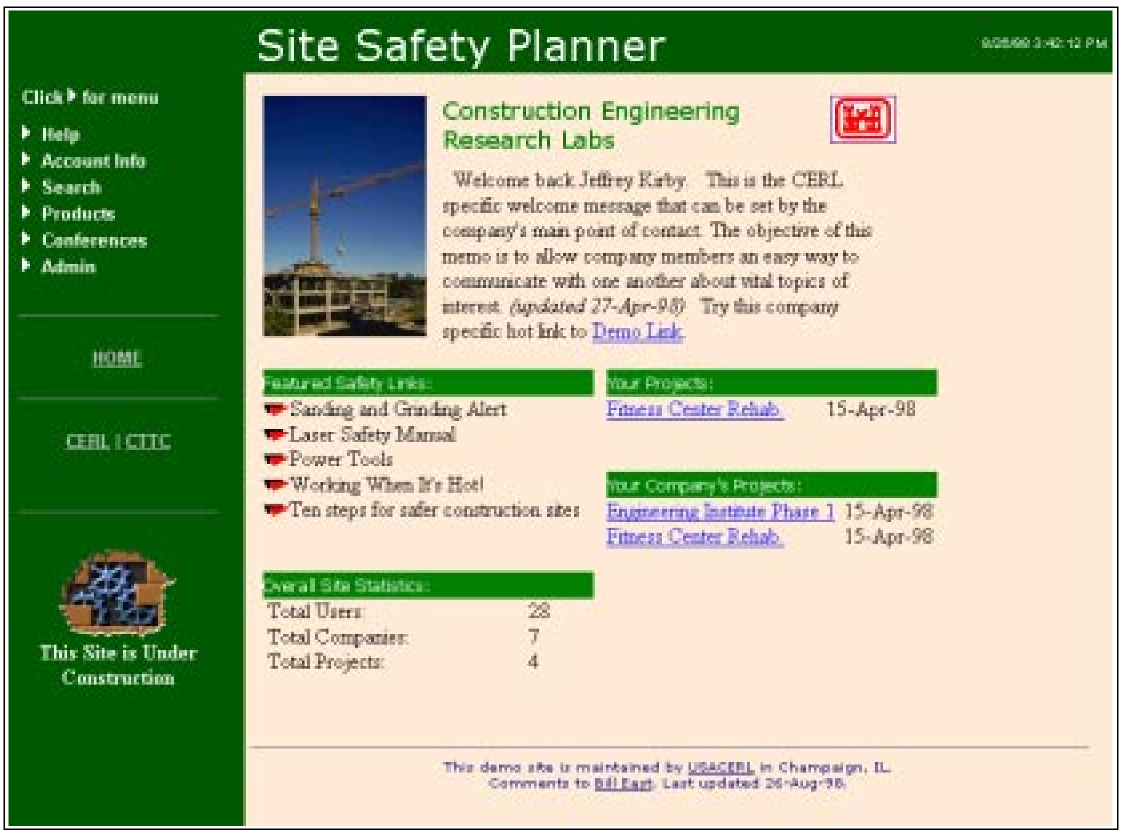

Figure 12. Main Screen for Site Safety Planner.

Design Approach

The purpose of the Site Safety Planner is multifold. Primarily, it allows users to develop, store, and retrieve project-specific safety plans. As shown in Figure 13, this result is accomplished by defining a project in terms of Construction Specification Institute (CSI) Specifications and associated work tasks. Specific safety checks of interest also can be selected from those attached to each work type. Once a contractor has defined a couple of templates for recurring project types, the creation of a new safety plan for a new project becomes more of a modification to an existing template. The real power of the system is the informational linkage possible with each check, and ready access to other safety information sources. The system design allows for links to supplemental references, definitions, and photos/videos for each identified safety check. Featured safety links on the home page can be used to branch to tool box talks and other informational sites. The system design allows each user to create and store individual plans and company-specific templates within their “own” domain on the server. The CTTC maintains the basic information from which each user can create tailored templates and specific plans. Users can, of course, create and add company-specific work types and associated checks or attach unique checks to existing work types. Figure 14 shows an example of a selected project-specific safety check.

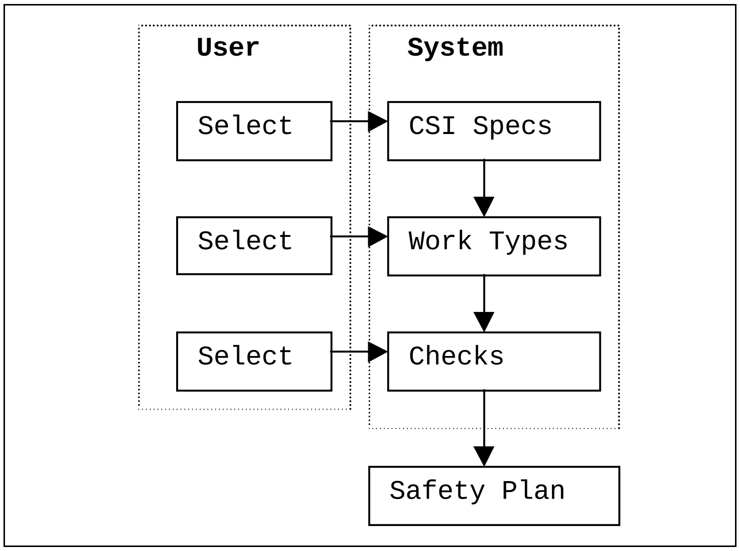

Figure 13. Functionality of Safety Planner.

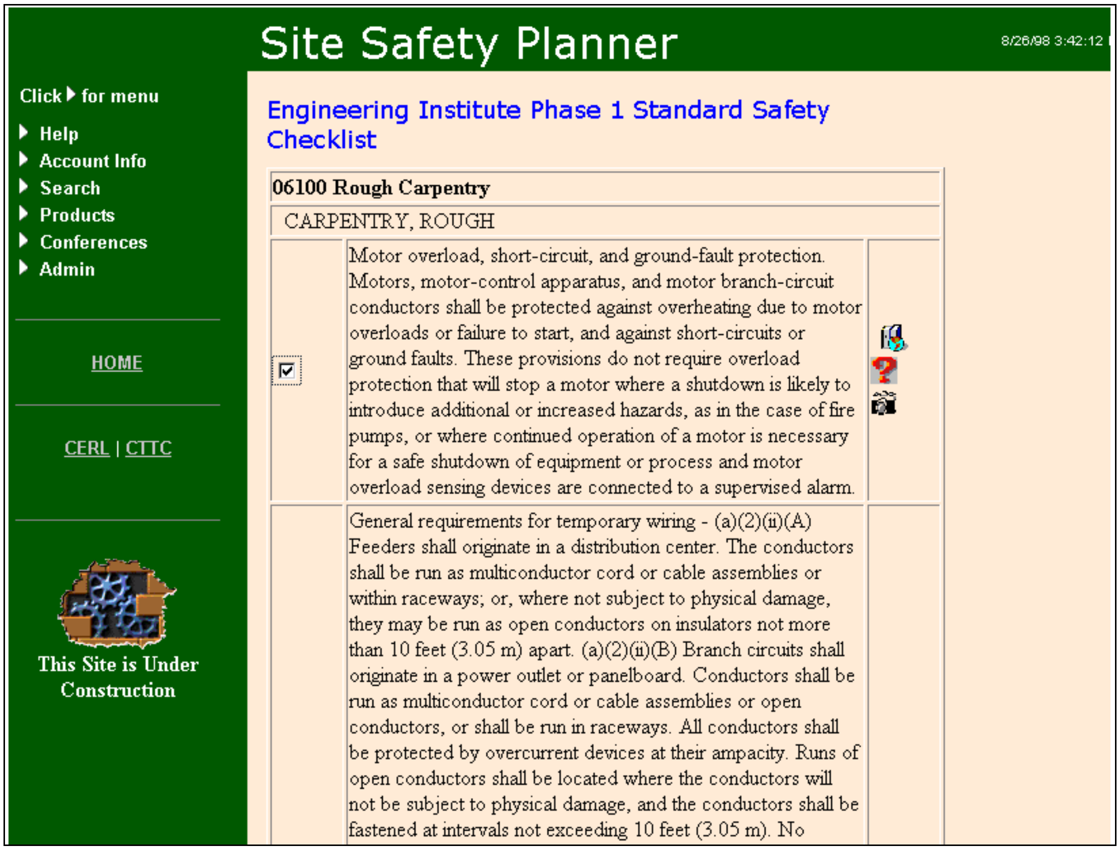

Figure 14. Example of project-specific check that has been selected.

Focus Group

A focus group was identified to both review and shape the development of the Safety Planner. The composition was varied to include representatives from a professional organization (i.e., AGC), constructors, and a casualty insurance company. Periodic meetings are scheduled to review the initial concept of the Safety Planner, prototype design, and final design.

Status

Two focus group meetings have been held. The initial meeting was used to verify that the need existed for a system such as the Safety Planner and to critically review a functional demonstration that had been prepared. Comments were positive as to the need for such a system and specific design guidance was obtained on how such a system should function. These comments and suggestions were used to design and code an initial limited capability demonstration version of the Safety Planner.

The CTTC has to date input a majority of the safety checks from OSHA, Part 1926, Safety and Health Regulations for Construction. In excess of 3,000 checks have been entered. Since the Safety Planner performs a full text search for each reference query, great care was taken to ensure that the coding schema would retrieve each appropriate check. General search queries will use the text of the Standard Title as well as alpha and numeric subcategory headings or the full text of the check. Existing work types used by the COE RMS have been partially reviewed and modified to allow better linkage between checks and specifications.

Proposals have been developed to complete the development efforts that cover finalization of data entry, linking operations, and incorporation of multimedia tool box talks.

6 Conclusions and Recommendations

The goals of this effort were focused fairly narrowly: identify and transfer COE technologies to small- and medium-sized construction contractors in the Wabash Valley Region. However, successful and timely transfer activities were more difficult to achieve than originally anticipated.

Conclusions

Commercial Usability

COE laboratory technologies are developed primarily to meet a specific COE need that is not currently met by the marketplace. While functionally the COE, as an agent of the owner, is similar to a commercial construction manager, the end product needs to meet sometimes unique performance requirements. COE software products often produce specialized reporting outputs. Hence, many of the COE laboratory products or concepts are not appropriate for small- to medium-sized contractors.

Slow Industry Adoption

As a very large consumer of construction products and services, the COE must sometimes explore new and novel solutions that are not currently being offered by the marketplace. While these new products (such as lightweight concrete blocks) are technically feasible and can be designed, industry-wide adoption is a slow, costly, and time-consuming process. Since COE laboratory funding is typically limited and sufficient only to develop a proof-of-concept prototype, partnering approaches are often used to accomplish development of pre-production prototypes and retail efforts. Some notable successes in the hardware area have occurred. Examples include the real-time weld quality monitor and the ceramic anode for corrosion protection. Historical experience at USACERL has indicated successful software transfer to a wide consumer market can be accomplished within 2 yr. Hardware products, however, take considerably longer. More than 10 yr to achieve wide-market penetration is not unusual.

Given the experienced-based timeframe, progress on MAMA technology transfer should not be considered abnormal.

During initial demonstrations, MAMA generated a lot of interest both from potential users and possible manufacturers. The MAMA proof-of-concept prototype was not as fully functional as portrayed, but this could not be identified until after it had been debugged and field tested. These evaluations determined that almost every component of the prototype was found to have significant design deficiencies. The only practical solution was to conduct a total redesign based upon the experience gained from repairing and field testing the prototype.

The redesigned MAMA addresses most of the issues that hindered earlier transfer: cost, complexity, reliability, ease of setup/removal, and manufacturing difficulty. A patent for the new MAMA is being submitted and a CRaDA is being pursued between USACERL, ISU, and Torque Technologies Ltd.

Recommendations

The general recommendations provided below have been reached as a result of efforts to transfer COE-developed technologies to commercial users.

Identification of Customer Needs

The approach used in this effort—performing an initial comprehensive survey of potential end users—is highly recommended. Clearly, an understanding of end-user needs is a primary requirement for effective technology transfer.

It is suggested, however, that future surveys should include more focused questions to sharpen the understanding of specific issue areas. Additional information as to whether the respondent was willing to invest time or money in finding a solution or establishing new methods or processes would have been useful during the matching of new technologies to the survey-identified problem areas.

Although not used for this effort, the establishment of a user's group to review and clarify the survey findings would have been useful. This group could have been used to answer interpretation questions and follow-on questions identified after the survey had been completed.

Technology Selection

It is necessary to establish an objective scoring schema to identify potentially transferable technologies. This study followed a three-step process: initial potential candidate selection, scoring and ranking by end-user ratings, and a detailed evaluation of highly ranked possibilities. This methodology allowed a large number of possible technologies to be evaluated in a short time. One additional step is recommended for any future effort. The review of the results by a steering committee would serve as a final check of the selection(s) prior to expenditure of transfer effort. It is also suggested that potential commercial partners be included within this steering committee.

Transfer Mechanism Used

Experience has shown that it is best to use several transfer mechanisms in parallel. Recommended methods include public announcements, demonstrations, and telephone contacts.

Public announcement. The CTTC obtained local television coverage for a demonstration of MAMA. Announcement articles were placed in a professional magazine (*Engineering News Record*) as well as a general information magazine (*Popular Mechanics*). The articles in both of these publications produced contacts from potential users and manufacturers. In addition, the Safety Planner has been presented at professional meetings and has received follow-up informational inquiries.

Public demonstration. Two pre-announced public demonstrations of MAMA have been held at the CTTC. Attendance at both demonstrations was good (20 and 15). Invitations were extended to a wide range of possibly interested parties. For users, invitations were extended to trade organizations and contractors. For development of support, invitations were extended to professional organizations and workers compensation insurers. For manufacturers, invitations were sent to scaffolding and lift equipment manufacturers.

Several impromptu demonstrations were held when individuals stopped at CTTC to discuss MAMA. The ability to demonstrate on demand is highly recommended.

Telephone contacts. Cold calls were sometime effective in locating interested parties. Although this can be time consuming, good contacts were made by this effort and they have become active supporters of the transfer effort. Classes of contacts should be defined and representative contacts identified. Often unsuccessful calls can still result in the identification of other successful points of contact. Several workers' rights organizations, professional organizations, and contractor points of contact were located in this way.

Follow-up mailings with detailed information to clarify the earlier telephone conversations are highly recommended.

Establishment and Management of Schedule

It is important to recognize that technology transfer is a ***process*** (Rogers 1995) not an event. Given that understanding, it is important to build a schedule with the process timeframe in mind. Adequate time must be budgeted to allow for the initial identification, review, and acceptance of a technology opportunity to be staffed within the participant's organization. Parallel efforts can shorten the overall process if both the user and supply sides of the effort are approached simultaneously.

Since the transfer process should be expected to require several years of effort, a staffing and funding commitment must be identified and agreed to at the beginning of the effort. The initially conceived USACERL/CTTC partnership was planned for 5 years and funded for about 2 or 3 full-time employees. Experience has shown that this planning period was too short and, to a degree, underfunded. This approach may have been adequate had a candidate technology already been identified. Phase I and II of the effort (establishment of the CTTC and identification of potential technologies) required effort for the better part of 2 years. Phase III of the effort (transfer of existing technologies) was more time consuming than anticipated because existing laboratory products were often not completely ready for transfer. Movement from a proof-of-concept prototype to a marketable prototype was found to be necessary to generate commercial interest. The initially established timeframe and budget did not anticipate this requirement. Efforts are underway to locate additional funding to complete the transfer efforts of MAMA and the Safety Planner.

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Appendix A: Survey Results of Construction Productivity Study

Construction Productivity Study:

Factors Which Affect Construction Productivity

August 1995

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Introduction

As most profit based enterprises, the construction industry has been quietly concerned about its overall productivity for many years. A more overt concern became apparent after reports of declining productivity began to appear in the middle to late 70's. Those reports indicated soaring costs and a lack of response to, and incorporation of, modern management tools and techniques. A much quoted series of reports, published in 1982 and 1983, the Business Roundtable's "Construction Industry Cost Effectiveness Project (CICE)[1]," identified areas of poor performance by the construction industry and made recommendations for improvement.

Beginning at approximately the same time, economists such as Stokes (1981)[2], followed by Schriver and Bolby (1985)[3], Allen (1985[4],1989[5]), ENR (1985)[6] and Pieper (1989)[7] attempted to identify what the actual causes were for the reported decline in productivity. Results of these studies, however, did not address remedies or courses of action for companies to follow to increase their own level of productivity.

An outgrowth of the CICE report was the development of the Construction Industry Institute (CII). This development was in response to the results of CICE's study which indicated that the construction industry's decline in productivity during the 1970's was due in part to a lack of construction industry productivity data and research.[8] The CII was therefore formed to gather, analyze, and provide assistance in the development of productivity enhancing information, techniques, and research.[9,10] Membership in the CII is obtained by a $25,000 annual membership fee, which provides funding for research in the areas of productivity improvement. Results of that research are then offered to the industry at a nominal cost.

A parallel effort to the CII that also embraced the findings of the CICE report was the development of the Construction Productivity Advancement Research program (CPAR) by the US Army's Corps of Engineers.[11,12] The initial intent of the CPAR program was and remains to carry out research and development that will improve the industry's productivity and international competitiveness. The initial focus of the R & D effort was in the areas of design, construction site productivity, advanced materials, and technology transfer management. As the CPAR program has developed, the Corps and its partners share in the cost of each project. Results of CPAR activities include new materials such as structural lightweight concrete block (reduced weight from a typical structural lightweight) and new management systems for improved productivity.

The Construction Technology Transfer Center

Many of the aforementioned programs and research efforts (CICE, CII, and CPAR) have been directed and funded by large corporations and construction organizations. The results of their research efforts and programs, therefore, have in most cases been targeted at large construction organizations (although smaller companies could also benefit from their efforts).

To service small to medium sized construction organizations in the improvement of their business productivity, it was proposed to develop a "Construction Technology Transfer Center," which would focus its efforts in assisting small to medium sized construction firms – both residential and commercial in nature. As a result of direct legislative support from the United States Congress, the Construction Technology Transfer Center (CTTC) was formed at Indiana State University to provide productivity improvement assistance to small to medium sized construction firms in the Wabash Valley region. The CTTC is a cooperative effort supported by both Indiana State University's Construction Technology program as well as the U.S. Army Corps of Engineers Construction Engineering Research Laboratory at Champaign, Illinois.

The initial activities of the CTTC center around four major areas. Those areas include: (1) an assessment of the issues that contractors believe both detract and also assist the level of productivity that they may attain, (2) special topic seminars/training sessions in computer applications, (3) special topic seminars/ training sessions in productivity improvement techniques, and (4) transferring technology developed by the Corps of Engineers to small to medium sized construction firms.

This article deals specifically with the first major area for which the CTTC has been formed.

Construction Productivity: *An Assessment of the Industry*

To determine those issues that small to medium sized construction firms in the Wabash Valley region believe both detract and also assist the level of productivity that they may attain, an initial search was completed to identify suitable measurement instruments. While Arditi's (1985)[13] productivity improvement study did provide an example of an instrument similar to the needs of this study, it was determined that a suitable current instrument was not available. The development of the *Construction Productivity Study* questionnaire began with a thorough review of current construction based literature to identify areas which had the potential to both negatively as well as positively effect construction productivity. A listing of those factors are found below:

Negative Productivity Factors

Claims for damages	Historic information retrieval
Duplication of paperwork	Data transfer from jobsite
Job costing	Cash flow
Regulatory issues	Workers compensation
Human resources	Job site safety
Quality control	Insurance
Company marketing	Financing
Relationships with subcontractors	Relationships with A/Es
Contract disputes	

Positive Productivity Factors

Word processing	Historic information retrieval
Computerized scheduling	Data transfer from job site
Job costing	Cash flow analysis
Computerized estimating	Workers compensation
Job site safety	Quality control / TQM
Insurance costs	Company marketing
Financing	Relationships with subcontractors
Relationships with A/Es	Dispute resolution boards
Craft training	Litigation avoidance
Computer based contract documents	CAD
Increased company specialization	Employee ownership
Strategic Planning	

Upon identification of those positive and negative factors, items were developed with responses based upon a 5 point Likert response technique. In addition, items were generated to gather demographic data about the respondents' organizations as well as preferences for potential services to be provided by the CTTC. To provide a sense of content validity as well as instrument reliability, a pretest was conducted on a random sample of the population. Upon review of the pretest results, minor modifications of the *Construction Productivity Study* questionnaire and cover letter were completed in preparation of the mailing to the entire identified population.

Population Identification

The population used in the pursuit of this study included construction organizations in a two state area, west central/southern Indiana (25 counties) and east central/southern Illinois (37 counties), which were contiguous to the Wabash Valley region. Contractors in the region were identified through the use of a purchased listing of contractors (Caldwell List Company) with validation and augmentation through the use of sixteen construction related professional organization's listings of members (AGC, ABC, NAHB, etc.). This process identified a total of over 1900 contractors in the region. Of the 1900+ contractors which were contacted for inclusion in the study, 193 returned questionnaires for a 10% response rate.

Population Demographics

Of those responding, 42.6% identified themselves as residential contractors while 41.6% fell into a more “commercial” category. Approximately 15.8% of the respondents fell into what could be categorized as “specialty contractors” which may work in residential as well as commercial construction.

The average age of companies responding to the questionnaire was 20.3 years, with the newest company at one year, and the oldest respondent at 99 years. Approximately three fourths of those completing the questionnaire were either the owner or president of the company.

Results indicated that the educational backgrounds of those responding included a high school education for almost all responding and four year college degrees for almost half of all respondents (46.1%). Undergraduate majors were varied with the largest single major identified as business (5.2%) followed by Civil Engineering (4.7%), Construction (3.1%), and Education (2.6%). Very few of those responding had completed any graduate education. Craft training had been obtained by over 40 percent of those responding, with carpentry (16.8%) and electrician (3.7%) being the two largest identified crafts.

Company size varied with the average size of those responding at slightly over 17 employees. Company size ranged however, from 1 to over 300 employees.

Sales volume of those responding ranged from less than 1 million (42.9%) to over 20 million (3.7%). Other levels of sales volume were 1-2 million (25.7%), 3-4 million (11%), 5-6 million (6.8%), 7-10 million (4.2%), 11-15 million (3.1%) and 16-20 million (1.6%). Profit margins for the past four years of the respondents had remained relatively constant from the average 1990 level of 10.610% to the average 1993 level of 10.386%.

Of those responding to the questionnaire, approximately 30% had been involved in litigation during the past five years. Of those involved, 67.3% had reached agreement on the resolution of the issues involved. The average time to reach resolution was approximately 22 months and of those reaching resolution, 61.5% were satisfied with the results. Of those responding, only 28.1% had been involved in any type of dispute resolution or arbitration boards.

Computer hardware and software were in use by the majority of those responding. The most used computer system was based on the 80486 Intel series, with engineering workstations, the 80386, 80286, Macintosh, and Pentium following. With over 130 separate software packages identified as in use, the four software packages which were cited most often included WordPerfect, Lotus, Timberline, and Quicken.

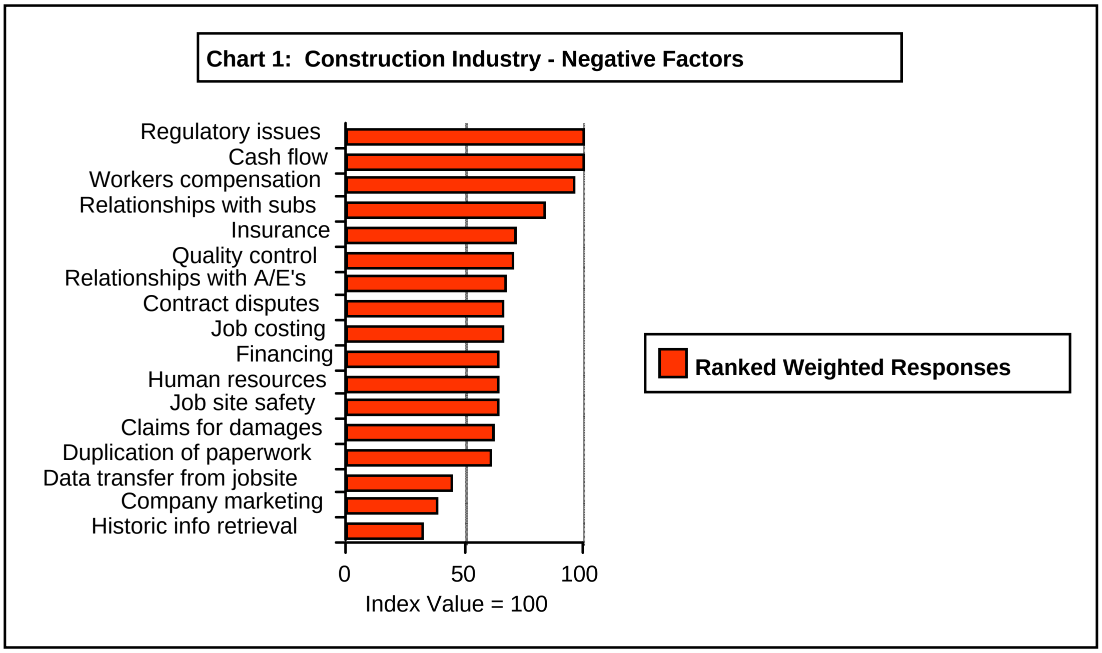
Analysis of Productivity Factors

During the development of the *Construction Productivity Study* questionnaire, factors which had both a negative as well as a positive effect on productivity were identified. Respondents were asked to rate these factors in two ways, i.e., (1) how they felt the productivity factor affected the overall construction industry, and (2) how they felt the productivity factor effected their individual company.

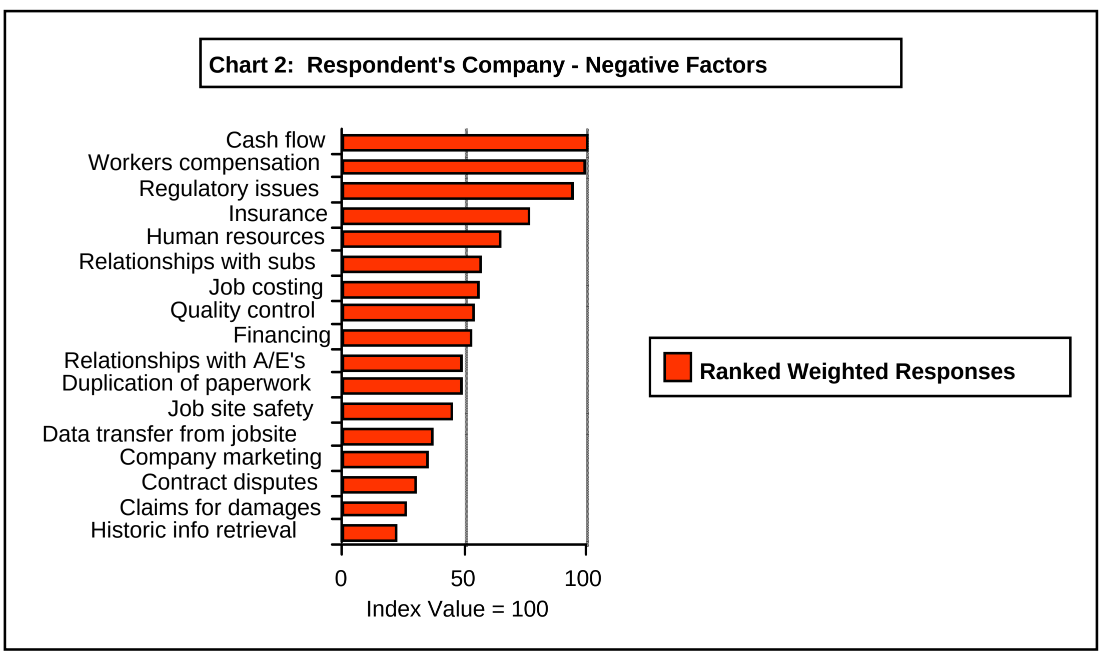
The initial analysis of productivity factors was completed through two techniques: (1) the use of ranked weighted responses of the overall population, commercial contractors, and residential contractors and (2) a change score analysis based upon weighted responses. The first technique, a weighted response, was used to determine overall ranking of the productivity factors identified by the *Construction Productivity Study* questionnaire. The second technique, a change score analysis, was used to remove the bias of the respondents on the reported level of their own companies performance on each of the identified productivity factors. In addition, results were analyzed based upon the overall population of respondents, as well as the individual groupings of commercial and residential contractors.

Overall Population of Respondents – Weighted Response

The top five *Negative Productivity Factors* for the *construction industry* as identified by respondents included: (1) Regulatory Issues, (2) Cash Flow, (3) Workers Compensation, (4) Relationships With Subcontractors, and (5) Insurance (please see chart 1).

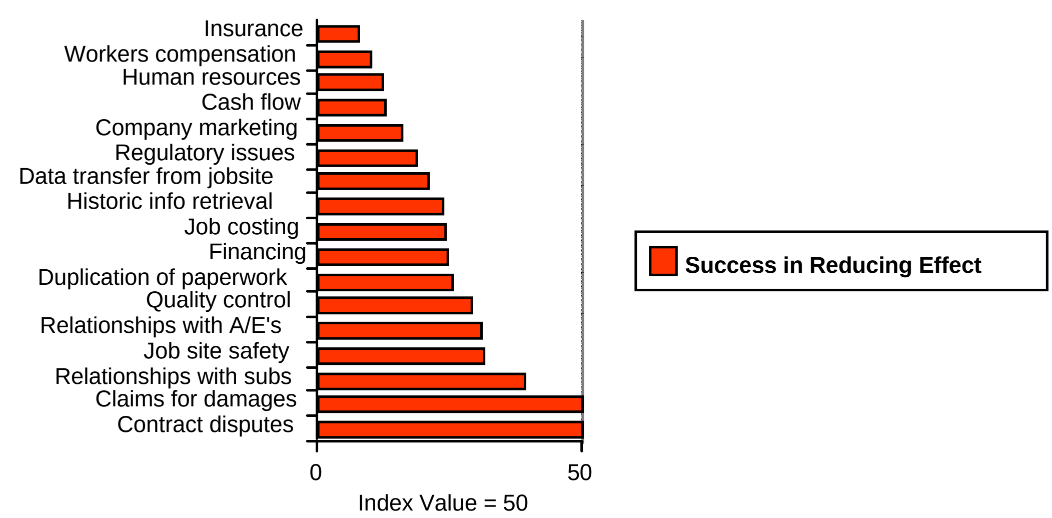


The top five identified *Negative Productivity Factors* for the *respondent's company* included: (1) Cash Flow, (2) Workers Compensation, (3) Regulatory Issues, (4) Insurance, and (5) Human Resources (please see chart 2).



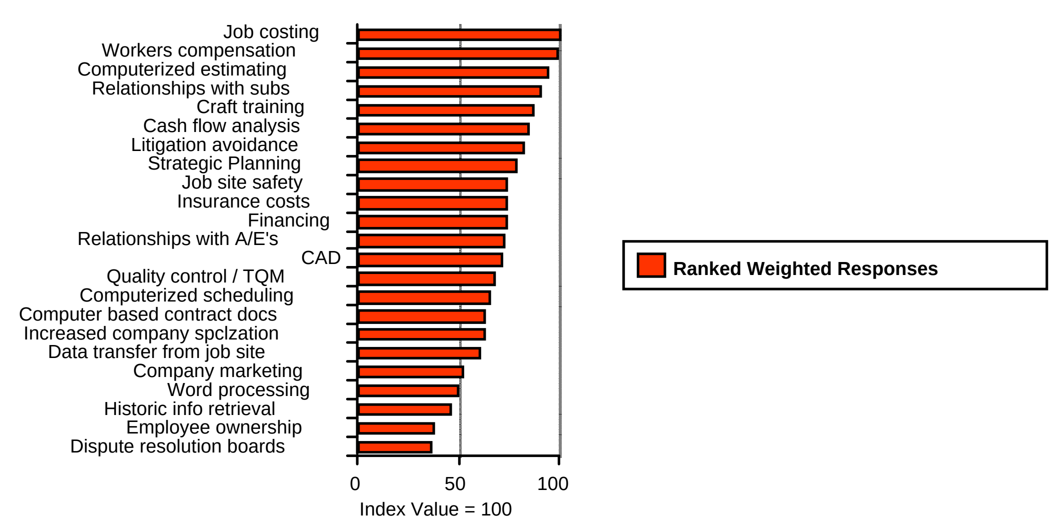
To compare the identified effect of *Negative Productivity Factors* for the *Construction Industry* versus the *Respondents Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Negative Productivity Factor.* The resulting data indicated that respondents had less success in reducing the effect of *Negative Productivity Factors* in the following areas: (1) Insurance, (2) Workers Compensation, (3) Human Resources, (4) Cash Flow, and (5) Company Marketing (please see chart 3).

Chart 3: Change Score Analysis - Negative Factors

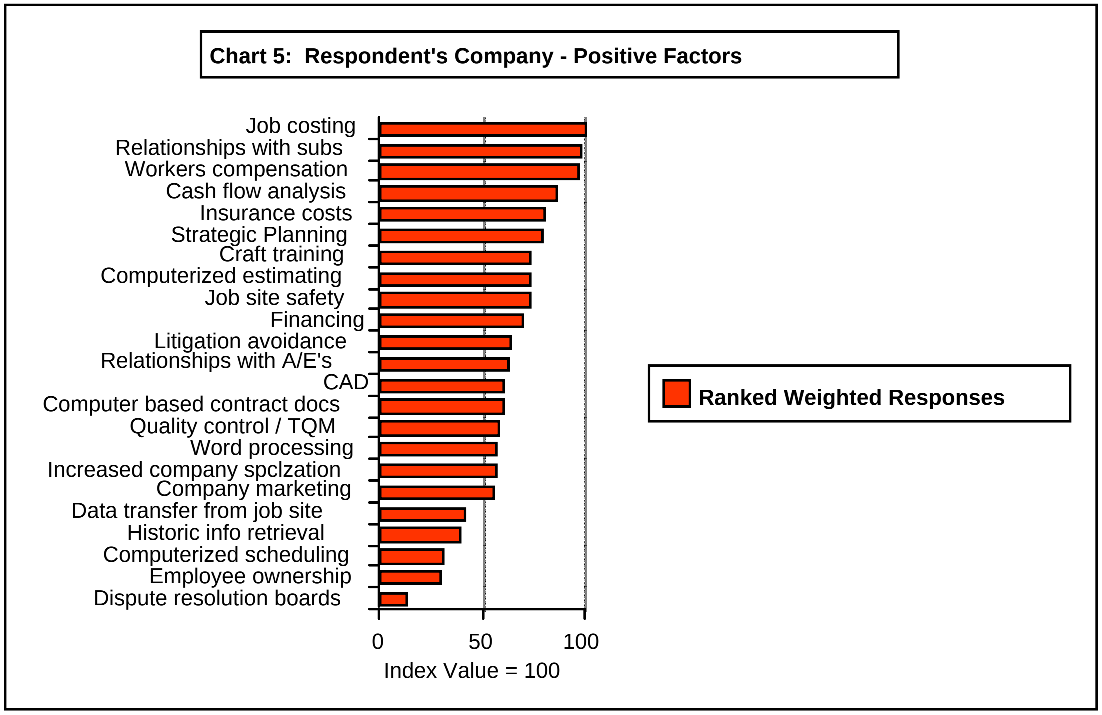


The top five *Positive Productivity Factors* for the *construction industry* as identified by respondents included: (1) Job Costing, (2) Workers Compensation, (3) Computerized Estimating, (4) Relationships With Subcontractors, and (5) Craft Training (please see chart 4).

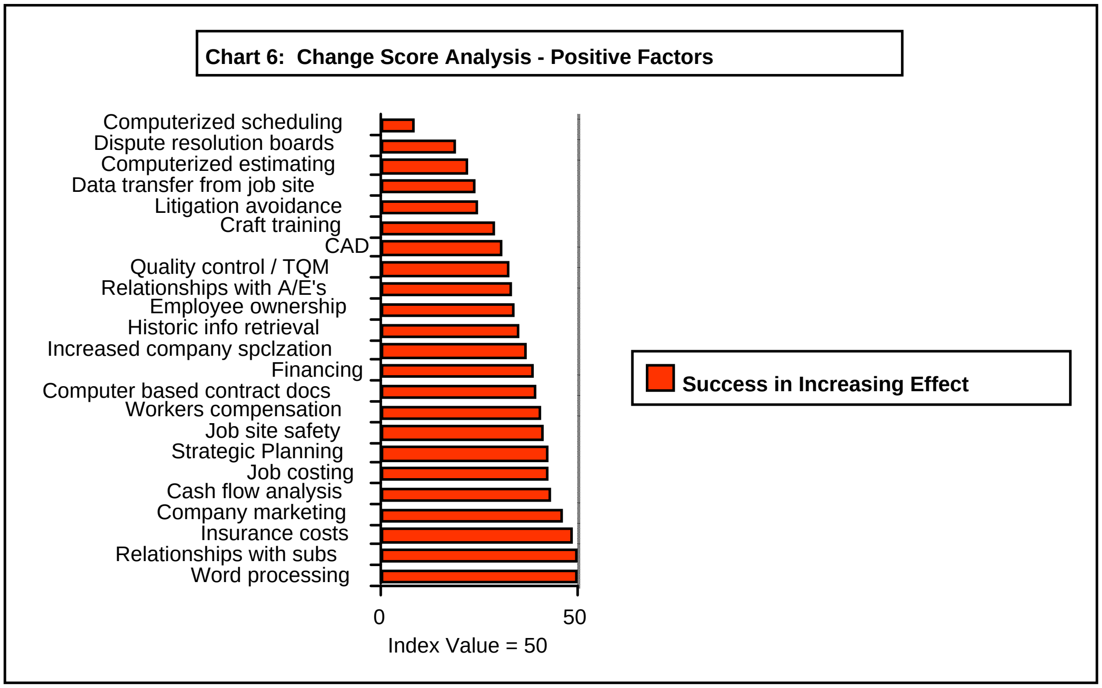
Chart 4: Construction Industry - Positive Factors



The top five identified *Positive Productivity Factors* for the *respondent's company* included: (1) Job Costing, (2) Relationships With Subcontractors, (3) Workers Compensation, (4) Cash Flow Analysis, and (5) Insurance Costs (please see chart 5).

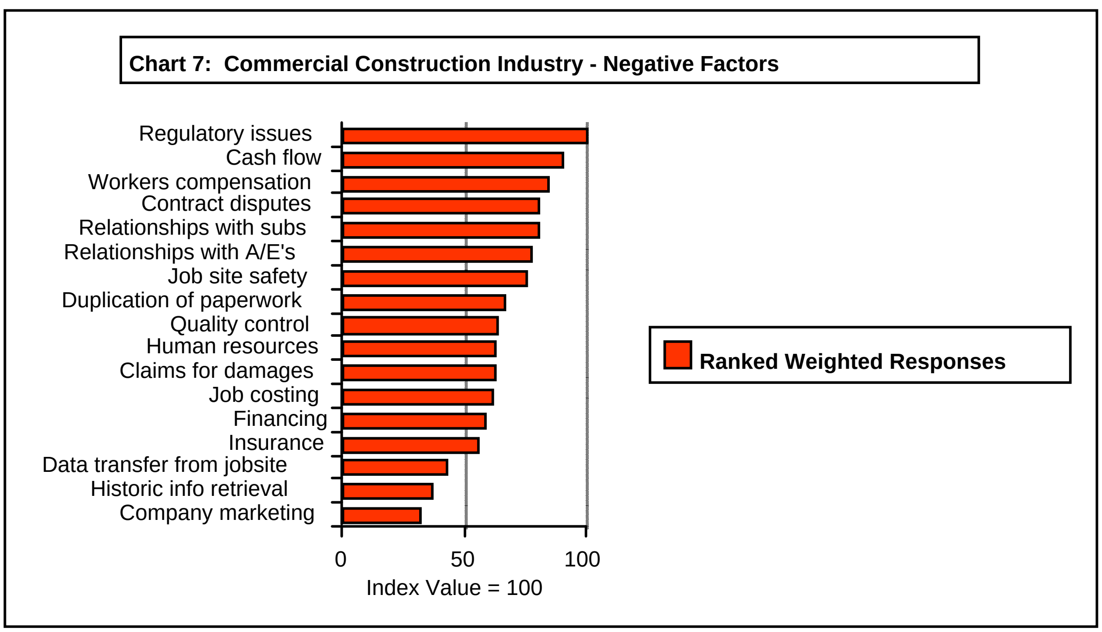


To compare the identified effect of *Positive Productivity Factors* for the *Construction Industry* versus the *Respondents Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Positive Productivity Factor*. The resulting data indicated that respondents had less success in incorporating the effects of *Positive Productivity Factors* in the following areas: (1) Computerized Scheduling, (2) Dispute Resolution Boards, (3) Computerized Estimating, (4) Data Transfer From Jobsite to Office, and (5) Litigation Avoidance (please see chart 6).

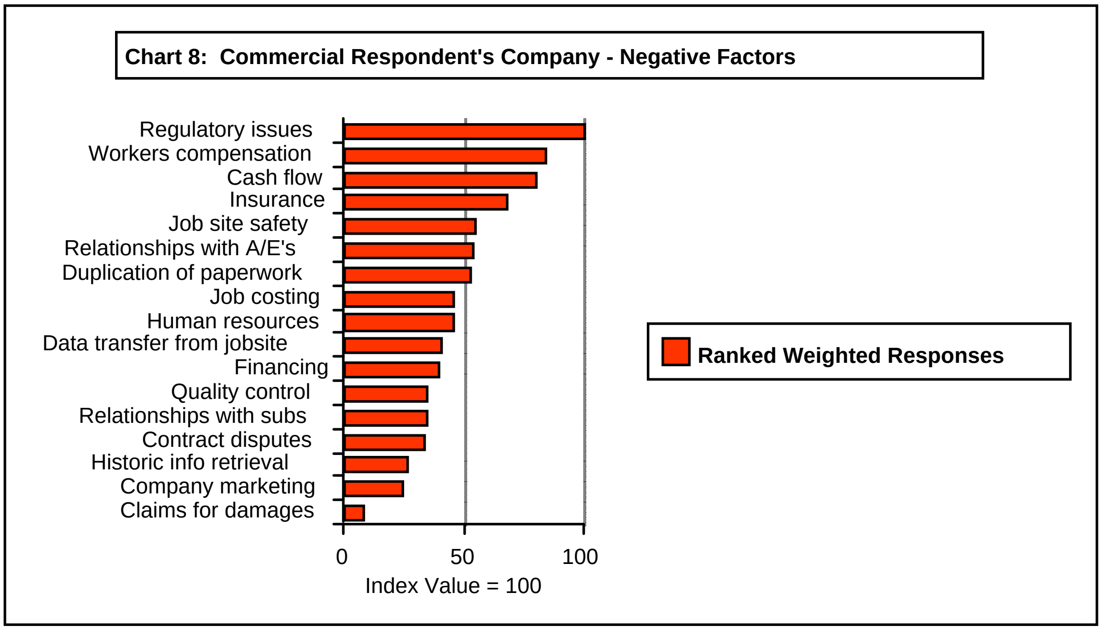


Commercial Contractors - Weighted Response

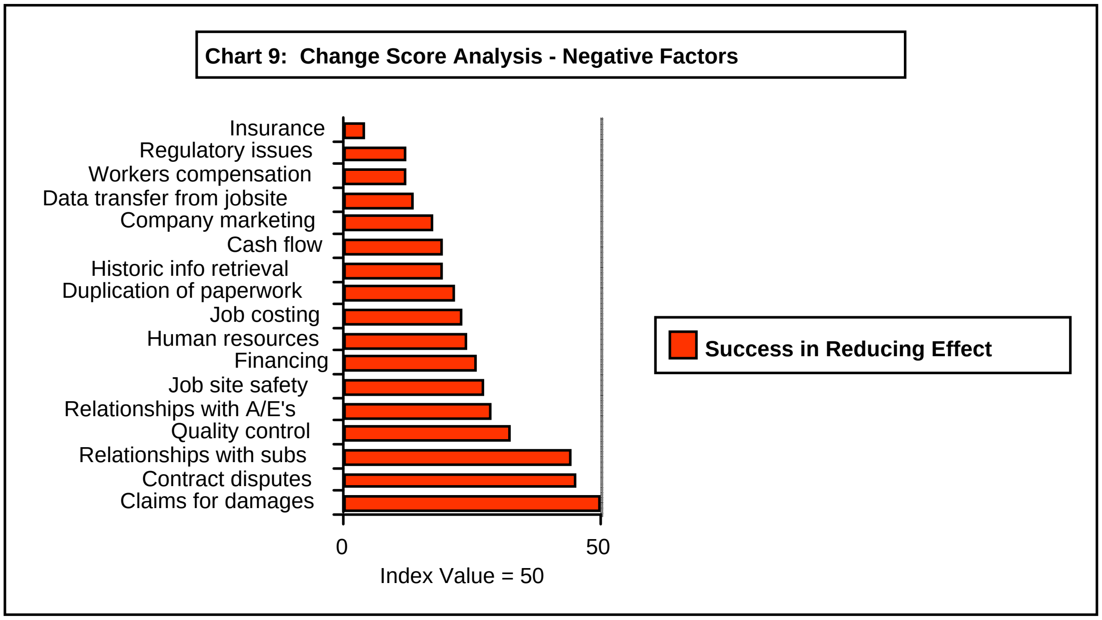
The top five *Negative Productivity Factors* for the *construction industry* as identified by this subgroup of respondents included: (1) Regulatory Issues, (2) Cash Flow, (3) Workers Compensation, (4) Contract Disputes, and (5) Relationships With Subcontractors (please see chart 7).



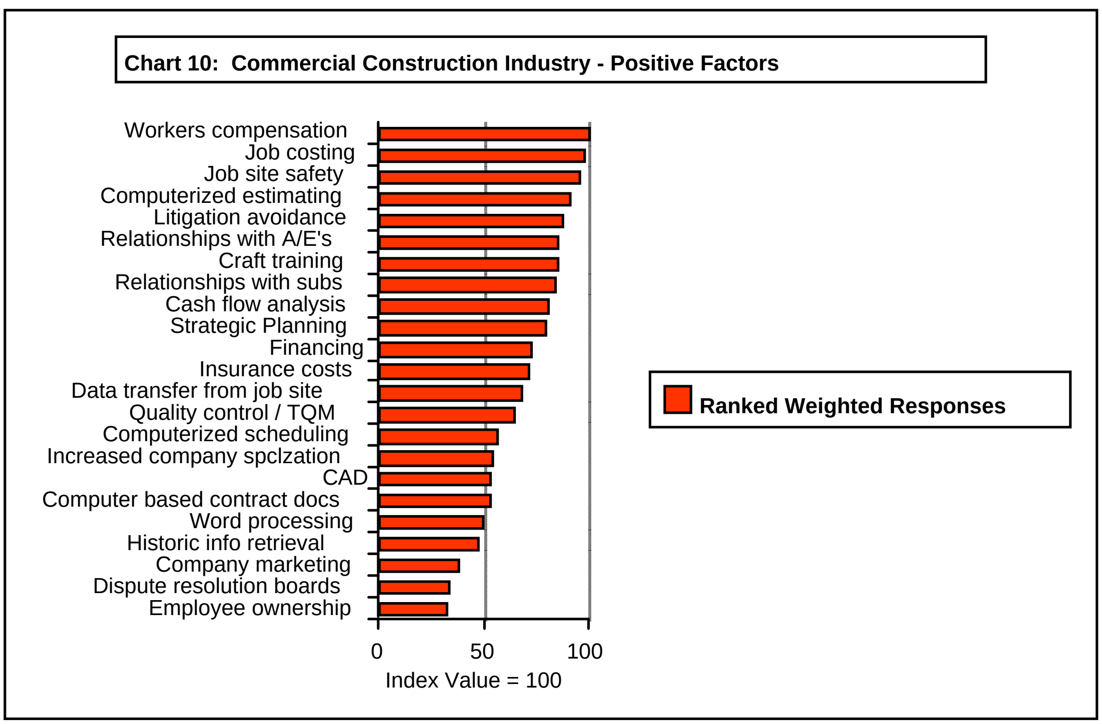
The top five identified *Negative Productivity Factors* for the *respondent's company* included: (1) Regulatory Issues, (2) Workers Compensation, (3) Cash Flow, (4) Insurance, and (5) Job Site Safety (please see chart 8).



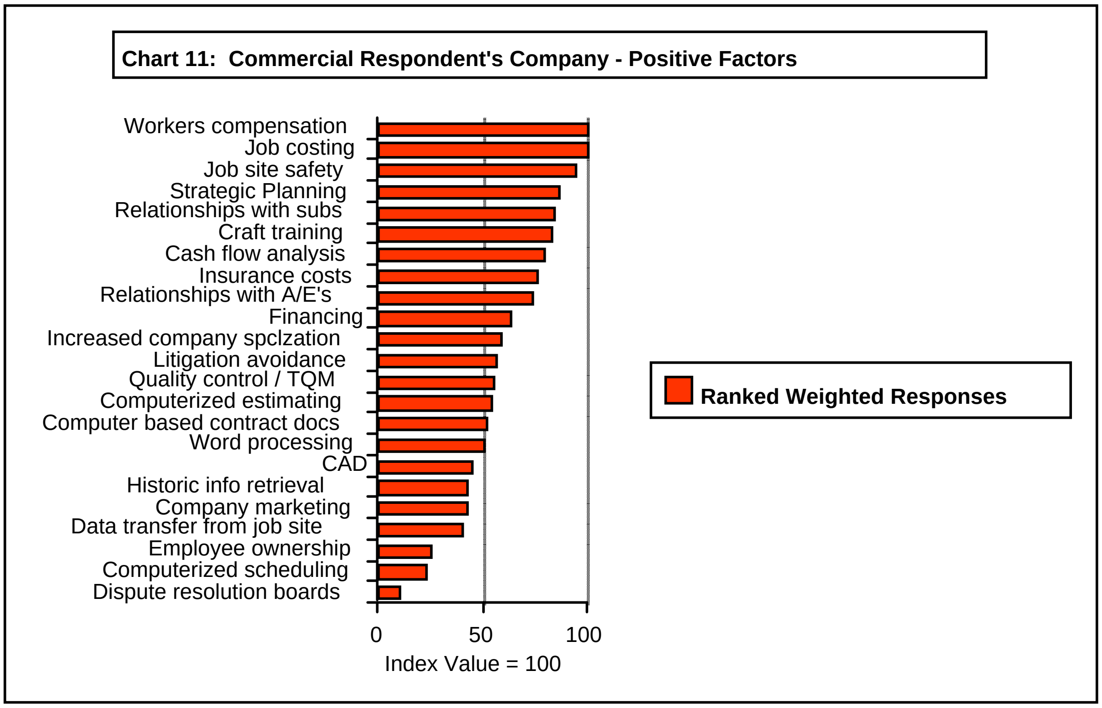
To compare the identified effect of *Negative Productivity Factors* for the *Construction Industry* versus the *Respondents Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Negative Productivity Factor.* The resulting data indicated that respondents had less success in reducing the effect of *Negative Productivity Factors* in the following areas: (1) Insurance, (2) Regulatory Issues, (3) Workers Compensation, (4) Data Transfer From Jobsite to Office, and (5) Company Marketing (please see chart 9).



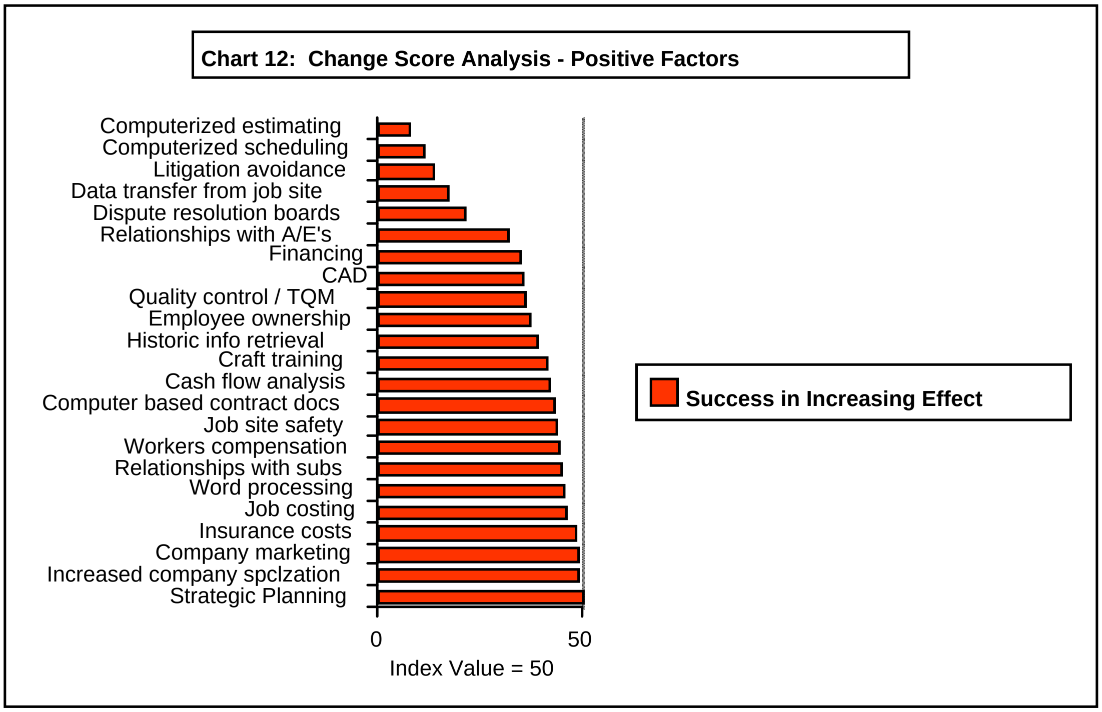
The top five *Positive Productivity Factors* for the *construction industry* as identified by this subgroup of respondents included: (1) Workers Compensation, (2) Job Costing, (3) Job Site Safety, (4) Computerized Estimating, and (5) Litigation Avoidance (please see chart 10).



The top five identified *Positive Productivity Factors* for the *respondent's company* included: (1) Workers Compensation, (2) Job Costing, (3) Job Site Safety, (4) Strategic Planning, and (5) Relationships With Subcontractors (please see chart 11).

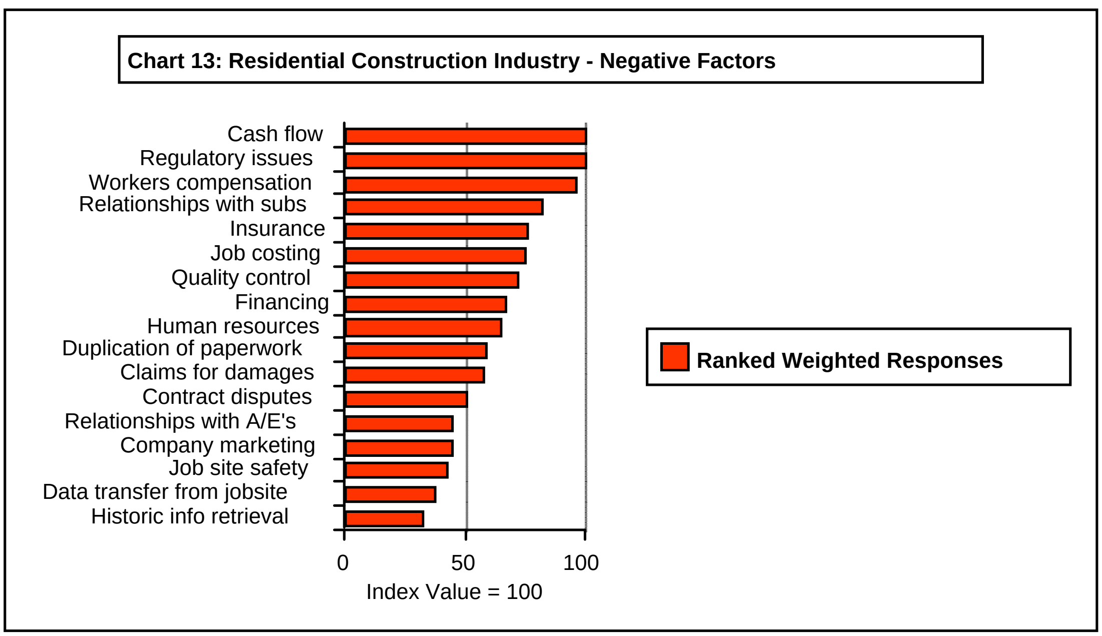


To compare the identified effect of *Positive Productivity Factors* for the *Construction Industry* versus the *Respondents Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Positive Productivity Factor.* The resulting data indicated that respondents had less success in incorporating the effects of *Positive Productivity Factors* in the following areas: (1) Computerized Estimating, (2) Computerized Scheduling, (3) Litigation Avoidance, (4) Data Transfer From Jobsite to Office, and (5) Dispute Resolution Boards (please see chart 12).



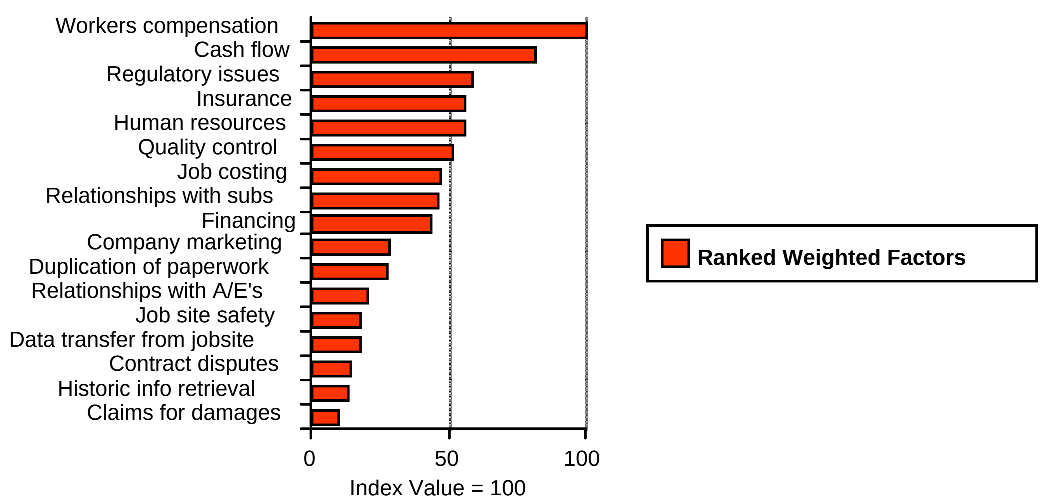
Residential Contractors - Weighted Response

The top five *Negative Productivity Factors* for the *construction industry* as identified by this subgroup of respondents included: (1) Cash Flow, (2) Regulatory Issues, (3) Workers Compensation, (4) Relationships With Subcontractors, and (5) Insurance (please see chart 13).

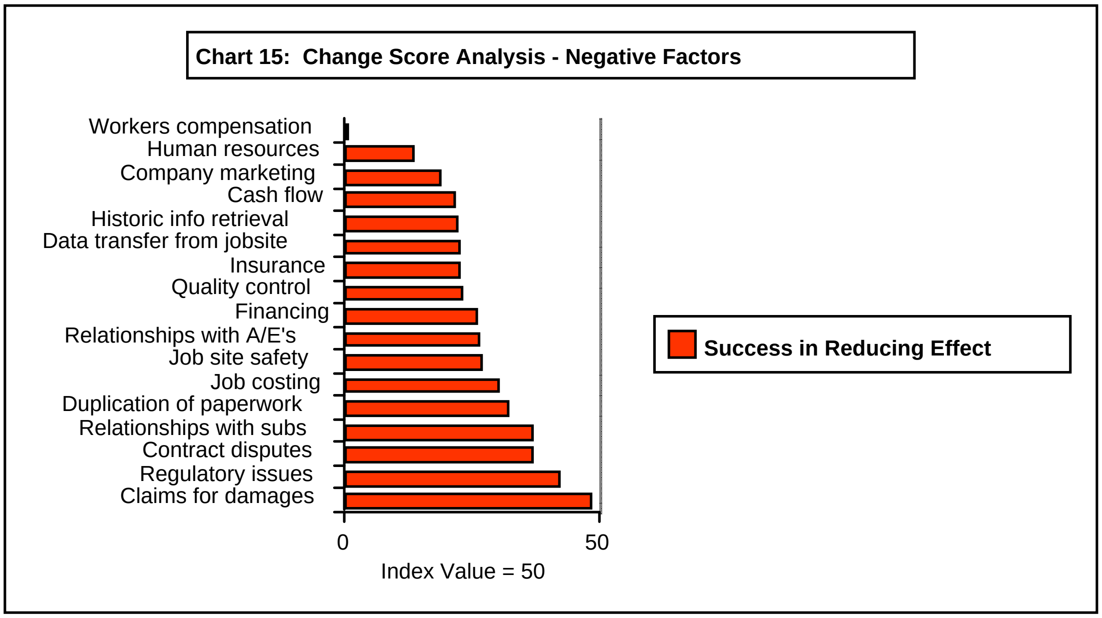


The top five identified *Negative Productivity Factors* for the *respondent's company* included: (1) Workers Compensation, (2) Cash Flow, (3) Regulatory Issues, (4) Insurance, and (5) Human Resources (please see chart 14).

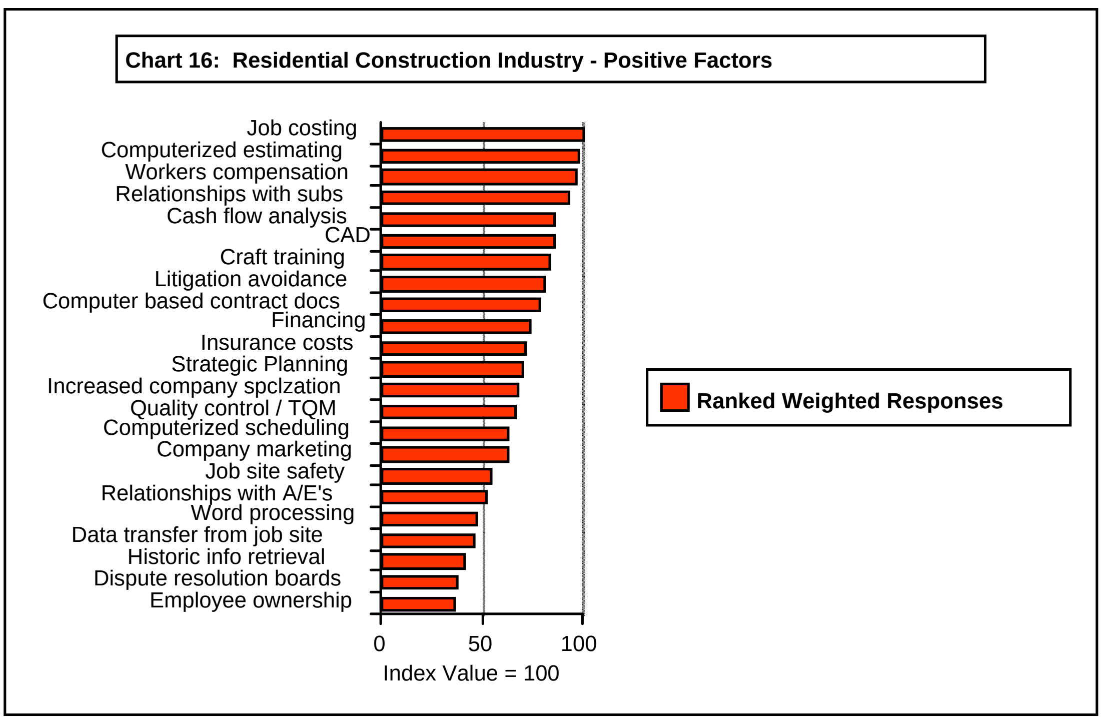
Chart 14: Residential Respondent's Company - Negative Factors



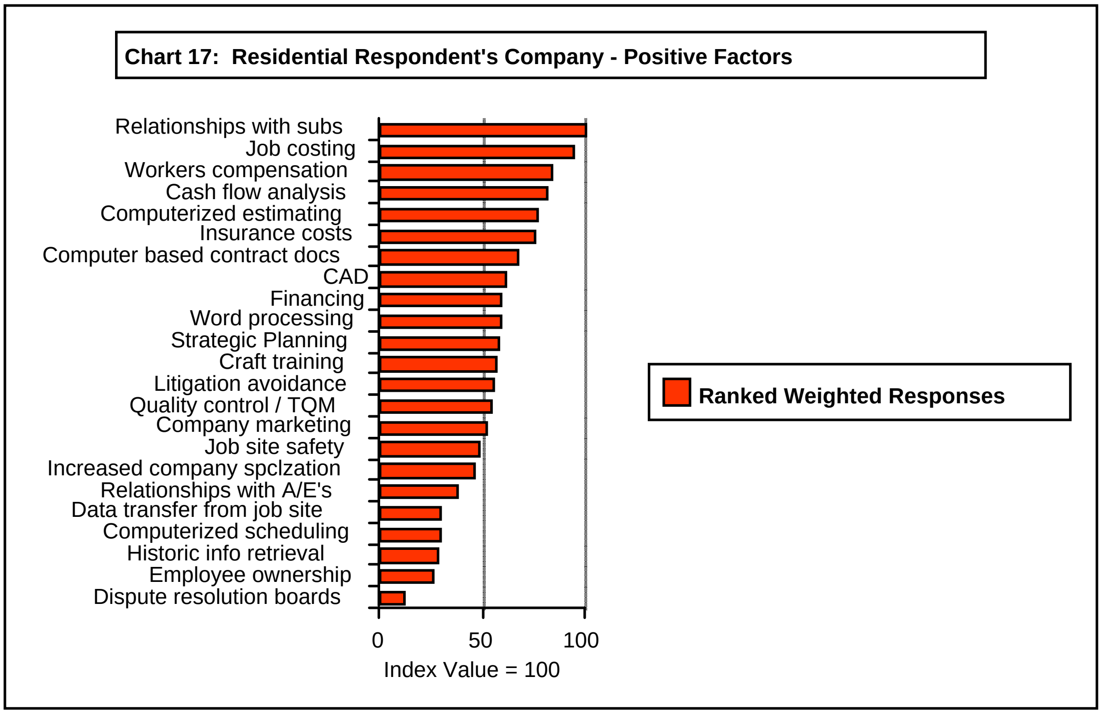
To compare the identified effect of *Negative Productivity Factors* for the *Construction Industry* versus the *Respondent's Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Negative Productivity Factor*. The resulting data indicated that respondents had less success in reducing the effect of *Negative Productivity Factors* in the following areas: (1) Workers Compensation, (2) Human Resources; (3) Company Marketing, (4) Cash Flow, and (5) Historic Information Retrieval (please see chart 15).



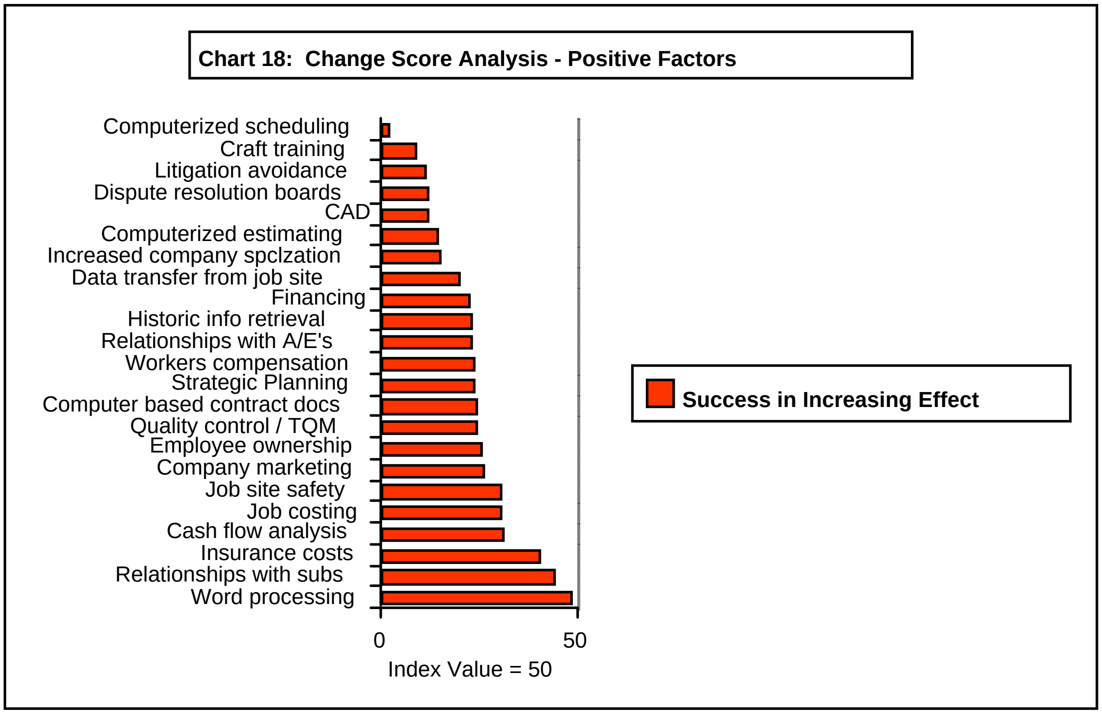
The top five *Positive Productivity Factors* for the *construction industry* as identified by this subgroup of respondents included: (1) Job Costing, (2) Computerized Estimating, (3) Workers Compensation, (4) Relationship With Subcontractors, and (5) Cash Flow Analysis (please see chart 16).



The top five identified *Positive Productivity Factors* for the *respondent's company* included: (1) Relationships With Subcontractors, (2) Job Costing, (3) Workers Compensation, (4) Cash Flow Analysis, and (5) Computerized Estimating (please see chart 17).



To compare the identified effect of *Positive Productivity Factors* for the *Construction Industry* versus the *Respondents Company*, a change score analysis was completed. This analysis procedure compared the two weighted mean scores for each *Positive Productivity Factor.* The resulting data indicated that respondents had less success in incorporating the effects of *Positive Productivity Factors* in the following areas: (1) Computerized Scheduling, (2) Craft Training, (3) Litigation Avoidance, (4) Dispute Resolution Boards, and (5) CAD (please see chart 18).



Conclusions

Without exception, respondents to the *Construction Productivity Study* rated themselves as doing better on the factors that affect their levels of productivity than that of the overall industry. While at first glance this may be a reality, it probably is in the same light as the contractor who always goes into a job knowing that "they will make good money on this one."

The issues that were identified as most negative and as most positive were fairly consistent across the overall population of respondents as well as the sub-groupings of commercial and residential construction firms. Negative productivity factors that were identified included several interrelated issues such as insurance and workers compensation as well as financial issues such as cash flow. Issues dealing with personnel also were identified as top negative productivity factors, i.e., human resources and relationships with subcontractors and architectural/engineering personnel.

When a change score analysis was completed to remove the bias from the results of the *Construction Productivity Study*, negative productivity factors for which construction organizations are having the least success in removing their effects included insurance, workers compensation, human resources, cash flow, and company marketing.

Positive productivity factors identified by the respondents to the *Construction Productivity Study* included financial issues such as job costing, computerized estimating, and cash flow analysis. Other factors included personnel issues such as relationships with subcontractors and craft training.

When the bias from the responses was removed from the positive productivity factors to indicate the level of success respondents had in increasing their effect on overall productivity, those issues which contractors had the least success in implementing their positive effects included computer-based systems such as scheduling, estimating, and data transfer. Issues involving legal concerns also included dispute resolution boards and litigation avoidance.

Results of the *Construction Productivity Study* indicated that many of the issues that had been identified in earlier research efforts were still issues that had an important role to play in the productivity levels of the construction industry. Results of this study have also identified areas for which tailored assistance will be provided to Wabash Valley construction firms through the Construction Technology Transfer Center.

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[5] Allen, S. G. "Why construction industry productivity is declining: Comment." *The Review of Economics and Statistics*. Vol. 71, No. 3, August 1989, pp. 547-549.

[6] "Productivity fall overstated?" *Engineering News Record*. July 18, 1985, p. 89.

[7] Pieper, P. "Why construction industry productivity is declining: Comment." The Review of Economics and Statistics. Vol. 71, No. 3, August 1989, pp. 543-546.

[8] Krizan, W.G. "Institute pushing hard in productivity plan." *Engineering News Record*, August 14, 1986, p. 48.

[9] Constructibility Task Force, Construction Industry Institute. "Constructibility means lower project costs, better productivity." *Pulp & Paper*, September 1988, pp. 153-155.

[10] Krizan, W. G. "CII research paying off in industry productivity." *Engineering News Record*, August 17, 1989, p. 9.

[11] Kraker, J. "Corps ready to roll on R & D." *Engineering News Record*, June 2, 1988, p. 8.

[12] Ichinowski, T. and Setzer, S. "Corps seeks plans to boost productivity." *Engineering News Record*, February 9, 1989, p. 11-12.

[13] Arditi, D. "Construction productivity improvement." *Journal of Construction Engineering and Management*. Vol. 111, March 1985, pp. 1-14.

Appendix B: Product Evaluation

Comparison of Product's Impact

Source	Reference	Product Name	Score*
CERL	PL 11	Data Exchange Standard for Scheduling Software	3.81
CERL	FF 19	Construction Automation Support Center (CASC)	2.20
CERL	AM 13	High Performance UltraLight Concrete Masonry	2.05
CERL	FL 11	Acceptance Testing of HVAC Systems	1.95
CERL	FL 1	Paint Test Kit	1.83
CERL	PL 2	Homeowners Assistance Program (HAP)	1.83
CERL	FL 14	Lead-based Paint Hazard Mitigation	1.78
CERL	PD 6	Building Energy Performance Commissioning	1.67
CERL	UL 18	Trenchless Rehabilitation of Sewer Pipes	1.53
CERL	FF 17	Teaching Assistant for AutoCad	1.49
CRREL	AM 11	Antifreeze Admixtures for Winter Concreting	1.40
CERL	PD 2	Building Assemblies Systems (interior partitions)	1.34
WES	PRR 4	Concrete Pavement Restoration	1.29
CERL	FL 47	Using Exterior Insulation and Finish System	1.19
CERL	PL 17/PL	Barcode Technology for QA Inspections	1.13
CERL	CP 1	Mechatronically Assisted Mason's Aide (MAMA)	1.12
CERL	FM 9	Copper Piping System Workmanship Test Loop	0.97
WES	AM 4	Improved Sealing and Resealing Concrete Joints	0.93
CERL	CP 17	Vitrification and Removal of Lead Based Paint	0.89
CRREL	AM 5	Determination of Freeze Thaw Resistance of Aggregate	0.85
CERL	PD 11	Optimization of Prefabricated Joist	0.84
CERL	UL 10	Asbestos Management Program Video Tapes	0.83

* Based on positive industry productivity factors.

Source	Reference	Product Name	Score
CERL	FL 39	Welding Technology Center	0.80
CERL	PL 14	Microstation Mentor	0.79
WES	AM 1	High Performance Blended Cement Systems	0.73
CERL	CP 2	Asbestos Abatement/Destruction Using Plasma Arc	0.70
CERL	FE 4	Building Loads Analysis and System Thermodynamics	0.68
CERL	TA 7	Self Help Service Center Management System	0.67
CERL	UL 32	Bar Code Tracking System for Hazardous Waste	0.60
CERL	FL 40	Paint Technology Center	0.59
CERL	FL 12	Knowledge Base: Alternative Construction Methods	0.55
CERL	FL 20	Retrofit Lighting Technologies	0.48
CERL	FL 27	pipe Corrosion Inspection Crawler	0.47
CERL	UL 5	Underground Storage Tank Locator	0.47
CERL	PD 7	Nondestructive Testing of Structural Systems	0.47
CERL	FL 25	Builder Engineered Management System	0.39
CERL	UL 9	Used Solvents Testing and Reclamation	0.39
WES	AM 7	Asphalt Rubber Concrete Criteria for Mix and App.	0.39
CERL	FL 21	HVAC Control Systems and Control Panels	0.38
CERL	FL 26	Lead-based Paint Abatement Using Vitrification	0.36
CERL	UL 7	Carbon Dioxide for Scale Removal in Domestic W	0.33
CERL	FL 33	Recycle of construction and Demolition Waste	0.30
CERL	FL 13	Pipe Corrosion Monitor (not available)	0.00
		Smart Tagged Composites for Infrastructure Apps	0.00
		Facility Layaway Procedures (O&M checklists)	0.00

Project Evaluation Reports

Appendix B information is available in hardcopy from the Defense Technical Information Center, 8725 John J. Kingman Road, Suite 0944, Fort Belvoir, VA 22060-6218.

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