



THE EFFECTS OF CHANGES ON LABOR PRODUCTIVITY: WHY AND HOW MUCH

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**A Report to
The Construction Industry Institute
The University of Texas at Austin**

**Under the Guidance of the
Change Order Impacts Task Force**

from
**The Pennsylvania State University
University Park, Pennsylvania**

**SD-99
August 1994**

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Printed in the United States of America.

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EXECUTIVE SUMMARY

Changes and change orders are a source of concern to owners and contractors alike. Changes are an important contributor to cost overruns, schedule extensions, and contract acceleration. This report examines the quantitative effect of changes on labor productivity using productivity data from four active construction sites. In total, the database contains 151 weeks of data and shows a significant average loss of efficiency when performing changes work. Importantly, the report also investigates the reasons why there is a degradation of labor productivity. Understanding the causes is a prerequisite to formulating effective strategies for managing changes.

The report begins with a brief literature review on changes and change orders. It shows that there is little substantive information on the quantitative aspects of changes and that most articles seem directed more toward publicity and advertising. The activities of the Change Impact Task Force to categorize changes is also reviewed.

The analysis of the productivity data reveals that, on average, the efficiency when performing changes work is about 70 percent of normal, that is, there is a 30 percent loss of efficiency. Various statistical analyses are explained that validate this conclusion. The research also reveals that it is possible to perform changes work without loss of efficiency. About a third of the days when changes work was done show no loss of efficiency.

Additional analyses support the conclusion that changes negatively affect labor efficiency. First, it is shown that labor efficiency is negatively affected by disruptions to the work. Next, it is shown that when changes work is performed, there are more disruptions. The percentage of days when disruptions occur increase by about 50 percent when changes occur compared to normal days. The conclusion of this analysis is that disruptions are the proximate cause of loss of efficiency.

The reasons why there is loss of efficiency are investigated by examining the disruption by type. The data reveals that when changes work is performed, there is an increase in disruptions caused by the lack of availability of materials, tools, and equipment. The most significant increase, a four-fold increase, occurs in material deficiencies. There is also an increase in performing out-of-sequence work.

Based on this work, it is concluded that the principal factor leading to disruptions and loss of efficiency is timing. Late changes are particularly detrimental. If changes are identified early, before the work is given to the crafts, the effect of changes is probably minimal. However, if the crew, through their work, identifies the need for a change, then there is an adverse effect of having to stop and wait for information and materials. If the extent of the change cannot be resolved at that point in time, further negative effects will occur. The crew must move to another work location, one for which they may not have planned the work, and returning to the location of the change at some later time may require support services or outage permits. Thus, the early identification of the need for a change is an important element in cost-effective construction.

CHAPTER 1

INTRODUCTION

Changes during construction are a particularly irritating and costly problem for the contractor. It is recognized that some changes are necessary and inevitable. However, many argue that changes are time consuming and expensive compared to the cost of the original scope of work. Yet there is a serious lack of understanding about the impact of changes. To date, there have been no definitive studies reporting in quantitative terms the impact of changes.

OBJECTIVES

The objectives of this report are to:

- Quantify the impact of changes on field labor efficiency
- Determine the relationship between changes and various types of disruptions
- Establish why and to what extent changes affect labor efficiency
- Present a conceptual model for estimating the impact of a particular change on labor efficiency

SCOPE

The cost of changes is comprised of largely indirect, engineering, material, equipment, and labor costs. Of these, labor costs are the most difficult to estimate, control, and measure. Since workhours are directly related to labor costs, the impact of changes is measured by quantifying workhour inefficiencies at the crew level.

DEFINITIONS

In this report, the following definitions are used:

Changes--A reference to any change made to the original scope of work. No distinction is made regarding whether payment is promised or why the change was needed. There is no association in this report with construction disputes or claims.

Conversion Factors (CF)--The ratio of unit rates based on the earned value concept used to convert quantities of one or more items to an equivalent quantity of another single item.

Disruption--An event that is known or has been reported in the literature to adversely affect labor productivity. Examples include lack of materials, lack of tools or equipment, congestion, and accidents.

Disruption Factor (DF)--The ratio of the average daily number of non weather related disruptions during a baseline period divided by the average number of disruptions for a particular week. A number less than unity means more than the average number of disruptions.

Disruption Frequency--The average number of disruptions per 10-hour workday.

Disruption Index (DI)--The ratio of the performance factor on days when a certain type of disruption occurred divided by the average performance factor on days when no disruption occurred. The index shows the level to which output was reduced because of the particular type of disruption.

Earned Value--This technique is used for calculating the percent complete of a control account. It uses a weighted average approach in which the weight assigned to individual accounts in the control account is based on the initial workhour estimate for the account.

Efficiency--The relative loss of productivity compared to some baseline period. A value less than unity means a performance poorer than normal.

Performance Factor (PF)--The ratio of the expected or baseline unit rate divided by the actual unit rate. It is defined such that values greater than unity mean that performance is better than expected.

Performance Ratio (PR)--The inverse of the performance factor.

Productivity--This parameter is defined as the workhours during a specified time frame divided by the quantities installed during the same time frame. The time frame can be daily, weekly, or the entire project (cumulative). It is commonly called the *unit rate*.

Rework--A subset of changed work. It usually involves correction or removal of earlier work. The cause can be design or construction related and can be caused by poor workmanship, design errors, design changes, misreading of drawings, weather, fabrication errors, and so forth.

CHAPTER 2

BACKGROUND

There have been numerous articles written about changes and change orders. These are divided into the following categories: general articles, Construction Industry Institute (CII) Cost and Schedule Task Force reports, articles quantifying the effects of changes, a CII Changes Impact Task Force investigation of the influence on cost and schedule growth, and the CII Changes Impact Task Force investigation of the categories of changes and factors. These are described below.

GENERAL ARTICLES

Many articles have been written describing in general terms the effects of changes on labor productivity. Most deal with legal aspects, documentation, substantiation, and claims management. Many of the articles appear to have been written for promoting business interest. An article by Dellon and Dellon (1988) is typical. The basic causes of claims as listed by the authors are:

- Schedule variations
- Field conflicts
- Access delays
- Change orders
- Acceleration
- Work out of sequence
- Owner furnished equipment delay
- Owner furnished material delay

Dellon goes on to outline the owners and contractors position for damages by citing a laundry list of potential impacts. Steps of an action plan in the event of a claim and guidelines for support system for documentation are also included. The article concludes by

presenting a matrix that relates potential impacts to the eight basic causes. From looking at the matrix in figure 1, all eight causes (effects) can lead to each of the impact types. Therefore, the article is too general to be of much value in preventing claims. Its main contribution is the list of documents needed to support a claim.

Several articles describe resolution techniques (Yanoviak 1987). Most provide the author's perspective on negotiated settlements, arbitration, and litigation. The emphasis is on after-the-fact documentation and resolution techniques. Little guidance is provided for understanding or minimizing the impact of changes.

Substantiating cost is the subject of a paper by Dieterle and Maziarz (1991). A distinction is made between incurred cost and claimed cost. The author argues that much of the difference results from federal and state unemployment taxes, social security payments, and other elements of payroll burden.

The author also compares the Blue Book and CRG equipment rental rates, and shows that the monthly charges for the a D7G dozer and an Insley 600 excavator are considerably less when the CRG Ownership rate is used. The author then details parts of the Federal Acquisition Regulation (FAR). The focus of the paper seems to be on accounting procedures.

A University of Texas thesis sponsored by the Construction Education Institute provides a good general description of the influence of changes on cost (Brown 1988). A forward-change pricing concept is presented, and an influence diagram is developed. However, as is typical of most reports and articles, the diagram shows everything affecting everything else. The diagram is shown in figure 2. The concept of the ripple effect is also discussed.

CAUSE

IMPACT EFFECT	AREA ACCESS	OWNER FURNISHED MATERIAL DELAY	OWNER FURNISHED EQUIP. DELAY	SCHEDULE CHANGES
Stop Work	•	•	•	•
Redirect Crews	•	•	•	•
Replan Work	•	•	•	•
Schedule Impact	•	•	•	•
Manpower Fluctuations	•	•	•	•
Manpower Reduction	•	•	•	•
Added Coordination	•	•	•	•
Wage Escalation	•	•	•	•
Interference with Others	•	•	•	•
Work Flow Disruption	•	•	•	•
Inefficient Work Sequence	•	•	•	•
Inefficient Work Planning	•	•	•	•
Increased Overhead	•	•	•	•
Labor Problems	•	•	•	•
Equipment Handling	•	•	•	•
Material Handling	•	•	•	•

CAUSE

IMPACT EFFECT	ACCELERATION	WORK OUT OF SEQUENCE	MANAGEMENT INTERFERENCE	CHANGE ORDER PROCESSING
Redirect Crews	•	•	•	•
Replan Work	•	•	•	•
Interference with Others	•	•	•	•
Work Flow Disruptions	•	•	•	•
Turnover of Personnel	•	•	•	•
Added Coordination	•	•	•	•
Schedule Impact	•	•	•	•
Fluctuations in Manning	•	•	•	•
Compacted Work Areas	•	•	•	•
Reassignment of Personnel	•	•	•	•
Increased Supervision	•	•	•	•
Start/stop Work	•	•	•	•
Effect on other Work	•	•	•	•
Increased Tooling	•	•	•	•
Assignment to Task	•	•	•	•
Work Directions	•	•	•	•
Loss in Productivity	•	•	•	•
Estimating Proposal	•	•	•	•
Negotiations	•	•	•	•
Documentation	•	•	•	•

Figure 1. Cause Effect Matrix.

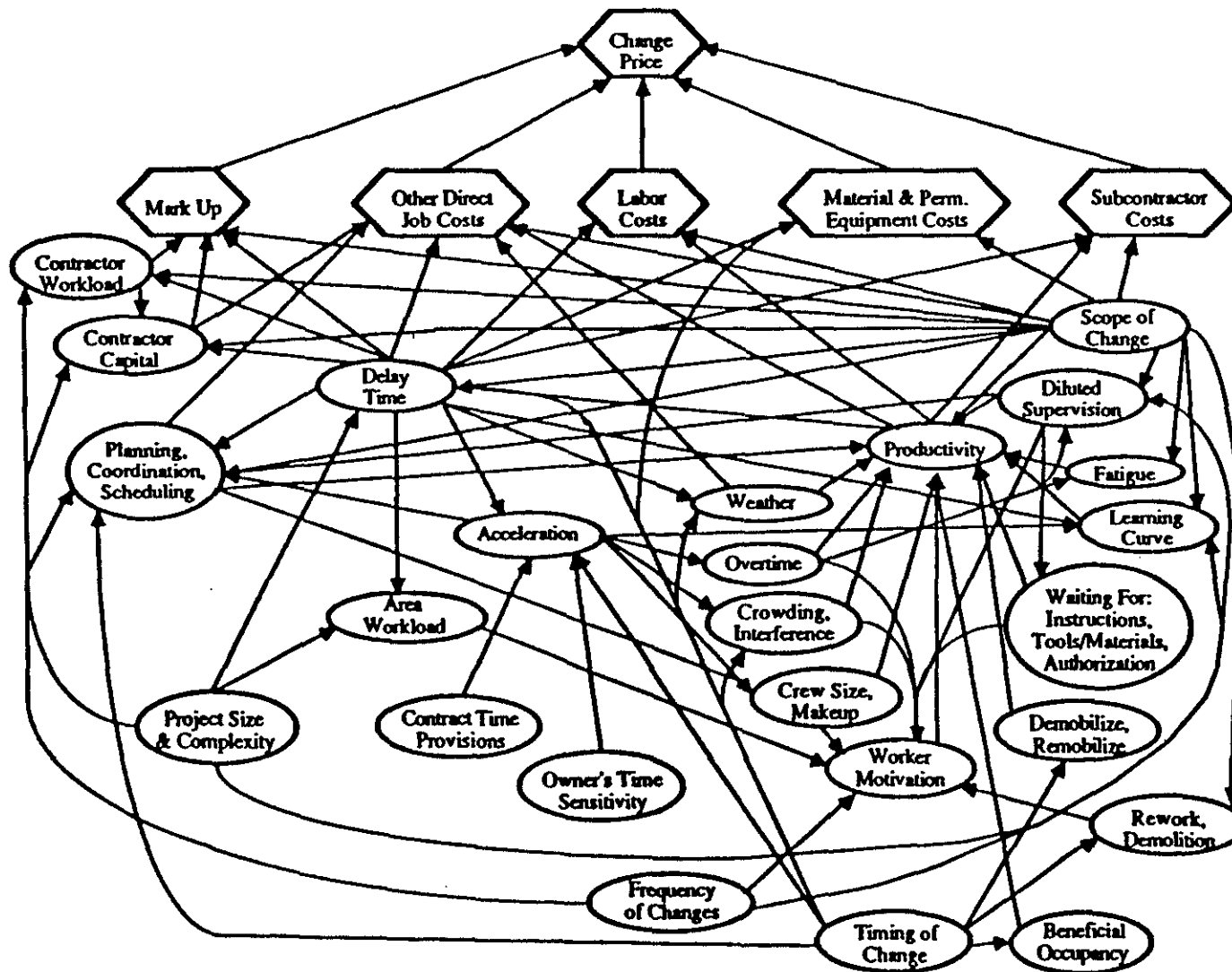


Figure 2. Change Price Influence Diagram.

CII COST AND SCHEDULE TASK FORCE REPORTS

The CII Cost and Schedule Task Force compiled a literature review of articles and reports describing changes and the development of management techniques related to changes (Hester et al. 1988). It contains a comprehensive bibliography.

The Task Force also prepared a report on the impact of changes on cost and schedule (Zietoun and Oberlender 1993). They concluded that changes were inevitable on all projects, but were most troublesome on fixed price or guaranteed maximum price contracts--therefore, the consequences need to be understood by the person directing the change. Recommendations for managing the changes process to minimize impacts were presented. This is one of the few sources of information directed toward prevention and minimization of the effects of changes.

QUANTIFICATION OF THE EFFECTS OF CHANGES

Very little information has been published on the quantification of the effects of changes. The two articles described below rely on data from contract claims and disputes.

Zink (1990) described a measured mile method (MMM), which is a method for establishing a baseline for quantification purposes. The focus of the paper is on labor efficiency. The author suggests that the MMM can be used to quantify workhour overruns of an unimpacted trend as a percentage of work completed in each labor division. The methodology relies on a workhour trend curve rather than a productivity trend curve. An example is given on how to assign responsibility for each significant event to a particular party.

Leonard (1987) described his quantification investigation of the effects of changes on labor productivity. The study was based on the detailed review of 90 claim cases, each from

a separate contract. The cases were divided into two groups: civil/architectural and mechanical/electrical. The major causes of labor overruns were:

- Loss of rhythm
- Schedule deterioration
- Unbalanced crews
- Acceleration
- Increased site administration
- Manpower fluctuation

Figures 3 and 4 show the percentage loss of productivity as a function of the percentage of change orders. The slope of the curves is much shallower than might be expected. A four- or five-fold increase in the percentage of changes leads to a 10 to 20 percent loss of productivity. Leonard also reported that as the hours spent on changes exceeded about 10 percent of the total hours, there was a noticeable departure in the curves of earned and actual hours. Although not stated, this may be caused by the ripple effect.

IMPACT ON COST AND SCHEDULE GROWTH

The CII Changes Impact Task Force investigated 106 projects to determine the factors impacting cost and schedule growth (Zietoun and Oberlender 1993). The data were sorted according to fixed-price and cost-reimbursable contracts. A number of factors were examined. Figures 5 and 6 show the relationship of money left on the table (MLOT) and the number of bidders to cost and schedule growth on fixed-price projects. On cost-reimbursable projects, three driving factors were studied: cost, schedule, and quality. Cost overruns were more acute when the primary driving factor was schedule. Schedule overruns were more frequent when the driving factor of cost was most dominant. The quality driving factor was not a major factor in either type of overrun.

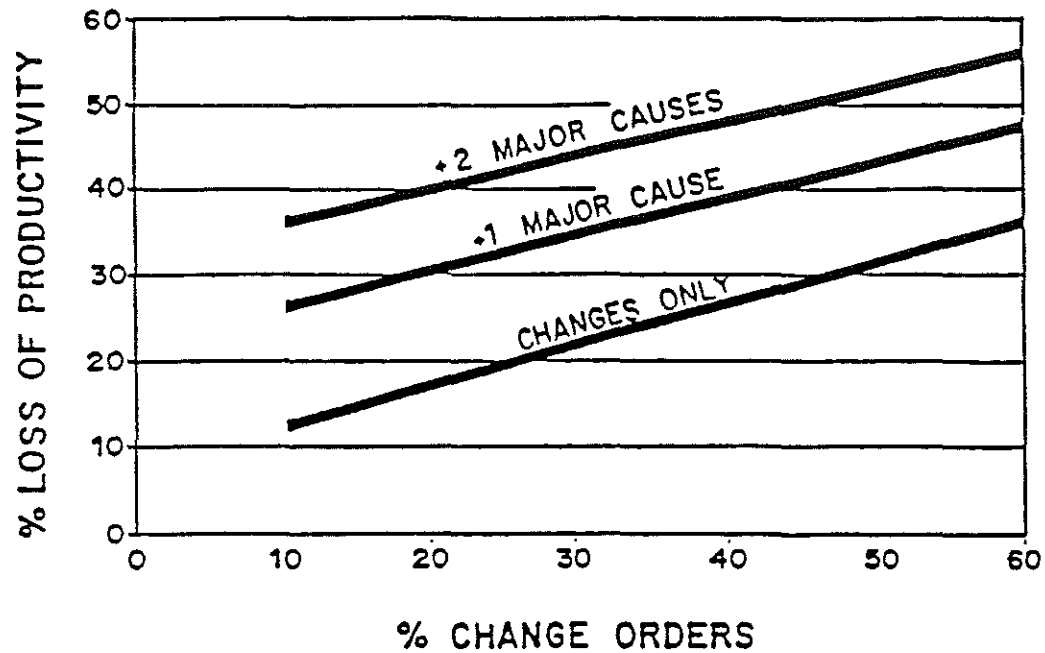


Figure 3. Electrical and Mechanical Work.

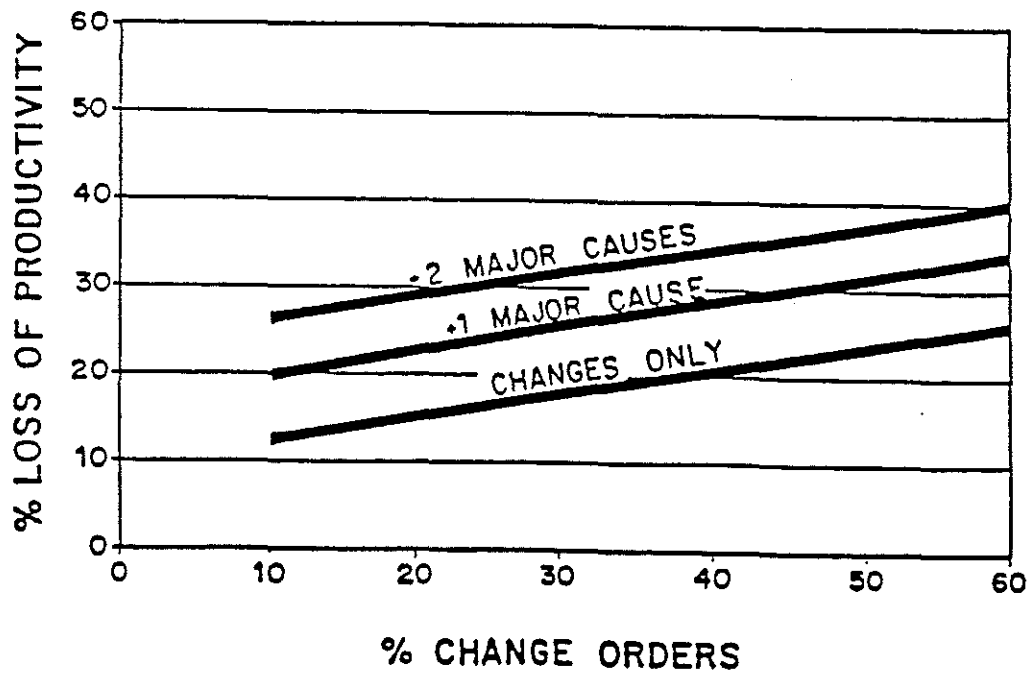
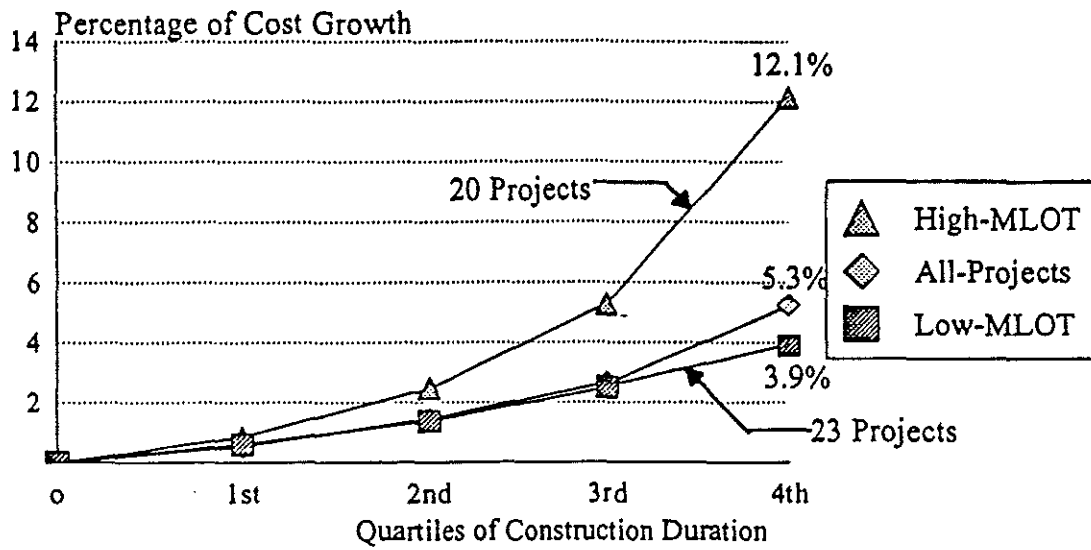


Figure 4. Civil and Architectural Work.



Cost Growth Trend Curves

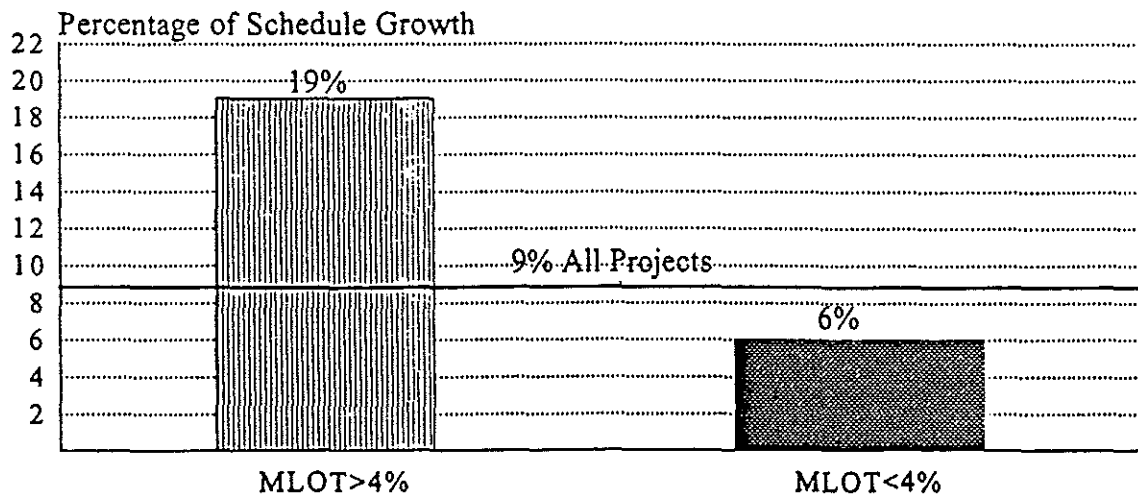
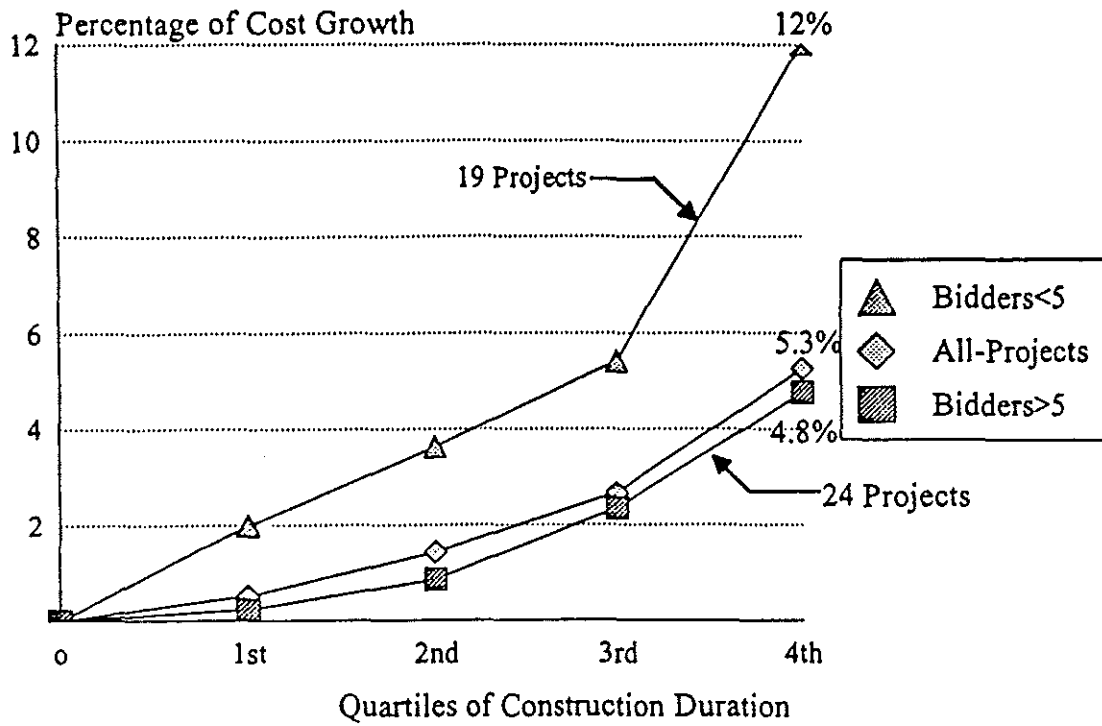
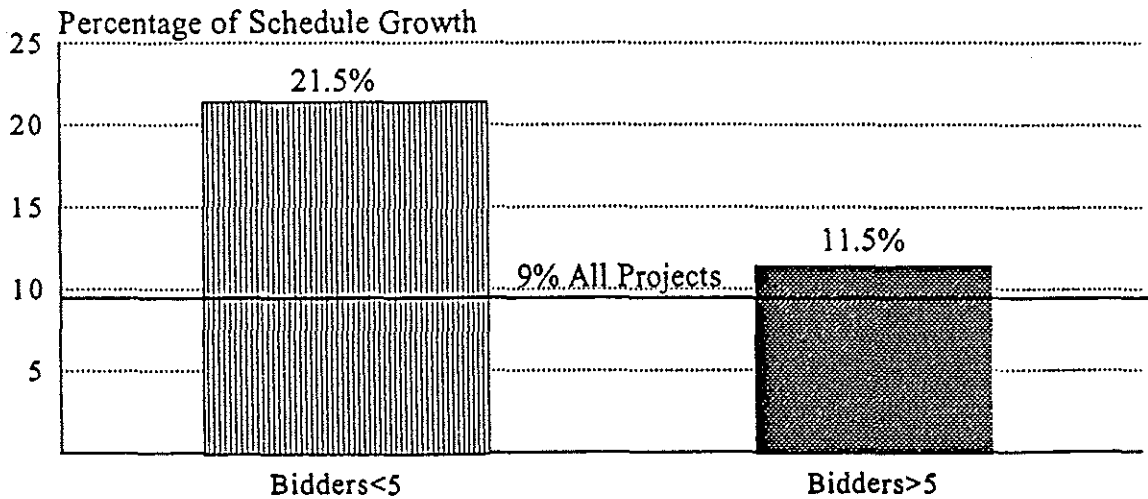


Figure 5. Money Left on the Table.



Cost Growth Trend Curves



Schedule Growth Trends

Figure 6. Number of Bidders.

CATEGORIES OF CHANGES

The Changes Impact Task Force recognized that there is much misinformation about individual changes. Many changes are necessary and some are not costly in terms of labor hours. The task force began by developing a matrix of types of changes and their usual origin. This matrix is shown in table 1. As can be seen, changes can originate from many sources.

The task force also examined how changes might be classified. A conceptual list included the following:

- Changes to process design
- Changes to plot plan and/or equipment arrangements
- Changes to the specification of equipment items
- Changes to the specification of bulk items such as instruments
- Operations-directed changes for operability and maintainability
- Value-engineering changes

The task force felt that changes classified in this manner would be too general and would not aid in understanding of control.

Other possible classifications were presented. These lists included criteria for classification and expected impacts. (See tables 2, 3, and 4.)

There is considerable similarity among the lists, reflecting commonality among practices. However, these classifications are reflective of the need for backcharging for changes and were likely developed for accounting purposes.

Table 1. Matrix of Types and Origins of Changes.

Types of Changes	Originating or Responsible Party				
	Outside	Engineer	Owner	Contractor	Vendor
Omissions		.			
Engineering Errors		.			
Design Changes		.			
Unforeseen Conditions	.				
Change in Work Sequence		.	.	.	
Schedule Change		.	.	.	
Specification Change		.			
Vendor Change		.			
Process Change		.	.		
Aesthetic Change			.		
Operations Directed Change			.		
Value Engineering		.		.	
Cost Reduction Change		.	.	.	
Constructability Change		.		.	
Intended Use Change		.	.		
Regulatory Change	.		.		
Concept Change		.	.		
Scope Change			.		
Design Evolution Change		.			
Design Coordination Change		.			
Safety/Insurance Change (Design)		.			
Change in Available Resources	.				
Force Majeure	.				
Mobilization Delay			.		
Quantity Change		.			
Code Change	.				
Material Availability	.				
Seasonal Work Change		.	.		
Accident-Change in Safety Approach (Construction)	.				
Work Rules (Labor)				.	
Work Rules (Operations)			.		
Failure to Perform (Owner-Engineer-Contractor-Vendor)		.	.	.	.
Late Issue of Design		.			
Late Receipt of Equipment		.	.	.	.
Change in Timing of Vendor Drawing Approval		.	.		
Late Procurement Activities		.	.	.	.
Change in Access to Work Area			.		
Change in Basic Data Requirements		.	.		
Change in Raw Materials			.		
As-builts Used for Design were Incorrect			.		
Change in Engineering Support to Construction		.			

Table 2. Change orders and criteria for classification.

Types of Change Orders

Criteria for Classification

1. Process Change/Functional Change	The basic purpose for which the facility is being constructed can be improved, i.e., a better building layout, a recent development in a manufacturing process, etc.
2. Added/Deleted Scope of Work	No change in the purpose but the owner wants/needs more or less of a facility than was planned.
3. Safety Change	The facility will not be safe to construct or use if this change is not made.
4. Environmental Change	An improved emissions pattern can be achieved.
5. Regulatory/Permit Change	Required by an approving agency to allow the project to proceed.
6. Purchase Order	What was specified by the engineer/architect is not manufactured, has been improved, can not be supplied as originally designed.
7. Aesthetic Change	The owner usually prefers another color, a different fixture, etc.
8. Productivity Change	Construction man-hour unit rates are different than the estimate/bid resulting in changes to the project cost or schedule.
9. Schedule Change	Anything that improves or delays the completion of the project.
10. Cost change	Anything that raised or lowers the cost of the project.
11. Force Majeure	The result of influences outside the control of the parties to the contract.

Table 3. Category of change listed by cause.

1. Improper scope definition
2. Changing owner needs and requirements
3. Lack of timely involvement by owner throughout the life of the project
4. Fast-tracking
5. Changes in staff—both owner and design firm
6. Errors
7. Omissions
8. Deficiencies in estimating
9. Value engineering and attempts to reduce costs
10. Lack of sufficient detail in design documents "Conceptual Design"
11. Unforeseen requirements by regulatory agencies (building inspectors, FDA, etc.)

Table 4. Type and definition of change order.

Code	Category	Acct. Group	Definition
1.	Scope Change	Client	Additions, deletions, and modifications to project scope and schedule.
2.	Plant Actions	Client	Waiting longer than promised for equipment and services (steam, electricity, etc.) supplied by plant; longer-than-agreed delays in obtaining hazardous work permits and explosion tests; delays caused by fire alarms and area evacuations; requests for temporary connections; ventilation or barricades to maintain operations or plant service.
3.	Design Development	Home Office	Changes initiated by design as a result of more complete definition of scope and design details.
4.	Vendor Information	Home Office	Contract extras caused by late design information from Wilmington Material vendors or F/R details that differ from contract design basis.
5.	Corrections	Home Office	Contract extras caused by design corrections using information that was available prior to contract award (includes most changes resulting from design checking and auditing).
6.	Schedule	Field	Cost incurred to meet project schedule, charges for overtime, second shift, abnormal delivery cost (including subcontractors and contractors' suppliers), and contractor inefficiency.
7.	Temporary Facilities	Field	Installation and removal of temporary construction facilities, services for construction.
8.	Estimated Line Item	Field	Items included in the project scope/design and not originally part of the awarded contract, but which are subsequently added to the contract.
9.	Field Conditions	Field	Unanticipated physical problems, such as poor soil, flooding, and weather.
10.	Contract Interface	Field	Interfaces among multiple contractors in the same area.
11.	Material and Equipment	Field	Items supplied by owner (not a contractor's subvendor) which are late, fabricated incorrectly, or otherwise different than we told the contractor (except for #12); contractor refabricates and/or reinstalls items.
12.	Escalation	Field	Validated labor and material price increases not covered in the contract.
13.	Others		Work financed by other than the project that is being reported; i.e., the contract shares work with other construction projects, plant projects, or plant SWOs.