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Economic Analysis of Experimental Lead Paint Abatement Methods: Phase I

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[2] Located at Boulder, Colorado 80302.

Economic Analysis of Experimental Lead Paint Abatement Methods: Phase I

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PREFACE

This research was conducted under the sponsorship of the Department of Housing and Urban Development as a supporting economics effort for the Office of Housing and Building Technology, in the Center for Building Technology, Institute for Applied Technology, National Bureau of Standards. This report, prepared by the Building Economics Section, analyzes the direct cost figures for lead-based paint abatement collected during Phase I of the Experimental Hazard Elimination Program (EHEP) and provides public and private decision makers with a procedure for estimating the direct costs of lead-based paint abatement.

Appreciation is extended to Dr. Harold E. Marshall, Building Economics Section, who reviewed the economic aspects of this paper. Appreciation is also extended to Dr. Stephen F. Weber, Building Economics Section, and Mr. Harvey W. Berger, Office of Housing and Building Technology, who provided useful suggestions for improving the treatment of certain topics in this paper. Special appreciation is extended to Dr. Joseph G. Kowalski, Building Economics Section, for his valuable assistance throughout the preparation of the paper.

Economic Analysis of Experimental
Lead Paint Abatement Methods: Phase I

Robert E. Chapman

Public and private concern about the potential for lead poisoning in children due to the ingestion of lead-based paint chips has resulted in a Federally sponsored program to develop technologies by which the lead-based paint hazard may be eliminated from the nation's housing. Through this program lead-based paint abatement techniques were tested in field deleading operations conducted in Washington, D.C., and Atlanta, Ga. The program also focused on the collection of data on the direct costs of labor, materials and special equipment associated with these abatement techniques.

This report provides a statistical analysis of this direct cost data by abatement technique and building component (i.e., walls, doors, door frames, windows and frames, and miscellaneous trim). Abatement techniques are ranked according to their relative costs. A cost model is developed for each ranking which identifies the key factors which affect direct cost and provides a framework whereby direct costs may be estimated. Recommendations are made for further refinement of the model; a methodology through which the optimal combination of lead-based paint abatement techniques can be identified is also outlined.

Key words: Abatement; building economics; building materials; economic analysis; housing; lead-based paint; lead poisoning.

EXECUTIVE SUMMARY

Lead poisoning in children through the ingestion of lead-based paint chips is a serious health problem in American housing. Interest in how to eliminate the lead-based paint hazard from housing has lead to the passage of the "Lead-Based Paint Poisoning Prevention Act" (PL 91-695) in January, 1971. Through this Act Congress has delegated to the Department of Housing and Urban Development (HUD) the leadership role in the research and development of technologies by which the lead-based paint poisoning hazard may be eliminated from the nation's housing. One part of HUD's research role has been the formulation of the Experimental Hazard Elimination Program (EHEP). This program is intended to aid in the identification of potential lead-based paint abatement techniques and to gather data on the direct costs associated with these techniques. An economic model is needed to determine the efficiency of the potential lead-based paint abatement strategies.

This study analyzes the direct cost data collected in two cities, Washington, D.C., and Atlanta, Ga., during Phase I of EHEP. Additional cost data, which will facilitate the analysis of variations both in direct costs and a contractors' bid price, are currently being collected in Boston, Mass., under Phase II of EHEP. The Phase I direct costs associated with each abatement technique are analyzed by building component (walls, doors, door frames, windows and frames, and miscellaneous trim). The per unit direct costs (per square foot, per item, per linear foot) are presented as are statistical analyses of per unit direct costs at the dwelling unit level. The various abatement techniques are then ranked according to their per unit direct costs. These categories (rankings) are so designed that every abatement technique in the same category has comparable per unit direct costs whereas those in another

category have significantly higher or lower per unit direct costs. For example, there were 9 different wall abatement techniques used during Phase I of EHEP with average per unit direct costs varying from $0.20 to $1.65 per square foot. When these abatement techniques were tested to see if any significant differences in per unit direct costs existed, 4 categories resulted. The 4 categories in increasing order of per unit cost were (1) painting techniques, (2) mixed techniques (plastering, wallboard and fabric coverings), (3) plastering techniques, and (4) paneling techniques. Furthermore, in addition to similarity of costs within a category, some of the abatement techniques also exhibited similarities in the method of application (e.g., the various painting techniques included in category 1). Cost models were then formulated for each category, within which those variables which have the greatest impacts on direct cost are identified and the impacts quantified.

The cost models presented in this report have been formulated in such a manner that variations in per unit direct cost due to the quantity of surface abated, prevailing wage rates, the productivity of labor, or the size of the abatement contract are captured. Since this method of cost estimating addresses the major sources of variation in direct cost, it also captures differences in direct costs due to regional effects. Thus most of the cost models may be used with confidence in most demographic regions of the nation as a means whereby decision makers can estimate the direct costs of lead-based paint abatement.

An alternative cost-estimating method based on the cost models developed with the Phase I EHEP data is also discussed which permits the prediction of per unit direct cost through the use of a graphical procedure.

Since many of the techniques used for lead-based paint abatement are useful in the rehabilitation or renovation of housing, the cost models developed in this report can also provide a reliable procedure for obtaining estimates for the direct costs of certain aspects of rehabilitation.

A comprehensive cost estimating model which could aid in the identification of that combination of lead-based paint abatement techniques which are economically optimal is shown to require a broader view of costs than that provided by direct costs. It is demonstrated that total project costs, which include the contractors' markup, should be considered to ensure that those strategies for lead-based paint abatement which are least cost will be selected.

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SI CONVERSION UNITS

The conversion factors and units contained in this report are in accordance with the International System of Units (abbreviated SI for Systeme International d'Unites). The SI was defined and given official status by the 11th General Conference on Weights and Measures which met in Paris in October 1960. For assistance in converting U.S. customary units to SI units, see ASTM E 380, ASTM Standard Metric Practice Guide, available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA. 19103. The conversion factors for the units found in this Standard are as follows:

Length

1 in = 0.0254* meter

1 ft = 0.3048* meter

1 mil = 0.001* in

Area

1 in^2 = 6.4516* x $10^{-4} meter^2$

1 ft^2 = 0.0929 $meter^2$

Volume

1 in^3 = 1.639 x $10^{-5} meter^3$

1 liter = 1.00* x $10^{-3} meter^3$

Mass

1 grain = 6.479 x 10^{-5}kilogram

1 ounce-mass (avoirdupois) = 2.835 x 10^{-2}kilogram

1 pound-mass (avoirdupois) = 0.4536 kilogram

Pressure or Stress (Force/Area)

1 inch of mercury (60°F) = 3377 newton/$meter^2$

1 pound-force/inch (psi) = 6894 newton/$meter^2$

---

*Exactly

Energy

1 inch-pound-force (in-lbf) = 0.1130 joule

Plane Angle

1 degree (angle) = 1.745×10^{-2} radian

Power

1 watt = $1.00^{*} \times 10^{7}$ erg/second

Temperature

°C = 5/9 (Temperature °F - 32)

---

*Exactly

1. INTRODUCTION

1.1 Background (The Experimental Hazard Elimination Program (EHEP))

Lead poisoning represents a serious problem to the health and well-being of the nation's children. The disease, as indicated by elevated blood lead levels, has been estimated to affect approximately 600,000 children below the age of seven.[1] There are a number of potential environmental sources of lead, including leaded gasoline, food and water, as well as lead-based paint.

Lead-based paint (LBP) poisoning is presumed to be precipitated by the ingestion of LBP chips. The nature of LBP poisoning is such that children, usually between the age of one and seven, are the primary victims. Many children in this age bracket have a natural tendency to place foreign objects into their mouths. Also they are usually unable to distinguish a potentially dangerous substance from one that is not dangerous. Therefore, LBP chips may be eaten without the child realizing that lead poisoning may result. And if illness should result, the child may not associate the effect with the eating of LBP chips. The disease is most acute among children who suffer from pica, or the abnormal craving for unnatural food substances. The greatest potential for LBP poisoning may therefore exist in dwelling units where young children have access to LBP chips which have fallen to the floor or are easily picked or dislodged from a painted surface.

LBP is found primarily in older housing, especially those units constructed before 1950. Before the advent of modern coatings technology, LBP was considered to be the most durable paint available for

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[1] Judith F. Gilsinn, Estimates of the Nature and Extent of Lead Paint Poisoning in the United States, National Bureau of Standards, Technical Note 746, December 1972, p. 104.

residential use. A recent survey involving a random sample of approximately 3,300 dwelling units in Pittsburgh, Pennsylvania, indicated that approximately 1,900 dwelling units had a lead content (on at least one wall) of 2.0[1] milligrams per square centimeter (mg/cm^2) or more.[2] This survey also revealed that approximately 62% of all dwelling units constructed before 1940 and that slightly over 31% of all dwelling units constructed between 1940 and 1960 had lead contents of 2.0 mg/cm^2 or more on at least one wall. It was also revealed in this survey that lead-based paint was used in a significant number (approximately 13%) of dwelling units constructed after 1960. The Pittsburgh survey provides some measure of how widespread the use of lead-based paint was in housing in the Middle Atlantic geographical region. It can also give some insight into what proportion of the nation's housing contains lead-based paint.

A national estimate prepared in 1972 indicated that approximately 7,750,000 or about 27% of the 29,000,000 pre-1940 dwelling units were deteriorating or dilapidated and also contained LBP.[3] Data collected during the Pittsburgh survey indicated that 32% of the pre 1940 dwelling units had peeling paint or poor substrate conditions which can be used as a surrogate for deterioration or dilapidation. Thus the two figures (of 27% for the initial estimate and 32% in the Pittsburgh

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[1]A lead content of 2.0 mg/cm^2 is used in this illustration due to potential measurement inaccuracies of the lead detection instruments at lead levels below 2.0 mg/cm^2.

[2]Based on computer analyses conducted by William Hall, Mathematician, Operations Research Section, Applied Mathematics Division, Institute for Basic Standards, National Bureau of Standards.

[3]Judith F. Gilsinn, Estimates of the Nature and Extent of Lead Paint Poisoning in the United States, National Bureau of Standards, Technical Note 746, December 1972, p. 136.

Survey) for the proportion of all pre 1940 dwelling units which represent lead paint hazards are roughly comparable.

The magnitude of the problem has stimulated a great deal of interest and concern from private individuals and public officials alike. This increased interest resulted in the "Lead-Based Paint Poisoning Prevention Act" (PL 91-695) enacted by Congress on January 13, 1971 and amended (PL 93-151) on November 9, 1973, and established the need for Federal participation.

Through the "Lead-Based Paint Poisoning Prevention Act," Congress has delegated to the Department of Housing and Urban Development (HUD) the leadership role in developing the technical information which is required to determine the abatement procedures which will effectively abate LBP hazards and which will promote economic efficiency in the allocation of resources to eliminate high levels of LBP in housing. The Experimental Hazard Elimination Program (EHEP) is intended to contribute to the accomplishment of these goals in two ways. First, it permits the technical evaluation of experimental LBP abatement techniques in field deleading operations. Second, through the collection of data on direct costs it provides a framework for estimating the costs of future LBP hazard abatement operations.

The EHEP deleading operations involved the abatement of hazardous levels of LBP in 110 housing units during Phase I. Thirty dwellings were initially deleaded in Washington, D.C.; the remaining 80 were deleaded in Atlanta, Georgia shortly thereafter. Information on the technical and engineering aspects of the Washington and Atlanta portions of Phase I is given in The Demonstration of Experimental Lead Paint

Hazard Abatement Methods in Washington, D.C.,[1] and The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Atlanta, Georgia.[2]

1.2 Purpose

Under Title III of the "Lead-Based Paint Poisoning Prevention Act," HUD was directed by Congress to conduct a research program which would facilitate the development of technologies by which the LBP hazard could be eliminated. Implicit in Title III is an analysis of the associated costs of LBP abatement.

The purpose of this report is to present an analysis of the direct costs of experimental abatement techniques based on an evaluation of cost data collected in two cities, Washington and Atlanta, during Phase I of EHEP. The analysis of this data will aid in the identification of those hazard abatement techniques which promote economic efficiency at the dwelling unit level. Cost estimating procedures based on the Phase I EHEP data are proposed that (1) rank LBP abatement techniques with regard to their relative costs, (2) identify those variables which have greatest impact on direct costs, and (3) provide computational and graphical procedures for estimating direct costs of deleading applicable to future LBP hazard abatement operations.

1.3 Scope and Approach

The focus of this study is on Phase I of HUD's Experimental Hazard Elimination Program.

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[1] Thomas H. Boone, Harvey W. Berger, A. Philip Cramp, Herbert A. Jackson, The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Washington, D.C., National Bureau of Standards, Interagency Report 75-761, June 1975.

[2] Thomas H. Boone, Harvey W. Berger, A. Philip Cramp, Herbert A. Jackson, The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Atlanta, Georgia, National Bureau of Standards, Interagency Report 75-974, December 1975.

The emphasis of this study is on the analysis of direct cost data from field deleading operations undertaken in Washington and Atlanta. The analysis of the data is directed at the formulation of a cost model which provides a methodology for the estimation of direct costs at the dwelling unit level.

The available cost data was analyzed by building component, i.e., walls, doors, door frames, windows and frames, and other miscellaneous trim. The various abatement techniques utilized within a building component were compared and contrasted to determine if some form of ranking was possible. Once abatement techniques were grouped into categories with regard to their relative costs, the determinants of direct cost were hypothesized and relevant functional relationships established. Suggestions for further research which will refine the procedures developed with the Phase I EHEP data are given in the remainder of this report.

In its focus on cost estimation, this study does not attempt to develop a methodology for the definition and quantification of benefits to be derived from LBP hazard abatement. Nor does it attempt to estimate future costs or life-cycle costs resulting from maintenance or repair necessitated by lack of long-term durability of an abatement technique. The data collected from Phase I of EHEP did not allow the identification and quantification of the sources and determinants of variations in markup over direct costs. In the absence of information on the potential benefits to be derived from abatement, expected future costs, and associated markups, no attempt was made to identify the economically optimal abatement technique at either the dwelling unit level or the national level. Similarly, incentives for large-scale abatement programs such as cost-sharing and low-interest loans are not treated.

2. DESCRIPTION OF PHASE I EHEP

2.1 Site Selection

The selection of candidate cities for field deleading operations reflected both the desire for the collection of meaningful cost information and the constraints under which this portion of EHEP had to operate. Since the allocation of EHEP resources did not involve LBP abatement in privately owned dwellings, the availability of housing owned by the Federal government or local housing authorities had to be considered in the selection of a candidate city. Furthermore, in order to obtain a cross section of housing types, in addition to HUD-owned properties, some local housing units were required to be included. Thus the interests and willingness of local housing authorities to participate in EHEP had to be assessed. Lead poisoning incidence data for cities were then reviewed to see if the incidence of elevated blood lead levels was high, since it was hypothesized that this would be a strong indication that the number of dwelling units with acute lead levels was also sizable. Implicit in these considerations was that the city should have housing representative of those types and ages of dwellings deemed likely to contain hazardous levels of LBP.

2.1.1 The Selection of Washington, D.C.

A preliminary review of available data for cities indicated that Washington had a relatively high incidence of children with elevated blood lead levels. Furthermore, investigation of census tract data showed that there exists within the city a varied stock of housing types which are deemed likely to contain hazardous levels of LBP.

Early discussions with District officials laid the groundwork for a cooperative agreement between HUD, the National Bureau of Standards

(NBS) and the National Capital Housing Authority (NCHA)[1]. This agreement coupled with the proximity of HUD and NBS facilitated both the implementation and control of this portion of Phase I. Interactions between HUD, NBS, NCHA and the contract management firm, the Boeing Aerospace Company, indicated that several modifications could be made in Phase I which would significantly enhance overall program performance. These modifications improved efficiency in screening, selection and monitoring of dwelling units as well as in data collection.[2]

2.1.2 The Selection of Atlanta, Georgia

Once the initial field operations were underway in Washington, the selection of a second city with a larger number and variety of housing units which could be tested was necessary to complete Phase I of EHEP.

Atlanta was a likely candidate because of its high incidence of elevated blood lead levels. There was also a large stock of housing owned by the local housing authority which was easily available for abatement. In addition, Atlanta's census tract data indicated that it had those housing types which are most likely to contain hazardous levels of LBP. There was also a strong indication that the construction and material types involved were representative of the Southeast as a demographic region. Finally, the availability of approximately 600 dwelling units acquired by HUD through default on HUD insured mortgages presented the opportunity to gather abatement costs on single-family dwellings.

2.2 Dwelling Unit Selection

Implicit in the selection of dwelling units for abatement was the requirement of the overall program to collect meaningful cost information.

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[1]Thomas H. Boone, et al., The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Washington, D.C., p. 7.

[2]Ibid., p. 7.

In order to be able to retrieve the most usable information from the experiment, it was necessary to select enough dwelling units so that statistical testing would be possible. To do this efficiently, some form of experimental design was required to distribute the appropriate number of dwelling units according to some attribute or combination of attributes, such as construction type, age of the dwelling, substrate condition (i.e., the underlying material to which the paint film adheres), or occupancy status.[1] The reliability of statistical comparisons is facilitated when constraints are placed on variables such as the geographical distribution of the dwelling units and the maximum and minimum surface which can be abated. If adequate control is not exercised in the form of experimental design and variable constraints, the ability to estimate per unit direct costs is unnecessarily complicated. In fact, if relevant constraints are removed, the potential sources of variations increase rapidly and may confound the data so that the confidence with which statistical tests can be applied and considered relevant is significantly reduced.

Once a pool of dwelling units had been selected from the overall stock of housing, a team was sent to each dwelling to ascertain whether or not the units contained hazardous levels of LBP. The team was equipped with a portable x-ray flourescence (XRF) lead detector with which lead level readings were taken and recorded. The physical measurements and other attributes of the units were also taken and recorded at that time.

Any unit for which abatement was to take place had to satisfy a set of three selection criteria, outlined below, as well as fit a housing

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[1] In both portions of Phase I a housing sample selection plan was formulated. Problems in implementing these plans with available housing however, resulted in departures from the experimental design set forth in the housing sample selection plans.

sample selection plan. The three criteria set constraints on acceptable lead content, on physical conditions, and on LBP locations and surface dimensions.

Throughout Phase I of EHEP, a hazardous level of LBP was said to exist if a dwelling unit had painted surfaces which revealed a lead content of 2.0 milligrams per square centimeter or more.[1] Second, a hazardous level of LBP was said to exist if the paint was cracked, scaling, peeling or chipping, or there was LBP painted trim within four feet of the floor.[2] The third criterion was that the unit had to have surfaces requiring abatement that satisfied at least one of the following constraints: 500 square feet of wall area; four windows; four doors; or 50 linear feet of miscellaneous trim. Finally, the unit had to fit the housing sample selection plan.

2.2.1 Dwelling Unit Selection in Washington, D.C.

All dwelling units which had hazardous levels of LBP abated in Washington were selected from the National Capital Housing Authority (NCHA) housing stock. This stock comprises about 12,000 units the majority of which are in large apartment complexes. Most of the 50 NCHA apartment complexes are relatively new, only 10 having been built before 1945. There are also between 300 and 400 single-family units within the jurisdiction of the NCHA, the majority of which were constructed before 1940.

During the course of the survey only single-family attached and multi-family low rise units were found to meet the criteria for lead

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[1]Standards as to what is the minimum level of lead content above which it is considered hazardous may vary from city to city. The definition cited above was selected due to the potential inaccuracies of the instruments used in this phase of EHEP at lead levels below 2.0 mg/cm^2.

[2]Painted trim within five feet of the floor constituted a hazardous level of LBP in the Washington portion of Phase I.

content, physical conditions, locations, and surface dimensions. Of the 30 dwelling units selected for LBP abatement in Washington, 13 were single-family attached, and 17 were multi-family low rise. The multi-family low rise units were distributed between two apartment complexes with 12 and 5 dwelling units each; the single-family attached units were spread throughout the city. All but 3 of the 30 units were occupied. In addition to the high occupancy rate, all units were found to be structurally sound. Thus potential variations in cost due to occupancy status or substrate condition were not identifiable.

The distribution of dwelling units deleaded in Washington is given in Table 2.1.

TABLE 2.1

DISTRIBUTION OF DWELLING UNITS DELEADED IN WASHINGTON, D.C.
BY CONSTRUCTION TYPE AND AGE OF UNIT

Construction Type	Age of Unit			Total
	Pre 1920	1920-1940	1940-1950	
Single-Family Attached	5	7	1	13
Multi-Family Low Rise	0	17	0	17
TOTAL	5	24	1	30

2.2.2 Dwelling Unit Selection in Atlanta, Georgia

The stock of housing available for LBP abatement under Phase I of EHEP in Atlanta, Georgia, consisted of approximately 10,800 units owned by the local housing authority and about 600 units which HUD had acquired through mortgage default. The HUD acquired properties differ from those owned by the local housing authority in that they are primarily single-family detached dwellings.

Eighty units from the local housing authority's stock were screened, of which 48 were found to satisfy the three dwelling unit selection criteria. All 48 of these units were occupied, and they were distributed between three apartment complexes. From the 600 HUD-owned properties, 32 units were selected, all of which were unoccupied.

As in Washington, the condition of the substrate of the dwelling units selected for deleading was relatively good, so that estimates of repair costs were not usually available.

The distribution of dwelling units deleaded in Atlanta is given in Table 2.2.

TABLE 2.2

DISTRIBUTION OF DWELLING UNITS DELEADED IN ATLANTA, GEORGIA BY CONSTRUCTION TYPE AND AGE OF UNIT

Construction Type	Age of Unit			Total
	Pre 1920	1920-1940	1940-1950	
Single-Family Detached	4	23	5	32
Multi-Family Low Rise	0	40	8	48
TOTAL	4	63	13	80

2.3 Abatement Technique Selection

The experimental abatement techniques tested in Phase I of EHEP were selected on the basis of recommendations set forth after an extensive laboratory testing program conducted at the National Bureau of

Standards. Detailed descriptions of the testing procedures, the performance criteria, and the experimental abatement techniques tested are available.[1]

The effective abatement of LBP may be accomplished through three basic methods: (1) paint removal, (2) component replacement, and (3) barrier materials. The method actually used will depend upon the building component to be deleaded. Building components are conveniently grouped into two types: (1) planar surfaces (walls, ceilings, porch decks), and (2) trim (doors, door frames, windows and frames, porch railings and other miscellaneous trim surfaces). For the purposes of this study, doors are separated from door frames as a building component since doors may be physically removed from the dwelling and treated independently of their frames.

A breakdown of the three basic abatement methods into specific techniques exhibiting the building components applicable to that technique is given in Table 2.3. The abatement techniques used in Phase I of EHEP are described briefly in Appendix A. Detailed requirements for the preparation, installation and finishing work as well as construction specifications of the individual abatement techniques may be found in the two reports by Boone et al.[2]

Eight of the sixteen LBP abatement methods demonstrated in Atlanta were used in the Washington portion of Phase I of EHEP. This repetition should be emphasized in that it facilitates the identification and

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[1] David Waksman, John B. Ferguson, McClure Godette, and Thomas Reichard, Potential Systems for Lead Hazard Elimination: Evaluations and Recommendations for Use, National Bureau of Standards, Technical Note 808, December 1973.

[2] The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Washington, D.C., pp. 71-95, and The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Atlanta, Georgia, pp. 78-111.

TABLE 2.3

EXPERIMENTAL METHODS FOR LEAD-BASED PAINT ABATEMENT USED IN PHASE I OF EHEP

METHOD	TECHNIQUE	APPLICABLE BUILDING COMPONENT
PAINT REMOVAL	SOLVENT STRIPPING	ALL TRIM COMPONENTS
	HAND SCRAPING	ALL TRIM COMPONENTS
	ELECTRIC HEAT GUN	ALL TRIM COMPONENTS
	INFRA-RED DEVICE	ALL TRIM COMPONENTS
	PROPANE TORCH	EXTERIOR SURFACES ONLY
	DIP TANK	DOORS ONLY
COMPONENT REPLACEMENT		ALL TRIM COMPONENTS
BARRIER MATERIALS	CEMENTITIOUS COATING	WALLS & BASEBOARDS
	FILLED PAINT	WALLS
	GYSUM JUTE	WALLS
	GYPSUM FIBERGLASS	WALLS
	VINYL-COATED FABRIC	WALLS
	VENEER PLASTER	WALLS
	PLASTER WITH LATH	WALLS
	GYPSUM WALLBOARD	WALLS
	PLYWOOD	FLOORS
	MELAMINE PANELING	WALLS

determination of variations in costs or quality of workmanship resulting from regional differences, different housing conditions and types, the availability of local labor, the prevailing labor rates, and the types of contractors performing the abatement.

2.4 Assignment of Abatement Techniques to the Stock of Dwelling Units

The collection of meaningful cost information from the dwelling units selected for LBP abatement hinges on a methodology through which factors contributing to the variation in direct cost can be adequately determined and measured. Recognition of this problem as well as other constraints, such as contractor unfamiliarity with some abatement techniques, prompted the formulation of a set of package plans. These package plans were designed to tailor the abatement techniques to meet the specific requirements of the individual dwelling unit. The use of the package plans also provided some assurance that each abatement technique would be used at least once.

The combinations of abatement techniques used in the package plans was a synthesis of laboratory test results and engineering judgment. Though the rationale behind the formulation of the package plans was sound, it did not guarantee that abatement techniques would be assigned in such a way that the cost data collected could be rigorously analyzed.

The package plans implemented during Phase I were of two basic types, reflecting the need for different methods for planar surfaces and trim. Due to their composition and size, planar surfaces such as walls and ceilings, generally require some form of barrier material. Scraping and sanding is an alternative, albeit one which can produce sizable quantities of leaded dust. Wall surfaces in bathrooms and kitchens (wet walls) present additional problems with regard to adhesion since in these areas moisture may cause separation of the barrier material from the wall. This moisture may also accelerate the aging process so much so that the barrier material rapidly becomes ineffective. The abatement requirements for trim components such as doors or windows differ from those of planar surfaces in that the former components are usually designed to be operable by the occupant (e.g., adjusting ventilation by opening or closing a window). Thus the application of barrier materials to some trim components would generally not be acceptable since it would severely limit the usefulness of these components. For trim components there is also the question of taste and overall finished appearance. Hence LBP abatement for trim components may be more easily accomplished through the use of a paint removal or component replacement method.

Once special conditions such as unsound substrate, inoperable doors or windows, or deterioration of other trim had been noted and assessed, the dwelling units were assigned to the various package plans through engineering judgment.

The distributions of dwelling units deleaded in Series I (planar surfaces) and Series II (trim) package plans in Washington and Atlanta are given in Tables 2.4 and 2.5 respectively. It should be noted that Series I and Series II package plans are independent of each other; that is, the trim deleaded in package plan I A may or may not use the same set of abatement techniques as the trim deleaded in package plan II A. The abatement techniques assigned to the Series I and Series II package plans for each city are given in Appendix B.

2.5 Format and Methodology for Cost Data Collection

Upon the completion of the assignment of the abatement techniques to the stock of dwelling units, competitive bids were solicited from local contractors. Explicit in these bids were requirements for the reporting of all direct costs for labor and materials. It should be noted that direct cost figures differ from bid price figures in that

TABLE 2.4

THE DISTRIBUTION OF DWELLING UNITS ASSIGNED TO SERIES I AND SERIES II PACKAGE PLANS IN WASHINGTON, D.C.

Series	Package Plan							Total
	A	B	C	D	E	F	G	
I	2	2	0	3	0	3	5	15
II	4	3	4	1	2	1	0	15
								30

The abatement techniques used in Series I and Series II package plans in Washington are given in Appendix B.1 and B.2.

TABLE 2.5

THE DISTRIBUTION OF DWELLING UNITS ASSIGNED TO SERIES I AND SERIES II PACKAGE PLANS IN ATLANTA, GEORGIA

Series	Package Plan								Total
	A	B	C	D	E	F	G	H	
I	9	8	8	4	5	4	0	2	40
II	3	3	10	2	6	10	6	0	40
									80

The abatement techniques used in Series I and Series II package plans in Atlanta are given in Appendix B.3 and B.4.

they represent the basic costs to the abatement contractor of labor and materials, and hence exclude any markup for such things as employee fringe benefits, overhead and profit. Phase I data were not collected for estimating all project costs; rather, they were collected to provide more basic information for estimating the quantities and types of labor and materials which are required to perform a relatively unfamiliar construction process.

The direct cost, DC, of an abatement technique may be expressed by the following equation

$$DC = LC + MC \qquad 2.1$$

where

LC = direct labor cost, and

MC = direct material/equipment cost.

Labor costs for each abatement technique were further broken down by component labor skills (e.g., laborer, carpenter and painter). To compute the direct labor cost for a particular skill, it is necessary to have data giving the number of manhours expended to perform the abatement process and the wage rate. The direct labor cost for that skill is then given by the product of the manhours expended and the wage rate. To derive the direct labor cost for a particular abatement technique, the labor costs for the individual skills are summed.

The following equation expresses this concept mathematically

$$LC = \sum_{k=1}^{q} M_k W_k \qquad 2.2$$

where

M_k = the number of manhours expended by the kth skill type,

W_k = the wage rate of the kth skill type, and

q = the number of distinct skills.

The computation of the direct material/equipment cost for each abatement technique is analogous. Each material/equipment type associated with a particular abatement technique is identified. The unit price of the material and quantity consumed are recorded; direct material cost for that material type is calculated by taking their product. To arrive at direct material/equipment cost those material/equipment types required for the abatement technique under consideration are identified; individual material costs are then summed.

This concept may be expressed mathematically by the following equation

$$MC = \sum_{k=1}^{p} U_k Q_k \qquad 2.3$$

where

U_k = the unit price of the kth material/equipment type,

Q_k = the quantity of the kth material/equipment type consumed, and

p = the number of distinct material/equipment types.

The comparison of direct costs is facilitated by the introduction of an average cost measure, which is a function of the total number of units (square feet, item, linear feet) deleaded. This allows cost data to be presented and analyzed on a per unit basis. The resultant figure is denoted per unit direct cost, PDC. As with direct cost, per unit direct cost may be expressed as

$$PDC = PLC + PMC \qquad 2.4$$

where

PLC = per unit labor cost, and

PMC = per unit material/equipment cost.

For purposes of this study, per unit direct cost figures are computed at the dwelling unit level. Another measure which may also be considered is the contract package level. This differs from the dwelling unit level in that a contract package may contain more than one dwelling unit. In this study the contract package level was not used, since it provides less information on variations in wage rates, materials/equipment costs and the productivity of labor. Contract package size was useful however, as a variable in this study since wide variations in the number of dwelling units deleaded by different contractors were experienced in Phase I of EHEP.

The collection of direct cost data outlined above was accomplished through the use of the Dwelling Unit Cost Data Form, a sample of which is shown in Figure 2.1. The form is divided into several parts, each representing a different abatement operation. This form improved the efficiency with which data on each abatement technique could be collected on the preparation, installation and finishing operations of the abatement process. As such it aided in the identification of those portions of the abatement process which were or were not major sources of variations in direct cost figures. Although the Dwelling Unit Cost Data Form did prove satisfactory for the Phase I deleading operations, it has a serious limitation in that whenever extensive abatement work was required in a dwelling unit, it was difficult to separate all of the abatement techniques in a package plan into their respective labor and material/equipment components.

As mentioned earlier, abatement contractors were required to report direct cost figures to the contract management firm. The method of recording cost figures from abatement contractors however differed between Washington and Atlanta. This resulted from a desire to improve both the efficiency and accuracy with which cost figures were reported.

In Washington, cost data was collected after all abatement work was completed. Unfortunately, the length of time between the start and

CONTRACT NUMBER: ADDRESS:

Operation (Series II Package Plan)	Material/Equipment		Sq. Ft Lin. Ft	Labor	
	Type	Quant.		Man-Hours	Wage Rate
A. Paint Removal or Replacement:					
Doors Door Frames Windows and Frames Other Misc. Trim Exterior Surfaces					
B. Surface Repair:					
Doors, Windows and Trim Exterior Surfaces					
C. Covering:					
D. Painting:					
Doors Door Frames Windows and Frames Other Misc. Trim Exterior Surfaces					
E. Clean up:					
Door, Windows and Trim Exterior Surfaces					
F. Waste Disposal:					
Door, Windows, and Trim Exterior Surfaces					
G. Other:					

Figure 2.1 SAMPLE DWELLING UNIT COST DATA FORM.

finish of the contract was long enough so that the accuracy with which cost figures were reported may have suffered, especially if adequate records were not kept during the abatement work. Furthermore, all abatement work in Washington was done by the same contractor so that less variations in wage rates, materials/equipment costs and productivity were experienced.

The major changes in the methodology by which cost data were collected in Atlanta involved the reduction of the size of the contract packages so that more contractors were performing abatement work and the added requirement that cost data figures be reported each week. With a variety of contractors it became possible to measure the effects which variations in wage rates and productivity have on direct costs. The collection of cost figures each week strongly encouraged good record keeping and hence improved the reliability of the figures recorded.

3. THEORETICAL ANALYSIS OF BUILDING COMPONENT COST DATA

The building component cost data collected in Phase I of EHEP was analyzed by using a series of statistical tests. Statistical analysis is needed because the data collected from Phase I deleading operations have some degree of uncertainty associated with them. The sources of this uncertainty are basically twofold. First, the data are incomplete in that they contain cost information on only a small sample of what may be denoted as the population of presently available LBP abatement methods. Second, even for the abatement methods tested, the data are based on only a small sample of units, not enough to capture all of the potential sources of variation due to the effects of changes in wage rate, the efficiency of labor, or the size of the abatement contract.

A statistical approach to the data analysis provides a methodology which identifies and quantifies differences which may exist in direct cost at the dwelling unit level. In addition, the use of statistical procedures permits probabilistic levels of significance to be attached to any conclusion regarding differences in direct costs. Furthermore, a statistical approach facilitates the formulation of a model capable of predicting direct costs for abatement techniques at the dwelling unit level.

The level of confidence which can be attached to any conclusion is dependent upon several factors. First, the underlying assumptions for any statistical procedure must be known and must be relevant to the data under consideration. Second, the relative importance of rejecting a hypothesis when it is true or accepting it when it is false must also be assessed.[1] Finally, implicit in all of these considerations is the

[1] The probability of rejecting the formulated (null) hypothesis when it is true is denoted a type I error; the probability of accepting the alternative hypothesis when it is false is denoted a type II error.

trade-off between the size of the sample and the power of the test.[1] These considerations together with output requirements determined this project's statistical approach as detailed in sections 3.1 through 3.5. The reader who is interested primarily in the results of the analysis may proceed directly to chapter 4.

3.1 Statistical Techniques Utilized

To facilitate the analysis of the Phase I EHEP cost data, the statistical procedures of oneway analysis of variance and multiple regression were used. Both were selected because the type and nature of the data collected indicated that rather sophisticated methods were needed. Furthermore, they permit the data to be reduced to a form from which a prediction mechanism can be constructed. The application of these statistical procedures to the cost data was accomplished through the use of the NBS computer package OMNITAB II.[2] OMNITAB II was selected because of its availability and its highly reliable statistical programs. Also, its numerical and graphical output provide an effective way of testing if any of the underlying assumptions have been violated.[3]

The initial testing of the Phase I EHEP cost data involved the analysis of variance for a oneway classification.[4] As a statistical

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[1]The probability of accepting the alternative hypothesis when it is true is denoted the power of the test. Other things being equal, the larger the sample, the greater is the power of the test.

[2]David Hogben, Sally T. Peavy, Ruth N. Varner, OMNITAB II User's Reference Manual, National Bureau of Standards, Technical Note 552, October 1971.

[3]If the power of a test is relatively insensitive to the relaxation of one or more of its underlying assumptions, it is referred to as a robust test. In the absence of robustness some means of testing for the violation of the underlying assumptions is required.

[4]The analysis of variance used here is referred to as oneway since the data being analyzed are subject to only one dimension of classification, the abatement technique.

procedure, the oneway analysis of variance permits the testing of the null hypothesis, whether observed differences among more than two sample means can be attributed to chance, versus the alternative hypothesis, that the observed differences are indicative of actual differences among the means of the corresponding populations.[1] That is, it provides a way to test whether, for a particular building component, the observed differences in direct costs for each abatement technique are attributable to chance versus the hypothesis that they indicate that real differences in direct cost do exist between the different abatement techniques. On the surface this may seem a rather simplistic statement since the chance of having two or more abatement techniques with identical direct costs is very unlikely. Because of uncertainty, however, finding a difference does not necessarily indicate that one is significantly more or less expensive than the other. What is of central importance here is that an analysis of variance approach permits the statement to be made with a given level of confidence that there does or does not exist, for a given building component, a significant difference in direct costs for different abatement techniques.[2]

If after application of the analysis of variance the null hypothesis is rejected, it must be assumed that significant differences do exist in the direct costs for different abatement techniques. Thus it may be possible to rank abatement techniques with respect to their

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[1]An introduction to the analysis of variance is given in K.A. Brownlee, Statistical Theory and Methodology in Science and Engineering, John Wiley and Sons, Inc., 1960. For a more mathematical treatment see H. Scheffé, The Analysis of Variance, John Wiley and Sons, Inc., 1959.

[2]A confidence level of 95% does not mean that the null hypothesis is 95% true; it is either true or false. It implies that if the null hypothesis were true and the experiment were repeated over and over under identical circumstances 95 out of every 100 times the null hypothesis would be accepted.

relative costs. Implicit in this ranking is a predetermined level of confidence[1] which is used to define the appropriate categories in which the abatement techniques are grouped.

The division of the data into categories within which it is reasonable to assume equal average direct costs then permits further analysis across abatement techniques of the structure and determinants[2] of direct cost through the use of multiple regression. Multiple regression may be defined as a statistical procedure for investigating and quantifying the relationship between the dependent or response variable and two or more independent variables.[3]

In the course of the analysis of the Phase I cost data, three measures of direct cost were used as response variables: (1) the per unit direct cost, (2) the per unit labor cost, and (3) the per unit material/equipment cost. Independent variables (those which determine per unit direct cost) included the average wage rate, the quantity of surface deleaded, the productivity of labor, and the contract package size.[4] Throughout the analysis, the structure of the model was assumed to be of the linear form

$$PDC = \beta_o + \sum_{j=1}^{m} \beta_j X_j + e, \qquad 3.1$$

---

[1]For purposes of ranking, a confidence level of 95% was used.

[2]The term structure is used to denote the basic relationship between the variables and how they affect direct cost; determinants refer to specific variables which affect direct costs.

[3]For a general discussion of multiple regression see K.A. Brownlee, Statistical Theory and Methodology in Science and Engineering, John Wiley and Sons, Inc., 1960. For an indepth analysis see N.R. Draper and H. Smith, Applied Regression Analysis, John Wiley and Sons, Inc., 1966.

[4]Precise definitions of these variables will be given in section 3.2.

where PDC = per unit direct cost, the response variable,

β_o = the intercept term,[1]

β_j = the coefficients of the independent variables,

X_j = the independent variables, and

e = the error term.

The methodology through which the underlying structure and determinants of per unit direct cost were analyzed involves a four stage iterative process of (1) selecting a model, (2) estimating the coefficients, β_j, (3) testing the validity of the underlying assumptions, and (4) testing the adequacy of the model. Once estimated, the finalized model can be used as a mechanism with which to predict direct costs for abatement techniques at the dwelling unit level. Under relatively mild assumptions, the regression curves can be plotted, providing a framework for a graphical cost estimating procedure.

3.2 Comparison and Ranking

Initially the data were analyzed through the use of the oneway analysis of variance. The null hypothesis that the per unit direct costs for all abatement techniques within a building component were equal was tested against the alternative hypothesis that per unit direct costs were not all equal. The acceptance or rejection of the null hypothesis was based on whether or not the resulting F ratio was greater than the theoretical F ratio for the predetermined confidence level.[2]

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[1] The intercept term is included since the assumption that the response is zero when all independent variables are zero is a rather strong and usually unjustified assumption.

[2] The acceptance region for the null hypothesis is given by the 95% point of the F distribution with k-1 and $\sum_{i=1}^{k} n_i - k$ degrees of freedom, where k equals the number of abatement techniques and n_i equals the number of experimental observations for the ith technique. The F ratio resulting from the observed data is computed by dividing the among-techniques mean square by the within-techniques mean square.

For the purposes of the experimental LBP abatement program, the set of abatement techniques may be considered to be fixed. This has as a consequence that the type of analysis of variance model under consideration is a fixed effects model.[1]

The data base was prepared for analysis by first separating it into its respective building components.[2] The data were then subdivided within each building component into abatement techniques. To provide an adequate point of reference from which abatement techniques could be compared, they were tabulated with respect to their dwelling units. Once the data base was arranged in this way, it was possible to read the relevant information directly from the Dwelling Unit Cost Data Form. However, before the actual analysis could begin, it was necessary to reduce all cost data to a per unit basis. To accomplish this, the figures for labor costs, material/equipment costs, the quantity of surface deleaded, and the total manhours expended were calculated. At this time several other variables which were involved in the analysis were computed. These were the average wage rate, the productivity of labor and the contract package size. The average wage rate reflects the average wage which would be paid per manhour for a given abatement technique over the complete abatement process. It may be expressed mathematically as

$$AWR = \sum_{i=1}^{n} P_i W_i \,, \qquad 3.2$$

---

[1]This assumption has some interesting theoretical implications, in that it permits, generally speaking, more definitive statements to be made with the same set of data than other analysis-of-variance models. Future studies may indicate that additional abatement techniques are feasible in which case the assumption of a fixed effects model would be a bit stronger than required. In the absence of any such indication, however, it appears that the assumption of a fixed effects model is justified.

[2]It should be recalled that building components denote walls, doors, door frames, windows and frames, and other miscellaneous trim.

where AWR = average wage rate,

P_i = the proportion of the total manhours expended by the ith labor type,

W_i = the wage of the ith labor type,

and

$$\sum_{i=1}^{n} P_i = 1. \qquad 3.3$$

The average productivity of labor is the number of units[1] which can be processed in one manhour, that is the total number of units processed divided by the total manhours. The contract package size is the total number of dwelling units being deleaded by the contractor who is performing the abatement work in the dwelling unit under consideration.

The analysis of variance model was applied to data for each building component on per unit direct cost, per unit labor cost, per unit material/equipment cost, and the productivity of labor. The results of tests on direct cost for each building component are given in chapter 4.

To insure that the underlying assumptions were not violated,[2] two backup tests were used. First, the Cochran C test[3] was used to test the validity of the assumption that the variance of the abatement techniques was the same. Second, should the assumption of an underlying normal distribution be unjustified, the Kruskal-Wallis H test was used.[4] The Kruskal-Wallis H test was selected because it is a non-parametric test which uses the ranks of the experimental observations and avoids any assumption about the underlying distribution.

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[1]Units denote square feet, linear feet, the number of doors, door frames, or windows and frames.

[2]The sample observations assumed to be independent normally distributed random variables with equal variance.

[3]W.J. Dixon and F.J. Massey, Introduction to Statistical Analysis, McGraw-Hill Book Company, 1957, p. 180.

[4]K.A. Brownlee, Statistical Theory and Methodology in Science and Engineering, pp. 194-196.

If the oneway analysis of variance results indicated that the difference between abatement techniques for a particular building component was not attributable to chance, a pairwise multiple comparison of means was performed. The purpose of this test was to group the abatement techniques into categories such that the means of the abatement techniques within a category were not significantly different at the 95% confidence level, but that the means in different categories were significantly different at this level. The grouping into categories was accomplished through the application of the Scheffé method.[1] This method was selected since it did not require an equal number of observations for each abatement technique.[2]

The results of the Scheffé method permitted abatement techniques to be ranked by their direct costs into categories from least expensive to most expensive. If a oneway analysis of variance were applied to the abatement techniques within a given category, the null hypothesis (i.e., equality of means for direct costs) is expected to be accepted.[3] This is due to the way in which the test was formulated.

3.3 Establishment of Functional Relationships

The categories established through the sequence of the analysis of variance and the Scheffé method for pairwise multiple comparison of

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[1] K.A. Brownlee, Statistical Theory and Methodology in Science and Engineering, pp. 252-254.

[2] In the event that an equal number of observations for each technique does occur, the Newman-Keuls-Hartley method may be used. Details of this method are given in G.W. Snedecor, Statistical Methods, Fifth Edition, Iowa State University Press, 1956.

[3] If the 95% confidence interval constructed with the Scheffé method was wide enough, it is conceivable that when an analysis of variance is performed the resulting F ratio would exceed the 95% point of the appropriate F distribution. However, this problem did not arise with any of the Phase I data.

means open the way for the analysis of the underlying structure and determinants of direct cost. The similarity of the structure of direct costs for abatement techniques within a category lends itself to across technique comparisons of variables and the establishment of functional relationships through the use of multiple regression. As mentioned earlier, the form of the multiple regression model was taken to be linear.

To begin the four stage iterative process for the regression model development, four variables were selected for intial testing: (1) the quantity of surface deleaded, (2) the average wage rate, (3) the productivity of labor, and (4) the size of the contract. The response variable for this portion of the model development was per unit direct cost. Attempts were also made for each building component and category to develop separate regression models for both per unit labor and material/equipment costs.

The construction of the regression model was facilitated by the use of two statistical procedures, the sequential F test and the partial F test. These tests were used to assess the relative importance of variables added to the structure of the model. The sequential F test is used to test whether the model is made significantly better by the addition of a particular variable whereas the partial F test is used to test whether the whole model is significantly better than a reduced model which includes this particular variable.[1] Taken in conjunction,

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[1]When the form of the model is given by

$$Y = \beta_o + \sum_{j=1}^{m} \beta_j X_j + e,$$

the sequential F test will tell if

$$Y = \beta_o + \sum_{j=1}^{t} \beta_j X_j + e$$

is significantly better than

(Continued on Next Page)

they permit the deletion of variables which have negligible impact on direct costs and provide a well defined stopping procedure to insure that the model does not become unwieldly.

New variables continue to be added to the model until the values of the partial and sequential F tests are no longer significant. The coefficients of the model variables, β_j, are then estimated through the use of the method of least squares.[1] The method of least squares was chosen because the estimates it provides possess several highly desirable statistical attributes.[2]

(1 continued from preceding page)

$$Y = \beta_o + \sum_{j=1}^{t-1} \beta_j X_j + e,$$

whereas the partial F test will tell if

$$Y = \beta_o + \sum_{j=1}^{m} \beta_j X_j + e$$

is significantly better than

$$Y = \beta_o + \sum_{j=1}^{t-1} \beta_j X_j + e.$$

where $m \geq t > 1$.

[1]The method of least squares provides a methodology where by the sum of the squared difference of the observed and predicted values of the n experiemental observations

$$\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \quad \text{is minimized,}$$

where Y_i = the experimental value of the observations, and
$\hat{Y}_i$ = the predicted value of the observation.

[2]Least squares estimates are both linear combinations of the experimental observations, Y_i, and minimum variance unbiased estimators of the β_i. Furthermore, they exhibit normality whenever the Y_i are normally distributed.

The finalized model is assessed for adequacy through the use of a graphical technique[1] which plots the standardized residuals[2] under the assumption that they are independent normally distributed random variables. This test for adequacy is of great importance since, if the standardized residuals are not independent normally distributed random variables, it is not possible to perform either the sequential or partial F test as an aid in determining when to stop adding variables.[3]

A second test used involved correlation techniques.[4] These techniques describe the linear, statistical, relationship between two normally distributed random variables. As such they provide a tool for identifying potential sources of multicollinearity, a situation that arises when one or more of the explanatory variables provide essentially the same information. Multicollinearity is undesirable since it reduces the precision of the estimates of the β_j. The correlation coefficient takes on values between -1 and +1. Values close to +1 or -1 indicate a high degree of positive or negative correlation respectively.[5] A value of 0 indicates that the two variables are uncorrelated. When variables were found to be highly correlated at the 95% confidence level they were either transformed or deleted from the analysis to prevent the problems for estimation caused by multicollinearity.

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[1]This graphical technique is sometimes referred to as a probability plot.

[2]The standardized residuals are equal to the residuals (the difference between the observed and predicted values) divided by the standard deviation of the predicted values (a measure of dispersion between the observed and predicted values).

[3]This as well as other consequences are outlined in N.R. Draper and H. Smith, Applied Regression Analysis, p. 59.

[4]David Hogben, Sally T. Peavy, and Ruth N. Varner, OMNITAB II User's Reference Manual, pp. 155-162.

[5]Positive correlation means that the values of the two variables move in the same direction; negative correlation means that they move in opposite directions.

To gain some measure of what portion of all variations in direct costs are explained by the finalized model, it was necessary to compute the coefficient of multiple determination, R^2. The coefficient of multiple determination takes on values between 0 and 1, where the closer R^2 is to 1 the more complete the model is at explaining the variations in direct costs. Since the number of observations for the different categories was subject to a great deal of variability, it was necessary to adjust R^2 to reflect both the number of observations and the number of variables used to predict per unit direct cost. This adjusted value of R^2 is denoted $\bar{R}^2$. The observed values of $\bar{R}^2$ for the Phase I data ranged from 0.43 to 0.94. It should be noted that some of these low values resulted since separating data into distinct groups may be a formidable task when problems of interaction occur. The introduction of a dummy variable[1] may relieve this situation somewhat. Examples of uses of a dummy variable to improve the predictive capabilities of the model are dividing wages into union and nonunion pay scales and indicating if a dwelling unit is occupied or not. The two dummy variables just mentioned would not be effective, however, if union scale labor were used only in occupied dwellings and nonunion scale labor only in unoccupied dwellings. This problem did occur in Phase I and as a result relatively low values of $\bar{R}^2$ on some building components are included. To improve the predictive capability of the model for these components would require additional data.

3.4 Graphical Cost Estimating Procedure

Ideally a cost estimating procedure should be both reliable and easy to use. The multiple regression model described earlier has several attributes which make it attractive, especially its ability to

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[1]Dummy variables take on a value of either 0 or 1 depending on whether some specific statement is true or false.

predict direct costs. The finalized form of the regression model was found to be

$$PDC = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + e, \qquad 3.4$$

where

X_1 = the quantity of surface deleaded,

X_2 = the average wage rate,

X_3 = the productivity of labor,

X_4 = the contract package size, and

e = the error term.

When the estimated values of the β_j's (b_j's) are incorporated in the model, it may be written as

$$PDC = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4. \qquad 3.5$$

This basic form may be further simplified with several reasonable assumptions. Under the assumption that productivity and contract package size are held constant,[1] it becomes possible to plot per unit direct cost versus the quantity of surface deleaded. It should be noted that the simplified form of equation 3.5 is given by

$$PDC = b_o' + b_1 X_1 + b_2 X_2, \qquad 3.6$$

where b_o' now reflects b_o, the constant values for productivity, the contract package size, and the estimated values b_3 and b_4.[2]

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[1]The assumption that productivity is constant implies that productivity is independent of the other variables, that is $E(X_3 | X_1, X_2, X_4) = E(X_3) = c$. If this is deemed too strong an assumption, it should be noted that rejecting it would require computing the expected value of X_3 for each set of given values of X_1, X_2 and X_4. It is doubtful that such an endeavor, which would be affected by uncertainty, would produce any better results than that of assuming productivity constant.

[2]The use of the b_j notation reflects that the equation in question contains the estimated values of the β_j's.

For purposes of illustration, consider a certain category of wall abatement techniques. Cost data was collected for wall areas ranging from 300 square feet to 900 square feet. At the same time the respective average wage rate, AWR, varied from \$3.75 to \$8.75 per hour. Using this information, it is possible to construct a family of curves associated with various average wage rates (see Figure 3.1). So that each curve may be easily distinguished, the respective per unit direct costs are denoted PDC_{X_2}, where X_2 denotes the average wage rate. Individual values of X_1 on the curve PDC_{X_2} are denoted PDC_{X_2,X_1}. Taking as initial values for X_2 and X_1 the average wage rate of \$3.75 per hour and the minimum value of wall area deleaded of 300 square feet, the equation for per unit direct cost becomes

$$PDC_{3.75,300} = b_o' + b_1 300 + b_2 \cdot 3.75. \qquad 3.7$$

Holding X_2 constant at \$3.75 per hour and increasing X_1 until it equals the maximum value of wall area deleaded (i.e., 900 square feet), the equation for per unit direct cost then becomes

$$PDC_{3.75,900} = b_o' + b_1 900 + b_2 \cdot 3.75. \qquad 3.8$$

Since the finalized regression model was linear in form, it is possible to connect the two points, $PDC_{3.75,300}$ and $PDC_{3.75,900}$, with a straight line. The resultant curve is denoted $PDC_{3.75}$.

In a similar fashion the curves $PDC_{4.00}$, $PDC_{4.25}$ and so on in increments of 0.25 to $PDC_{8.75}$ may be constructed. Furthermore the PDC_{X_2} curves are parallel with slope equal to b_1 so that the vertical difference between any two curves is constant. This has as the consequence, since the family of curves is infinite, that any per unit cost curve can be approximated arbitrarily closely.[1] However the improvement

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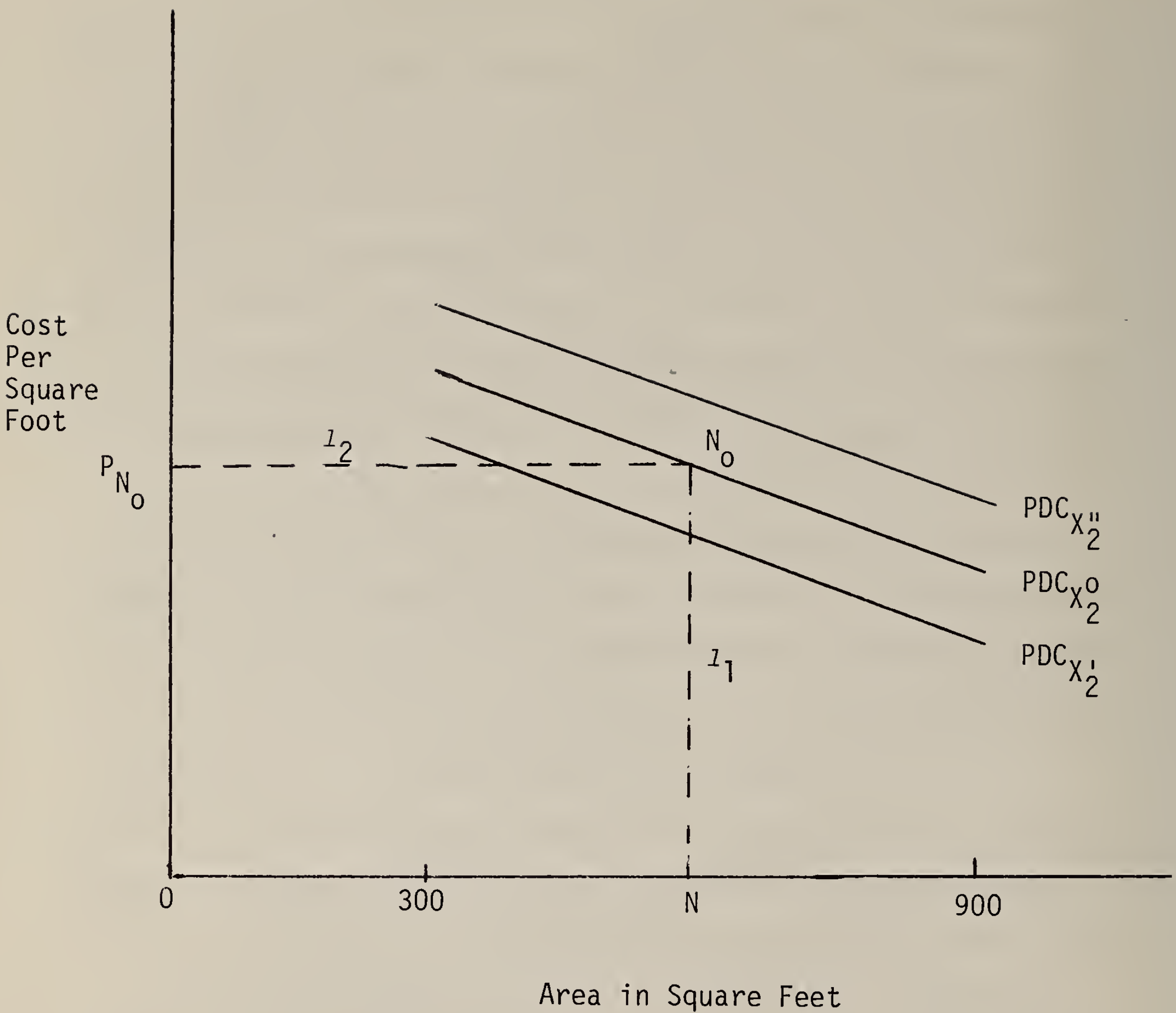
[1]Since the vertical distance between any two curves $PDC_{X_2'}$ and $PDC_{X_2''}$ is a constant d, any curve in between, $PDC_{X_2^o}$, may be determined by dividing $X_2^o - X_2'$ by $X_2'' - X_2'$ and multiplying by d to get the constant distance d^o between $PDC_{X_2'}$ and $PDC_{X_2^o}$.



where $PDC = b_o' + b_1X_1 + b_2X_2$

with X_2 fixed at three particular average wage rates

Figure 3.1 GRAPHICAL COST ESTIMATING PROCEDURE FOR A HYPOTHETICAL WALL ABATEMENT TECHNIQUE.

in accuracy in estimating per unit costs with a specific curve, such as $PDC_{5.45}$, over that of another more standardized curve, say $PDC_{5.50}$, when the average wage rate is $5.45 per hour, is questionable. To avoid attributing more precision to the model than exists, a standardized graduation of 0.25 or 0.10 seems appropriate.

The ease with which this graphical cost estimating procedure[1] can be used can be demonstrated by applying a straightedge to Figure 3.1. The straightedge is used to construct lines which, when read off the verticle axis, give the predicted per unit direct cost. For example, to return to the previous illustration, to find the per unit direct cost of deleading N square feet of wall area, where $300 \leq N \leq 900$, the value corresponding to N is first found on the horizontal axis. A vertical line, l_1, is extended from N to the point where it intersects the appropriate average wage rate curve, $PDC_{X_2^0}$, at N_0. From this point a horizontal line, l_2, is drawn until it intersects the vertical axis. This point, P_{N_0}, will give the per unit direct cost for the given area and average wage rate.[2]

It should be noted that the per unit direct cost lines are not extended indefinitely in either direction. Likewise the average wage rate is not allowed to become arbitrarily small or large. The domain of definition for both of these variables is constrained for two reasons. First, extrapolating beyond the range of observation is unwise even if the basic form of the model is correct. Second the model may no longer be linear in these regions. However, when these constraints are recognized

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[1]Procedures of this type which allow a graphical solution are usually referred to as nomograms.

[2]Productivity and contract package size are assumed constant. A different family of curves will be associated with each set of assumptions about the values of productivity and contract package size.

and the model's underlying assumptions are satisfied, this procedure for graphically estimating costs is both a simple and effective method for computing per unit direct costs at the dwelling unit level.

3.5 Computational Cost Estimating Procedure

It was demonstrated in the previous section that the regression model, in a slightly simplified form, could be plotted, thus allowing costs to be estimated graphically. These nomograms were shown to be both a simple and efficient method for estimating PDC. However, if the nomograms are not already available, their construction requires that some care be exercised to insure that the family of curves plotted provides the desired information. As such it may be preferable to use a more generalized procedure which involves the computation of PDC directly through the use of the regression model. It has already been shown that the finalized form of the regression model was

$$PDC = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + e \qquad 3.4$$

where

X_1 = the quantity of surface deleaded,

X_2 = the average wage rate,

X_3 = the productivity of labor,

X_4 = the contract package size, and

e = the error term.

Furthermore, when the estimated values of the β_j's (b_j's) are incorporated in the model, it may be written as

$$PDC = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4. \qquad 3.5$$

In this form the model may be used to estimate PDC when the values of determinants X_1, X_2, X_3, and X_4 are known.

For purposes of illustration, consider a dwelling unit where gypsum veneer plaster is to be used to abate hazardous levels of LBP on 650 square feet of wall area. Assume that this dwelling unit is part of a contract package which contains 15 dwelling units. Using this information, values for two of the determinants of direct cost can be assigned. That is, the value for X_1 is 650 (the quantity of surface deleaded), and the value for X_4 is 15 (the contract package size). By referring to Appendix C.1, where the values for the different determinants of direct cost observed during Phase I are tabulated, an estimate of 12.6 square feet per manhour for the value of X_3 (the productivity of labor) is selected. An estimate of X_3 is taken from Appendix C.1 since the productivity of labor is not usually known or easy to compute unless some empirical data is available.

The value for X_2 (the average wage rate) may be derived through the application of the formula

$$AWR = P_1W_1 + P_2W_2 + P_3W_3, \qquad 3.9$$

where P_1 = the proportion of the total manhours expended by the plasterer,

P_2 = the proportion of the total manhours expended by the painter,

P_3 = the proportion of the total manhours expended by the laborer,

W_1 = the wage rate of the plasterer,

W_2 = the wage rate of the painter, and

W_3 = the wage rate of the laborer.

The values for the proportions P_i were empirically estimated and found to be: $P_1 = 0.71$, $P_2 = 0.19$ and $P_3 = 0.10$. A sample of wages was taken from the Phase I EHEP deleading operations involving the use of gypsum veneer plaster for the different labor types. The values for the wages of the different labor types were found to be: $W_1 = \$7.25$, $W_2 = \$7.66$ and $W_3 = \$5.03$. Thus the average wage rate may be expressed as

$$AWR = (0.71)(\$7.25) + (0.19)(\$7.66) + (0.10)(\$5.03) = \$7.11 \qquad 3.10$$

Through the method of least squares, the estimates for the coefficients of the determinants of direct cost were found to be: $b_0 = 0.54$, $b_1 = -2.27\text{x}10^{-4}$, $b_2 = 0.11$, $b_3 = -0.02$, and $b_4 = -8.1\text{x}10^{-3}$.

With this information it is now possible to compute the direct cost per square foot for this example using gypsum veneer plaster as the abatement technique. Table 3.1 shows how the figures would be combined to arrive at a PDC figure.

TABLE 3.1

COST ESTIMATING PROCEDURE FOR ABATEMENT OF LEAD-BASED PAINT ON WALLS BY USE OF GYPSUM VENEER PLASTER

Determinant[1] Value		X_1 650	X_2 7.11	X_3 12.6	X_4 15
Coefficient Value	b_o 0.54	b_1 -2.27×10^{-4}	b_2 0.11	b_3 -0.02	b_4 -8.1×10^{-3}
Product	0.54	-0.15	0.78	-0.25	-0.11

Summing the entries in the product row yields a direct cost per square foot figure of $0.81. Thus, the direct cost of deleading 650 square feet of wall area with gypsum veneer plaster would be $526.50 (0.81x650) in this dwelling unit.

[1]It should be noted that the values for the determinants of direct costs used in this example are well within the minimum - maximum range given in Appendix C.1, since exceeding these values could cause changes in the model's structure and as such produce misleading results.

4. RESULTS OF DATA ANALYSIS BY BUILDING COMPONENT AND ABATEMENT TECHNIQUE[1]

The analysis of the Phase I EHEP cost data was accomplished through the use of a series of statistical procedures. These procedures permitted both the ranking of abatement techniques with regard to their relative costs and the establishment of functional relationships between the determinants of direct cost. These functional relationships once established may in turn be used to estimate the direct costs associated with a particular abatement technique. Since certain abatement techniques may be used on several different building components,[2] per unit direct cost (PDC) for that technique may vary across building components. Therefore, to improve the reliability of the estimate of PDC for an abatement technique, functional relationships are developed for each building component.

These functional relationships have associated with them both structure and determinants. The model's structure refers to the way in which the determinants combine to produce a PDC figure, whereas determinants are taken here to mean specific variables which affect PDC. The structure of all cost models presented in this section is linear.

Associated with each determinant (variable) is a coefficient by which it is multiplied. Since the data available for analysis was limited, the cost models presented in this section were developed through statistical methods which estimate these coefficients. These

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[1]This chapter is designed so that it may be read independently of chapter 3. Hence some repetition of the topics discussed in chapter 3 is inevitable.

[2]For example some paint removal methods can be used on doors, door frames, windows and window frames and miscellaneous trim surfaces.

estimated coefficients taken together provide a means of predicting PDC when values for the determinants (variables) are given.

There are four basic determinants of PDC which are dealt with in this study: (1) the quantity of surface deleaded, (2) the average wage rate, (3) the productivity of labor, and (4) the contract package size. The quantity of surface deleaded provides a measure of how much abatement work was done for a particular building component; it is equal to the square feet of wall area, linear feet of trim or the number of doors, door frames, or windows and frames deleaded in a given dwelling unit. The average wage rate is that wage which would be paid on the average per manhour over the complete abatement process for the particular building component. The average productivity of labor is equal to that quantity of surface which can be deleaded in one manhour. The contract package size is the total number of dwelling units being deleaded by the contractor who is performing the abatement work in the dwelling unit under consideration.

The results of the analysis of each building component are presented in a series of three tables. These tables are intended to show how direct costs vary, what statistical significance can be attached to these differences, and what are the sources of these variations.

The first set of tables[1] gives information on PDC, per unit labor cost (PLC), and per unit material/equipment cost (PMC). The ranges of the direct cost figures and the number of dwelling units in which the abatement techniques were used are also presented in this set of tables. At times differences in the way in which the abatement procedure was performed indicated that a different set of measurement units would be

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[1]Tables 4.1, 4.4, 4.7, 4.10, and 4.13.

preferable. For example, procedures for paint removal on doors, door frames, and windows and frames, required that paint be removed to a height of 5 feet above the floor in Washington whereas it was removed only to a height of 4 feet above the floor in Atlanta. Thus to avoid the introduction of systematic bias into the analysis of the cost figures, the unit of measure was taken to be linear feet of door or door frame deleaded rather than the door or door frame itself. In the cases where an alternative unit of measure was used, for example, some paint removal methods on doors and door frames, direct costs were computed using both measures. In the first set of tables the PDC, PLC and PMC are designated with an (a) if they are on a per door or per door frame basis and by a (b) if they are on linear foot basis. In this manner it is possible to obtain a rough estimate of how paint removal methods compare with replacement methods.

The second set of tables[1] groups abatement techniques into categories with regard to their relative costs. This is performed in such a way that PDC for those techniques falling in the same category are judged to be not statistically different, whereas any techniques in a different category are judged to have PDC's that are statistically different.

The third set of tables[2] provides estimates of the coefficients of the determinants of PDC. To provide an indication of the relative importance of these estimates, probabilistic levels of significance are associated with them. Estimates are marked with an asterisk (*), two asterisks (**), or an (n) to denote respectively significance at the 5%

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[1]Tables 4.2, 4.5, 4.8, 4.11, and 4.14.

[2]Tables 4.3, 4.6, 4.9, 4.12, and 4.15.

level, 10% level, or no statistical significance. When the estimates of the coefficients of the determinants of PDC are significant at either the 5% or 10% level they provide two types of information about how PDC varies. First, the value of the coefficient tells the magnitude of the change in PDC for a given change in a specific determinant. Large absolute values are an indication PDC is relatively sensitive to any change in this determinant. Second, the sign of the coefficient tells the direction of the change. For instance, a negative sign implies that increasing the variable under consideration will result in a decrease in PDC. Thus from the value and the sign of the estimated coefficient it is possible to say, other things being equal, both how much and in what direction PDC will vary for a given change in a specific determinant. Associated with each model is also a coefficient of multiple determination. This gives an estimate of how completely the model explains variations in PDC. Since the number of observations (the number of dwelling units in which a particular abatement technique was used) varied considerably, the coefficient of multiple determination adjusted for both the number of observations and the number of variables used was computed. This coefficient is denoted $\bar{R}^2$. Values of $\bar{R}^2$ which are close to 1.0 indicate that the model comes close to completely explaining variations in PDC; values which are significantly below 0.5 indicate that additional information would be useful and therefore predictions of PDC from these models should be used with caution.

Before proceeding to the data analysis, it should be noted that the cost figures presented in this section were derived from a specific set of observations, namely Phase I of EHEP. The use of these figures to estimate LBP abatement costs for cases which are statistically different from this set could result in misleading figures. To facilitate the use of the models presented in this report, guidelines to show under what circumstances the model results are valid for the determinants of PDC for each model are given in Appendix C.

4.1 Wall Abatement Techniques

Nine barrier methods were used to abate hazardous levels of LBP in Phase I of EHEP. Four of these--veneer plaster, gypsum impregnated jute fabric (gypsum jute), gypsum wallboard, and melamine paneling--were used in both the Washington and Atlanta portions of Phase I. Gypsum impregnated glass fabric (gypsum fiberglass) was used only in the Washington portion of Phase I; and cementitious coating, filled paint, vinyl-coated fabric, and plaster with metal lath were used only in the Atlanta portion of Phase I.

The average PDC, PLC, and PMC figures for each of these techniques as well as their ranges are given in Table 4.1. Average direct costs for the various abatement techniques were found to range from a low of $0.20 per square foot for cementitious coating to a high of $1.65 per square foot for melamine paneling.

The wall abatement techniques were then tested to see if some form of grouping with regard to their relative costs was possible. The results of these tests are given in Table 4.2. The statistical grouping[1] of wall abatement techniques resulted in 4 categories: (1) cementitious coating and filled paint (painting techniques); (2) veneer plaster, gypsum fiberglass, gypsum jute and gypsum wallboard (mixed techniques); (3) plaster with metal lath (plastering technique); and (4) melamine paneling (paneling technique). The grouping in this case also demonstrates that some techniques in the same category exhibit similarities in the method of application.

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[1]Vinyl-coating fabric was not included in this portion of the analysis because it was used in only one dwelling unit.

TABLE 4.1

AVERAGE DIRECT COST PER SQUARE FOOT FIGURES FOR PHASE I WALL ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	NUMBER OF OBSERVATIONS[c]		DIRECT COST PER SQUARE FOOT		LABOR COST PER SQUARE FOOT		MATERIALS/EQUIPMENT COST PER SQUARE FOOT	
	W	A	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Cementitious Coating	0	3	0.20	0.19-0.22	0.14	0.13-0.15	0.06	0.06-0.07
Filled Paint	0	4	0.21	0.17-0.26	0.10	0.06-0.13	0.11	0.07-0.13
Vinyl-Coated Fabric	0	1	0.49	0.49	0.18	0.18	0.31	0.31
Veneer Plaster	2	7	0.74	0.50-0.89	0.61	0.40-0.75	0.14	0.08-0.27
Gypsum Fiberglass	5	0	0.77	0.65-0.97	0.49	0.33-0.70	0.28	0.26-0.32
Gypsum Jute	4	5	0.79	0.59-1.17	0.41	0.19-0.60	0.37	0.31-0.57
Gypsum Wallboard	2	10	0.92	0.60-1.50	0.72	0.41-1.28	0.20	0.11-0.22
Plaster with Lath	0	9	1.31	0.55-1.69	0.92	0.34-1.20	0.40	0.21-0.52
Melamine Paneling	3	3	1.65	0.84-1.97	0.70	0.43-0.96	0.95	0.41-1.18

[c]Number of dwelling units in which technique was used.

W = Washington, D.C.

A = Atlanta, Ga.

TABLE 4.2

RANKING OF WALL ABATEMENT TECHNIQUES BY AVERAGE DIRECT COST

CATEGORY	ABATEMENT TECHNIQUES GROUPED BY SIMILARITY OF MEANS[a]	AVERAGE DIRECT COST PER SQUARE FOOT
1	Cementitious Coating Filled Paint	\$0.20 \$0.21
2	Veneer Plaster Gypsum Fiberglass Gypsum Jute Gypsum Wallboard	\$0.74 \$0.77 \$0.79 \$0.92
3	Plaster with Lath	\$1.31
4	Melamine Paneling	\$1.65

[a]Those techniques falling in the same category are judged to be not statistically different while there does exist a statistically significant difference between categories.

The estimates of the coefficients of the determinants of direct cost are given in Table 4.3. It should be noted that in the case of category 1 abatement techniques the only satisfactory estimate of direct cost per square foot was the arithmetic average which is given in the intercept column. In cases where more than one coefficient are being estimated, the intercept term does not equal the average or constant PDC. For these cases the inclusion of the intercept term is of an algebraic rather than an economic interest. Upon closer examination it can be seen that some patterns across categories have emerged. For example, an increase of 100 square feet of wall area deleaded, other things being equal, causes a decrease in direct cost per square foot of 2.3¢ for the category 2 abatement techniques, 6.2¢ for plaster with lath, and 19¢ for melamine paneling. On the other hand, increasing the average wage rate by $1.00 per manhour translates into an increase of 10.6¢ per square foot for the category 2 abatement technqiues, 73.2¢ for plaster with lath, and 66.9¢ for melamine paneling. In the cases where contract package size was used as a variable, its coefficient implied that increasing the contract package size would decrease direct cost per square foot.[1] From Table 4.3 it can be seen that the rate at which direct cost per square foot changes as either the area or the average wage rate changes is significantly higher for the category 3 and category 4 wall abatement techniques than for those in category 2. This high rate of change is most probably caused by the high degree of labor intensity of these techniques. For instance, increasing area can result in scale efficiencies. Similarly, due to the high degree labor intensity,

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[1]Contract package size was not used as a variable for every category since some abatement techniques were used only in one city. In some of these cases there was little or no variation in contract package size.

TABLE 4.3

ESTIMATES OF THE COEFFICIENTS OF THE DETERMINANTS OF DIRECT COST PER SQUARE FOOT FOR WALL ABATEMENT TECHNIQUES

CATEGORY	NUMBER OF OBSERVATIONS	COEFFICIENT ESTIMATES					
		INTERCEPT	SQUARE FEET OF WALL AREA	AVERAGE WAGE RATE	PRODUCTIVITY OF LABOR	CONTRACT PACKAGE SIZE	$\overline{R}^2$
1. Cementitious Coating, and Filled Paint	7	0.20*	--	--	--	--	--
2. Veneer Plaster, Gypsum Fiberglass, Gypsum Jute, and Gypsum Wallboard	35	0.54*	$-2.27x10^{-4}$*	0.11*	-0.02*	$-8.1x10^{-3}$*	0.50
3. Plaster with Lath	9	-3.70*	$-6.2x10^{-4}$*	0.73*	--	--	0.94
4. Melamine Paneling	5	-4.75*	$-1.9x10^{-3}$*	0.67*	--	$-7.2x10^{-2}$*	0.83

*Indicates significance at the 5% level.

the category 3 and category 4 abatement techniques are sensitive to any changes in the wage rate. The direct cost per square foot may also be affected by changes in the productivity of labor. Category 2 abatement techniques[1] can be seen to be relatively sensitive to changes in productivity in that an increase in the productivity of labor of 1.0 square foot per manhour will cause a reduction in direct cost per square foot of approximately 2¢. The coefficient of multiple determination adjusted to reflect both the number of observations and the number of variables used indicates that PDC's per square foot estimated using either the category 2, 3 or 4 cost models are fairly reliable. PDC estimates for category 1 abatement techniques are merely averages and hence should be used with caution until more data has been collected on these techniques.

4.2 Door Abatement Techniques

Eight door abatement techniques were used in Phase I of EHEP. Four of these--the replacement of interior doors, paint removal through the use of a heat gun, paint removal by solvent stripping, and paint removal by the dip tank method--were used in both the Washington and Atlanta portions of Phase I. Four techniques, the replacement of exterior and screen doors and paint removal through the use of an infra-red device and by hand scraping, were used only in Atlanta.

The average PDC, PLC, and PMC figures, as well as their ranges are given in Table 4.4. Since differences in the height to which doors were

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[1]The productivity of labor was not used as a variable in the model for plaster with lath since it was highly correlated with the average wage rate. It was not used in the model for melamine paneling since only five observations were used in the analysis and there were already four coefficients being estimated.

TABLE 4.4

AVERAGE DIRECT COST FIGURES FOR PHASE I DOOR ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE		NUMBER OF OBSERVATIONS		DIRECT COST PER UNIT		LABOR COST PER UNIT		MATERIALS/EQUIPMENT COST PER UNIT	
		W	A	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Infra-Red Device	a	0	1	9.51	9.51	4.50	4.50	5.01	5.01
	b	0	1	1.19	1.19	0.56	0.56	0.63	0.63
Hand Scraping	a	0	3	13.02	11.65- 15.09	10.56	8.00- 13.19	2.46	1.82- 3.65
	b	0	3	1.63	1.46- 1.89	1.32	1.00- 1.65	0.31	0.23- 0.46
Heat Gun	a	1	12	18.91	6.81- 36.49	16.08	4.33- 33.88	2.83	2.35- 4.35
	b	1	12	2.36	0.85- 4.56	2.01	0.54- 4.24	0.35	0.29- 0.54
Solvent Stripping	a	11	24	25.38	11.13- 71.46	22.31	8.63- 69.12	3.07	0.83- 10.60
	b	11	24	2.92	1.19- 7.15	2.55	0.95- 6.91	0.36	0.10- 1.32
Dip Tank		5	2	56.47	23.17- 95.02	40.30	8.00- 78.00	16.17	12.18- 18.90
Replace Interior		13	3	94.57	38.29-268.24	50.07	17.84-160.19	44.50	15.56-216.24
Replace Screen		0	7	123.15	63.30-161.70	52.81	23.58- 80.13	70.35	27.91-138.12
Replace Exterior		0	27	130.96	56.95-191.50	47.95	15.00- 81.88	83.01	40.57-126.00

W = Washington, D.C.
A = Atlanta, Ga.

[a]Denotes that costs are on a per door basis.
[b]Denotes that costs are on a linear foot basis.

NOTE - All estimates unless designated with a (b) are on a per door basis.

abated above the floor differed between Washington and Atlanta[1] the cost per linear foot of door abatement has also been computed.[2]

The door abatement techniques were then tested to see if some form of grouping with regard to their relative costs was possible. Table 4.5 shows the two categories that resulted from this test, paint removal methods and the replacement of components. The grouping of door abatement techniques indicate that the PDC for the dip tank method is similar to those of the other category 1 abatement techniques. For the purpose of estimating the coefficients of the determinants of direct cost, however, the dip tank method was separated from the other category 1 abatement techniques. This was done since the dip tank method removes LBP from the entire door whereas the other category 1 techniques only remove LBP from the door stiles. Also, by separating the dip tank method from the other category 1 abatement techniques, it was possible to develop direct cost estimates per linear foot of door deleaded.

The estimates of the coefficients of the determinants of direct cost are given in Table 4.6. Some of the patterns which emerged from the data for wall abatement techniques are again present. For instance, an increase in the number of units processed (number of doors or linear feet of door deleaded) causes PDC to decrease. It should be noted that PDC's for replacement methods and to some extent the dip tank method are considerably more sensitive to any change in the number of units processed than are the PDC's for the paint removal methods. This reflects both the higher labor and material/equipment costs associated with these

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[1]Doors were deleaded to a height of 5 feet in Washington, whereas they were deleaded only to a height of 4 feet in Atlanta.

[2]Computations of the direct costs, labor costs, and materials/equipment costs per linear foot for door abatement techniques appear on lines marked (b) of Table 4.4.

TABLE 4.5

RANKING OF DOOR ABATEMENT TECHNIQUES BY AVERAGE DIRECT COST

CATEGORY	ABATEMENT TECHNIQUES GROUPED BY SIMILARITY OF MEANS[a]	AVERAGE DIRECT COST PER DOOR
1	Scrape and Sand	$13.02
	Heat Gun	$18.91
	Solvent Strip	$25.38
1A	Dip Tank	$56.47
2	Replace Interiors	$94.57
	Replace Screen	$123.15
	Replace Exteriors	$130.96

[a]Those techniques falling in the same category are judged to be not statistically different while there does exist a statistically significant difference between categories.

TABLE 4.6

ESTIMATES OF THE COEFFICIENTS OF THE DETERMINANTS OF PER UNIT DIRECT COST FOR DOOR ABATEMENT TECHNIQUES

CATEGORY	NUMBER OF OBSERVATIONS	COEFFICIENT ESTIMATES					
		INTERCEPT	NUMBER OF UNITS	AVERAGE WAGE RATE	PRODUCTIVITY OF LABOR	CONTRACT PACKAGE SIZE	$\bar{R}^2$
1. Hand Scraping Heat Gun and Solvent Stripping a	50	20.37*	$-0.33^{(n)}$	2.68*	-42.0*	0.25**	0.67
b	50	2.83*	$-4.8\times10^{-3(n)}$	0.29*	-0.60*	$0.01^{(n)}$	0.71
1A. Dip Tank	7	$-38.42^{(n)}$	$-3.77^{(n)}$	10.27**	$-14.05^{(n)}$	$0.21^{(n)}$	0.82
2. Replace (Interior, Screen, Exterior)	50	127.59*	-10.74*	7.33**	-203.7*	$0.06^{(n)}$	0.43

[a] Denotes that estimates are on a per door basis.
[b] Denotes that estimates are on a per linear foot basis.
NOTE - All estimates unless designated with a (b) are on a per door basis.

* Indicates significance at the 5% level.
** Indicates significance at the 10% level.
n Indicates not statistically significant.

abatement techniques (see Table 4.4). As with wall abatement techniques, increasing the average wage rate causes direct costs to increase. The effect on PDC of a given change in the average wage rate is significantly larger for the dip tank and component replacement methods than for the category 1 (paint removal) abatement techniques since the former methods are more labor intensive.[1] The value of the estimate of the coefficient of productivity indicates that the PDC's are sensitive to any change in the productivity of labor. Since some of the abatement techniques used in Phase I were relatively unfamiliar to the construction industry there may be a learning process through which the productivity of labor can be increased to such a point that the PDC's are significantly reduced. One anomaly which has occurred with this set of data concerns the sign of the coefficient of contract package size. Since the sign is positive, it indicates that larger contract packages result in a higher PDC. It should be noted however, that the estimate for contract package size is (statistically) not significantly different from zero for the dip tank and component replacement methods. It is significant at the 10% level for category 1 abatement techniques. However, this is more a reflection that doors were deleaded to five feet above the floor in Washington[2] where large contract packages were observed and only four feet above the floor in Atlanta where smaller contract packages were observed.[3] When the unit of measure is changed

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[1]The number of manhours expended per unit for category 1A and 2 abatement techniques is roughly 2 to 4 times that for category 1 abatement techniques.

[2]All dwelling units deleaded in Washington were done by the same contractor, so that the contract package size was equal to 30.

[3]The contract package size in Atlanta varied from 1 to 16 dwelling units.

from the number of doors to the linear feet of door deleaded, the differences in the abatement procedures between Washington and Atlanta are resolved. Under these conditions the coefficient of the contract package size is (statistically) no longer significantly different from zero. $\bar{R}^2$ has also reacted favorably to this change in the unit measure, indicating that this measure permits a greater percentage of PDC to be explained. The values of $\bar{R}^2$ for categories 1A and 2 indicate that PDC estimates for the dip tank method (1A) are very reliable but that estimates of PDC for component replacement techniques (2) should be used with caution.

4.3 Door Frame Abatement Techniques

Five door frame abatement techniques were used in Phase I of EHEP. Three of these--the replacement of exterior components, paint removal by means of a heat gun, and paint removal by solvent stripping--were used in both the Washington and Atlanta portions of Phase I. Two paint removal techniques, hand scraping and an infra-red device, were used only in Atlanta.

The average PDC, PLC, and PMC figures as well as their ranges are given in Table 4.7. Since door frames were deleaded to a height of 5 feet above the floor in Washington, but only to 4 feet above the floor in Atlanta, direct costs per linear foot were computed.[1]

The door frame abatement techniques were then tested to see if some form of grouping with regard to their relative costs was possible. Table 4.8 gives the results of these tests. Two categories resulted from this grouping procedure, reflecting differences in relative costs

[1] Table 4.7 gives on lines (a) the direct costs per door frame deleaded and on lines (b) the direct costs per linear foot of door frame deleaded.

TABLE 4.7

AVERAGE DIRECT COST FIGURES FOR PHASE I DOOR FRAME ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	NUMBER OF OBSERVATIONS		DIRECT COST PER UNIT		LABOR COST PER UNIT		MATERIALS/EQUIPMENT COST PER UNIT	
	W	A	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Hand Scraping a	0	4	12.08	6.93- 17.09	10.86	6.00- 14.59	1.22	0.69- 2.50
Hand Scraping b	0	4	1.51	0.87- 2.14	1.36	0.75- 1.82	0.15	0.09- 0.31
Heat Gun a	2	19	18.30	6.34- 36.59	16.16	4.20- 34.68	2.14	1.18- 3.82
Heat Gun b	2	19	2.22	0.79- 4.57	1.96	0.53- 4.33	0.26	0.15- 0.48
Infra-Red Device a	0	4	22.30	8.81- 36.26	16.83	6.00- 30.00	5.47	1.33- 12.26
Infra-Red Device b	0	4	2.79	1.10- 4.53	2.10	0.75- 3.75	0.68	0.17- 1.53
Solvent Stripping a	10	35	22.66	7.22- 70.68	20.58	6.57- 69.12	2.08	0.37- 6.82
Solvent Stripping b	10	35	2.65	0.90- 7.07	2.40	0.82- 6.91	0.25	0.05- 0.85
Replace (Exterior)	7	11	98.45	37.71-156.37	69.14	21.65-121.29	29.31	15.75- 68.48

W = Washington, D.C.
A = Atlanta, Ga.

[a]Denotes that costs are on a per door frame basis.
[b]Denotes that costs are on a per linear foot basis.

NOTE - All estimates unless designated with a (b) are on a per door frame basis.

TABLE 4.8

RANKING OF DOOR FRAME ABATEMENT TECHNIQUES BY AVERAGE DIRECT COST

CATEGORY	ABATEMENT TECHNIQUES GROUPED BY SIMILARITY OF MEANS[a]	AVERAGE DIRECT COST PER DOOR FRAME
1	Scrape and Sand Heat Gun Infra-Red Device Solvent Strip	$12.08 $18.30 $22.30 $22.66
2	Replacement (Exterior)	$98.45

[a]Those techniques falling in the same category are judged to be not statistically different while there does exist a statistically significant difference between categories.

between paint removal methods (category 1) and the replacement of components (category 2).

The estimates of the coefficients of the determinants of direct cost are given in Table 4.9. The PDC for door frames differs from that for doors for component replacement in that it increased by $2.85 for each additional door frame replaced. The PDC for paint removal methods also increased, but only by 4¢ for each additional door frame. This figure in addition to being relatively small is (statistically) not significantly different from zero. When direct costs for the paint removal methods (category 1) were estimated on the basis of linear feet abated, increasing the linear feet abated does result in a decrease in PDC. However the coefficient was still (statistically) not significantly different from zero. For both category 1 and category 2 abatement techniques increasing the average wage rate, other things being equal, increased the PDC. As would be expected, component replacement exhibits considerably more sensitivity to changes in the average wage rate. Increases in the productivity of labor cause PDC to decrease for both component replacement and paint removal methods. But the sensitivity of component replacement to changes in the productivity of labor is considerably higher than that for the paint removal methods. The sensitivity exhibited by component replacement to both changes in the productivity of labor and the average wage rate highlights the fact that replacement of components is a labor intensive process. Varying contract package size produces slightly different results for component replacement methods than for paint removal methods; increasing the contract package size by 1 dwelling unit decreases the PDC by $2.53. This in part reflects a rather sizable difference in PDC between Washington ($73.32), where larger contracts were observed, and Atlanta

TABLE 4.9

ESTIMATES OF THE COEFFICIENTS OF THE DETERMINANTS OF PER UNIT DIRECT COST FOR DOOR FRAME ABATEMENT TECHNIQUES

CATEGORY	NUMBER OF OBSERVATIONS	COEFFICIENT ESTIMATES					
		INTERCEPT	NUMBER OF UNITS	AVERAGE WAGE RATE	PRODUCTIVITY OF LABOR	CONTRACT PACKAGE SIZE	$\bar{R}^2$
1. Hand Scraping, Heat Gun, Infra-Red Device, Solvent Stripping a	74	22.20*	$0.04^{(n)}$	1.88*	-40.41*	0.28*	0.69
1. Hand Scraping, Heat Gun, Infra-Red Device, Solvent Stripping b	74	3.04*	$-1.07\times10^{-4(n)}$	0.20*	-0.59*	$0.02^{(n)}$	0.70
2. Replacement (Exterior)	18	$120.94^{(n)}$	2.85*	7.10*	-289.96*	-2.53*	0.85

[a] Denotes that estimates are on a per door frame basis.
[b] Denotes that estimates are on a per linear foot basis.
<u>NOTE</u> - All estimates unless designated with a (b) are on a per door frame basis.

* Indicates significance at the 5% level.
n Indicates not statistically significant.

($114.44), where smaller contracts were observed.[1] This may be an indication that larger contract packages for door frame replacement methods permit more efficient scheduling of resources. For paint removal methods an increase in contract package size causes PDC, taken on a per door frame basis, to increase. However, when the coefficient was reestimated on a linear foot basis to take into consideration the differences in abatement procedures between Washington and Atlanta, the coefficient was (statistically) no longer significantly different from zero although the sign remained positive. The relatively high values of $\bar{R}^2$ demonstrate that the models given in Table 4.9 are quite complete in the estimation of PDC for both paint removal (category 1), and component replacement (category 2) methods. The higher value of $\bar{R}^2$ resulting from estimating PDC on a linear foot basis for category 1 abatement techniques indicates that the linear foot measure is preferable to the per door frame measure.

4.4 Window and Window Frame Abatement Techniques

Five window and window frame abatement techniques were used in Phase I of EHEP. Three of these--the replacement of wooden windows and window frames, paint removal by the use of a heat gun and paint removal by solvent stripping--were used in both the Washington and Atlanta portions of Phase I. Two paint removal techniques, the use of an infrared device and hand scraping, were used only in Atlanta.

The average PDC, PLC, and PMC figures along with their ranges for the Phase I window and window frame abatement techniques are outlined in Table 4.10.

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[1] The productivity of labor was also higher in Washington, 0.137 door frames per manhour, than in Atlanta, 0.095 door frames per manhour.

TABLE 4.10

AVERAGE DIRECT COST FIGURES FOR PHASE I WINDOW AND WINDOW FRAME ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	NUMBER OF OBSERVATIONS		DIRECT COST PER WINDOW & FRAME		LABOR COST PER WINDOW & FRAME		MATERIALS/EQUIPMENT COST PER WINDOW & FRAME	
	W	A	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Hand Scraping	0	2	22.87	18.61- 27.12	20.00	15.00- 25.00	2.87	2.12- 3.61
Infra-Red Device	0	4	28.06	17.91- 34.93	23.73	14.50- 29.92	4.33	2.39- 6.50
Heat Gun	2	7	29.50	15.70- 78.32	26.73	13.69- 69.20	2.76	1.41- 9.12
Solvent	8	11	38.67	10.51-128.42	34.65	9.81-121.40	4.02	0.70-16.40
Replace (Wood)	10	6	128.82	48.79-227.11	72.01	25.98-162.12	56.81	22.81-90.62

W = Washington, D.C.

A = Atlanta, Ga.

The window and window frame abatement techniques were then tested to see if some form of grouping with regard to their relative costs was possible. The results of these tests are given in Table 4.11. From Table 4.11 it can be seen that the window and window frame abatement techniques can be grouped into two categories: (1) paint removal methods, and (2) component replacement. As with door and door frame abatement techniques, the procedure for the removal of LBP from windows and window frames differed between Washington and Atlanta, being de-leaded to a height of 5 feet in Washington but only to a height of 4 feet in Atlanta. The data on windows and window frames unlike that for doors and door frames did not permit a realistic estimate of the number of linear feet deleaded since the height of the window sill above the floor and the width of the opening was not available. An estimate of the cost of deleading an extra foot of height was made for the various paint removal methods. The inclusion of this new variable, however, tended to complicate rather than simplify the problem of estimating PDC, so it has been omitted from the analysis presented here.

Some of the difficulties caused by deleading an extra foot of height in Washington become apparent when the estimates of the coefficients of the determinants of direct cost given in Table 4.12 are studied. For example, the PDC for paint removal methods (category 1) increases as the number of units processed increases. This reflects two things. First, the number of windows and window frames deleaded per dwelling unit for all paint removal methods was 5.4 in Atlanta versus 6.6 in Washington. That is, the larger values for the number of units processed are associated with the Washington observations. Second, the average direct costs per window for the heat gun and solvent stripping

TABLE 4.11

RANKING OF WINDOW AND WINDOW FRAME ABATEMENT TECHNIQUES BY AVERAGE DIRECT COST

CATEGORY	ABATEMENT TECHNIQUES GROUPED BY SIMILARITY OF MEANS[a]	AVERAGE DIRECT COST PER WINDOW AND FRAME
1	Scrape and Sand Infra Red Heat Gun Solvent Strip	$22.87 $28.06 $29.50 $38.67
2	Replacement	$128.82

[a]Those techniques falling in the same category are judged to be not statistically different while there does exist a statistically significant difference between categories.

TABLE 4.12

ESTIMATES OF THE COEFFICIENTS OF THE DETERMINANTS OF PER UNIT DIRECT COSTS FOR WINDOW AND WINDOW FRAME ABATEMENT TECHNIQUES

CATEGORY	NUMBER OF OBSERVATIONS	COEFFICIENT ESTIMATES					
		INTERCEPT	NUMBER OF WINDOWS & FRAMES	AVERAGE WAGE RATE	PRODUCTIVITY OF LABOR	CONTRACT PACKAGE SIZE	$\bar{R}^2$
1. Hand Scraping, Infra-Red Device, Heat Gun, and Solvent Stripping	34	18.51**	0.28$^{(n)}$	4.69*	-139.72*	1.14*	0.75
2. Replace (Wood)	16	42.96$^{(n)}$	-0.61$^{(n)}$	16.27*	-641.85*	2.32*	0.85

* Indicates significance at the 5% level.
** Indicates significance at the 10% level.
n Indicates not statistically significant.

techniques[1] in Washington were higher than in Atlanta.[2] For both paint removal and component replacement methods, increases in the average wage rate cause PDC to increase and increases in the productivity of labor cause PDC to decrease. The replacement of windows and window frames are very sensitive to small changes in either the average wage rate or the productivity of labor. Again this is probably due to the labor intensive nature of the component replacement process. The coefficient of contract package size also has a positive sign indicating higher PDC's are associated with larger contract packages. This again reflects the fact that the large contract packages were observed in Washington. In looking at window replacements, the rather large (2.32) coefficient of contract package size does not seem correct, since the PDC was lower in Washington ($116.15) than in Atlanta ($137.33), and the number of windows and window frames replaced per dwelling unit was higher in Washington (5.4) than in Atlanta (2.2). Moreover, the per unit direct costs for Washington were much more variable ($48.79 - $227.11) than for Atlanta ($105.61 - $161.81). Contract package size was also slightly correlated with both the average wage rate and the productivity of labor so that a portion of the variation in PDC has already been taken up in the estimation of these coefficients. The $\overline{R}^2$ for each category is relatively high indicating that these complications have not seriously interfered with the models ability to estimate PDC. Since some of the problems which arose in the analysis of this set of data were not resolved,

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[1]These were the only paint removal methods which were used in both Washington and Atlanta.

[2]Though the PDC for Washington is higher than Atlanta it is not possible to say how much of this difference is due to the extra foot of height of window and frame deleaded.

however, caution should be exercised in the use of these models to predict PDC for abatement of LBP on windows and window frames.

4.5 Abatement Techniques for Miscellaneous Trim Components[1]

During Phase I, LBP was removed from trim surfaces by means of hand scraping, solvent stripping or through the use of the following special equipment: heat gun, infra-red device, and propane torch. The abatement of miscellaneous trim surfaces was done only in the Atlanta portion of the program. The average PDC, PLC, and PMC figures associated with each abatement technique for miscellaneous trim components are outlined in Table 4.13.

The abatement techniques for miscellaneous trim components were then tested to see if some form of grouping with regard to their relative costs was possible. Table 4.14 gives the results of these tests. From Table 4.14 it can be seen that no statistically significant differences exist between the direct costs per linear foot for these abatement techniques.

The estimates of the coefficients of the determinants of direct cost are given in Table 4.15. Several interesting points can be seen from this table. First, if quantity of trim deleaded in a dwelling unit increases by 50 linear feet the direct cost per linear foot decreases by about 15¢. Second, an increase in the average wage rate of $1.00 per hour causes direct cost to increase by approximately 20¢ per linear foot. A one foot per manhour increase in the rate at which trim can be deleaded (an increase in the productivity of labor) reduces direct cost by 19¢ per linear foot. Finally, the use of a heat gun, an infra-red device, or a propane torch, denoted here as special equipment to remove

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[1]Miscellaneous trim components denote such items as baseboards, handrails, and molding.

TABLE 4.13

AVERAGE DIRECT COST PER LINEAR FOOT FIGURES FOR PHASE I TRIM ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	NUMBER OF OBSERVATIONS		DIRECT COST PER LINEAR FOOT		LABOR COST PER LINEAR FOOT		MATERIALS/EQUIPMENT COST PER LINEAR FOOT	
	W	A	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Solvent Stripping	0	16	1.76	0.42-3.91	1.53	0.34-3.67	0.23	0.04-0.93
Hand Scraping	0	11	1.90	0.41-3.48	1.75	0.33-3.25	0.15[a]	0.07-0.28
Propane Torch	0	4	2.34	0.42-3.39	1.83	0.21-2.81	0.50	0.22-0.98
Heat Gun	0	6	2.84	0.97-6.12	2.06	0.57-4.05	0.78	0.17-2.07
Infra-Red Device	0	5	3.24	0.93-6.76	2.79	0.69-6.24	0.45	0.25-0.66

W = Washington, D.C.
A = Atlanta, Ga.

[a]Material costs were not available for all dwelling units due to a recording error.

TABLE 4.14

RANKING OF TRIM ABATEMENT TECHNIQUES BY AVERAGE DIRECT COST

CATEGORY	ABATEMENT TECHNIQUES GROUPED BY SIMILARITY OF MEANS[a]	AVERAGE DIRECT COST PER LINEAR FOOT
1	Solvent Strip	\$1.77
	Scrape and Sand	\$1.90
	Propane Torch	\$2.34
	Heat Gun	\$2.84
	Infra-Red	\$3.24

[a]Those techniques falling in the same category are judged to be not statistically different while there does exist a statistically significant difference between categories.

TABLE 4.15

ESTIMATES OF THE COEFFICIENTS OF THE DETERMINANTS OF DIRECT COST PER LINEAR FOOT FOR TRIM ABATEMENT TECHNIQUES

CATEGORY	NUMBER OF OBSERVATIONS	COEFFICIENT ESTIMATES					
		INTERCEPT	LINEAR FEET OF TRIM	AVERAGE WAGE RATE	PRODUCTIVITY OF LABOR	SPECIAL EQUIPMENT[a]	$\overline{R}^2$
1. Solvent Stripping Hand Scraping Propane Torch Heat Gun Infra-Red Device	42	1.95*	-2.93×10^{-3}**	0.20**	-0.19*	0.85*	0.48

* Indicates significance at the 5% level.
** Indicates significance at the 10% level.
n Indicates not statistically significant.

[a]Special equipment indicates use of a heat gun, infra-red device, or propane torch.

LBP, causes direct cost to increase by 85¢ per linear foot. The value of $\bar{R}^2$ of 0.48 indicates that the model has been able to in capture only about half of the variation in PDC. One omitted element which is likely to affect PDC is the occupancy status of the dwelling unit. Although both occupied and unoccupied dwelling units had trim deleaded, a dummy variable for occupancy has not been included for two reasons. First, although not by design all occupied units were done by union scale labor and unoccupied units by nonunion scale labor; thus average wage rate would be highly correlated with this variable. Second, the quantity of trim deleaded was significantly larger in the unoccupied units than in the occupied, thus the linear feet of trim deleaded would also be correlated with occupancy status. Once these constraints are recognized, however, the model may be used to provide a baseline estimate which will probably be slightly high if the dwelling unit is unoccupied and probably a little low if it is occupied.

5. SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Summary

The potential of lead poisoning through the ingestion of lead-based paint (LBP) chips is a serious threat to the health and well-being of young children. As such, this problem has stimulated interest in both the public and private sectors into ways in which the hazards of LBP could be eliminated from the nation's housing. A method for estimating the costs of LBP abatement is required to insure that the resources devoted to eliminating the hazards of LBP will be used efficiently.

This study develops a series of cost models for the estimation of the direct costs of LBP abatement. Direct costs were analyzed at the dwelling unit level by building component (walls, doors, door frames, windows and frames, and miscellaneous trim) and abatement technique. They were compared on the basis of per unit direct cost (PDC), that is, the direct cost per item, per square foot, or per linear foot, to determine whether some form of ranking was possible. If significant differences in PDC existed, the abatement techniques were grouped into cost categories ranked from least expensive to most expensive. These categories were designed so that abatement techniques in the same category had roughly equal PDC's whereas those in another category had significantly higher or lower PDC's. Furthermore, it was frequently the case that techniques in the same category were also similar in the procedure they used to abate LBP. Once the abatement techniques were grouped into categories, the variables which accounted for variations in PDC were analyzed; estimates of how these variables affected PDC, both the magnitude and the direction of the change, were also developed. The estimates were then combined to form a cost model which permitted the prediction of PDC's for each abatement technique.

To provide a measure of the confidence with which the LBP abatement cost models can be used, a statistical estimate of how complete the model is at explaining variations in PDC was presented. These statistics took on values which ranged from 0.43 to 0.94 for the eleven separately estimated cost models; the average value was 0.71. That is, on the average, 71% of the variation in PDC was explained by a linear cost model. It should be noted that the estimate of how complete the model was at explaining variations in PDC exceeded 0.70 for eight of the eleven models. Three models did have values of this statistic between 0.43 and 0.50, however, which pulled the average down somewhat. The reason for these lower values can be attributed, at least in part, to difficulties in separating variations in PDC due to the affects of union versus nonunion pay scales and occupancy status. When more data becomes available on these abatement techniques, it seems likely that the completeness with which variations in PDC can be measured (and predicted) will be significantly increased. Thus most of the cost models developed in this study provide a reliable direct cost estimating procedure for both public and private decision makers faced with LBP abatement in housing. Furthermore, most of the cost models which were developed in this study are of a general enough nature that they have captured potential differences in PDC due to regional effects. For example, any constraints which may result from special pay scales or limitations on the amount of work which can be performed in a work day are included, or can easily be incorporated, within the model's framework.

An alternative cost estimating method is also discussed which permits the decision maker to estimate PDC through the use of a graphical procedure.

Since the methods used for LBP abatement can also be used in the rehabilitation or renovation of housing, these cost models provide a means for readily obtaining baseline estimates for PDC in the rehabilitation of either a single dwelling or a contract involving as many as 25 to 30 dwelling units.

5.2 Recommendations for Further Research

In order to expand the cost models developed in this study to include total project costs, to determine the optimal combination of LBP abatement techniques, and to gain a fuller knowledge of what policy options are most likely to be both economically and socially acceptable, further research on several topics would be useful.

Since the emphasis of this study was on direct costs, the cost models developed did not provide a measure of total project costs. Total project costs, which are being assessed in Phase II of EHEP and include markup, will probably influence the economically optimal level of LBP abatement in that markup may vary as a function of ownership (for example HUD, a local housing authority, or a private individual) or the number of dwelling units having abatement work done (the contract package size).

Due to the lack of information on building repairs, it was not possible to assess the effect that repair costs had on the different LBP abatement techniques. Since repair costs enter into the determination of PDC in different ways for different abatement techniques, it is useful to know how the introduction of these costs will affect the choice of an optimal combination of LBP abatement techniques. Nor was it possible to ascertain the extent to which direct costs would change as a function of occupancy status. The resolution of these problems, which are being addressed in Phase II of EHEP, should significantly improve the accuracy with which direct costs can be estimated. In this report it was demonstrated that, for some trim abatement methods, better

PDC estimates could be achieved if costs were recorded on a linear foot basis rather than a per item basis. This method of recording data is also preferable in that regulations for the height to which LBP should be removed vary from city to city. Therefore, if estimates based on a linear foot measure are available, they provide a means for estimating direct costs independent of local regulations.

This study has not focused on the benefits to be derived from LBP abatement. The establishment of what benefits are associated with LBP abatement and their quantification is essential to the identification of an optimal combination of LBP abatement techniques. Furthermore, the estimation of total project benefits may also be used as a tool in the development of alternative LBP abatement strategies at the national level. Developing such estimates in future research will reduce the probability of the rejection of an LBP abatement strategy which is optimal or of the acceptance of a strategy which is economically less than optimal.

Previous studies have determined the types of housing which were most likely to contain LBP. At present, however, only crude estimates are available for the number of each type, which are occupied or awaiting occupancy, and what effect current housing trends will have on this number and hence how potential benefits would be affected. It would be helpful if better estimates were available.

It might also be useful to investigate incentives programs which could be used to eliminate the LBP hazard. Such incentives could include financing LBP abatement through low-interest loans or some form of cost-sharing. Analyses such as these could provide public and private decision makers with the information necessary to make the efficient choice among competing policy alternatives.

APPENDIX A: DESCRIPTION OF ABATEMENT TECHNIQUES

This appendix is intended to supply background information on the three basic methods of lead-based paint (LBP) abatement. The three abatement methods are subdivided into individual abatement techniques. The abatement techniques are then described individually in some detail with regard to their composition, method of application, and/or any special skill or material/equipment requirements.

Since the body of this appendix is formed of excerpts from publications in which these abatement techniques are described in greater detail, the interested reader is referred to the two reports by Boone et al.[1]

A.1 Paint Removal Methods

The safety of workmen and dwelling occupants is a primary consideration in the implementation of paint removal methods. Procedures should be taken to avoid the inhalation or absorption of lead fumes or dust. In addition attention should be given to the potential fire hazard associated with the use of open flame paint removal techniques.

A.1.1 Solvent-Based Paint Removers

A number of "industrial grade" paint removers may be used to remove LBP from windows, doors and other wood trim and components. These normally viscous liquids are applied to both horizontal and vertical surfaces by brush, allowed to react with the lead paint coatings and then removed along with the softened paint using various metal scrapers.

Paint removers are extremely variable in their ability to penetrate and react with multiple layers of dried paint. The effectiveness of the

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[1] The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Washington, D.C., and The Demonstration of Experimental Lead Paint Hazard Abatement Methods in Atlanta, Georgia.

remover depends not only on its own composition but also on the nature of the multi-layered coating to which it is applied. Most removers will react with only 2 to 4 layers of paint at a time. In such cases, where more than that number of layers of paint is present, the remover-paint agglomeration must be removed and fresh remover applied as often as necessary to achieve complete removal.

Generally, the reaction time for paint removers is about one-half hour. The remover-paint waste, which is scraped from the treated surfaces, is collected on polyethylene drop cloths and discarded. Prior to light sanding and repainting, the surface is wiped with a water-saturated rag in order to remove any residue of remover-paint mixture.

Proper precautions regarding open flames, adequate ventilation and avoidance of contact with skin is necessary to assure the safe use of this class of products.

A.1.2 Hand Scraping

Simple hand tools such as paint scrapers and putty knives may be used to remove loose and flaking paint. Electrical sanders may then be used to achieve the complete removal of paint which adhered too tightly to those surfaces for hand scraping.

A.1.3 Electrical Heat Gun

When paint is heated sufficiently, it softens, swells and usually blisters so that it can be removed easily from its substrate with metal scrapers. Several techniques are available for removing paint from doors, windows and other wood surfaces, by means of heat generation.

One such technique, a portable flameless electric hot air blowing device is quite effective in removing paint from wood substrates as demonstrated in laboratory tests; it also presents an apparent low risk of fire and injury to the operator or bystanders.

This commercially manufactured device consists essentially of an air blower attached to a reinforced flexible plastic hose, with a cylindrical electric heater at the outlet. The heater is heavily insulated, so that it can be hand held while in operation. This apparatus is mounted on a stand which is quite mobile. It is capable of producing a strong stream of hot air at temperatures of between 350° and 1000°F (175° and 540°C). The working end of the device is very light in weight and a single workman can perform the continuous operations of heating the paint to its softening point and scraping it off with metal tools. Electrical circuits or portable generators supplying 20 ampere currents at 110-120 volts are required for operation of the hot air blower.

A.1.4 Infra-Red Heat Device

The infra-red heat device used in the Atlanta portion of EHEP consists of a propane burner whose flame is recessed in a metal reflector covered with a metal grid. When the flame is lit, the grid is heated. The device is held near the surface that is to be stripped and the heat radiating from the grid softens the paint so that it can be scraped off with metal tools.

This device is somewhat less hazardous than a propane torch because the open flame is recessed. It is completely portable, uses one pound disposable propane cylinders or a 25 pound refillable propane tank. The process of heating and scraping can be carried out by a single workman.

A.1.5 Propane Torch

The open flame produced by a propane torch can be used to heat paint directly to the softening point so that it can be scraped off with metal tools. The process is easily carried out by a single workman using a one pound propane bottle.

Until recently, the use of propane torches had been quite widespread for this purpose. They are now falling into disfavor, however, due to the extreme fire hazard of an open flame (especially in occupied and furnished dwellings) and the danger of over-heating paints to the point of vaporization of the lead pigments. As a safety precaution its use in the Atlanta portion of EHEP was restricted to the stripping of exterior wood trim surfaces.

A.1.6 Dip Tank Method

Commercial furniture stripping plants have facilities for removing old paint and varnish by totally immersing the object of interest in large tanks containing heated alkaline solvents in an aqueous medium.

Doors may be stripped by this process, requiring two to three hours of treatment during which time they are alternately soaked and scrubbed with heavy bristle brushes. The total stripping time is dependent on the type of paint, the number of paint layers and the temperature and strength of the solvent bath. Doors can be stripped with hinges and other hardward still attached. After the paint is completely removed the doors are washed with water, allowed to air dry and then returned to the dwelling from which they were taken where they are reinstalled and repainted.

A.2 Replacement of Components

Removal of doors, door drames, windows and frames, and other trim components and replacement with new materials is an accepted technique of LBP abatement. Replacement is used primarily when building components are deteriorated or damaged beyond the point of functionality and due to their poor condition the cost of abatement by other means would be prohibitively expensive. This method in addition to restoring the building component to functionality also provides an opportunity to upgrade the quality of the dwelling unit significantly.

Carpentry skills are required for rehanging, fitting and remounting hardware. Custom carpentry may be required for replacing wooden sash windows and frames in some dwelling units.

A.3 Barrier Materials

The complete stripping of LBP from surfaces or the removal and replacement of building components which are coated with LBP can unequivocally be defined as LBP elimination methods. The effectiveness of such methods is essentially total. However, the application of those methods to large wall surfaces appears to be both impractical and prohibitively expensive. The application of materials, which are intended to act as barriers is frequently the most reasonable approach to the abatement of LBP on planar surfaces. The effectiveness of barrier materials is a function of the degree to which they prevent access to the existing lead paint which they cover. The material's strength, durability and permanence are the primary characteristics that establish its effectiveness in LBP abatement.

A.3.1 Cementitious Coating

The cementitious coating consists of portland cement, sand, and acrylic resin to which water is added to make a slurry. It can be tinted to desired colors by the addition of pigments recommended by the manufacturer.

The cementitious coating is viscous and it has a rough texture. It can be applied by brush or roller or any other equipment designed to apply viscous filled coatings.

The surface to be coated must be clean and free from loose particles. Glossy surfaces must be roughened with an abrasive and chaulky surfaces sealed with a sealer to ensure good adhesion. The applied coating has a final thickness of about 1/16-inch (about 1.6 mm).

A.3.2 Aggregate Filled Paint (Filled Paint)

This coating is a latex based product which contains sand or other mineral aggregate which provides a thick finish comparable in texture to sand finished plaster.

Filled paint is viscous. The product used was formulated for application by airless spray equipment but it, and most other formulations, can be applied using a brush or roller. It requires no mixing or thinning and it can be applied successfully to any surface which is free of dirt, oil or grease. Primers are not required for use on previously painted surfaces and thicknesses as high as 20 mils (0.02 inch or 0.05 cm) can be obtained with one coat. The finish texture, ranging from smooth to coarse, depends upon the aggregate quantity and particle size.

A.3.3 Gypsum Impregnated Jute Fabric (Gypsum Jute)

This wall covering product consists of jute fabric which is impregnated with uncrystallized gypsum (hydrated calcium sulfate). It is applied to walls, in the same manner as wallpaper, with a water base adhesive which is recommended by the manufacturer of the fabric. As the gypsum absorbs moisture from the air, it hydrates, hardens and becomes a fairly rigid and penetration-resistant material. A protective coating can be applied if the material is to be used in wet areas.

A clean substrate, in good repair, is necessary for adequate adhesion. The covering will, however, bridge minor voids and mask minor substrate imperfections.

A.3.4 Cement Impregnated Glass Fabric (Gypsum Fiberglass)

This product is similar in appearance to the gypsum jute fabric described above. It consists of glass fabric impregnated with portland cement and develops into a rigid, strong material by absorbing moisture from its environment. The general comments regarding method of application, intended use and finishing are the same for this product as for the previous one.

A.3.5 Vinyl-Coated Fabric

Vinyl-coated fabric is basically similar to wallpaper or vinyl-clad paper. Its strength and durability exceeds that of the other two materials because of its combination of vinyl surface and textile fabric backing.

Vinyl-coated fabric may be installed on any wall surface that is free of dirt, grease, oil and moisture. The method used for hanging vinyl-coated fabric is the same as used for hanging wallpaper. The adhesive used depends upon the weight of the vinyl coated fabric. These fabrics normally resist soiling and staining even by objects such as crayon, lipstick, or ink. A mild detergent and a sponge usually will remove most soils and stains. They conform to the bends and contours of most surfaces and are installed readily by workmen who are familiar with wallpaper installation using ordinary hand tools and equipment.

A.3.6 Gypsum Veneer Plaster

This product is a component pre-packaged material which becomes plastic when mixed with water so that it can be trowel applied to form a highly polished finish or can be worked to achieve a textured finish. It may be applied to solid plaster walls which have first been treated with a vinyl polymer bonding compound to improve adhesion to the existing painted surfaces. The finished thickness of the plaster is approximately 1/8-inch (3.2 mm) thick. Skilled workmen are required for the satisfactory application of this product.

A.3.7 Gypsum Plaster with Metal Lath

Gypsum plaster is applied to a metal lath which serves as a support for the plaster and a means of adhesion to the surface being treated.

The lath is a netting of 20 gauge galvanized steel which is fastened to a surface with nails, staples or screws.

The plaster is usually applied in two stages resulting in a final thickness of 1/2-inch (1.3 cm). In the first application, wood fiber is added to the gypsum plaster to improve its working characteristics by making it easier to apply and to increase its adhesion to the metal lath. This first coat is applied by trowel to a uniform thickness of about 3/8-inch (1 cm). The plaster sets up (hardens) rapidly and must be applied quickly. Highly calcined gypsum plaster is used for the second or top-coat. This plaster contains a retarder which delays hardening so that the desired finish (smooth or textured) can be achieved. The final coat is about 1/8-inch (0.3 cm) thick. The finished dried surface is usually painted.

The application of plaster to lath should be done by skilled workmen. The temperature of the work area and surface should be above 50°F and adequate ventilation (for proper drying of the plaster) should be provided.

A.3.8 Gypsum Wallboard

Gypsum wallboard is a product which is composed of a thick layer of gypsum to which paper or other materials are bonded to provide a finished or finishable surface. It is intended for use on walls, ceilings, or partitions and can be applied directly to existing surfaces or to wood or metal furring strips.

It can be applied directly to existing walls with adhesives and nails. The installed wallboard is prepared for painting by finishing the joints between the sheets with joint tape and compound. Nail heads are then covered with compound and both areas are sanded to a smooth finish.

A.3.9 Plywood on Floors

Plywood may be used to cover-up lead painted exterior wood decks on porches. Warped and rotted boards are replaced with new or sound ones and a 15 lb. (6.8 kg) roofing felt is put down as an underlayment before installing the plywood.

Four by 8 foot (1.2 x 2.4 m) sheets of 3/8-inch (9.5 mm) A-B grade, exterior or marine plywood is used. All edges are treated with wood preservative and the sheets are nailed or screwed to the existing deck with its A grade surface up. All exposed edges are covered with wood trim and the new surface is painted with one coat of primer and two coats of exterior paint.

Skilled workmen are required to install plywood on existing porch decks with satisfactory workmanship. Although the job can be done with hand tools it can be accomplished much more easily with ordinary power tools such as electric drills and saws.

A.3.10 Melamine Coated Hardboard

This product is a 1/4-inch (6.4 mm) thick tempered hardboard to which a 1-1/2 mil (.038 mm) thick melamine film has been laminated to provide a serviceable, decorative finish. The material is supplied in 4 x 8 feet panels (1.2 x 2.4 m) and is applied to existing walls with an adhesive. Pre-formed strips are used to cover vertical butted seams and as a molding at the ceiling line. Baseboards are applied over the paneling at the floor.

APPENDIX B: PACKAGE PLANS USED IN PHASE I

B.1 Washington, Series I

Washington Series I Package Plans for Dwelling Units Requiring Abatement of Interior Walls and Trim

PACKAGE PLAN	WALLS DRY AREA	WALLS WET AREA	DOORS	WINDOWS AND WINDOW FRAMES
I-A	Gypsum Wall-board Paint	Gypsum Wallboard Paint	Replace	Replace
I-B	Veneer Plaster Paint	Veneer Plaster Paint	Replace	Replace
I-D	Gypsum Jute	Gypsum Jute	Replace	Replace
I-F	Cementitious Coating	Melamine Panel	Solvent Strip Repaint	Solvent Strip Repaint
I-G	Plywood Panel	Gypsum Fiberglass	Dip Tank Repaint	Solvent Strip Repaint

B.2 Washington, Series II

Washington Series II Package Plans for Dwelling Units Requiring Abatement of Interior Trim Only

PACKAGE PLAN	WINDOWS	DOORS	BASEBOARD	ALL OTHER TRIM
II-A	Replace	Replace	Replace With Wood	Replace With Wood
II-B	Replace	Replace		
II-C	Solvent Strip Repaint	Solvent Strip Repaint		Replace With Wood
II-D	Solvent Strip Repaint	Solvent Strip Repaint	Solvent Strip Repaint	Solvent Strip Repaint
II-E	Heat Gun Repaint	Heat Gun Repaint	Heat Gun Repaint	Heat Gun Repaint
II-F	Solvent Strip Repaint	Dip Tank Repaint	Solvent Strip Repaint	Solvent Strip Repaint

B.3 Atlanta, Series I

Atlanta Series I Package Plans for Dwelling Units
Requiring Abatement of Interior Walls and Trim

PACKAGE PLAN	WALLS DRY AREA	WALLS WET AREA	DOORS, WINDOWS AND WINDOW FRAMES	ALL OTHER TRIM
I-A	Gypsum Wall-board, Paint	Gypsum Wall-board, Paint	Replace	Replace With Wood
I-B	Veneer Plaster, Paint	Veneer Plaster, Paint	Replace	Replace With Wood
I-C	Plaster with Lath, Paint	Plaster with Lath, Paint	Solvent Strip Repaint	Solvent Strip Repaint
I-D	Gypsum Jute	Gypsum Jute	Replace	Solvent Strip Repaint
I-E	Filled Paint	Filled Paint	Solvent Strip Repaint	Solvent Strip Repaint
I-F	Cementitious Coating	Melamine Panel	Solvent Strip Repaint	Solvent Strip Repaint
I-H	Gypsum Jute	Vinyl-Coated Fabric	Scrape Repaint	Scrape Repaint

B.4 Atlanta, Series II

Atlanta Series II Package Plans for Dwelling Units
Requiring Abatement of Trim Components Only

PACKAGE PLAN	WINDOWS AND WINDOW FRAMES	DOORS	ALL OTHER TRIM
II-A	Replace	Replace	Replace
II-B	Solvent Strip Repaint	Solvent Strip Repaint	Solvent Strip Repaint
II-C	Heat Gun Repaint	Heat Gun Repaint	Heat Gun Repaint
II-D	Solvent Strip Repaint	Dip Tank Repaint	Solvent Strip Repaint
II-E*	Solvent Strip Repaint	Solvent Strip Repaint	

Continued on Next Page.

Atlanta Series II Continued

PACKAGE PLAN	WINDOWS AND WINDOW FRAMES	DOORS	ALL OTHER TRIM
II-F*	Replace	Replace	
II-G*	Scrape Repaint	Plywood	

*Denotes Exterior Surfaces

APPENDIX C: APPROXIMATE RANGES OVER WHICH COST MODEL ESTIMATES ARE VALID

The tables presented in this Appendix are intended to serve as guidelines as to what are or are not appropriate values for the determinats of direct cost. Each table presents by abatement technique the average values and the range of values for the four main determinants of direct cost.

If it is desired to estimate the per unit direct costs of LBP abatement using the cost models outlined in Chapter 4, the most reliable estimates will result if the value of the determinant lies within the range of values observed in Phase I. Prudence should be exercised whenever a value outside this range is desired to be used since the structure of the cost model may have been altered. Attention should especially be given to the values used for the productivity of labor since these values usually have a significant effect on per unit direct cost. It is recommended that the average value for the productivity of labor be used unless strong empirical evidence establishing a figure which is different from that used in this study exists.

The tables presented in this Appendix give values for each determinant even if that determinant was not used in the cost model. This additional information provides the cost estimacor with a better knowledge of just what type of figures went into the formulation of the cost models.

TABLE C.1

VALUES OF THE DETERMINANTS OF DIRECT COST FOR WALL ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	AREA IN SQUARE FEET		AVERAGE WAGE RATE		PRODUCTIVITY OF LABOR[a]		CONTRACT PACKAGE SIZE	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Cementitious Coating	612	594- 621	8.33	8.33	58.4	56.5-62.1	11	11
Filled Paint	504	464- 592	7.62	6.00- 8.35	87.6	53.3-128.0	9	1-11
Gypsum Jute	531	104-1046	8.11	6.46- 8.65	22.1	13.9-34.5	18	1-30
Gypsum Fiberglass	507	309- 575	8.32	7.87- 8.70	18.2	12.3-26.0	30	30
Veneer Plaster	657	448-1139	7.43	6.52- 8.7	12.6	10.4-16.4	14	1-30
Gypsum Wallboard	570	448-1437	7.08	6.51- 8.65	10.4	5.8-16.3	14	11-30
Plaster with Lath	672	448-1592	7.41	6.91- 7.74	9.4	6.4-20.4	12	11-16
Melamine Paneling	415	180-600	7.47	5.88-10.00	11.8	7.5-23.3	21	11-30

[a]Productivity figures are in square feet of wall area abated per manhour.

TABLE C.2

VALUES OF THE DETERMINANTS OF DIRECT COST FOR DOOR ABATEMENT TECHNIQUES

	NUMBER OF DOORS		AVERAGE WAGE RATE		PRODUCTIVITY OF LABOR[a]		CONTRACT PACKAGE SIZE	
ABATEMENT TECHNIQUE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Hand Scraping	2.3	1-5	5.83	4.00-8.24	0.54	0.50-0.63	14	11-16
Heat Gun	4.9	1-15	6.06	4.00-8.25	0.53	0.24-1.00	15	11-30
Solvent Stripping	4.8	1-19	7.05	4.25-8.64	0.38	0.13-0.71	18	11-30
Dip Tank Method	4.7	2-9	6.07	4.36-7.81	0.24	0.10-0.55	26	16-30
Replace (Interior)	4.6	1-8	7.65	4.97-8.59	0.20	0.05-0.47	27	16-30
Replace (Screen)	1.3	1-2	6.32	5.38-6.83	0.15	0.08-0.27	11	11
Replace (Exterior)	1.4	1-3	6.46	4.74-8.68	0.16	0.07-0.44	12	1-16

[a]Productivity figures are in number of doors abated per manhour.

TABLE C.3

VALUES OF THE DETERMINANTS OF DIRECT COST FOR DOOR FRAME ABATEMENT TECHNIQUES

	NUMBER OF DOOR FRAMES		AVERAGE WAGE RATE		PRODUCTIVITY OF LABOR[a]		CONTRACT PACKAGE SIZE	
ABATEMENT TECHNIQUE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Hand Scraping	3.0	1-8	5.46	4.00- 8.19	0.53	0.31-0.67	15	11-16
Heat Gun	4.2	1-17	6.83	4.00-10.38	0.52	0.22-1.04	14	1-30
Solvent Stripping	5.1	1-22	7.16	4.13- 8.70	0.43	0.11-1.12	16	1-30
Infra-Red Device	2.0	2	4.29	4.00- 5.00	0.39	0.17-0.67	16	16
Replace (Exterior)	4.6	1-15	7.54	4.06- 9.43	0.11	0.06-0.33	21	11-30

[a]Productivity figures are in number of door frames abated per manhour.

TABLE C.4

VALUES OF THE DETERMINANTS OF DIRECT COST FOR WINDOW AND WINDOW FRAME ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	NUMBER OF WINDOWS AND WINDOW FRAMES		AVERAGE WAGE RATE		PRODUCTIVITY OF LABOR[a]		CONTRACT PACKAGE SIZE	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Hand Scraping	2.0	2	4.27	4.00-4.55	0.22	0.18-0.27	16	16
Heat Gun	6.0	1-16	5.26	4.27-9.89	0.22	0.14-0.32	19	16-30
Infra-Red Device	2.5	1-4	4.14	4.00-4.27	0.19	0.14-0.28	16	16
Solvent Stripping	7.1	2-21	6.05	4.00-9.11	0.24	0.05-0.53	15	11-16
Replace	4.3	1-14	7.64	4.10-8.89	0.15	0.05-0.33	25	16-30

[a]Productivity figures are in number of door frames abated per manhour.

TABLE C.5

VALUES OF THE DETERMINANTS OF DIRECT COST FOR MISCELLANEOUS TRIM ABATEMENT TECHNIQUES

ABATEMENT TECHNIQUE	LINEAR FEET OF TRIM		AVERAGE WAGE RATE		PRODUCTIVITY OF LABOR[a]		CONTRACT PACKAGE SIZE	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Solvent Stripping	7	8-459	6.38	4.00-8.35	6.8	1.4-24.0	13	1-16
Hand Scraping	69	8-386	4.50	4.00-8.10	3.8	1.2-12.0	15	11-16
Propane Torch	26	8-55	4.73	4.14-6.00	6.6	1.6-20.0	16	16
Heat Gun	128	4-283	5.54	4.00-8.10	4.2	2.0-7.0	14	11-16
Infra-Red Device	31	8-54	4.22	4.00-4.50	3.3	0.7-6.4	16	16

[a]Productivity figures are in linear feet of trim abated per manhour.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Public and private concern about the potential for lead poisoning in children due to the ingestion of lead-based paint chips has resulted in a Federally sponsored program to develop technologies by which lead-based paint may be eliminated from the nation's housing. Through this program lead-based paint abatement techniques were tested in field deleading operations conducted in Washington, D.C., and Atlanta, Ga. The program also focused on the collection of data on the direct costs of labor, materials and special equipment associated with these abatement techniques.

This report provides a statistical analysis by abatement technique and building component (i.e., walls, doors, door frames, windows and frames, and miscellaneous trim) of this direct cost data. Abatement techniques are then ranked according to their relative costs. A cost model is developed for each category (ranking) which identifies the key factors which affect direct cost and provides a framework whereby direct costs may be estimated. Recommendations are made for further refinement of the model; a methodology through which the optimal combination of lead-based paint abatement techniques can be identified is also outlined.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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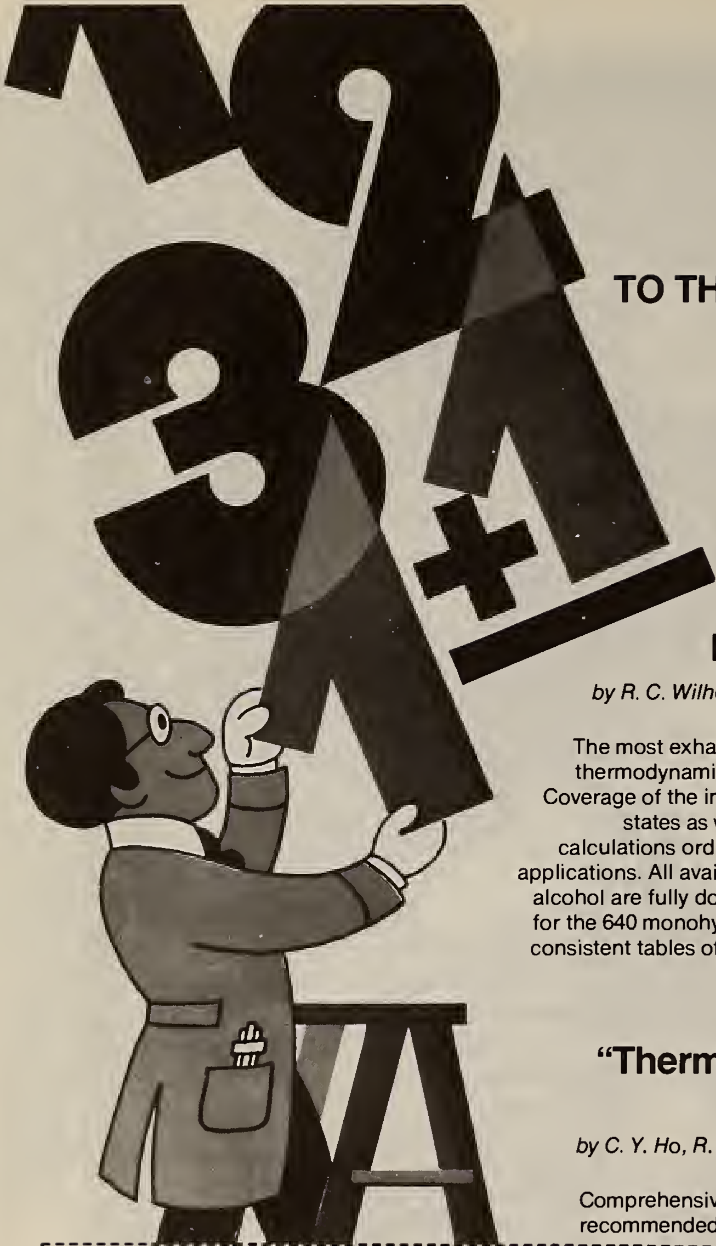

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