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ORIGINAL

PRELIMINARY ESTIMATING MODELS FOR BRIDGE REPAIR PROJECTS

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A Report to the

Highway Research Center

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I. INTRODUCTION

The condition of concrete bridges in the state of Alabama today is a cause of great concern for public officials. In these days of limited funding and increasing maintenance and construction costs, it is critical to maximize the use of available funds. In 1987 and 1988 the Alabama Highway Department (AHD) spent a total of over $75 million on urban highway bridge widening projects.

NEEDS

Each year senior AHD officials (Chief Engineer, Bureau Chiefs, and Division Engineers) meet to examine potential projects that are in various stages of development. These projects are reviewed with regard to actual needs, available funding, long range plans, and compliance with federal funding programs. From this assessment, the officials decide which projects to develop, delay, or continue. This procedure is very complex and critical to ensure the best use of available funds.

Throughout the decision making process, it is imperative that officials have accurate estimates of a proposed project's cost. A decision based on an estimate which is too high would prohibit the maximum number of projects from being started, and therefore increase the backlog of projects.

A more serious, and common, problem the AHD encounters is with estimates that are too low. Very often a project is selected for development based on a very low preliminary cost estimate. After investing a lot of money on engineering, plans and specifications, the AHD realizes, either from the detailed estimate or bid opening, that the cost far exceeds allocated funds. Officials must then find additional funds to complete the project, reduce the scope of work to fit the funding level, or delay the project. Since this is basically the same decision they had to make at the yearly assessment, the previous time and money expended have been wasted. The engineering cost of redesigning the project, modifying the plans and specifications, and the additional time required of senior management must be charged to the project. Therefore, even if the construction cost can be reduced, the total cost of the project is increased. It is important to understand that not only do low estimates not show true costs, they also increase project costs.

The AHD's current method of preliminary estimating consists of three independent estimates. The AHD division which identifies the need for a particular project does a preliminary estimate. This is then passed to AHD officials for examination at the annual review. At this stage, detail design has not begun. Only preliminary data such as project length, number of bridges, old bridge dimensions, and new bridge deck area are known. There is no uniform, prescribed estimating method for divisions. Each has its own technique for developing preliminary estimates.

If, at the yearly review, the project is forwarded for development, the location section at AHD headquarters does an independent estimate. The location section uses an estimating system which includes unit prices for various project types. To estimate a bridge widening project, a factor of $75 per square foot of widened deck area is used. This is added to the cost of other parts of the project such as base and pavement to get the total estimated price. This technique has only recently been employed by the location section and its accuracy has not been tested.

The location section forwards the project to the office engineer for the third independent estimate. The estimating method used by this section is based on historical data. Bids previously received for a project of similar scope are examined. The proposed project is then compared to those let earlier. The estimate is a modification of the previous bid with the modifications being based on the knowledge and experience of the estimator instead of statistical data. The accuracy of this method depends on the ability of the estimator, and past results have varied greatly.

To increase the accuracy, detailed estimates could be used. Detailed estimates, however, are expensive to produce in terms of time and manpower, and require a complete set of plans and specifications. The average bid documents for a urban highway bridge widening project contain approximately 140 to 180 line items, each with a unit price. This unit price is multiplied by the quantity to get the total, or extended price of that work item (see Table 1). The extended price of all work items are added together to form the total bid price. The cost of doing a detailed estimate for every project being considered would be far greater than the savings produced. Therefore, this is not a feasible solution.

OBJECTIVES

The primary objective of this report is to provide the AHD with a statistical model, based on AHD historical data of actual projects, for creating preliminary cost estimates of urban highway bridge widening projects. This model will allow the estimator to apply easily determined project information and produce a viable estimate before the plans and specifications are started. This will complement the procedures now used and improve the effectiveness of the system.

The secondary objective is to develop a methodology for creating preliminary estimating models for bridge and other heavy construction projects. The same steps used to develop the model presented here could be used for other similar projects.

Table 1

Example of an Alabama Highway Department
Summary of Bids

SUMMARY OF BIDS ALABAMA HIGHWAY DEPARTMENT

PROJECT NUMBER
DESCRIPTION
LOCATION BIDDER 1

ITEM NO	QUANTITY	ITEM	UNIT PRICE	EXT PRICE
206A000	1	LUMP SUM REMOVAL OF OLD BRIDGE	LUMP	65000.00
206A001	1	LUMP SUM REMOVAL OF OLD BRIDGE	LUMP	74000.00
206A002	1	LUMP SUM REMOVAL OF OLD BRIDGE	LUMP	141000.00
206C003	1034	SQ YD REMOVING CONCRETE FLUMES	2.00	2068.00
206D001	767	LIN FT REMOVING CURB	3.00	2301.00
206E000	18	EACH REMOVING HEADWALLS	350.00	6300.00
210D001	10150	CYIP BORROW EXCAVATION	6.00	60900.00
215A000	684	CU YD UNCLASSIFIED BRIDGE EXCAVA	15.00	10260.00
224A000	200	CU YD LIME SINK EXCAVATION	9.00	1800.00
224D000	100	CU YD CONCRETE SEAL FOR LIME SINK	110.00	11000.00
327A000	11634	TONS PLANT MIX BITUMINOUS BASE	22.30	259438.20
401A000	54461	SYCIP BITUMINOUS TREATMENT A	0.33	17972.13
416B000	600	TONS BITUMINOUS CONCRETE PLANT MIX	43.20	25920.00
450A000	31820	SQ YD REINFORCED CEMENT CONC PAVE	29.05	924371.00
450B000	5272	SQ YD REINFORCED CEMENT CONC END S	68.40	360604.80
455A000	2000	SQ YD GRINDING CONCRETE PAVEMENT	10.55	21100.00
502A000	210718	POUNDS STEEL REINFORCEMENT	0.25	52679.50
505C000	2760	LIN FT STEEL PILING (HP 10X42)	29.50	81420.00
508A000	2890	POUNDS STRUCTURAL STEEL	2.10	6069.00

Definitions

To clarify the intent of the research, some basic terms must be defined. The term "preliminary" estimate is used to describe the process of predicting a project's cost before design of the project is completed. An estimate produced after design, plans, and specifications are complete is called a detailed estimate.

The definition of a "viable" estimate varies greatly from individual to individual and agency to agency. A model that estimates to within seventy-five percent may be acceptable to some, while others require at least ninety percent. There is an inverse relationship between the accuracy of an estimate and its preparation cost. At some point, increased accuracy cannot justify the additional costs incurred. The goal of this model is to produce an estimate within plus or minus twenty percent of the low bid price.

Accuracy

Two factors associated with the bid data used to create this model have a tremendous impact on its accuracy. These are the practice of bid unbalancing and the omission of overhead and profit line items in the bid documents.

Unbalanced bidding is a common practice used by contractors to receive increased progress payments early in the project, without increasing the total bid price. The contractor must pay for labor, materials, and equipment as they are used. He then bills the owner, and is reimbursed approximately thirty to sixty days after paying for the work. Since most contractors must borrow money during this lag period, the total bid price includes money for the interest costs. To be more competitive, and to keep the total cost low, some contractors increase the unit price of work items that will be performed and paid for early in the project, and decrease the price of work to be done at the end of the job. This allows the contractor to receive money early to cover the overdraft time between billing and payment, eliminating the cost of borrowing money. While this practice keeps the total cost of the project down, it hides from the owner the true cost of a work item. Since this research is based on individual line item bid data, instead of total cost, bid unbalancing affects the accuracy of the model. Efforts to compensate for bid unbalancing will be discussed in detail later.

Bid documents do not include line items for every cost incurred by the contractor. Money for overhead and profit must be included somewhere since there is no line item for them. Some contractors distribute this money over all work items, and others put the money in only a few. This is another example of how work item costs are hidden and can vary tremendously between contractors and between projects.

Principles

This research was guided by two principles to meet the stated objectives: to keep the model as simple as possible and to require only information that is known or can be estimated before design is complete. These principles determine the model form and content.

The estimators who use this model should be experienced and knowledgeable in bridge construction and repair, but need not have any experience with statistical models. A straightforward, easy-to-use model would meet the needs of estimators and improve their performance. If complex mathematical operations or new computer systems were required, the model would require extensive and costly training or quickly be rejected and prove to be a waste of time and money. Also, the model needs to be relatively simple to use, so the estimators will update the estimate as the scope of the project changes. A model that is difficult to use might be utilized to create an initial estimate, but not to continually update as needed.

Since the estimate is produced before design is complete, it is imperative that the quantities be measured in a unit that is known or can be obtained without complete plans and specifications. The quantities used to develop the model come from actual bid quantities, but these quantities could be estimated prior to the final design by an experienced estimator. Most of the quantities are a function of the length and width of the existing bridge(s) to be repaired, so the dimensions are relatively easy to determine.

II. PROPOSED MODEL

INTRODUCTION

This report describes a method for estimating the total bid price of urban highway bridge widening projects, based on the quantities of nine work items. The proposed model is the result of a statistical analysis of past bids received by the AHD for similar projects. It consists of nine separate simple regression models, each of which predicts the cost of one of the work items. The simplicity of this model allows it to be executed on a calculator, or by writing a simple computer program. This method will be discussed in greater detail in subsequent chapters.

This model was designed to be used by the AHD to create preliminary cost estimates for urban highway bridge widening projects. It is applicable to projects which also include additional lanes, concrete pavement rehabilitation, and signing. It is not intended for use on projects in which another type work is more prominent than widening. A viable preliminary estimate can be produced with the assistance of this model. However, the limitations of the model must be understood to prevent it from being used in a manner leading to reduced accuracy.

This model cannot provide a viable preliminary estimate if the scope of the work changes after the estimate is made.

Preliminary estimates are made while the project is still in the conceptual planning stage. Too often, as the project develops, the scope changes, but the estimate does not. No model can read the mind of the designer and adjust its price to his design changes. However, the makeup of this model as nine separate sub-models allows the estimate to be easily changed. For example, if during development it became necessary to double the amount of steel reinforcement, the estimate can be changed with a single keyboard entry.

Each of the nine sub-models are computed independently of the others before being summed. However, none of these are designed to be used as stand alone models of that particular work item cost, and should not be used in conjunction with other models.

DEVELOPMENT METHODOLOGY

The following list summarizes the steps used to develop the estimating model. Each of these is discussed in detail in the following sections.

1. Collect and record data from previous projects.
2. Identify line items that constitute more than 1% of the total bid.
3. Develop a regression equation for each of the selected line items.

4. Total the estimated cost modeled by the regression equations.
5. Determine the cost not modeled by the regression equations.
6. Develop a procedure to model the cost not included in the regression equations.

APPLICABILITY TO OTHER TYPES OF PROJECTS

The model presented in this report applies strictly to urban highway bridge widening projects. However, the same development methodology used for this model could be used for creating other preliminary estimating models for heavy and highway work. All of these types of work use unit price contracts with 100+ line items, just as were used for the projects included in this study.

III. LITERATURE REVIEW

A literature review was conducted in an effort to incorporate findings of research done by others into the construction of this model. This review included a search of the Ralph B. Draughon Library at Auburn University, other universities, and state and federal agencies. The conclusion of this search was that practically no published research has been done on the topic of predicting the cost of urban highway bridge widening projects.

BRIDGE MANAGEMENT SYSTEMS

The only related subject found was predicting the life-cycle cost of bridges using Bridge Management Systems (BMS). Numerous studies have been conducted on this topic. The Center for Transportation Engineering Studies at North Carolina State University and the North Carolina Department of Transportation have done much research in this area. The BMS is a comprehensive, long-term management tool used to control bridge rehabilitation, repair, and replacement at an optimum cost/benefit ratio. Highway department officials record all costs associated with a bridge throughout the bridge's life span into a database. This information is then analyzed to compare bridge strategies and determine the most efficient program of bridge repair, rehabilitation, and replacement.

Most states that use BMS employ a "condition rating" or an "urgency of need" designator system to describe the physical condition of the bridge.[1] The condition rating is depicted by a number, which represents a level of maintenance. Every dollar that is spent on a particular bridge is recorded in a database which includes the condition rating of the bridge when the project began, and the condition rating when work was completed. Cost estimates are then developed by adding the total cost of all projects of a particular type, i.e., deck repair, and dividing by the unit of measure of that type (for deck repair the unit of measure would be square feet of deck area). The resulting model shows the cost of improving a bridge from one condition rating to another. Highway department officials can then consider these costs to develop the optimal bridge maintenance strategy.

A common example of where a BMS would be used is in determining when to replace a bridge deck. Is it better to repair the deck now and replace it in 25 years? Would it cost less in the long term to replace the bridge now and do deck repairs later? A tremendous amount of money rests on this decision, and the purpose of BMS is to ensure the most economical use of these dollars.

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[1]Farid, et. al. "Feasibility of Incremental Benefit-Cost Analysis for Optimal Allocation of Limited Budgets to Maintenance, Rehabilitation, and Replacement of Bridges"

Bridge Management Systems are very complex and address many issues affecting bridge costs. While systems vary from state to state, common features incorporated into the model include user costs and benefits; a method of treating all costs in constant dollars; and repair, rehabilitation, and replacement cost categories. A BMS is used to assist in making state-wide policies, not produce a specific estimate. Therefore, it is designed to systematically model the data, and ignores cost factors that affect individual projects.

While this approach works very well in a BMS, it is not sufficient for this research. The object of this work is to develop a model which will predict the cost of an individual bridge widening project within 20 percent. This is not what a BMS is designed or expected to do. Only by applying the BMS model to numerous projects would an accurate estimate be reached, and this would still not meet the purpose of the model.

FEDERAL HIGHWAY ADMINISTRATION PUBLICATIONS

The Federal Highway Administration annually publishes a document, "Unit Costs and Productivity Standards", listing unit prices for various types of highway maintenance projects. This is a compilation of data submitted by state departments of transportation. The state departments develop a unit price in their state by adding the total amount spent on all projects of a particular type, and dividing that sum by the total affected amount of that unit of measure. The only apparent use of these data is by FHWA officials comparing costs between states. Little value is placed on this document because too many factors are not addressed, and the data are not validated.

Cost for each repair activity is broken into the categories of labor, material, and equipment. This standard cost is listed by state, but is still just the average cost of projects, broken down by type, done in that state for that year. The only bridge related categories are bridge deck repair and bridge railing repair. The wide variance of costs between states demonstrates the effect of just one factor (location) being considered in estimating the cost of a future project. Simply averaging the cost of all work done is acceptable if applying that factor to numerous jobs. However, to predict the cost of a single project, the data must be examined more closely.

The FHWA also publishes a list of "bridge construction unit costs".[2] This includes a section on rehabilitation costs. The unit price is developed by adding the cost of all rehabilitation projects and dividing by the total area of all bridges, thus giving an average rehabilitation cost per square foot of deck area.

When totaling the projects, the FHWA directs that only bridge related work be included. Work items such as mobilization, slope paving, clearing and grubbing, and utility

[2] FHWA Memorandum, (Jan 1990) "Bridge Construction Unit Cost"

relocation are excluded. Detailed guidelines address methods for handling phased construction, special condition work and unusually high or low prices. Again, the general nature of these data preclude them from being used in this research.

HIGHWAY CONSTRUCTION ESTIMATING MODEL

In his research of "Preliminary Cost Estimating for Highway Construction Projects",[3] Kaminsky created a microcomputer database of historical unit-price bid data. He then researched the factors most directly impacting project cost and what caused them to vary. His model predicted the quantity of materials required, and their costs, for different type projects such as resurfacing or bridge replacement. The results were expressed in cost per mile.

There are many similarities between Kaminsky's work and the research presented in this paper. The database Kaminsky used was developed from Alabama Highway Department bid summary sheets, and contained the quantity and unit price associated with each work item of a given project. This format allowed him the flexibility to efficiently sort records. To incorporate this efficiency, the data base of this study was structured in a similar manner. Also incorporated were the basic procedures

[3]Kaminsky, (1986) "Preliminary Cost Estimating for Highway Construction Projects"

of analyzing the data base to determine which factors affect the project costs, and to what extent.

There are some differences between the studies, however. Kaminsky used only the unit prices of the low bidder. Unit prices often vary tremendously between bidders because of bid unbalancing. This can greatly skew cost estimates and decrease the accuracy of the model. To avoid this potential problem in developing the bridge widening model, unit prices from all bidders were included.

The highway construction model can be used when only the project length is known. This allows the model to be used early in the planning process, and is very simple. Bridge widening project costs are not a function of length only, therefore other variables must also be entered. The simplicity of the model, however, was noted and, where possible, incorporated into the bridge widening model.

OTHER PUBLICATIONS

Numerous books have been written on causes of deterioration and repair methods and materials. Several studies, such as "Bridge Maintenance" by the Organization for Economic Cooperation and Development (OECD) Road Research Group, have developed excellent strategies for bridge maintenance management, policy, and repair techniques. These studies and books provide complete information on how to incorporate all costs into determining the life-cycle cost, and the best techniques to get the lowest life-cycle cost. However, they do not provide the detailed data necessary to accurately predict the cost of one bridge rehabilitation project.

LESSONS LEARNED

Some valuable lessons were learned from the literature review. One of the most important was that statistical models do work. Computer based models are being used in several states as part of a BMS to determine the optimum bridge maintenance strategy. These models meet the need for which they were designed, and save the taxpayers money. Much of the database structure and methodology used by Kaminsky was of assistance in conducting this research.

Although much information was gained from this literature review, some outstanding issues remained. The selection of work items which significantly affect the total bid, and determining what percentage of the bid they represent, were not addressed in the literature. These questions, and the selection of variables for the statistical models, remained to be answered by this research.

IV. DATA COLLECTION

ALABAMA HIGHWAY DEPARTMENT DATA

In 1987 and 1988 the Alabama Highway Department (AHD) received bids for eleven urban highway bridge widening projects. The bidding format used was the AHD's standard competitive unit price bidding system. Bid summary sheets from each project were created after bids were opened. These contain information on the project, each bidder's total bid, and the unit price per work item. This model is based on data from the bid summary sheets of these eleven projects.

In the initial phase of this research, data from these bid sheets were entered into a database using the dBase III Plus computer software package (see Table 2). A preliminary list of 43 work items to be included in the data base was developed in consultation with the AHD. The list of bridge widening related work items will be discussed in detail in subsequent chapters of this paper. Records were entered into the data base for each work item and bidder on each of the eleven projects.

INFORMATION FROM OTHER STATES

Several surrounding states (Georgia, Mississippi, and Florida) were contacted for information on bridge widening

Table 2
Example of Database Structure and Records
Using dBase III Plus

ITEM NO	QTY	UOM	UNIT PRICE	EXT PRICE	PROJECT NO	BIDDER
206A000	170.00	FT	526.47	89500.00	I-IR-59-1(144)118	HARDAWAY
206A000	170.00	FT	494.12	84000.00	I-IR-59-1(144)118	HARDAWAY
206A000	294.67	FT	410.63	121000.00	I-IR-59-1(144)118	HARDAWAY
206A000	406.48	FT	453.16	184200.00	I-IR-59-1(144)118	HARDAWAY
206A000	170.00	FT	317.65	54000.00	I-IR-59-1(144)118	DEMENT
206A000	170.00	FT	364.71	62000.00	I-IR-59-1(144)118	DEMENT
206A000	294.67	FT	319.00	94000.00	I-IR-59-1(144)118	DEMENT
206A000	406.48	FT	307.52	125000.00	I-IR-59-1(144)118	DEMENT
206A000	170.00	FT	475.36	80811.72	I-IR-59-1(144)118	DUNN
206A000	170.00	FT	475.36	80811.72	I-IR-59-1(144)118	DUNN
206A000	294.67	FT	293.83	86583.98	I-IR-59-1(144)118	DUNN
206A000	406.48	FT	340.81	138534.37	I-IR-59-1(144)118	DUNN
206C002	1130	SQYD	1.00	1130.00	I-IR-59-1(144)118	HARDAWAY
206COO2	1130	SQYD	4.00	4520.00	I-IR-59-1(144)118	DEMENT
206C002	1130	SQYD	11.54	13040.20	I-IR-59-1(144)118	DUNN
214A000	670	CUYD	7.35	4924.50	I-IR-59-1(144)118	HARDAWAY
214A000	670	CUYD	10.00	6700.00	I-IR-59-1(144)118	DEMENT
214A000	670	CUYD	8.66	5802.20	I-IR-59-1(144)118	DUNN

project costs. The minimal information received from these states was of little assistance because of differences in the system each state uses. For example, several work items used by the AHD are combined to form a single work item in Mississippi. The Georgia Department of Transportation uses a single "bridge rehabilitation" work item. This includes work AHD breaks down into several work items and is also different from the Mississippi work item. The differences are significant enough to prevent direct comparisons. Any attempt to modify these work items to allow for comparison would necessitate too many assumptions for the results to be valid. Because of this high probability of error, data from other states were not used. The Georgia DOT, however, does use heuristic values to estimate broad areas of bridge repair. This information was recorded and used to assist in model validation.

V. SELECTION OF MODEL VARIABLES

DATA ANALYSIS

The primary objective of the preliminary data analysis was to determine which work items have the most impact on project cost, and what factors cause these work item costs to vary. In consultation with the Alabama Highway Department (AHD), a list of work items believed to significantly impact the total project cost was developed. Bid data concerning these work items were taken from every bidder on each of the eleven bridge widening projects used in this research. Data from each item was placed in a dBase record as previously discussed (Table 2). The resulting dBase file contained over 1700 records.

A dBase program was written to put the data in a format which showed the total work item cost as a percentage of the total bid amount. For example, consider a project which includes complete removal of three bridges, where each bridge is a separate line item. One contractor bids $78,000, $23,000, and $89,000 for these line items and has a total bid of $10,000,000. Another contractor, for the same project, bids $87,000, $40,000, and $100,000 for the bridge removal and has a total bid of $11,750,000. Summing the three bridge removal line items and dividing by the total bid for each contractor shows that bridge removal was 1.9 percent of each contractor's bid. Again, this was done for every bidder on each of the eleven projects. Bid amounts varied between bidders on individual projects, sometimes over 40 percent, but using the work item cost as a percentage allowed the data to be compared directly. These percentages were used only in the work item selection process, not in model development.

Other models based on historical bid data have generally used only the data from the lowest bidder because they wanted to predict the amount of the lowest bid. Applying this procedure to this research would allow data from only eleven of the 37 bidders to be included. Increasing the amount of data used to create the model improves the accuracy. Using data from all bidders also helps reduce the effect of unbalanced bidding. A low bidder, for example, bids steel reinforcement at half its actual cost. This will skew a model with eleven data points much more than a model with 37 data points.

Data from low and high bidders cannot be used directly to predict a low bid. The models created from high and low bid data will obviously be higher than the lowest bid. However, it is believed that the advantages of including all bidders in the study outweigh the disadvantages. The method used to adjust to the lowest bid will be discussed in Chapter VII.

SELECTION OF WORK ITEMS

The initial phase of work item selection consisted of reviewing the list of items believed to significantly impact the total project cost (see Table 3). This list contained 43 work items. Closer review of this list revealed that only ten work items individually made up greater than one percent of the total project cost. For a preliminary estimate, work items which account for less than one percent cannot be considered to "significantly" impact the total bid amount. To estimate each of these 33 work items would increase the complexity and preparation cost of the model, but not increase the accuracy. Therefore, they were removed from the list.

Two work items which represent a significant percentage of the total bid were later deleted from the model. These are mobilization (AHD Code 600A) and bridge substructure concrete (AHD Code 510A). Mobilization is traditionally the work item most affected by bid unbalancing. The mobilization work item is designed to pay for expenses such as moving equipment to the job site and establishing field offices. The nature of these expenses practically prohibit a bid from being declared non-responsive due to mobilization costs. This, coupled with the fact that it is the first pay item received by the contractor, makes the mobilization work item amount vary much more than any other. On one project, mobilization varied over 400 percent between bidders. This variance, coupled with the lack of a quantifiable unit of measure, prohibits the modeling of this work item.

Table 3

Preliminary List of Work Items Considered for the Model, Expressed as a Percentage of Total Bid Price.

AHD CODE	WORK ITEM DESCRIPTION	AVG % OF TOTAL COST
206A	Removal of Old Bridge (lump sum)	5.6
206C012	Removal of Bridge Deck	0.6
206C014	Removal of Bridge End Slab (sq yd)	0.6
206D	Removing Loose Bridge Joint Angle	0.1
207B	Removal of Old Bridge (each)	N/A
207E	Removal of Bridge End Slab (each)	N/A
215A	Unclassified Bridge Excavation	0.6
327A	Plant Mix Bituminous Base	4.1
450A	Reinforced Cement Conc Pavement	14.1
450B	Reinforced Cement Conc Bridge E S	3.3
490A	Blast Cleaning	N/A
490B	Concrete Overlay, Polymer Concrete	N/A
502A	Steel Reinforcement	1.6
502B	Epoxy Coated Steel Reinforcement	N/A
505A	Steel Test Piles, Concrete Test Pile	0.7
505B	Loading Tests	0.4
505C	Steel Piling, Concrete Piling	2.1
508A	Structural Steel	0.3
508B	Structural Steel Superstructure	13.7
508C	Bearing Plates Bronze	0.2
508G	Elastomeric Bearing Pads	N/A
508H	Steel Finger Expansion Joints	N/A
510A	Bridge Substructure Concrete	4.7
510B	Bridge Concrete, Class D	N/A
510C	Reinforced Bridge Conc Superstr	11.2
510D	Bridge Substructure Conc, Class E	N/A
510E	Grooving Concrete Bridge Decks	N/A
511A	Elastomeric Bearing Pads (1x12x12)	N/A
511B	Elastomeric Bearing Pads (1/8x12x15)	N/A
513A	PT/PS Concrete Griders (each)	N/A
513B	PT/PS Concrete Girders (l.f.)	N/A
514A	Bridge Surface Protective Coat	0.1
520A	Repairs to Existing Bridge	N/A
520B	Raising Existing Bridge	N/A
520C	Raising Portion of Existing Bridge	N/A
520D	Concrete for Slab Repair	N/A
520E	Sand Blast Slab	N/A
520F	Epoxy Coat Slab	N/A
522A	F/I Bridge Inter Joint Seal System	0.2
522B	F/Partial Inst Bridge End J S Sys	N/A

In an attempt to offset this large variance, mobilization was combined with bridge removal to form a work item group. This would allow the large amount of money represented by mobilization to be included in the model. Bridge removal was chosen for the work item group because it too is greatly affected by unbalanced bidding. This attempt, however, was not successful. The variance of the two work items did not offset each other as anticipated, and a viable model could not be developed. The mobilization work item was therefore deleted from the model. This cost will be included with the other work items that are part of the project, but are not modeled.

Bridge substructure concrete is not required for every bridge widening project. Only eight of the eleven projects reviewed for this study included this work item. The reason for the large cost variance of this work item could not be determined. A scatter diagram indicated no discernible pattern. Since no viable model could be produced from the data available from these projects, the work item was deleted from the model. It will also be included with the work items included in the project but not modeled.

Further analysis revealed that safety and traffic control costs were a significant part of the total bid amount. If there were a safety/traffic control work item it would certainly need to be included on the list. Instead, this cost is spread over many different work items. A "work item group" was formed to allow these costs to be examined in the same manner as the other work items. See Table 4. This work item group consists of thirteen separate work items which are related to safety/traffic control and are included in most bridge widening projects. This addition brought the number of work items on the final list to nine.

Table 4

Final List of Work Items Included in the Model with their Corresponding AHD Code Number.

WORK ITEM DESCRIPTION	AHD CODE
Removal of Old Bridge	206A
Plant Mix Bituminous Base	327A
Reinforced Cement Concrete Pavement	450A
Reinforced Concrete Bridge End Slab	450B
Steel Reinforcement	502A
Steel Piling	505C
Structural Steel Superstructure	508B
Reinforced Concrete Superstructure	510C
Safety/Traffic Control	
Broken Temporary Traffic Stripe	701C
Temporary Traffic Control Markings	703D
Portable Concrete Safety Barriers	726A
Portable Impact Attenuator	726D
Truck Mounted Impact Attenuator Unit	728A
Construction Signs	740B
Special Construction Signs	740C
Channelizing Drums	740D
Cones	740E
Warning Lights	740I
Vertical Panel	740L
Weight for Cone	740M
Sequential Arrow & Chevron Sign Unit	741C

VI. CREATING THE MODEL

The creation of the model is obviously the most critical phase of this research. Therefore, the work in this phase was guided by the objectives of simplicity and use of easily determined project information. To ensure ease of use by the estimator, only simple regression analysis was performed. Analysis was done on a personal computer, using the computer software package STATGRAPHICS.

MODEL FORM

To create the model a simple regression analysis was done for each of the nine work items selected as model variables. Bid data from all bidders on each of the eleven projects were used except those that were obviously unbalanced. If the bid was 100 percent or more off from the other bids, it was deleted. For example, on one project the bids for reinforced concrete superstructure (AHD Code 510C) were $49,000, $40,000, $54,000, and $117,225. The $117,225 bid was deleted. All models use a 95 percent confidence level and are in the slope-intercept equation form ($y = a + bx$). Models which had an intercept significance level of greater than 0.05 where recalculated with the intercept being zero.

One of the most important aspects of developing a viable model is the selection of variables. The first iteration of regression analysis was done using the work item's unit price as the dependent variable. The resulting R-square values and correlation coefficients were generally low. Another iteration of regression analysis was done using the extended price of the work item as the dependent variable. In each model this increased the R-square value and the correlation coefficient. It also made the model simpler for the user by eliminating the need to multiply the value from the model by the quantity. For these reasons, each model produces the estimated extended price of that particular work item.

Ideally the independent variable would be a value that is known, and would be the same for each model. Unfortunately, this is not possible. Analysis of each model was done using project length, then quantity, as the independent variable. Project length is known early in the planning process and does not require extensive estimates. However, it is so general it does not produce the accuracy required of the model. Work item costs depend on more factors than just project length. The width of the project is also a factor, as is whether the work is done in one specific area, or throughout the project area. Quantity accounts for these factors. Quantity requires more effort to estimate but it is the only value, for most work items, that will produce a viable model. Therefore, the independent variable used in eight of the nine models is the quantity of the work item. Quantity would not be practical for the safety/traffic control work item group. It would require the user to estimate another thirteen work item quantities which would be too expensive and time consuming. Also, the cost of each safety work item in the group is almost purely a function of length. Since items such as temporary traffic striping, cones, and safety barriers are placed linearly, they vary little with project width. The length of the project, however, greatly affects this cost. Therefore, the safety/traffic control model uses project length. Each work item is examined in detail in the following sections. Model equations are summarized in Table 5. Regression plots (scatter diagrams) of each work item model are included in Appendix A.

REMOVAL OF OLD BRIDGE

Removal of old bridges (AHD Code 206A) is a necessary, and costly, requirement of bridge widening projects. Sometimes only one side needs to be removed so that the bridge can be widened on that side. This is called partial bridge removal. Approximately 40 percent of the projects, however, require complete removal. Because of the cost variance between these two procedures, separate models were developed for each. To estimate the bridge removal cost the user must first determine whether the project calls for partial or complete removal and the length of the bridge. Bridge removal is bid lump sum, but the cost is a function of the length. Therefore, the model uses linear feet as the unit of measure. This can be done without

Table 5

Model Equation Summary

AHD CODE	DESCRIPTION	INDEP VARIABLE	DEPEN VARIABLE	EQUATION
206A(Part)	Old Bridge Removal	Qty	Ext price	16846.7+(55.1919*Qty)
206A(Comp)	Old Bridge Removal	Qty	Ext price	35904.7+(235.386*Qty)
327A	Plant Mix Bituminous Base	Qty	Ext price	24443.8+(22.3699*Qty)
450A	Reinforced Cement Concrete Pavement	Qty	Ext price	29.92*Qty
450B	Reinforced Cement Concrete Bridge End Slab	Qty	Ext price	58.17*Qty
502A	Steel Reinforcement	Qty	Ext price	0.41*Qty
505C	Steel Piling	Qty	Ext price	23.71*Qty
508B	Structural Steel Superstructure	Qty	Ext price	-10208+(779.212*Qty)
510C	Reinforced Bridge Concrete Superstructure	Qty	Ext price	21949.6+(439.604*Qty)
	Safety/Tr Cont	Project length	Total cost	278380+(171294*Length)

drawings by simply measuring the length of the existing bridge.

Partial bridge removal cost is estimated by the equation

P = 16846.7 + (55.1919 * Q)

where P = Extended price

Q = Quantity, in linear feet.

This model has an R-square of 43.94 percent, a correlation coefficient of 0.662909, and an F-ratio of 61.93. The significance level of the intercept and slope are 0.00000 each.

Complete bridge removal cost is estimated by the equation

P = 35904.7 + (235.386 * Q)

where P = Extended price

Q = Quantity, in linear feet.

This model has an R-square of 51.11 percent, a correlation coefficient of 0.714916, and an F-ratio of 93.04. This model also has a significance level of 0.00000 for both the intercept and slope.

Bridge removal costs vary much more than other work items, because of such variables as removal techniques used and unbalanced bidding. Therefore, when the data are plotted it appears as a cluster of dots with a few points outside the cluster. From these plots it would seem that an average cost, instead of a model, may be a more accurate predictor for this work item. Testing, as described in Chapter VI, revealed that the models were actually more accurate than the average cost. Therefore, despite the appearance of the regression plots, the bridge removal models were accepted.

The low R-square values and correlation coefficients indicate these models may not provide the accuracy required for this research. An R-square of 43.94 percent may seem low, and it would be for a detailed estimate requiring exact precision. However, it should be remembered that the goal of this research is to develop a model for <u>preliminary</u> estimating. Considering the amount of observational data, the many causes for its variance, and that it has a significance level of 0.0000, these models are the best available and acceptable for the purpose.

STEEL REINFORCEMENT

The steel reinforcement work item (AHD Code 502A) is estimated by the equation

$$P = 0.4142 * Q$$

where P = Extended price

Q = Quantity, in pounds.

This model was created using 36 data points. Using the standard regression equation, the significance level of the intercept was 0.86357. Therefore the model was recalculated with the intercept being zero. This yielded a model with an R-square of 98.3 percent and a t-value of 45.05.

Since quantity is estimated in pounds, this model is very dependent on the ability and experience of the estimator. The user must estimate the pounds of steel required based on experience or from comparisons to data of similar projects.

This quantity should be updated throughout the design process to correct possible mistakes in the estimated quantity.

STEEL PILING

To use this model, the quantity of steel piling (AHD Code 505C) is estimated in linear feet and entered into the equation

$$P = 23.7109 * Q$$

where P = Extended price

Q = Quantity, in linear feet.

This model was created using 49 data points and has an R-square value of 96.12 percent and a t-value of 34.5. The significance level of the intercept was 0.05560, so the intercept was set to zero.

The AHD bid documents have a separate line item for each size piling included in the plans and specifications. This model uses the same regression equation for sizes HP 10X42 to HP 14X73. If the pile size for the project being estimated varies significantly from this, the user should adjust the estimate. The predicted cost should be increased for larger piles, and decreased for smaller ones. The size of this adjustment should be based on the estimator's experience.

STRUCTURAL STEEL SUPERSTRUCTURE

The structural steel superstructure (AHD Code 508B) work item cost is estimated by the equation

$$P = -10208 + (779.212 * Q)$$

where P = Extended price

Q = Quantity, in linear feet of bridge.

This differs from the AHD's unit of measure (each), but linear feet is easy to estimate and produces a much better model. The R-square of this model is 73.14 percent. The correlation coefficient is 0.855217, the F-ratio is 1334, and it is based on 492 data points. Note that the intercept term is negative. This may seem a bit incongruous, but this best modeled the data. The significance level was 0.00002 for the intercept, and 0.00000 for the slope. The value for P would be negative only if Q is less than 13, which would never occur.

This work item includes both simple span and continuous span structures. The continuous span bridges are, as a rule, longer and therefore more expensive than the simple spans. This is very obvious from the scatter diagram produced from the extended price versus quantity plot. It appeared as if there were two models on the same graph. The regression analysis was performed again to model simple and continuous spans independently. Even though the scatter diagram indicated separate models may be more accurate, this was not true. The simple span model had an R-square of 32.95 percent, a correlation coefficient of 0.574015, and an F-ratio of 204.9. The continuous span model an R-square of 60.98 and a correlation coefficient of 0.780891. The obvious decision then was to keep the two span types combined to produce the strongest model.

PLANT MIX BITUMINOUS BASE

The plant mix bituminous base work item (AHD code 327A) is estimated by the equation

$$P = 24443.8 + (22.3699 * Q)$$

where P = Extended price

Q = Quantity, in tons.

This model has 36 data points and an R-square value of 97.32 percent. The correlation coefficient is 0.986518 and the F-ratio is 1236. The significance levels are 0.02801 for the intercept, and 0.00000 for the slope.

The quantity of this work item can easily be estimated, in tons, if the project area is known. This information is normally available early in the planning and development process. One square yard of plant mix bituminous base weighs approximately 110 pounds per inch of thickness. Applying an estimated thickness to this conversion factor produces the estimated weight of the material. This is simply converted to tons to get the value used in the model.

REINFORCED CEMENT CONCRETE PAVEMENT

A concrete bridge is widened, obviously, because lanes are being added to the highway and the bridge must be modified to accept the wider highway. The concrete for the additional highway lanes is bid as work item 450A. The quantity of concrete is measured in square yards. It can be estimated, without drawings, by measuring the area of the lanes to be added. The cost of this work item (AHD Code 450A) is estimated by the equation

$$P = 29.9234 * Q$$

where P = Extended price

Q = Quantity, in square yards.

This model was created from 37 data points and has an R-square of 98.38 percent and a t-value of 46.76. The significance level of the intercept was 0.33084, so here again the intercept was set to zero.

REINFORCED CEMENT CONCRETE BRIDGE END SLAB

The quantity of this work item (AHD Code 450B) is also measured in square yards. It is estimated by the equation

$$P = 58.1671 * Q$$

where P = Extended price

Q = Quantity, in square yards.

The R-square value is 95.9 and the t-value is 29.01. As with work items 502A and 450A, the best model for this data has an extremely high significance level for the intercept. This one is 0.88947, so the intercept was set to zero.

SAFETY/TRAFFIC CONTROL

The cost of work items in this group are almost purely a function of project length. Since safety barriers, cones, traffic striping, etc. are placed linearly along the work site, their cost can be estimated from the length of the project area. This length is established very early in the planning and development process and would be known when preliminary estimates are made.

This is the only model which uses project length, in miles, as the independent variable. Since this model estimates the cost of all 13 work items in the group, instead of a single work item cost, the term "total cost" is used instead of extended price. Total cost is the sum of the extended price of each of the 13 work items. This is estimated by the equation

$$P = 278380 + (171294 * L)$$

where P = Extended price

L = Project length, in miles.

The model's R-square value is 53.39 percent. The correlation coefficient is 0.730709 and the F-ratio is 37.81. The significance levels of the intercept and slope are 0.00002 and 0.00000 respectively.

REINFORCED BRIDGE CONCRETE SUPERSTRUCTURE

Reinforced bridge concrete superstructure (AHD Code 510C) is estimated by the equation

$$P = 21949.6 + (439.604 * Q)$$

where P = Extended price

Q = Quantity, in cubic yards.

The R-square is 82.99 percent. The correlation coefficient is 0.910965 and the F-ratio is 882.8. The significance level of the intercept is 0.00002, and 0.00000 for the slope.

AHD bid documents require a lump sum for this work item. Since lump sum is not an acceptable unit of measure to produce a model, the cubic yardage of concrete is used. This quantity is not difficult to estimate and produces a good model. Later in the planning process the required cubic yards must be estimated and included in the plans and specifications. This number can then be used in the equation to update the estimate.

Once the work items were selected and modeled, the next step was to determine how much of the total project cost these work items represent. A spreadsheet was generated showing the work items, as a percentage of the total bid amount, for each bidder on each project. Summing the percentage costs by bidder and project showed that the nine work items together average

63.3 percent of the total project cost, with a standard deviation of 4.1 percent. From this information a factor must be determined to account for the work items that are not on the list, but are included in the project. Initially it was thought that if the items in the model account for 63.3 percent of the costs, the remaining items must account for 36.7 percent. This was the factor first used in model testing.

VII. TESTING AND USE OF THE MODEL

MODEL TESTING

The best testing method available is to use the model to estimate past projects and compare the results to the bids received. The following procedure was used to estimate each project. The regression equation for each of the nine work item models were utilized, using work item quantities taken from the plans and specifications. The sums of each equation were then totaled for a project. To account for mobilization, bridge substructure concrete, and other items included in the project but not modeled, this total was divided by 0.633. This factor was used because the nine work items modeled constitute, on the average, 63.3 percent of the total project cost. This estimated bid (sum of the models divided by 0.633) was compared to the actual low bid received for that project. The estimates were generally higher than expected. The desired accuracy of the model required the estimate to be between 80 and 120 percent of the actual low bid. Estimates from the test ranged from 92 to 130 percent of the low bid.

Each model in this project was created using data from <u>all</u> bidders. However, the intent of the study is to predict the <u>lowest</u> bidder. A model created with data from low and high bidders will obviously predict amounts higher than the lowest bid. Some conversion process or factor must be applied.

One method attempted to alleviate this problem by adjusting all bids on each project to the lowest bidder. For example, if the second lowest bidder's total was five percent higher than the low bid, each line item of the second lowest bidder was reduced by five percent. After further investigation this method was rejected. Because of differing bid strategies between contractors, the lowest total bidder does not necessarily have the lowest bid on each line item. Adjusting bids would, in many cases, not normalize the data but only increase the variance and weaken the model.

The method used to solve this problem was to combine this adjustment with the factor which accounts for work items not estimated in the model. Originally, the sum of the nine models was divided by 0.633 to account for items such as mobilization, bridge substructure concrete, and low cost work items. The 0.633 value was used because the nine modeled work items account for 63.3 percent of the project costs. Combining the factor which adjusts for using all bidders with the factor to adjust for work items not modeled would also simplify the procedure for the user. The problem now was that the adjustment for items not modeled was 0.633, but the adjustment for all bidders was unknown. To determine the optimum value of this combined factor the projects were again estimated using the model. This time the difference between the estimated total bids and actual low total bids were squared and summed. This procedure was repeated, increasing the factor by one percent on each iteration, until the sum of squares reached its lowest point and began increasing. The factor which had the smallest sum of squares, and therefore the optimal value, was 0.7.

This factor was accepted and is used in the model as the only adjustment that must be applied to the sum of the nine models. Results of each iteration are shown in Table 6. Estimates produced using the model and 0.70 factor are compared to actual bids received, and shown in Table 7.

The model form was also tested using the following sequence:

1. Remove all data relating to Project 1.
2. Recalculate the model without the data from Project 1.
3. Estimate the cost of Project 1 based on the revised model.
4. Replace the data relating to Project 1.
5. Remove all data relating to project 2.
6. Perform steps 2 - 4 for Project 2 and all remaining projects.

This eliminates the problem of estimating the cost of a project based on a model created with data from that project. The results of this procedure are given in Table 7. All of the projects but Project 8 are within the 20% interval. The average of estimated/actual is 94%. There was no single discernible factor that caused these estimates to be consistently lower than the ones created when using all of the data.

Table 6

Factor to Account for Items Not in the Model and the Corresponding Test Error.

FACTOR	SUM OF SQUARES	FACTOR	SUM OF SQUARES
.633	0.246364	.683	0.135184
.643	0.210872	.693	0.130206
.653	0.182580	.703	0.129905
.663	0.160892	.713	0.133898
.673	0.145260	.723	0.141831

Table 7

Estimated Bids Compared to Actual Low Bids Received

Project Number	Estimated Cost and Percent of Cost Using Data From All Projects		Estimated Cost and Percent of Cost With Project Data Removed		Actual Cost
1	$6,253,855	91	$6,129,619	89	$6,885,768
2	$4,724,381	117	$4,672,899	116	$4,025,352
3	$7,299,101	106	$6,473,715	94	$6,914,660
4	$7,828,645	98	$7,013,856	88	$7,972,837
5	$9,222,218	99	$9,496,700	102	$9,314,527
6	$7,198,999	96	$6,727,566	90	$7,494,374
7	$2,994,247	89	$2,966,986	88	$3,375,290
8	$9,438,345	82	$8,760,833	77	$11,446,382
9	$6,446,814	113	$6,493,882	113	$5,731,481
10	$5,519,750	85	$5,232,540	80	$6,531,286
11	$6,309,906	105	$6,122,662	102	$6,021,695
	Average	98		94	

USE OF THE MODEL

This model is designed to provide a preliminary cost estimate of urban highway bridge widening projects in 1988 dollars. Inflation would need to be accounted for by using an acceptable construction cost index. The model is in a format that requires only basic mathematical operations and can be executed on a hand calculator. It also may be used on a computer by writing a simple program in practically any language, including BASIC, dBase, and LOTUS 123.

The model was tested using actual, not estimated, work item quantities. Inaccurate quantity estimates would of course lead to inaccurate bid estimates. It is important to identify inaccurate estimates as early as possible to allow management time to react. Throughout the development phase of a project the scope and quantity of work changes. The cost estimate must change also. Periodically during the development phase, the estimated work item quantities should be compared to the latest design data and revised. Revisions which can be made easily with one calculation or keyboard entry can save a lot of time and money later.

Work items included in the model which are bid as several line items must be entered into the model individually. For example, if several bridges are to be removed as part of a project, each bridge will be listed as a separate line item and bid as a lump sum for each bridge to be removed. In these instances each line item must be entered into the model individually. If the length of all bridges in the project were totaled and the sum used in the model, the results of the model would not be as accurate because the intercept term must be included for each bridge that is removed.

If a project being estimated does not include one of the modeled work items, the model is not affected. The model would be used in the same manner as if all work items were included. In none of the projects examined were two or more of the modeled work items excluded. Therefore, the validity of the model in this situation is unknown. Many projects similar to this one develop large multi-factor models instead of estimating individual work items as is done here. The multi-factor models are created to incorporate the interactions between work items. When such interactions exist, the multi-factor model is generally stronger than individual simple regression models. The data for this project indicates that interactions between work items do not exist. Therefore, each work item is estimated individually.

This model is designed to estimate the lowest bid for an urban highway bridge widening project. This should not be confused with total cost. The cost of engineering, inspections, right-of-way, and other items normally associated with total cost are not included.

VIII. CONCLUSION AND RECOMMENDATIONS

CONCLUSIONS

Use of the Model

Alabama Highway Department officials have a difficult task in determining which projects to develop and fund. This problem is compounded when bids received and actual costs are significantly more than the amount used during planning. This results in last minute scrambles for more money and sometimes a waste of limited resources. To facilitate the best use of available funds officials need accurate preliminary cost estimates. The AHD method of producing multiple estimates from different departments helps solve these problems by providing a checks and balances system. The accuracy of the techniques now being used is unknown. Since the model described in this paper has been tested to be accurate to within 20 percent, it could complement the methods currently being used and improve the checks and balances system.

This model could possibly be used at many levels, including estimators (at division and headquarters level), designers, and managers. The primary users, however, will be estimators. These people are very experienced at estimating all aspects of bridge construction and repair projects. They are more skilled at estimating work item quantities than at performing complex mathematical operations. Therefore, the model was designed to require only basic arithmetic, but relies heavily on the user's ability to accurately estimate work item quantities. Tests of the model used actual quantities, producing estimates within a range of 80 to 120 percent of the actual low bid. If the estimated quantities varied significantly from actual quantities required, this range could be much greater.

One of the major causes of inaccuracy of AHD estimates has been that the estimate does not change with the scope. Throughout the development stage, the scope of the project changes. As more detailed information is known the cost estimate must be updated. For this model to be used for its intended purpose it is imperative that it be reviewed and updated at each stage of development and design. This will alert officials of the changed cost earlier, and allow them time to react. It will also show what caused the estimate to change. Failure to revise the estimate will negate any improvement of the estimating process and bring AHD officials back to the original problem: how to make the best use of available funds.

This model was developed to estimate urban highway bridge widening projects. It is also applicable to projects which include additional lanes, concrete pavement rehabilitation, and signing. It should not be used to estimate other type projects, nor should individual work item models be used independently.

The data on which the study is based are from 1987 and 1988 projects. Therefore, the estimates produced from this model must be adjusted to present day dollars. The *Engineering News*

Record Construction Cost Index could be used to adjust the estimate to current dollars.

Bridge widening costs, as with all construction costs, vary between states. This is due to such factors as different labor rates, weather conditions, and material costs. Since this model is based on projects done in the state of Alabama, its validity in other locations is unknown.

Application to Other Types of Projects

The estimating model presented in this report obviously has very limited application. The data used for the model came only from interstate bridge widening projects in urban areas. Therefore, using the model to predict the cost of other types of projects would yield unreliable results. The purpose of the study was not just to create this model, but to develop a methodology that could be applied to a number of project types. The data consisted of unit price bids, with more than a 100 line items on each bid. A small percentage (5 - 10%) of these items accounted for the majority of the cost, so a reasonable total cost could be estimated by calculating the cost of the few major items. Other projects with the same characteristics, which would include most heavy and highway work, could be estimated using this methodology.

RECOMMENDATIONS

As subsequent bridge widening projects are let by the AHD, the bid data should be added to this database to update and improve the existing models. Also, attention should be given to new technologies and construction methods used in bridge widening. If a new technology or method that affects a work item price is used, that work item model should be modified to reflect the new development.

Additional testing of the model should also be conducted. Bridge widening projects in other states could be estimated and compared to the actual bids received. Because of differing work item descriptions, bid data from other states could not be included in the development of this model. However, careful examination of the plans and specifications of projects outside Alabama could produce the quantity information required for the model. This additional testing would provide a better analysis of the accuracy of the model.

Research comparing the cost of the nine modeled work items to their cost in other type projects should be considered. This would determine whether work item cost is affected by project type. Results of these studies could possibly then be incorporated into a comprehensive preliminary estimating system for all types of AHD construction and repair projects.

This procedure could also be used to estimate costs for other types of bridge projects. A similar analysis could be conducted to determine the major cost items and models developed to aid in calculating a preliminary estimate.

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APPENDIX A
SCATTER DIAGRAMS OF WORK ITEMS SELECTED AS MODEL VARIABLES

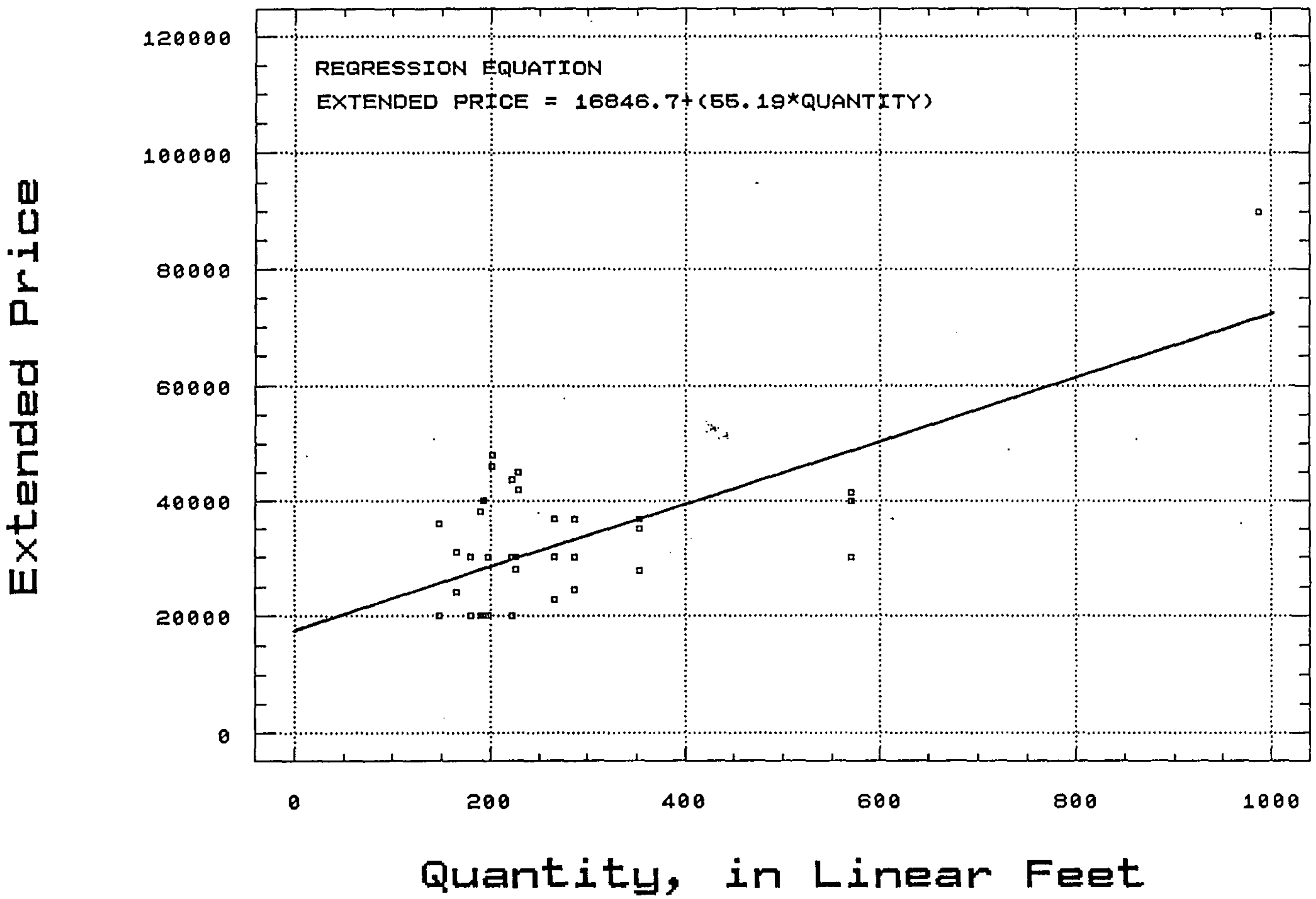

Figure A.1 Item 206A Partial Bridge Removal

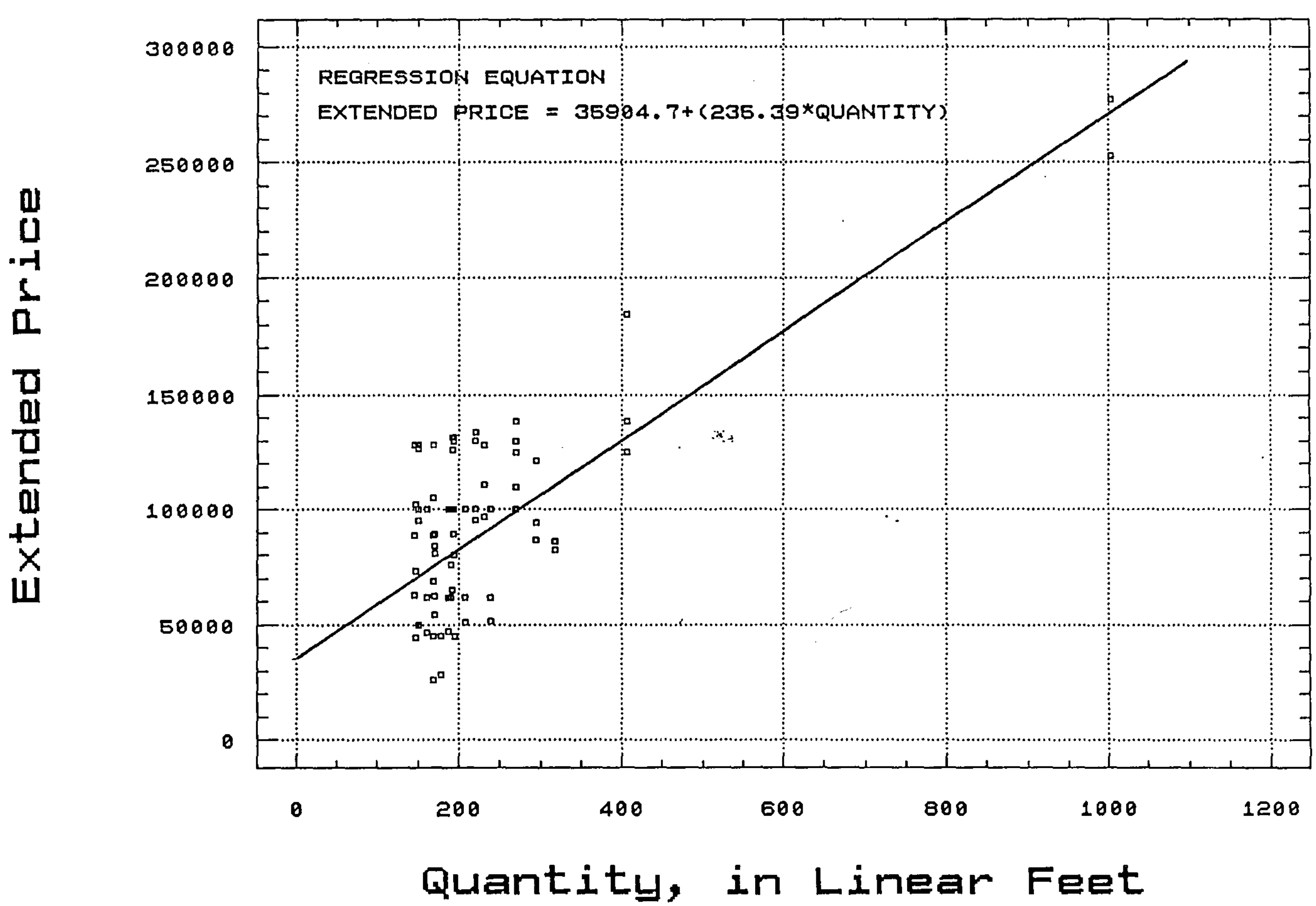

Figure A.2 Item 206A Complete Bridge Removal

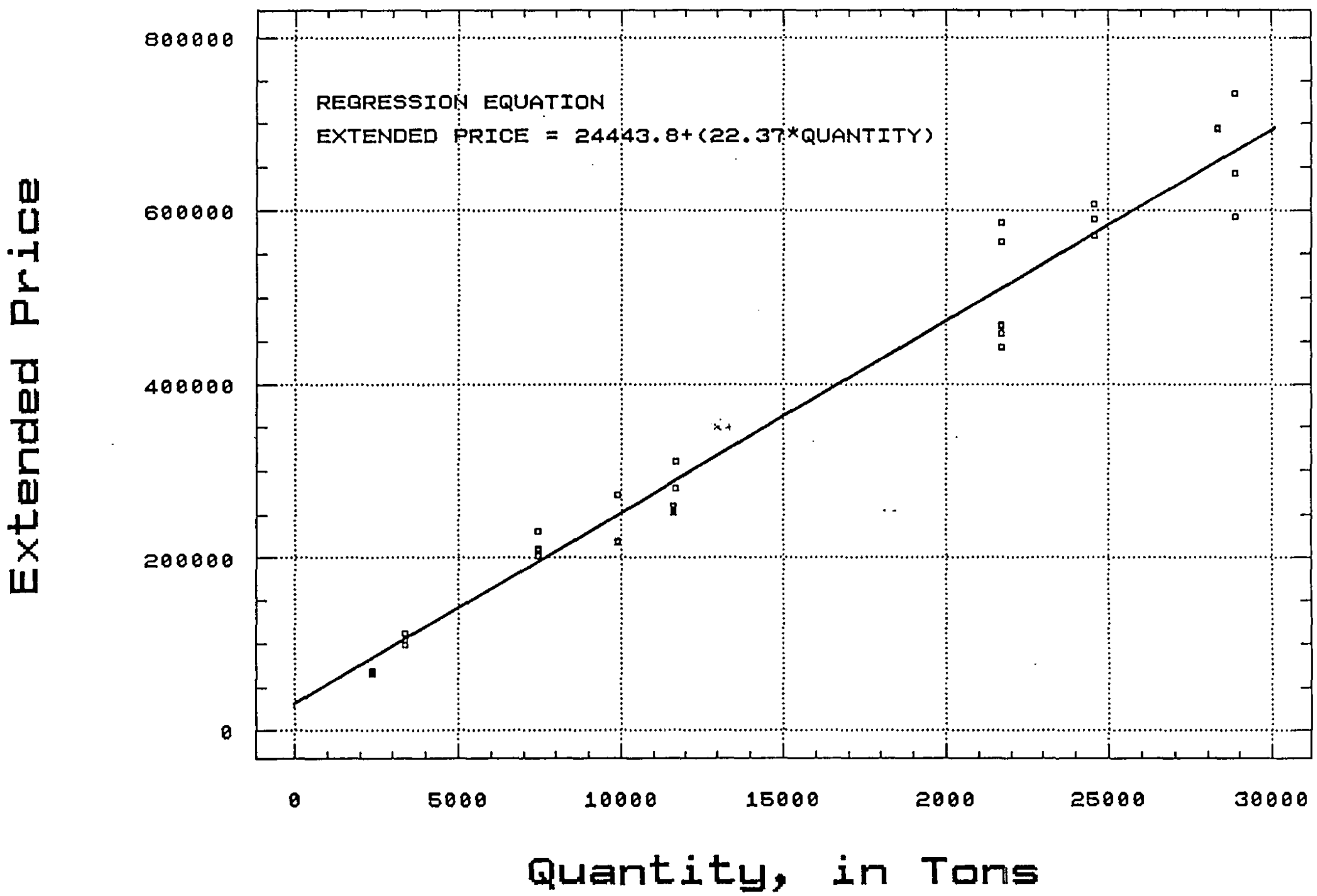

Figure A.3 Item 327A Plant Mix Bituminous Base

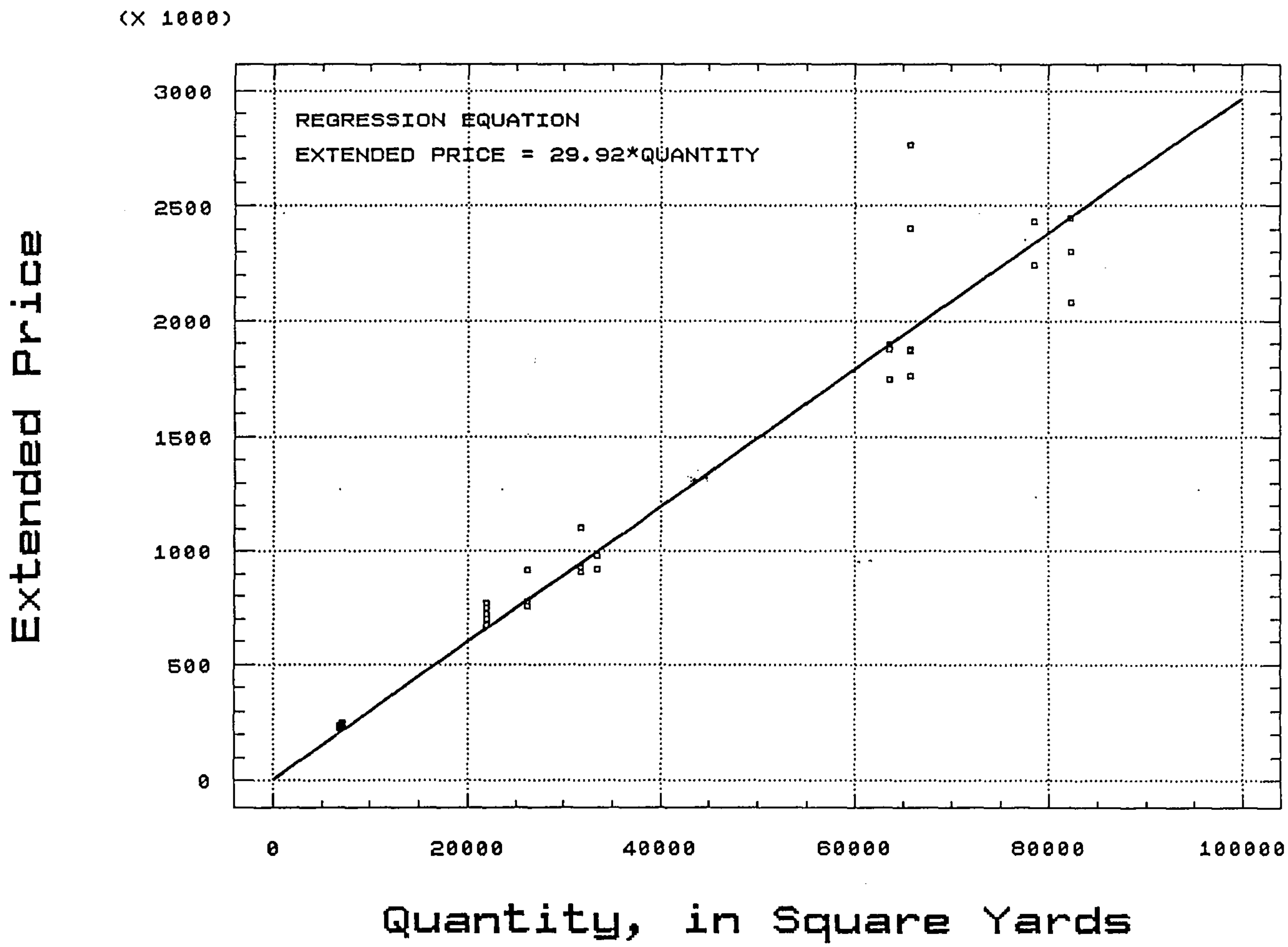

Figure A.4 Item 450A Reinforced Cement Concrete Pavement

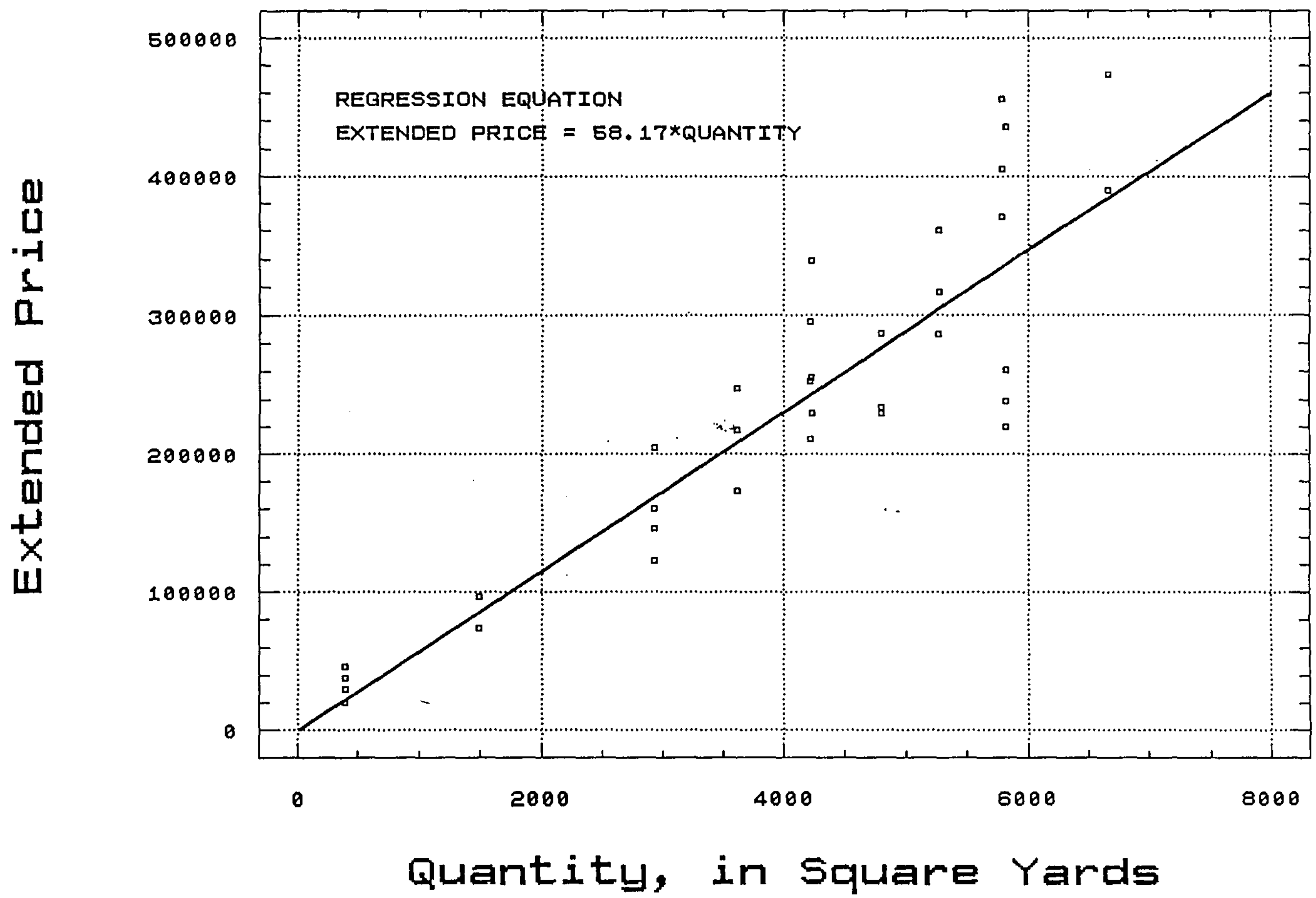

Figure A.5 Item 450B Reinforced Concrete Bridge End Slab

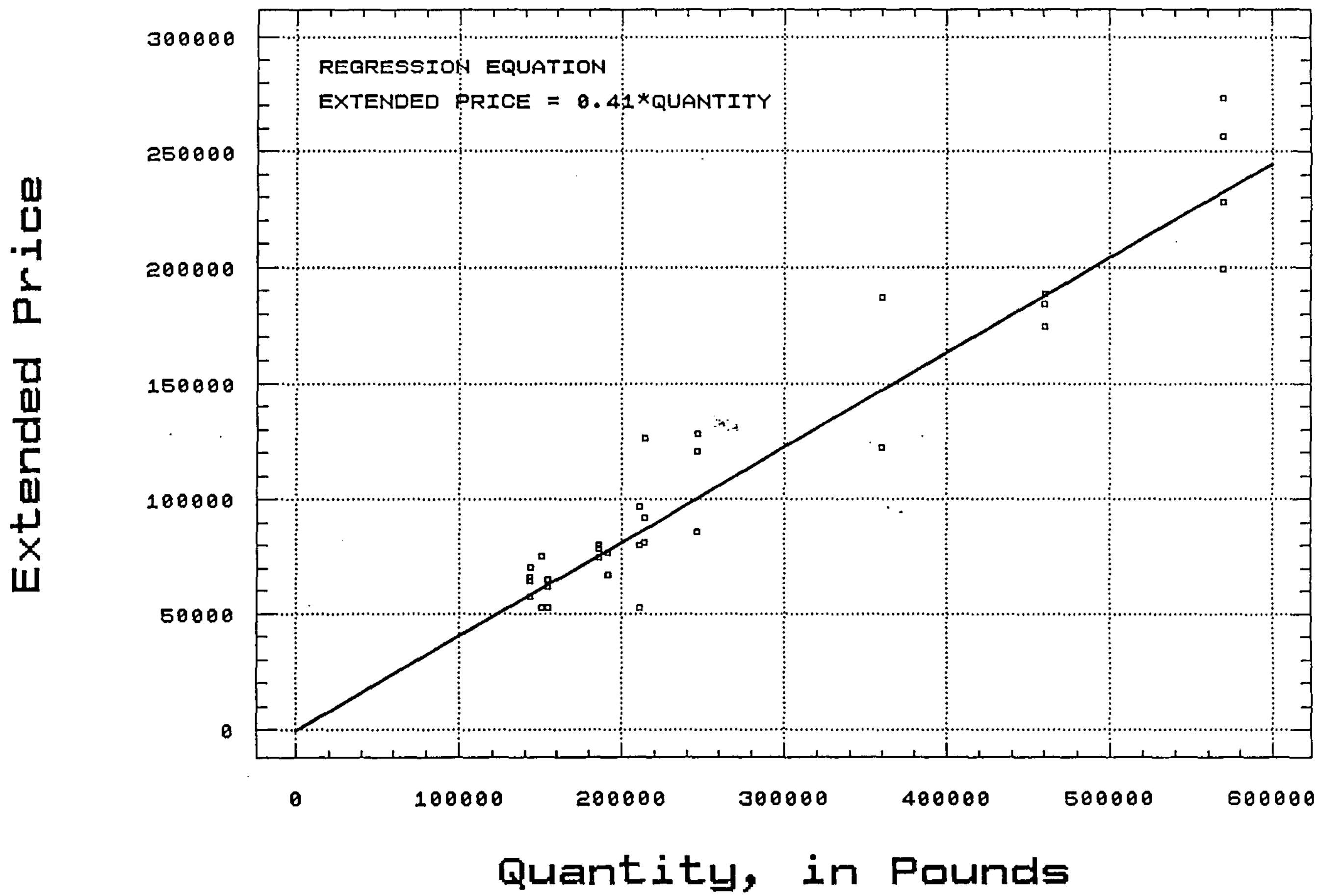

Figure A.6 Item 502A Steel Reinforcement

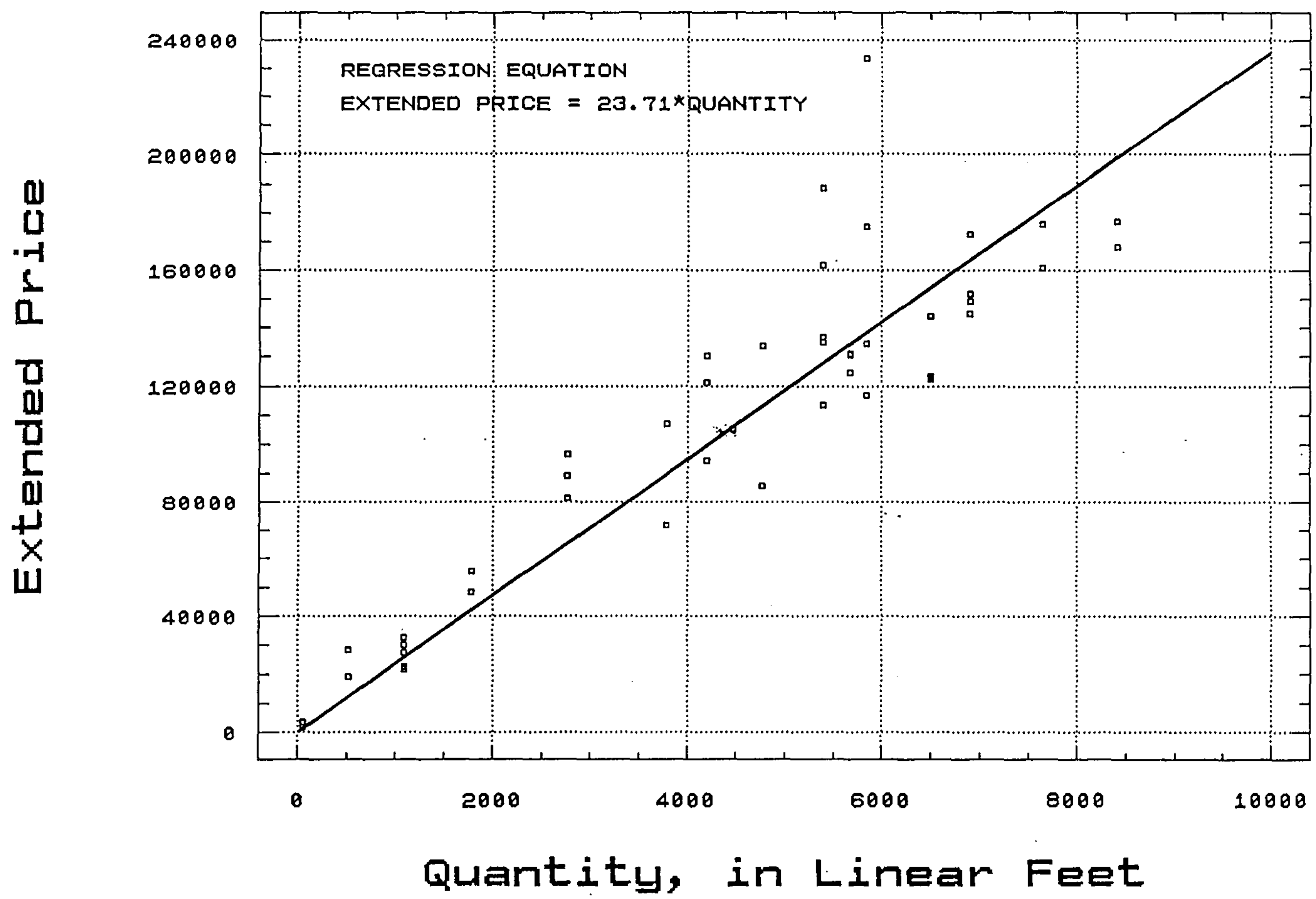

Figure A.7 Item 505C Steel Piling

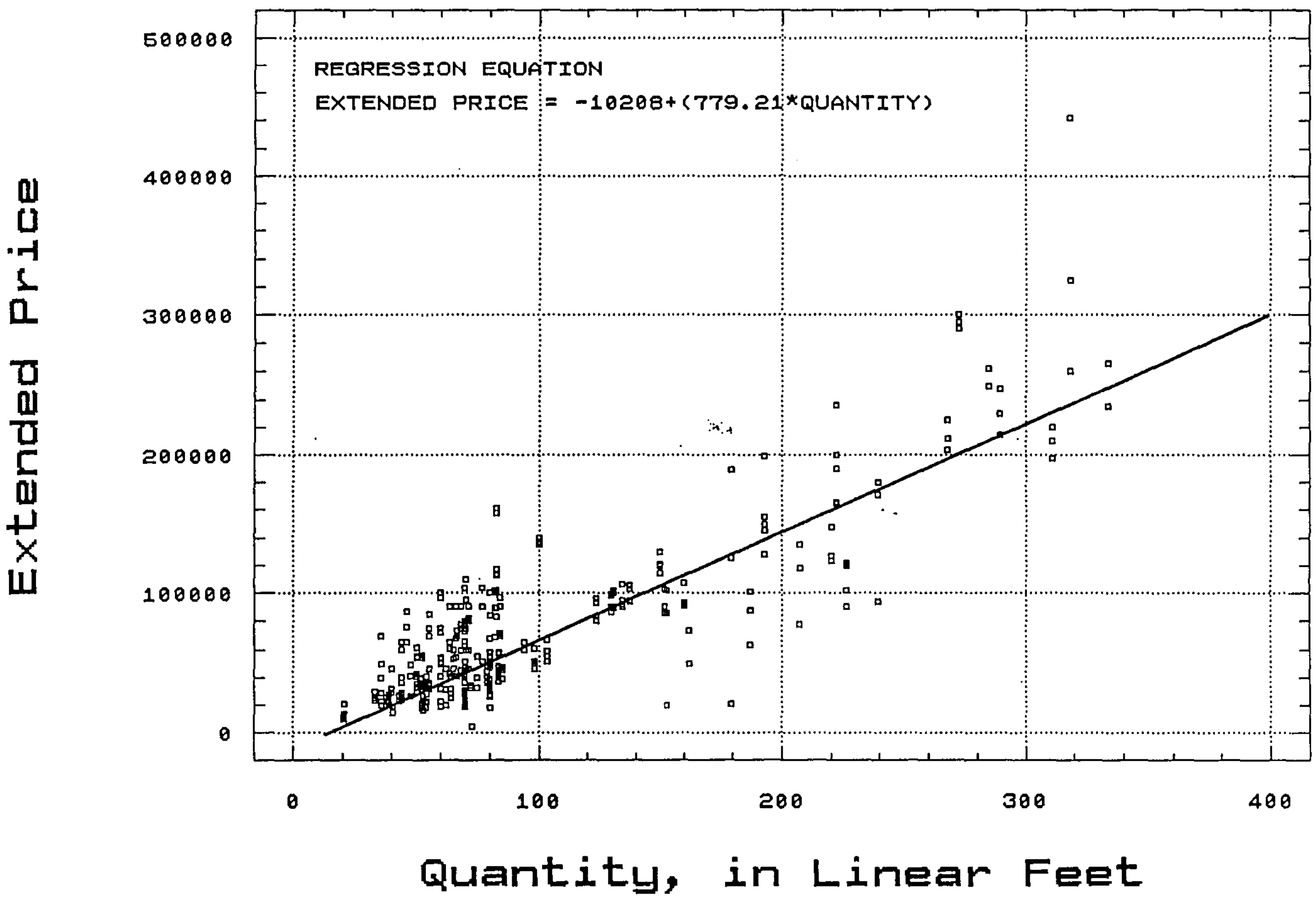

Figure A.8 Item 508B Structural Steel Superstructure

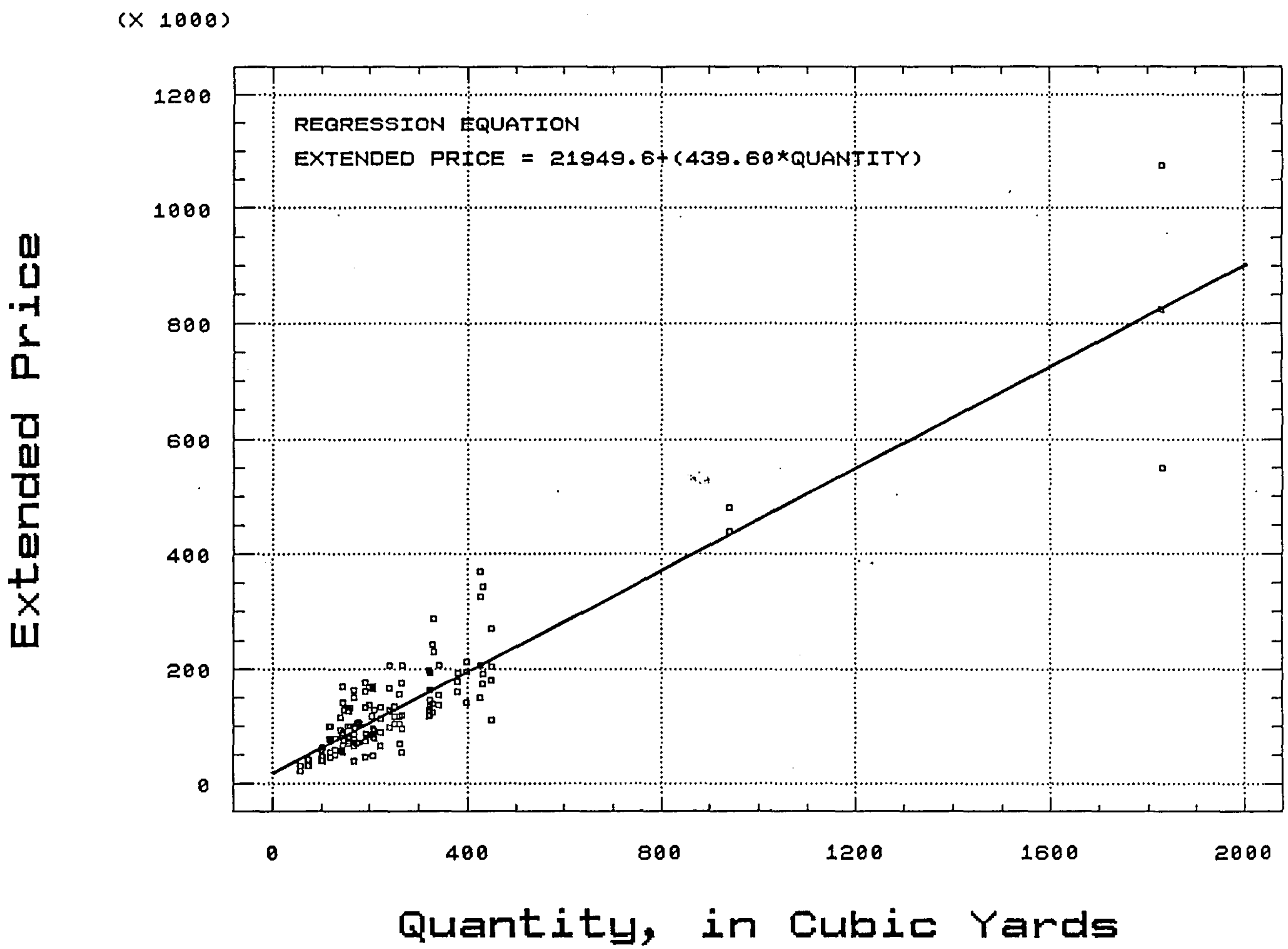

Figure A.9 Item 510C Reinforced Concrete Superstructure

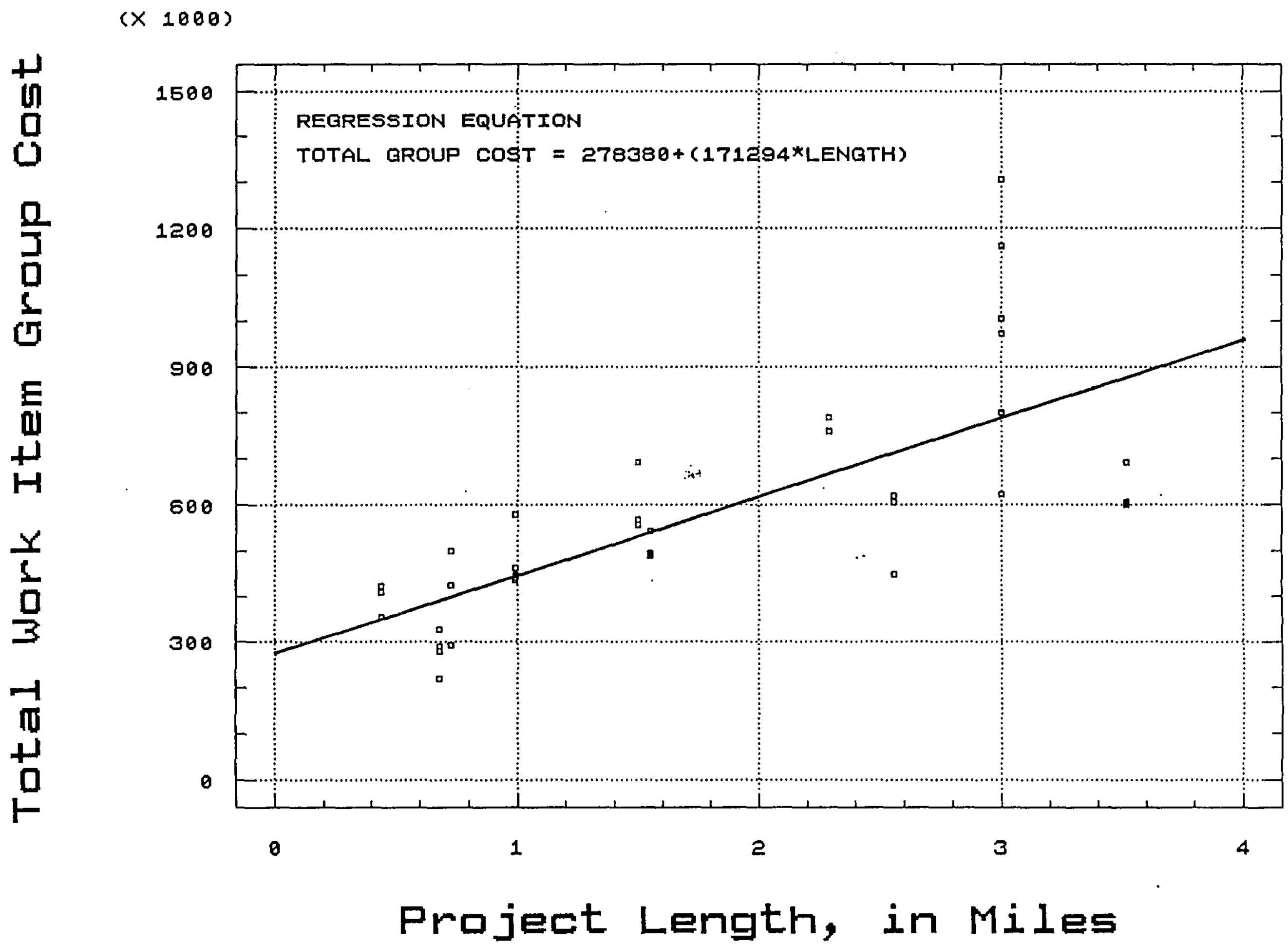

Figure A.10 Safety/Traffic Control