Multiskilled Labor Utilization Strategies in Construction

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Abstract: Construction industry craft divisions in the United States are currently based on narrowly defined skill groupings. The steady demand for improved productivity and the shortage of skilled craft workers call into question this traditionally accepted "single-skilled" strategy. While these craft patterns are prevalent throughout the union and nonunionized sectors of the industry, they are not necessarily responsive to construction sequence or the optimal use of worker skills. Alternative labor utilization strategies may provide increased project performance and may reduce craft shortages through better utilization of the existing workforce. An analysis model is developed in this study to measure the project impact of alternative labor utilization strategies. The model is used to assess four multiskilling strategies on the construction of a $70,000,000 project. Benefits of multiskilled labor utilization strategies were demonstrated including potentially a 5–20% labor cost savings, a 35% reduction in required workforce, a 47% increase in average employment duration, and an increase in earning potential for multiskilled construction workers.

INTRODUCTION

It is widely recognized that labor productivity, craft skill acquisition, and the declining number of craft entrants are critical issues facing the construction industry. It is proposed that alternative labor strategies may provide an effective way of addressing these growing concerns. The current "single-skill" strategy can be identified as a contributing factor to many well documented existing labor inefficiencies: Multiple tiers of field supervision that reduce overall crew efficiency (Cass 1992), worker idle times from 20–45% (Thomas 1991), unassigned labor costs from nonworking supervisors, difficult crew coordination leading to construction delays and rework (Halpin 1992), and delays/managerial costs associated with jurisdictional disputes (Clough and Sears 1994). Perhaps more significantly, a single-skill strategy has also been identified as a restricting factor in the implementation of new technologies and in the development of process-based innovations. It has been shown that, when work boundaries are crossed, shared, merged, or eliminated, new opportunities for innovation arise (Livesay 1996).

Craft worker utilization has changed very little even after these inefficiencies were documented. Because many auxiliary company and industry-wide systems are now organized by the same craft groupings (i.e., contracting work breakdown structures, training and apprenticeship programs, compensation systems, etc.), experimentation with alternative strategies has been very limited. Because contractors face severe penalties for slow or inadequate performance, a model that estimates the potential benefits associated with an alternative labor strategy may reduce risk and therefore foster greater innovation in labor utilization.

Falling numbers of new craft entrants and reports of record low construction unemployment indicate that there will not likely be enough skilled workers to meet rising demand for construction services (Krizan 1996). Increased recruiting and image development efforts will help draw additional workers into the industry. Another possible solution is to look at methods that optimize or better utilize the skilled workers already in the industry. If a smaller number of diversely trained individuals could be used on a project for longer periods, the demand for new craft entrants can be reduced. Multiskilling may provide this benefit.

Multiskilling labor strategies are commonly found in manufacturing and process industries and in foreign construction markets (Burleson 1997). This study explores the use of a multiskilled workforce in U.S. construction applications and evaluates the potential project impact of such a strategy. Four potential multiskilling strategies have been developed and evaluated using a prediction of total project labor costs. In addition, the project assessment model that was developed can be used by other researchers or individual companies to evaluate the potential project impact of other labor strategies not included in this study.

MULTISKILLING DEFINED

Multiskilling is a labor utilization strategy in which workers possess a range of skills that are appropriate for more than one work process and that are used flexibly on a project or within an organization. It is a managerial strategy based on developing competency within the workforce and the full utilization of these capabilities. Workers can be assigned to construction tasks based on their ability to perform the needed skill/task unrestricted by traditional job descriptions or work boundaries.

A multiskilled labor utilization strategy exists independently of the implementation strategy chosen by an organization. Self-managed work teams, formal job rotation systems, skill-based pay compensation plans, etc. are means by which companies have chosen to implement a multiskilling strategy and should not be considered synonymous with multiskilling.

RESEARCH SCOPE AND METHODOLOGY

Because the determination of significant potential benefits precedes the effort to fully explore the economic or implementation issues associated with a change, this study reflects an exploratory effort to quantify, at the project level, the potential benefits of utilizing a multiskilled workforce. The material presented here is part of a broad study that included (1) a survey of current multiskilling construction applications; (2) a detailed estimation of potential benefits measured at the project level; and (3) an initial exploration of implementation issues. The focus of this article will be the project level analysis

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including only an overview of the supporting survey findings. The scope of the project analysis was limited to domestic, direct hire, industrial construction using the CII Model Plant as a basis for analysis.

Traditional project management tools and measures, such as detailed material and effort hour estimates and resource-loaded electronic project schedules, have been used to perform the project analysis. The labor resource data were generated using the resource allocation and reporting features of Primavera Project Planner [(P3) Primavera Systems, Inc., Bala Cynwyd, Penn.]. Researchers worked closely with a team of industry experts to devise measures, validate data, and review methodology. The following list of key tasks provides an overview of the research described here:

1. Investigate the extent to which multiskilling has been adopted in the construction industry.
2. Develop a baseline data set and summary measures representing current labor utilization strategies.
3. Define alternative multiskilling strategies to be assessed and develop parallel summary measures for each additional strategy.
4. Develop an economic benefit model to measure the project impact and conduct a comparative analysis.
5. Use the model to assess the potential benefits of multiskilling strategies applied to a specific construction project.

EXISTING MULTISKILLING APPLICATIONS

A literature review of multiskilling research and industry applications was conducted at the start of this study. Published reports were identified in many manufacturing, process, and maintenance construction settings in countries as diverse as Japan, England, Sweden, and the United States. Benefits reported in these studies include a reduction in required workforce, reduced turnover and absenteeism, increased earning potential, increased productivity, improved job satisfaction, and increased innovation/technology implementation (Nallikari 1995; Cross 1996; Park 1996; "Skills" 1996; Burleson 1997).

Additional construction users of multiskilling strategies were identified through contact referrals. Many of these companies participated in a survey identifying that company's multiskill strategy design, observed benefits, compensation systems, and implementation barriers. The benefits reported by construction users were consistent with the literature review findings from other industries. The complete findings of this survey were documented as part of the broad original study (Stanley 1997).

BASELINE LABOR DATA

To conduct a project level impact analysis, researchers needed to establish benchmark data that could be used to quantify the changes due to the use of multiskill labor strategies. The CII Model Plant was chosen as the basis for analysis because of the availability of appropriate detailed project level data. Industry research partners were used to identify a staffing plan that is representative of current labor use patterns. A detailed explanation of the baseline methodology and benchmark data is presented in the following paragraphs.

CII Model Plant Project

The CII Model Plant is a theoretical, representative petrochemical processing facility. Nine major components of a typical plant (a refractionation unit, tank farm, compressor unit, two turbine generators, underground piping, pipe bridge, and a complete civil site package) were assembled to form the model plant. The model plant was developed over a 3-year period and has since been used in two productivity benchmarking studies and one multifunctional equipment utilization study. The documentation used to conduct this study included a detailed quantity and effort hour estimate, historic cost estimates for approximately $70,000,000 of the total $85,000,000 project value, a 78-week project schedule, and representative drawings documenting all major components of the project.

Developing Baseline Utilization Data

To identify baseline draft utilization patterns, three independent general contractors with extensive petrochemical experience assisted in developing independent estimates of labor resource requirements. These contractors used the model plant data in conjunction with company specific labor practices to develop a complete labor resource estimate for the project. A staffing exercise, performed by experienced project managers and superintendents, identified craft workers and the duration of use for each activity in the project schedule. These craft resources were then "loaded" into the electronic schedule and summarized using standard graphic resource use reports. A single "most representative" strategy was selected as the baseline data by researchers and industry team members. Fig. 1 illustrates a sample craft use curve.

Three standard descriptive data measures were developed from the labor resource use curves to be used as model input values: (1) The total number of contractor-initiated hires required to complete the project; (2) the average employment duration of a craft worker on the project; and (3) a profile of the employment duration distribution for all workers. Craft resource curves plotted from the electronic schedule indicate increases and decreases in craft workforce demand on a weekly basis. It is acknowledged that a resource-loaded project schedule does not dictate field hiring and firing practices. If demand increases are interpreted as an increase in required work hours rather than an increase in required workers, it is clear that the manager could also respond by requiring overtime or adjusting that start dates of specific work tasks to level demand peaks. A series of electronic and manual resource leveling techniques was applied to the schedule to more accurately represent probable hiring/layoff practices. The total number of hires can then be counted based on increases and decreases along the y-axis of the craft resource use curves.

Average employment duration was calculated from the x-axis by assuming a "first in, last out" approach within any single-craft grouping. This assumption implies that contractors hire the most desirable workers in each craft first and then attempt to retain these workers until no additional work in that craft is needed. The number of craft workers employed for each observed employment duration was read from the y-axis. A weighted mathematical average was calculated to determine the average employment duration of all crafts in a given labor strategy. Table 1 summarizes baseline craft resource utilization patterns.

ALTERNATIVE MULTISKILLING STRATEGIES

Four multiskilling labor strategies were defined and evaluated in this study. These strategies were developed cooperatively by researchers and industry partners to reflect a spectrum of multiskilling possibilities. No attempt was made, at this early stage of exploration, to identify an optimum labor utilization strategy. Using the alternative strategy definitions developed by the research team and the model plant schedule, revised staffing plans were developed for each strategy. New multiskill craft curves were plotted for each multiskilled craft in each of the alternative strategies. Comparative data values

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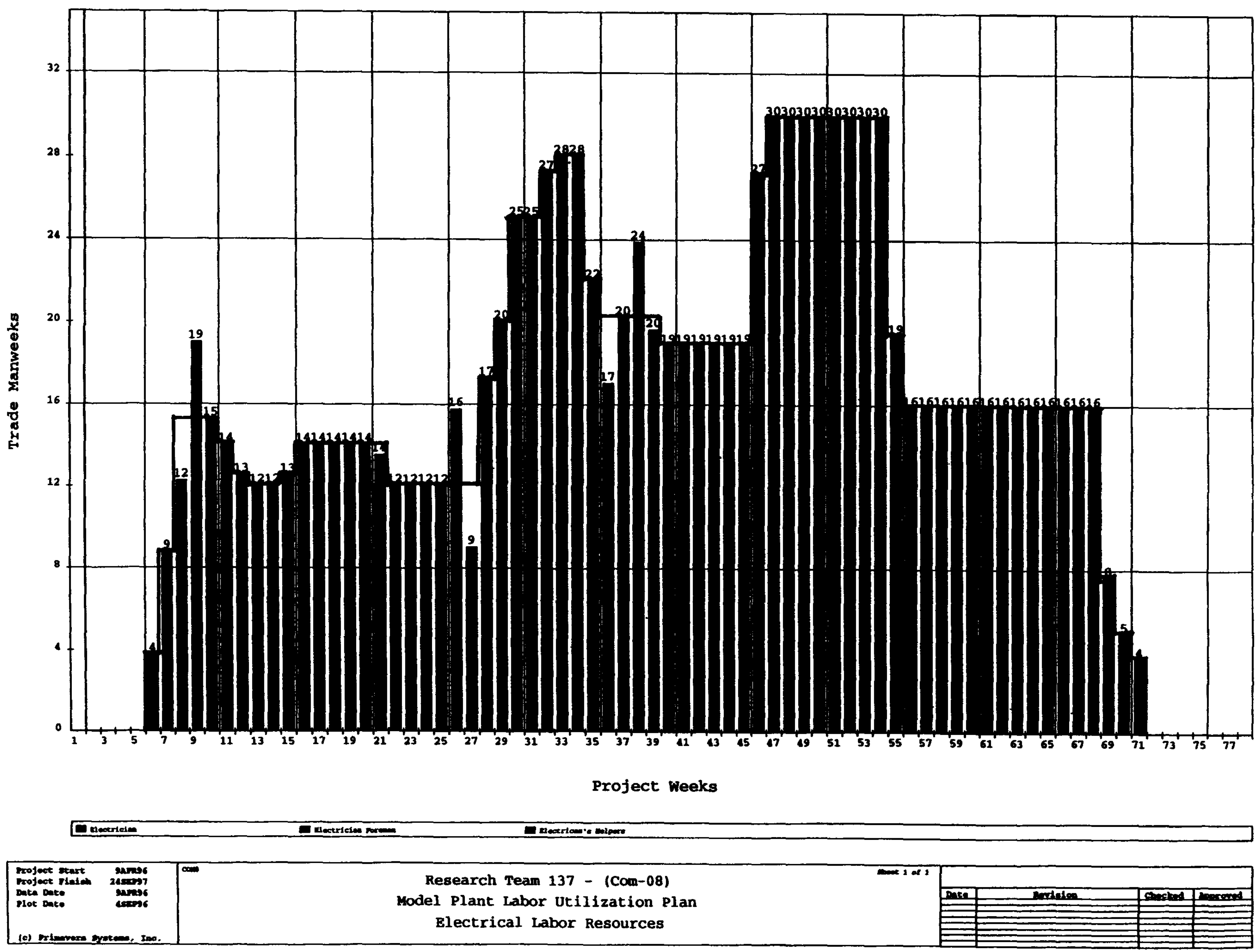

FIG. 1. Sample Resource Curve

TABLE 1. Summary Data for Baseline Staffing Plan

Craft classification (1)	Peak craft usage (2)	Average use for active period (3)
Carpenter	52	23
Concrete finisher	10	7
Crane operator	16	14
Electrician	30	18
Equipment operator	35	13
General laborer	39	12
Instrumentation worker	10	4
Insulator	27	15
Iron worker	34	14
Millwright	35	16
Painter	25	24
Pipe fitter	60	35
Rigger	13	6
Structural steel erector	15	10
Surveyor	11	6
Truck driver	14	6
Welder	60	27

TABLE 2. Summary Data for Dualskill Labor Strategy

Craft classification (1)	Peak craft usage (2)	Average use for active period (3)
Welder/general laborer	69	34
Electrical/insulation worker	43	24
Rigger/equipment operator	36	18
Carpenter/pipe worker	85	53
Surveyor/instrumentation worker	12	7
Iron worker/structural steel erector	46	19
Truck driver/crane operator/painter	35	19
Concrete finisher/millwright	41	15

for total contractor-initiated hires, average employment duration, and employment distribution were developed for each of the alternative strategies. Each multiskilling strategy is described here, and a summary presentation of multiskill craft resource utilization is provided.

Dualskill Labor Strategy

The "dualskill strategy" was developed as an extension of the traditional wave theory of project scheduling. "As a schedule is developed, the goal is to get the crews to come to the job, work continuously with maximum productivity until their work is complete and then move on to the next job" (Coombes 1990). From this description, it is clear that current labor strategies attempt to minimize disruptions while working within existing craft structures. The demand-driven dualskill strategy extends the wave theory to identify craft combinations with complimentary work loads so that workers arrive on the project and remain longer by working on multiple tasks before demobilizing. An example is an iron worker who remains on the job as a painter.

To identify the best dualskill combinations, baseline craft curves were matched together to create more stable (longer and flatter) curves. Craft identifiers were ignored so that no consideration would be given to how likely the combinations were to occur or the similarity of the crafts. Only the number of workers needed and the timing of the need were taken into consideration in the matching process. Note that this multiskilling strategy is a project specific solution. Table 2 shows a summary of the dualskill definitions and craft use patterns.

It is noted that some dualskill combinations are feasible while others appear to have no practical application. It is believed that baseline crafts that do not compliment any other craft group reflect crafts that would most likely remain single-skilled or may become subcontracted crafts in this labor utilization strategy. All dualskill combinations, however, were used in the analysis and were treated as direct hire labor for the purpose of comparative analysis.

Four Skills Labor Strategy

The "four skills" strategy was developed through discussions with the industry members of the research team. These individuals proposed that craft workers could be grouped into four general craft classifications that reflect the major phases of a project and, perhaps, also reflect varying skill complexity and craft similarities as well. The four skills craft groupings include civil/structural workers, general support workers, mechanical workers, and electrical workers. All craft workers in each original craft included in the baseline strategy were assigned to one of these four groupings. This approach is similar to some international construction labor strategies that identify only three craft groups: architectural, mechanical, and electrical (Burleson 1997). Table 3 provides a summary of the four skills definitions and craft use patterns.

Four Skills-Helpers Labor Strategy

The "four skills-helpers" strategy is a modification to the craft classifications defined in the four skills labor strategy. Each original craft group in the baseline strategy was composed of workers from three skill levels: novice/helper, journeyman, and foreman. To construct the four skills-helpers craft groupings, the helper level skill category was removed from the originating craft classification and added to the general support multiskill craft group. All helper level workers, regardless of originating craft discipline, are included in the general support grouping.

The theoretical basis for this strategy is twofold. First, a low skilled worker in any craft has very similar duties and is not solely responsible for any craft specific task. Therefore, these helpers could be used flexibly across the project without requiring significant additional training. Second, this strategy may have significant benefits during the implementation of a multiskilling strategy. Because new recruits will be assigned

TABLE 3. Summary Data for Four Skills Strategy

Craft classification (1)	Peak craft usage (2)	Average use for active period (3)
Civil/structural—carpenter, iron worker, concrete finisher, structural steel erector	99	37
General support—laborer, equipment operator, truck driver, crane operator, rigger, surveyor, painter	85	43
Mechanical—insulation worker, millwright, pipe worker, welder	132	67
Electrical—electrician, instrumentation worker	35	20

TABLE 4. Summary Data for Four Skills-Helper Strategy

Craft classification (1)	Peak craft usage (2)	Average use for active period (3)
Civil/structural—carpenter, iron worker, concrete finisher, structural steel erector	64	22
General support—all helpers, laborer, equipment operator, truck driver, crane operator, rigger, surveyor, painter	167	87
Mechanical—insulation worker, millwright, pipe worker, welder	81	43
Electrical—electrician, instrumentation worker	23	13

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TABLE 5. Summary Data for Theoretical Maximum Strategy

Craft classification (1)	Peak craft usage (2)	Average use for active period (3)
Construction worker—carpenter, iron worker, concrete finisher, structural steel erector, laborer, equipment operator, truck driver, crane operator, rigger, surveyor, painter, insulation worker, millwright, pipe worker, welder, electrician, instrumentation worker	296	160

TABLE 6. Summary of Comparative Data for All Utilization Strategies

Utilization strategy (1)	Craft hires (2)	Average employment duration (weeks) (3)
Baseline	675	18.6
Dualskill	555	22
Four crafts	508	23.9
Four crafts-helper	436	27.4
Theoretical maximum	366	33

as a helper to many craft workers during their first years, they will have the opportunity to observe each craft. When these helpers are ready for more detailed skill training, they can make informed choices of craft discipline(s) based on personal experience. Table 4 provides summary definitions of the four skills-helpers definitions and craft use patterns.

Theoretical Maximum Labor Strategy

The final strategy evaluated in this study is a "theoretical maximum" multiskilling strategy. This strategy assumes that there is only one craft classification for the construction industry—"construction worker." In theory, all construction workers are fully multiskilled and could be used flexibly across any task in the project. Varying levels of skill acquisition are still recognized within this multiskilled craft grouping. Functionally, this labor strategy identifies a maximum to the benefits of multiskill craft utilization that are quantified in this study. Development of a fully multiskilled workforce is probably not pragmatic or economically efficient. However, the theoretical maximum strategy provides a relative measure of the benefits achieved by each of the other multiskilling strategies. It provides, in essence, an upper bound. Table 5 summarizes the theoretical maximum craft use pattern.

Summary of Alternative Labor Strategies

Each of the four multiskilling strategies yielded different values for three key measures: (1) total number of hires; (2) average employment duration; and (3) employment duration distribution. These values are input variables for the economic model, which is described in the following sections. For each utilization strategy, total number of hires can be calculated from the y-axis of the resource curves while average employment duration and the employment duration distribution may be calculated from the x-axis (Fig. 1). Table 6 summarizes the key values calculated from the craft resource curves for each of the multiskilling strategies. It is clear that flexible skill use reduces hires and increases employment duration. Fig. 2 illustrates the shifts in the distribution curve of employment duration for workers in each of the utilization strategies evaluated in this study. The four graphs, from top to bottom, are the baseline, dualskill, and four skill-helper strategies' employment duration distributions. These graphs document the number of employees (y-axis) employed on the project for varying durations of consecutive weeks (x-axis). It is clear that flexible skill utilization strategy not only increase the average employment duration (vertical indicator), but that "long term" employees and "short term" employees become more distinct.

ECONOMIC BENEFIT MODEL

To quantify the potential benefits of using a multiskilled labor strategy in construction, a model equation that includes hiring costs, direct wages, and many indirect labor costs was developed. Based on the literature review and anecdotal evidence from the existing construction applications, it is believed that the primary benefits of multiskilled labor utilization will be seen in a reduction of total project labor cost. To make the model an effective evaluation tool, it was designed to produce values that can be compared across any multiskilling strategy as well as back to original company data or industry standards.

The economic benefit model was developed as a mathematical calculation of the difference between total project labor costs for any two labor strategies. Nine cost terms were identified, independently calculated, and then added to produce total project labor costs. Calculation methods for cost terms in the model were formulated by researchers using input values that were obtained from company specific records, project specific data, or published industry standards. Each calculation and all values used in the model plant analysis were validated by the industry participants as representative of industry practices and true costs.

A graphic representation of the economic model that identifies key input data and all cost terms of the total cost function is provided in Fig. 3. To calculate the estimated labor cost savings of a given multiskilling strategy, the cost model must be calculated for the baseline utilization plan and each multiskilling strategy considered in the analysis. The variables used in the cost equation showing the values assigned for the model plant analysis are provided in Table 7. A brief explanation of the calculations for each cost term in the equation is provided in the following paragraphs.

Direct Wages Cost Term

The direct project wage term is a function of total project work hours and the average wage of craft workers. Total project work hours for the CII Model Plant is 484,280. The "average project wage" for this analysis is $12.97, which is based on a weighted average of the crafts used in the model plant. Current wage data were gathered from research team members in Houston, Tex., the theoretical location of the model plant.

Recruiting and Screening Cost Term

The cost of recruiting and screening is applied to all hires and attempted hires. This includes contractor initiated hires, as counted from the resource curves, and replacement workers for voluntary quits. Voluntary turnover rate for this analysis is assumed to be 15%. Based on data provided by the research team, a per hire cost of $300 is used. A 5% rejection rate has been assumed in the model. Recruiting and screening costs may include application, interview, reference checks, physicals, respirator tests, drug screening, skill or performance testing, lead level testing, hearing loss tests, asbestos exposure tests, and the ancillary costs of administering any of these items.

Employee Orientation Cost Term

Employee orientation costs are calculated based on the total number of hours spent in any form of company or project specific orientation. Only the direct wages of the new employee and a minimal materials expense are included in this

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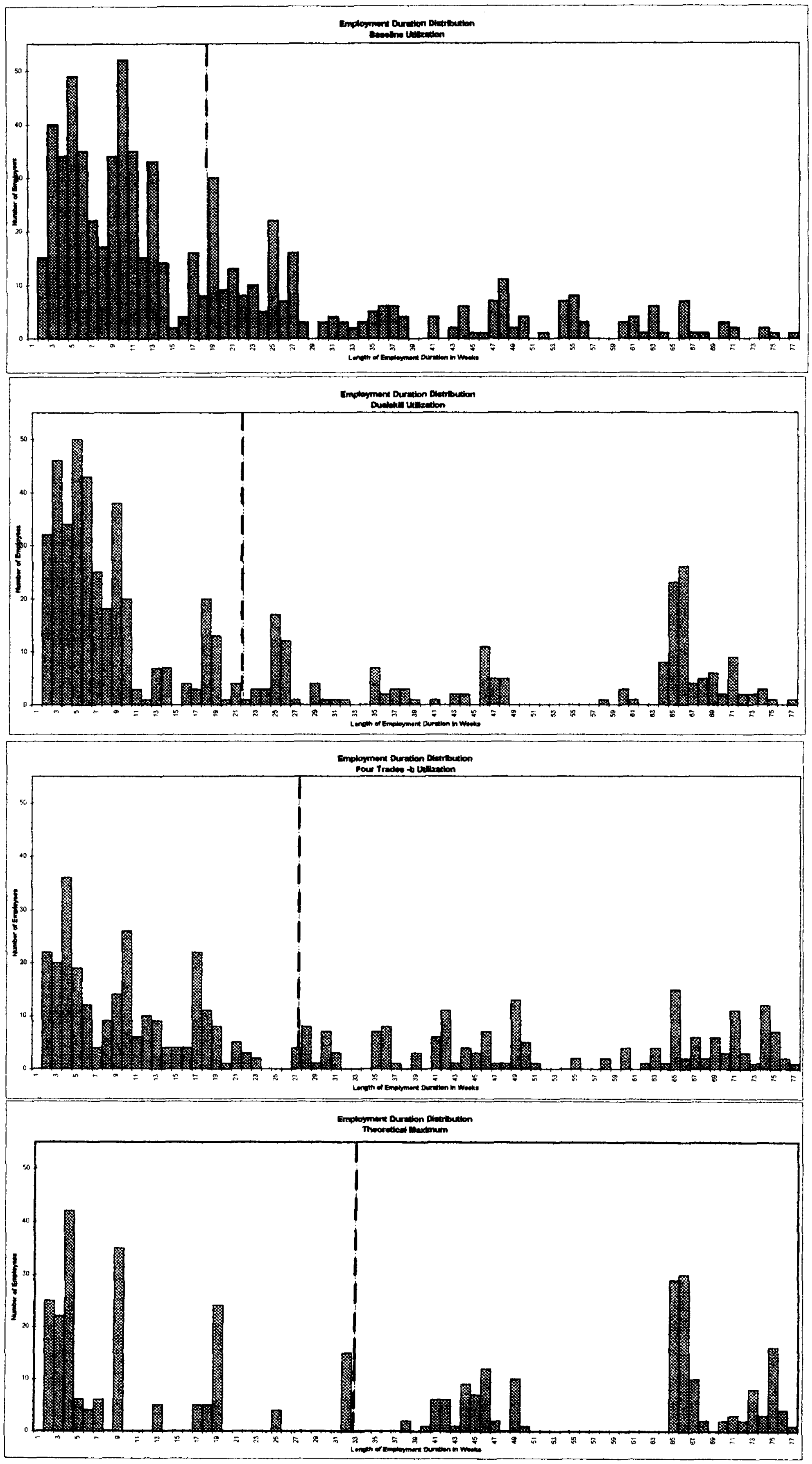

FIG. 2. Comparison of Employment Duration Distributions

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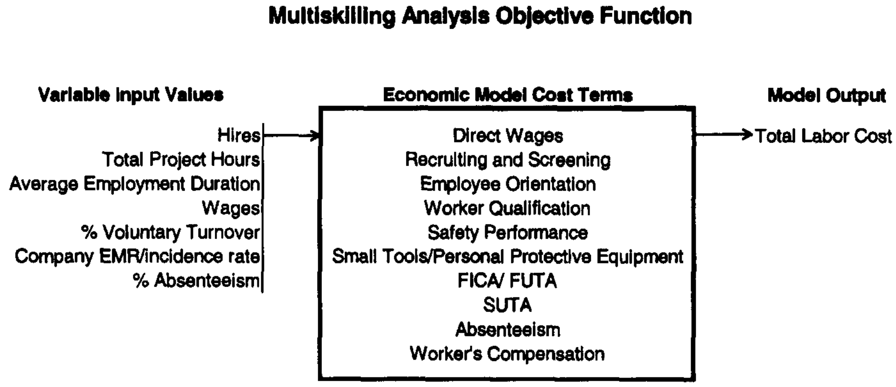

FIG. 3. Graphic Representation of Cost Model

TABLE 7. Variables in Cost Model

Description (1)	Value (2)
Total project hours	484,289
Average accident cost	$21,133
Company incidence rating	2.66
Voluntary turnover rate	0.15
Percent absenteeism expected (as a decimal)	0.02
Recruiting and screening costs	$300
Qualification costs for employees (safety)	$25
Percent of hires who must attend safety class	0.5
Number of welders from craft curves	71
Hours spent to qualify welders	4
Percent of welders rejected	0.15
Qualification costs for welder employees	$125
Cost of small tools and personal protective equipment	$586
Hours for employer qualification requirements	8
Experience modification rate	0.7
FICA rate	0.0765
FUTA rate	0.062
Maximum taxable wages for FUTA calculation	$7,000
Maximum taxable wages for SUI calculation	$9,000
SUI rate	0.027
Weighted average of project wages	$12.97
Orientation costs	$108.76

cost term. The model plant analysis includes 8 h or orientation and/or reduced productivity hours due to orientation and a $5 material expense.

Worker Qualification Cost Term

The worker qualification cost term identifies costs that arise from skill certification testing that may be owner initiated or from state/local regulatory requirements. Two such requirements are typical of the Houston area petrochemical construction sector. First, all individuals at the project site must have completed the Houston Area Contractor's Safety Council training and examination. It is estimated that half of all hires will require this course. The per student cost of this certification is $25. Additionally, it is estimated that half of the welders hired will require testing. The per welder cost for each test is $125. If the analysis project does not require any certification expenses or it is company policy not to pay for these items, the cost term could be entered as zero.

Safety Performance Cost Term

The safety performance cost term is based on a company and project specific estimation of the likelihood of an accident. This expected occurrence value can then be modified by a risk reduction factor based on the workforce distribution of employment duration. The distribution of employment duration varies from labor strategy to labor strategy and therefore is used to modify the project and company expected occurrence. Average accident cost data are used to place a monetary value on the safety performance cost term.

A company provided incidence rating, and the total number of project workhours are used to calculate the expected number of accidents during the course of the project. For the model plant analysis, the CII member incidence rating of 2.66 was assumed. Average accident costs, as reported in a 1991 research study, are valued at $21,133 (Hinze 1991). A risk reduction factor based on total workforce risk is calculated for each multiskilled labor strategy. The employment duration distribution of each strategy is used in conjunction with a lookup table constructed from a Department of Labor curve entitled Distribution of Injuries and Illnesses by Length of Service (US DOL 1988).

Small Tools and Personal Protective Equipment (PPE) Cost Term

The cost of tools and personal equipment is a function of the number of hires required to complete a project. Each employee is provided minimum personal protective equipment, often furnished by the employer, including hardhats, gloves, ear plugs, safety harnesses, goggles, etc. Additionally, a cost is incurred for the loss/replacement of company owned small tools used on the job. These tools often get stolen, lost, or destroyed by employees and therefore also vary based on hires. This analysis assumes a $500/hire cost for small tools and $86/person for initial PPE outfitting based on company data provided by industry participants.

FICA and FUTA Cost Terms

The Federal Insurance Contribution Act (FICA) and the Federal Unemployment Tax (FUTA) costs were calculated based on the 1996 modifications to the FICA. The maximum annual income subjected to social security tax is $62,700. In addition, the first $7,000 of wages paid to each employee is subject to FUTA. A break-even number of weeks was calculated for FUTA and FICA using the average model plant wage to determine tax liability. Based on the break-even calculation for FICA, all direct wages were subject to the FICA. To calculate the FUTA liability, the $7,000 base was applied to all employees that were expected to work 13 weeks or more, the cut-off duration for maximum taxable earnings. Using the employment duration distribution, those employees who worked <13 weeks were charged proportionately less FUTA tax ("Tax" 1996).

SUTA Cost Term

The maximum tax liability base for state unemployment tax (SUTA) in Texas is $9,000. A break-even or cut-off value calculated to determine this tax liability. The cut-off value for the

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model plant is 18 weeks. A proportionately lower SUTA tax was paid for those employees working <18 weeks. Most state unemployment rates vary based on individual company experience. For the model plant analysis, the Texas employer entry rate of 2.7% has been charged. It is clear that as the average employment duration of the workforce increases, overall employment taxes paid by the contractor, and ultimately the owner, will decrease.

Absenteeism Cost Term

The cost of absenteeism is a well-documented labor cost. Based on data provided by research team members, a simplified calculation has been developed. Most contractors indicated that they "carry" an additional 2% of workers to accommodate absent employees without disrupting the flow of work. Each cost term associated with recruiting/screening, hiring, orientation, or small tool/PPE costs is therefore increased by adding 2% to the required number of hires. No additional wages or wage premiums are calculated because the wages paid to the additional workers are offset by wages not paid to the original employee.

Worker's Compensation Cost Term

Worker's Compensation Insurance is calculated at a unique rate based on the worker's craft classification and past company safety performance. An average industry contribution rate, 24.7%, has been used in the model plant analysis. To reflect the premium savings due to the better than average safety performance of most industrial contractors, an experience modification rate of 0.7 was used.

Summary Model Calculations

The complete calculation of total project labor cost is at the end of this section. Abbreviations for model constants and variables, assigned in Table 7, are used in the equation. A key variable in the equation is the "productivity improvement factor" (PIF). This variable is used to estimate the probable performance improvement of multiskilled workers. It estimates work output benefits stemming from reduced wait time on other crafts, increased job familiarity, reduced mobilization/demobilization of crews, reduced rework from coordination errors, etc. Multiskilling benefits in the model plant analysis were calculated assuming a 0 and 15% PIF.

Project wages	(1 − PIF) × TPH × Wage
Recruit and screening	Hires × (1 + a + turn) × RSC
Orientation	Hires × (1 + a + turn) × OC
Qualification	{Hires × (1 + a + turn) × b × QC} + {.5W × QCW (1 + Wreject) + .5W × QHW × Wage
Safety performance	AAC × IR × (TPH/200,000) × (1 − SRF) × (1 − PIF)
Small tools and PPE	Hires (1 × a × turn) × STC × PPEC
FICA/FUTA	{FICA rate × TPH × Wage × (1 − PIF)} + {FUTA rate × Max Tax × Hires > 12 weeks + FUTA rate × Max Tax × ($Hires_i$ × $Weeks_i$)/13
SUTA	SUTA rate × Max Tax × Hires > 18 weeks + SUTA rate × Max Tax × ($Hires_i$ × $Weeks_i$)/18
Worker's compensation	TPH × Wage × (1 − PIF) × WC × EMR
	Total Project Labor Cost

RESEARCH RESULTS AND ANALYSIS

Each multiskilling strategy was evaluated using the previously described "total project labor cost" model. Initially, all calculations were conducted assuming a 0% productivity improvement factor. By performing the multiskilling benefit comparisons this way, the labor related cost savings solely associated with the more stable use of jobsite personnel was isolated. Finally, a second comparative analysis of each labor strategy was performed assuming a 15% productivity increase. This increase was chosen as a conservative estimate of improved productivity performance based on the results of the literature review and reported productivity increases by construction users. Based on the CII Model Plant project, significant potential benefits of multiskilled labor utilization were demonstrated using both productivity improvement factors.

Measurable project labor cost savings were demonstrated using the cost model and the assumption of 0% productivity improvement. The dualskill utilization strategy demonstrated the least labor cost savings in this analysis. Total labor cost savings from the dualskill approach were $260,187 or a 3% reduction from the baseline project labor costs. The most successful multiskilling strategy in this analysis was the four skills-helpers approach. This strategy produced total labor cost savings of $432,036 or a 5% reduction from the baseline labor costs. It is noted that the four skills-helpers strategy captured 75% of the potential savings indicated by the theoretical maximum.

Significant project labor cost savings were also demonstrated using the cost model and an assumption of a 15% productivity increase due to the utilization of multiskilled craft workers. Again, the dualskill strategy exhibited the lowest total labor cost savings, a 17% reduction equal to $1,578,218. The most successful strategy was still the four skills-helpers approach. This strategy produced total labor savings of $1,725,184 or a 19% reduction in total project labor costs. The analysis using a 15% productivity estimate shows that the four skills-helper labor strategy captures 94% of the potential savings indicated by the theoretical maximum. Tables 8 and 9 detail the project labor cost savings for the model plant analysis assuming a 0 and 15% reduction, respectively.

Additionally, a significant reduction in required workforce was documented in each of the multiskilling approaches. This reduction varied from a low of 18% in the dualskill to 35% in the four skills-helpers strategy (Table 6). The reduction of total workers coming onto the jobsite was a factor in the reduction of many of the cost terms. This phenomenon also has implications for perceived craft labor shortages throughout the industry. By using existing worker skills more efficiently, the demand for additional craft entrants may be lessened. It is also believed that the industry may hold greater appeal to potential recruits because of the development of career-type employment and skill enhancement opportunities afforded by multiskilled labor strategies.

The model plant analysis also demonstrated a significant increase in average employment duration of craft workers at the project site. This increase varied from a low of 18% using the dualskill strategy to a 47% increase provided by the four skills-helper strategy. It is clear that multiskilled craft workers are the direct recipients of longer and more stable employment opportunities. An inferred benefit of increased annual employment is also indicated. Because workers are trained to perform multiple tasks, they can be effectively utilized through many phases of each project. This leads to less "time off" which is normally spent seeking employment in their primary craft. Employers also have an economic interest in retaining their multiskilled workers from project to project. The combination of these factors is likely to ensure full annual employment and therefore earnings potential.

Finally, a review of multiskilling theories, based primarily on manufacturing applications, also indicates that multiskilling strategies may provide increased opportunities for the devel-

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TABLE 8. Results from 0% PIF

Cost term (1)	Labor Strategy: Baseline (dollars) (2)	Dualskill (dollars) (3)	Four skills (dollars) (4)	Four skills-helper (dollars) (5)	Theoretical optimum (dollars) (6)
Total project wages	6,281,112	6,281,112	6,281,112	6,281,112	6,281,112
Project safety	136,116	112,976	109,301	106,171	88,203
Orientation costs	85,893	70,623	64,643	55,481	46,573
Recruiting/screening	236,925	194,805	178,308	153,036	128,466
Qualification costs	16,817	15,062	14,374	13,321	12,298
Small tools and PPE	462,794	380,519	348,295	298,930	250,937
Worker's compensation	1,086,004	1,086,004	1,086,004	1,086,004	1,086,004
FICA/FUTA	717,169	648,163	653,304	630,502	603,527
SUI/SUTA	108,527	81,905	84,294	74,763	63,653
Total project labor cost	9,131,357	8,871,169	8,819,635	8,699,320	8,560,773
Total cost savings (%)	0.0	2.8	3.4	4.7	6.2

TABLE 9. Results from 15% PIF

Cost term (1)	Labor Strategy: Baseline (dollars) (2)	Dualskill (dollars) (3)	Four skills (dollars) (4)	Four skills-helper (dollars) (5)	Theoretical optimum (dollars) (6)
Total project wages	6,281,112	5,338,945	5,338,945	5,338,945	5,338,945
Project safety	136,116	96,030	92,906	90,245	74,973
Orientation costs	85,893	60,062	54,972	47,209	39,702
Recruiting/screening	236,925	165,672	151,632	130,221	109,512
Qualification costs	16,817	12,870	12,285	11,393	10,530
Small tools and PPE	462,794	323,613	296,188	254,365	213,913
Worker's compensation	1,086,004	923,104	923,104	923,104	923,104
FICA/FUTA	717,169	550,938	555,308	535,927	512,998
SUI/SUTA	108,527	81,905	84,294	74,763	63,653
Total project labor cost	9,131,357	7,553,139	7,509,634	7,406,172	7,287,330
Total cost savings (%)	0.0	17.3	17.8	18.9	20.2

opment of process innovations and technology implementation (Tatum 1989; Nonaka 1990; Ettlie and Rezo 1992; Carmichael and McLeod 1993). It is believed that multiskilled labor strategies may provide a "quantum leap" in construction labor utilization that leads to many other industry advancements yet to be seen.

Potential Impediments

While the potential benefits of multiskilled labor utilization strategies are many, there are perceived barriers to implementation that warrant discussion. First, a workforce "paradigm shift" is required throughout the industry. To utilize a multiskilled labor strategy, employers must alter their screening and hiring practices, compensation practices, staffing practices, and project management practices. In some sectors, owner practices that are designed around traditional craft definitions will have to be modified to fully utilize a multiskilling labor strategy (i.e., owner procurement packages, specification of number and types of craft workers, work reimbursement issues, etc.)

The availability of training and nationally standardized training curriculums is an issue that will impact the uniform application of multiskilling strategies. However, in manufacturing settings, the use of "uniform" multiskilling strategies is not common. Multiskill combinations are chosen and utilization strategies are typically designed to provide a "proprietary" competitive advantage to the employer company. It is unclear at this time whether unique company-based strategies or industry-wide multiskilling strategies provide the most economic benefit in construction.

Initial resistance to broad changes in construction labor strategies is likely to be experienced; however, survey data indicate that individual worker resistance may be very low and that managerial resistance can be reduced with good implementation training (Stanley 1997; Villalobo 1997). There is also likely to be varying levels of implementation difficulty experienced between maintenance construction and new construction applications. More flexible systems will be needed to manage a multiskilled workforce in nonmaintenance construction sectors. More in-depth research into these issues is needed before any definitive recommendations can be made.

RECOMMENDATIONS

Using the CII Model Plant as a basis for a benefit analysis, this research provided an exploratory investigation into the use of multiskilled labor utilization strategies in construction. Potential benefits have been demonstrated with regard to total project labor cost, employment opportunities for construction craft workers, and industry-wide labor issues. The most promising strategy included in this analysis was the four skills-helpers strategy that divided all craft workers into four broad categories and treated all "helpers" as a part of general project support category. The helpers were then used flexibly to support any skilled craft work throughout the project duration. The demonstrated potential benefits of multiskilled labor strategies included an estimated 35% reduction in required project workforce, a 47% increase in average employment duration, and between 5 and 20% reduction in total project labor costs. Additional benefits such as increased earning potential for multiskilled workers, improved jobsite safety environment, and increased opportunities for process innovation and technology implementation are also indicated.

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A project level analysis method was also defined as part of this research. This process combined widely accepted project management tools such as quantity and work-hour estimates, resource-loaded project schedules, and cost estimating to develop an estimated total project labor cost savings. This analysis process may be used by other researchers or construction companies to experiment with alternative labor strategies. In summary, multiskilled labor utilization strategies in construction may provide significant company and project performance improvements. Additional research, experimentation, and industry development is warranted in this area.

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APPENDIX. REFERENCES

Burleson, R. C. (1997). "An analysis of multiskilled labor strategies in construction," PhD thesis, Univ. of Texas at Austin, Austin, Tex.

Carmichael, L. H., and MacLeod, B. (1993). "Multiskilling, technical change and the Japanese construction firm." *Economic J.*, 103(416), 142–160.

Cass, D. J. (1992). "Labor productivity impact of varying crew levels." Trans. Amer. Assn. Cost Engrs., AACE, Morgantown, W.Va., C2.1–C2.9.

Clough, R. H., and Sears, G. (1994). *Construction contracting*, 6th Ed., John Wiley & Sons, Inc., New York.

Coombes, J. (1990). *Real world construction scheduling*. Frontier Publishing, Seattle, Wash.

Cross, M. (1996). "Multiskilling brings cost and productivity benefits." *Process Engrg.*, July.

Ettlie, J. E., and Rezo, E. M. (1992). "Organization integration and process innovation." *Acad. Mgmt. J.*, 35, 795–827.

Halpin, D. W. (1992). *Planning and Analysis of Construction Operations*, John Wiley & Sons, New York, 68–96.

Hinze, J. (1991). "Indirect costs of construction accidents." *Source Document 67*, Constr. Industry Inst., Austin, Tex.

Krizan, W. (1996). "Labor: Stability survives hiring boom." *Engrg. News Rec.*, 234(37), 35.

Livesay, H. C. (1996). "Human factors in the innovation process." *Technovations*, 16(4), 173–186.

Nallikari, M. (1995). "Multiskilled work teams." *J. Ship Production*, 11(4), 239–244.

Nonaka, I. (1990). "Redundant, overlapping, organizations: A Japanese approach to managing the innovation process." *Calif. Mgmt. Rev.*, 32, 27–28.

Park, K. S. (1996). "Economic growth and multiskilled workers in manufacturing." *J. Labor Econ.*, 14(2), 254–285.

"Skills based pay and multiskilling." (1996). *IRS Employment Rev.*, 605, S5–S8.

Stanley, A. (1997). "Benefits, impediments, and limitations associated with the use of multiskilled labor strategies in construction," MS thesis, Univ. of Texas at Austin, Austin, Tex.

Tatum, D. J. (1989). "Organizing to increase innovation in construction firms." *J. Constr. Engrg. and Mgmt.*, ASCE, 115(4), 602–617.

"Tax Guide for Small Business." (1996). Dept. of Treasury Publ. 334, Internal Revenue Service, Washington, D.C.

Thomas, R. H. (1991). "Labor productivity and work sampling: The bottom line." *J. Constr. Engrg. and Mgmt.*, ASCE, 117(3), 423–444.

U.S. Department of Labor (U.S. DOL). (1988). "Distribution of injuries and illnesses by length of service."

Villalobos, J. (1997). "Implementation of multiskilling strategies in the construction industry," MS thesis, Univ. of Texas at Austin, Austin, Tex.