NBS TECHNICAL NOTE 971

U. S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Guidelines for Cost-Effective Lead Paint Abatement

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Guidelines for Cost-Effective Lead Paint Abatement

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PREFACE

This research was conducted under the sponsorship of the Department of Housing and Urban Development by the Applied Economics Program, the Center for Building Technology, National Engineering Laboratory, National Bureau of Standards. This report analyzes for lead-based paint abatement the cost figures collected during Phase II of the Experimental Hazard Elimination Program (EHEP) and provides public and private decision makers with a procedure for estimating the costs of lead-based paint abatement.

Appreciation is extended to Drs. Harold E. Marshall and John S. McConnaughey, Applied Economics Program, who reviewed the economic aspects of this paper. Appreciation is also extended to Mr. Harvey W. Berger, National Engineering Laboratory, who provided useful suggestions for improving the treatment of certain topics in this paper and Mr. Philip T. Chen, Cost Engineer, Applied Economics Program, who critiqued the cost procedures presented in this paper. Special appreciation is extended to Ms. Barbara Cassard, formerly with the Applied Economics Program, and Ms. Kimberly Hockenbery, Applied Economics Program, for their valuable assistance in the data analysis phase of this research effort.

ABSTRACT

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 Boston, Massachusetts. The major focus of the program was on the collection of data on the direct costs of labor, materials and special equipment associated with these abatement techniques. Data were also collected on contractor's bids so that markup ratios could be calculated.

This report provides an overview of the statistical analysis of these direct cost data by abatement technique and building component (i.e., walls, doors and frames, windows and frames, and miscellaneous trim). An overview of the statistical analysis of the markup ratio is also included. Cost models for each abatement technique are developed which identify the key factors which affect direct cost and markup. Guidelines are given so that these models can be used by municipal officials and building owners to estimate deleading costs as well as provide input to policy evaluation and formulation.

Keywords: Abatement; applied economics; 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 led to the passage of the "Lead-Based Paint Poisoning Prevention Act" (PL 91-695) in Janaury 1971. Through this Act, Congress 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 costs associated with these techniques. An economic model is needed to determine the efficiency of the alternative lead-based paint abatement strategies.

This study provides an overview of the analysis of the direct cost and contractors' bid price data collected in Boston, Massachusetts during Phase II of EHEP. The Phase II direct costs associated with each abatement technique are analyzed by building components (walls, doors and frames, windows and frames, and miscellaneous trim). The per unit direct costs (per square foot, per item, per linear foot) are presented, as are results of statistical analyses of per unit direct costs at the dwelling unit level. Cost models which include those variables having the greatest impacts on direct cost are then formulated for each abatement technique.

The cost models are then validated against an independent set of data collected in Atlanta, Georgia during Phase I of EHEP. The validation procedure was undertaken to test the adequacy of the cost models in predicting per unit direct costs in another city at a different point in time. Once the cost models had been validated, a procedure for predicting the contractor's markup for overhead and profit was developed.

An important result of the EHEP Phase II cost data analysis was to underscore the fact that there is no uniform least-costly abatement technique. Thus the use of one technique exclusively is not economically efficient. If the least-cost combination of abatement techniques can be identified and installed, empirical results indicate that savings of approximately $100 per dwelling unit can be achieved. These savings depend on variations in direct costs and markup associated with different types of housing, supply and demand conditions in the labor and materials market, and differing contracting procedures.

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 deleaded, prevailing wage rates, and the productivity of labor are captured. Since this method of cost estimation addresses the major sources of variation in direct cost, it also captures differences in direct costs due to regional effects. Thus the cost models may be used with confidence in most demographic regions of the nation as a means of estimating lead-based paint abatement costs. To facilitate the use of these cost models by public officials and building owners, a small-scale computer program was developed. This program permits the user to input specific information on an anticipated contract package of dwelling units. The output tells the user what the least-cost combination of abatement techniques for each dwelling unit is; an estimate of the overall expected bid price for the contract is also provided.

Since many of the techniques used for lead-based paint abatement are useful in the rehabilitation on 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.

Due to the quantity and level of detail in the cost data collected during Phase II of EHEP and the degree of statistical analysis it required, details of individual statistical analyses are not presented in this report. This streamlining permits us to focus upon those results which are of greatest importance. However, for those readers wishing to verify that the results presented in this report have firm technical and theoretical underpinnings, a companion report has been prepared. This report, Lead Paint Abatement Costs: Some Technical and Theoretical Considerations, treats in detail the considerations and planning which went into the development and analysis of the Phase II EHEP cost models.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF DIAGRAMS

LIST OF TABLES

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, France 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 = $1.000^{*} \times 10^{7}$ erg/second

Temperature

°C = 5/9 (Temperature °F - 32)

1. INTRODUCTION

Lead is a metal which has been used extensively throughout recorded history. Currently it is used in pipes, tubing, flashing, sheathing for cables, and in shielding against radioactive substances. Lead alloys and lead compounds are used as casting alloys, gasoline additives, and paint pigments. Thus, lead occupies an important role in the functioning of modern industrialized societies, and is present in the environment in many forms.

People who are exposed to lead in sufficient quantities risk developing lead poisoning, or plumbism.[1] Although it affects the entire body, lead poisoning is usually concentrated in the nervous system, the gastro-intestinal tract, and the blood forming tissues. Lead poisoning is most acute among children due to their higher growth rates. They are therefore the most susceptible group to permanent brain damage by virtue of lead's effect on the nervous system.

Although the environmental sources of lead are many, those which are potential sources of lead poisoning can be grouped into four basic categories: (1) air, (2) dust, (3) soil, and (4) paint. The two paths through which lead can enter the body are (1) the digestive system and (2) the respiratory system.

Diagram 1.1 illustrates the ways in which the environmental sources of lead can enter the body. In this study we treat the branch of Diagram 1.1 which starts with lead-based paint (LBP) and ends with lead poisoning.[2]

Lead poisoning in children due to LBP is precipitated by ingestion of contaminated paint chips. Children between the ages of one and seven are most vulnerable to the disease, because they have a natural tendency

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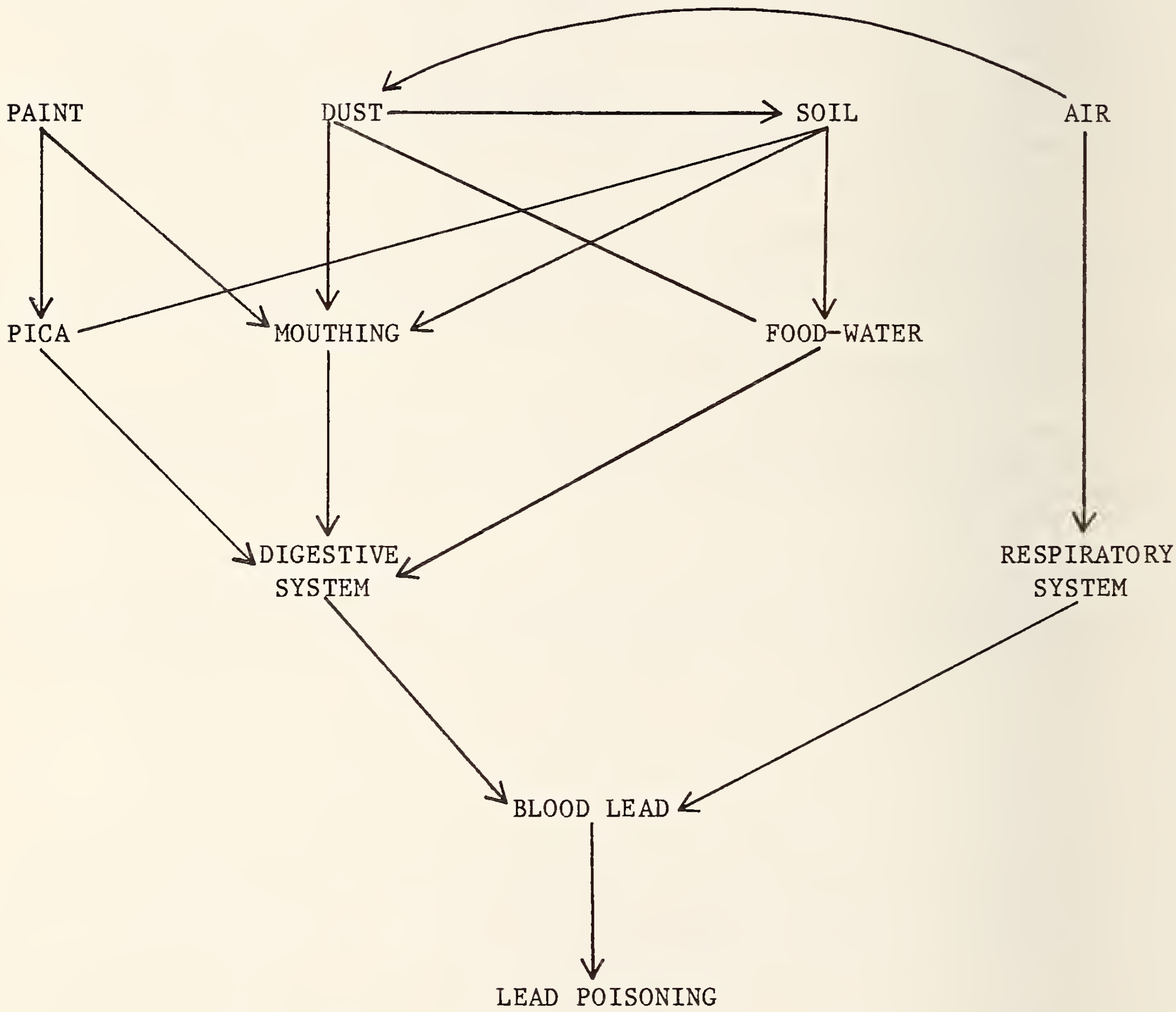
[1] For an authoritative source on lead poisoning, see J.J. Chisolm, "Lead Poisoning," Scientific American, Vol. 224, No. 2, February 1971.

[2] This does not imply that the major source of lead poisoning in children is directly attributable to LBP. In fact, a recent study (see Anthony J. Yankel, Ian von Lindern, and Stephen D. Walter, The Silver Valley Lead Study: The Relationship of Childhood Lead Poisoning and Environmental Exposure, draft report) has shown that excess ambient air lead can cause very high levels of blood lead in children. Therefore, LBP abatement decisions should not be made without considering other environmental sources of lead, such as smelters.

DIAGRAM 1.1 WAYS IN WHICH ENVIRONMENTAL SOURCES OF LEAD CAN ENTER THE BODY[1]



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[1] This diagram is patterned after one presented in Anthony J. Yankel, Ian von Lindern, and Stephen D. Walter, The Silver Valley Lead Study: The Relationship of Childhood Lead Poisoning and Environmental Exposure.

to mouth foreign objects.[1] At this age children usually can not distinguish between harmful substances and ones that are not harmful. Poisoning may therefore occur without either the knowledge of the child or of the other family members. Furthermore, the symptoms of lead poisoning are similar to those of other childhood ailments so that the disease may go undetected for long periods of time. Although mouthing may be an important cause of LBP poisoning, the potential for lead poisoning is more acute for children who suffer from pica, or the abnormal craving for non-food substances. In these cases, children may consume massive amounts of lead by eating LBP chips which they have peeled or pried from painted surfaces or picked up from the floor.

To determine the degree to which the presence of LBP affects the lead poisoning problem, it is first necessary to identify the age and type of housing where it is most likely to occur. Recent studies indicate that LBP is located primarily in housing constructed prior to 1950.[2,3,4] In this stock of housing, many interior paints contain lead pigments as their primary source of color and holding power. Since 1950, however, lead oxides and carbonates in paints have largely been replaced by titanium dioxide.

An analysis of the two surveys published by the National Bureau of Standards, indicated that approximately 30 percent of all pre-1940 residential dwelling units contain LBP which is either peeling or located on a poor substrate.[5] The survey conducted in Pittsburgh, Pennsylvania, which involved a random sample of 3300 dwelling units, indicated that approximately 1,900 dwelling units had a lead content (on at least one

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[1] Some estimates assert that as much as 1/4 of all confirmed LBP poisoning cases are due to mouthing contaminated surfaces which are in a tight or otherwise sound condition. See Thomas B. Sarb, "Lead Paint Poisoning: Remedies for the HUD Low Income Homeowner When Neglect is No Longer Benign," University of Michigan Journal of Law Reform, Vol. 8, Spring 1975.

[2] Selma J. Mushkin and Ralph Freiden, Lead Poisoning in Children: The Problem in D.C. and Preventative Steps, Public Services Laboratory, Georgetown University, Washington, D.C., 1971.

[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.

[4] Douglas R. Shier and William Hall, Analysis of Housing Data Collected in a Lead-Based Paint Survey in Pittsburgh, Pennsylvania Part I, National Bureau of Standards, Interagency Report 77-1250, May 1977.

[5] Substrate is the underlying material to which the paint film adheres.

wall) of 2.0[1] milligrams per square centimeter (mg/cm^2) or more. It also revealed that approximately 62 percent of all dwelling units constructed before 1940, and that slightly over 31 percent 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. LBP was also found in a significant number (approximately 13 percent) of dwelling units constructed after 1960.[2] The Pittsburgh survey looked at a cross section of all housing and not just that deemed likely to contain LBP. Therefore, it provides some measure of how widespread the use of LBP was in housing in the Middle Atlantic geographical region.

A comparison of the results of the Pittsburgh survey with those of a smaller test program carried out in Washington, D.C.[3] indicated that the distribution and levels of LBP in the two cities were very similar.[4]

Under the relatively strong assumption that the distribution and levels of LBP in the nation's stock of housing are similar to those observed in Pittsburgh, it becomes possible to estimate the total expenditure required to delead the nation's stock of housing. Combining census data and the results of the Pittsburgh survey with empirical cost data produces a national cost estimate (in 1976 dollars) of between 28 and 35 billion dollars depending on the minimum lead level[5] above which a dwelling unit is deemed to be "at risk." Furthermore, in analyzing these estimates it

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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 analysis conducted by William Hall, Mathematician, Operations Research Division, Center for Applied Mathematics, National Engineering Laboratory, National Bureau of Standards. Details are given in Douglas R. Shier and William Hall, Analysis of Housing Data Collected in a Lead-Based Paint Survey in Pittsburgh, Pennsylvania Part I, National Bureau of Standards, Interagency Report 77-1250, May 1977.

[3] William Hall, T. Ayres, and D. Doxey, Survey Plans and Data Collection and Analysis Methodologies: Results of a Pre-Survey for the Magnitude and Extent of the Lead-Based Paint Hazard in Housing, National Bureau of Standards, Interagency Report 74-426, January 1974.

[4] Douglas R. Shier and William Hall, Analysis of Housing Data Collected in a Lead-Based Paint Survey in Pittsburgh, Pennsylvania Part I, National Bureau of Standards, Interagency Report 77-1250, May 1977.

[5] The $28 billion figure is based on a minimum lead level of 2.0 mg/cm^2. The $35 billion figure is based on a minimum load level of 1.5 mg/cm^2. Details of the national cost estimates are given in Appendix A of the

(continued on next page)

was revealed that between 40 and 45 percent of the national deleading cost burden must be borne by the eight States in the Middle Atlantic and East North Central regions.

1.1 THE EXPERIMENTAL HAZARD ELIMINATION PROGRAM (EHEP)

The extent to which LBP is distributed throughout the nation's stock of housing and the potential it has for poisoning young children has generated a great deal of interest and concern among private individuals, community groups, and public officials. It has also posed some difficult legal questions regarding the responsibilities of building owners and occupants (i.e., who should bear the burden of the abatement costs).[1,2] As a result, the "Lead-Based Paint Poisoning Prevention Act" (PL 93-695) was enacted by Congress on January 13, 1971 and amended (PL 93-151) on on November 9, 1973. These acts provided for Federal participation, including grants to local governments for detection, treatment, and prevention of LBP poisoning.

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 deal with the LBP poisoning problem and which will promote economic efficiency in the allocation of resources to eliminate high levels of LBP in housing. HUD in return has requested the Center for Building Technology (CBT) of the National Bureau of Standards to provide technical support in attaining these goals through a detailed analysis of LBP abatement technologies. Past studies conducted by CBT for HUD have led to the formulation of the Experimental Hazard Elimination Program (EHEP). EHEP is intended to

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companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations. It is important to point out that the figures cited above do not include the costs of administering a nationwide lead paint abatement program. It is shown in Appendix A.4 of the companion report that including administration costs in the national estimate will increase the cost figures cited above by approximately 30 percent. In addition, no estimate was made on the cost of abating the lead-based paint hazard from the exterior surfaces of a dwelling unit. This was due to a general lack of information on the appropriate techniques for abatement, the cost of abatement, and the distribution of lead levels on exterior surfaces.

[1] R. Bruce Tepper, Jr., "Lead Paint Poisoning: The Response in Litigation," St. Louis University Law Journal, Vol. 19, Winter 1974.

[2] Thomas B. Sarb, "Lead Paint Poisoning: Remedies for the HUD Low-Income Homeowner When Neglect is No Longer Benign," University of Michigan Journal of Law Reform, Vol. 8, Spring 1975.

contribute to the accomplishment of HUD's responsibilities in three ways. First, it permits the technical evaluation of experimental LBP abatement techniques in field deleading operations. Second, through the collection of cost data, it provides a framework for estimating the costs of future LBP hazard abatement operations. Third, it provides a data base against which procedures for estimating abatement costs can be tested for accuracy and ease of application.

EHEP consists of two phases. Phase I of EHEP involved LBP hazard abatement operations in 110 dwelling units. Thirty dwellings initially underwent LBP hazard abatement in Washington, D.C.; the remaining 80 underwent LBP hazard abatement 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] Information on the costs experienced in Phase I of EHEP and how they impinge on abatement decisions is given in Economic Analysis of Experimental Lead Paint Abatement Methods: Phase I.[3] The cost information collected during Phase I of EHEP was also used as a data base against which procedures for estimating abatement costs were validated. Phase II of EHEP involved deleading operations in 71 dwelling units in Boston, Massachusetts. Phase II differed from Phase I in that an experimental design was rigorously defined and controlled so that variations in abatement technique cost could be analyzed with regard to such important factors as type and condition of housing as well as prevailing supply and demand conditions for construction skills and materials.

1.2 PURPOSE

The purpose of this report is to present an analysis of the costs of experimental abatement techniques based on an evaluation of cost data collected in Boston, Massachusetts during Phase II of EHEP. The analysis of these data will aid in the identification of those LBP abatement techniques which promote economic efficiency at the dwelling unit level.

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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.

[3] Robert E. Chapman, Economic Analysis of Experimental Lead Paint Abatement Methods: Phase I, National Bureau of Standards, Technical Note 922, September 1976.

Cost estimating procedures based on the Phase II of EHEP data are proposed that (1) identify those variables which have the greatest impact on direct costs and contractor markup, (2) show how the least-cost abatement technique may be identified, and (3) provide guidelines for estimating abatement costs at the dwelling unit level or for a major program.

1.3 SCOPE AND APPROACH

The focus of this study is on Phase II of HUD's Experimental Hazard Elimination Program. Cost data from field deleading operations undertaken in Boston, Massachusetts are analyzed. The analysis of these data is directed at the formulation of a cost model for estimating LBP abatement costs at either the dwelling unit level or the program level.

Cost data are analyzed by building component (i.e., by walls, doors and frames, windows and frames, and miscellaneous trim). Whenever possible a cost model is developed for each abatement technique. This approach was chosen because it permits a wider variation in costs to be explained and facilitates cost comparisons with other abatement techniques. The individual cost models are validated against the cost data collected during Phase I of EHEP. Suggestions for further work, including the preparation of a guide for municipal officials, conclude the 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 rigorously estimate future costs or life-cycle costs resulting from maintenance or repair necessitated by lack of long-term durability of an abatement technique. In the absence of information on the potential benefits to be derived from abatement and expected future costs, 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.

1.4 NEED FOR EHEP-TYPE COST MODELS

If the least-costly abatement techniques can be identified and used, results from EHEP indicate that, on the average, a reduction in costs of from \$80 to \$120[1] per dwelling unit can be achieved. If these figures are projected for a city-wide abatement program, it can be seen that the results of EHEP indicate that there is a great potential for reducing program costs.

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[1] These figures assume that the quantity of abatement work is given by the set of figures listed as "optimal" in the surface abatement criteria in Section 2.2. Empirical evidence also supporting the \$80 to \$120 savings per dwelling unit claimed above is presented in Appendix D.4 of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

We are now in a position to see how the objectives of EHEP relate to the dual requirement of keeping program costs down and carrying out an agressive city-wide program. One of the major objectives of EHEP was to produce a cost estimation procedure which was flexible, reliable, and straight-forward in its application. Attaining this objective permits abatement technique costs to be forecast with enough accuracy that they could be carefully compared and the least-cost techniques identified. Several important policy implications can also be derived from the use of the EHEP procedure. First, by reducing the uncertainty in cost estimation and identifying those abatement techniques which are least costly, a policy strategy that results in more abatement per dollar spent can be initiated and carried out. Second, a system of priorities can be established that would tend to maximize the number of injuries averted per dollar spent. Finally, it assists decision makers in both policy formulation and evaluation since it reduces the risks of either selecting a policy strategy that wastes scarce tax dollars or rejecting (or abandoning) a policy strategy that is economically sound.[1]

At this stage, it is only natural to ask, "What are the steps that can be taken to bring the results of an experimental program like EHEP into a form where they can be used in programs outside the context of EHEP?" The importance of this question cannot be overstressed. To answer this question we shall rely heavily on the concepts and methods of the discipline referred to as operations research.[2] By applying the methods of operations research it becomes possible, through four basic steps, to bridge the gap between the experimental data collected in EHEP and a cost estimation procedure suitable for policy analysis. These four steps are: (1) problem definition, (2) model formulation, (3) model validation, and (4) implementing and controlling the solution. In order to better understand the connection between each of the four steps, we shall examine them individually.

Clearly the first step which must be taken is defining the problem. But before the problem can be defined in enough detail to permit a meaningful solution, we must identify a suitable measure of performance, what constraints, if any, are applicable to the controlled variables,[3]

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[1] Each of the policy implications just outlined would be appropriate for building owners since it would permit them to achieve the maxium amount of abatement per dollar spent. This in turn would reduce the chance of litigation due to LBP poisoning cases in their properties.

[2] Operations research may be defined as the application of the scientific method to the management of organized systems.

[3] An example of a controlled variable is the quantity of surface to be deleaded. Other controlled variables are given in Table 2.1 (Surface Abatement Criteria) in Section 2.2.

and what are the uncontrolled variables[1] in the experiment. Since we are concerned with cost estimation, it is natural to choose as a measure of performance, the cost of a given level of hazard abatement. In this case, the level of hazard abatement could either be in the present or over the long term. However, since we do not have an adequate measure of the long-term durability of the alternative abatement techniques, we shall not attempt to differentiate between the levels of hazard abatement over the life-cycle of the alternative techniques. Therefore, it will be assumed that each technique has an equal level of hazard abatement.[2]

Thus, the relevant costs to be considered in defining the measure of performance are initial costs, in particular the bid price for the abatement work. We may now define the problem.

Problem Definition: To identify that abatement technique, which, for a given set of building considerations, minimizes the expected bid prices.

Explicit in this definition is a procedure for estimating the direct costs and markup for each abatement technique.

The second step in the approach is formulating a model which is consistent with the definition of the problem. This step relies not only on knowing which mathematical methods are appropriate for analysis of any data collected during the abatement process, but also on how the abatement process operates.[3] The initial step in this phase of the project involves the development of a theoretical model. The theoretical model usually differs from the final model in that it is based on operational knowledge of the abatement process rather than on empirical data.[4] The main purpose of the theoretical cost model is to identify the most efficient experimental design; in this case for Phase II of EHEP. As data arrive from the experiment, they are compiled and statistics on individual abatement technique costs are computed. Costs may then be

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[1] An example of an uncontrolled variable is work stoppage due to lockouts.

[2] The measure of performance may now be chosen as the cost per square foot or the cost per linear foot.

[3] Knowledge of the abatement process is based on construction experience in the rehabilitation field. An illustration of how this operational knowledge complements data analysis can be seen in the format of the Dwelling Unit Cost Data Form presented in Section 2.4.

[4] It should be noted that the development of the theoretical model used in Phase II of EHEP also relied on experience gained in analyzing the Phase I cost data.

analyzed using the analysis of variance[1] to see if significant differences result as a function of abatement technique, occupancy status, or substrate[2] condition. Further tests are then performed using multiple regression[3] to see if relationships between abatement cost and certain key factors can be identified and quantified. An iterative process using multiple regression is used so that all of the key factors which affect abatement costs can be identified and their relationships quantified. This process is followed for each abatement technique. Additional details on the formulation of the individual cost models are given in Chapter 3; a discussion of how the theoretical considerations in model building relate to EHEP is given in Appendix C of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

The third step in the approach is validating the model against an independent set of data. Validation is the important link which assures us that the structure of the cost model is consistent with the way the abatement process operates in general, rather than just a description of a specific set of data. To validate the Phase II EHEP cost models, cost data from the Phase I of EHEP are used. The Phase I EHEP cost data are used for four basic reasons. First, they were collected independently of the Phase II cost data. Second, they provide data on all but one abatement technique used in Phase II of EHEP. Third, the data base has a greater degree of detail than other available sources. And finally, the reliability of the data is very high when compared to other available sources. Using the Phase I data base for validation was very fruitful, because it stimulated feedback between the formulation and implementation phases of the project. Thus, it helped both to generalize and to simplify the cost models. It is thought that this will

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[1] Analysis of variance permits the hypothesis that observed differences in abatement technique costs are due to chance to be tested against the hypothesis that observed differences are indicative of actual differences in abatement technique costs. 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. Scheffe, The Analysis of Variance, John Wiley and Sons, Inc., 1959.

[2] The substrate is the underlying material to which the paint film adheres.

[3] 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, or explanatory, variables. 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.

help promote the use of the EHEP models since they can now be applied both more effectively and more efficiently by decision makers. More information on the mechanics of the validation procedure is given in Chapter 4.

The final step in the approach is to implement and control the solution of the problem by using the model's results. Of crucial importance here is that decision makers recognize the advantages that the EHEP cost estimation procedure has over other methods of cost estimation. Although there are many methods of estimating construction costs,[1] none is specifically directed at LBP hazard abatement. Similar skills and materials are involved in LBP hazard abatement, but the level of activity at which LBP hazard abatement is carried out is inconsistent with that assumed in the construction cost estimating guides.[2] This almost always causes the cost estimates based on simple averages to be well below those costs actually expected or experienced in field deleading operations. Consequently, the way in which the key factors are related may cause their impacts on costs to differ.[3] Furthermore, other procedures are not flexible enough to include ways of modifying labor costs (e.g., the productivity of labor) or material costs without relying heavily on judgmental decisions which can neither be confirmed nor denied. On the other hand, the EHEP procedure minimizes the degree to which judgmental decisions must be made, and concentrates on basing decisions on facts which can be easily observed or measured. Uncertainty is therefore reduced significantly. Another benefit of the EHEP procedure is that it is structured in such a way that the cost estimation phase of a large abatement program complements the dwelling unit screening phase. In this way, very specific dwelling unit information can be collected while lead readings are being taken at little or no extra cost to the overall program. To facilitate the application of the EHEP procedure, a computer program written in the BASIC[4] language has been prepared. This program

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[1] Examples of cost estimating guides are Building Construction Cost Data 1977, Robert Snow Means Company, Inc., Duxbury, Mass.; Dodge Manual for Building Construction Pricing and Scheduling, McGraw-Hill Information Systems Company, New York; Home-Tech. Estimator, Home-Tech Publications, Bethesda, Maryland.

[2] Joseph G. Kowalski, Cost Estimation in Residential Alteration and Repair Construction: An Economic Analysis, National Bureau of Standards, Interagency Report (in preparation).

[3] In the terminology of economic theory, the production function for LBP hazard abatement is not the same as the one in new construction or in major rehabilitation activities.

[4] BASIC is an acronym for Beginner's All-purpose Symbolic Instruction Code. A good introduction to BASIC is given in D. Spencer, A Guide to BASIC Programming: A Time-Sharing Language, Addison-Wesley Publishing Company, Inc., Reading, Mass., 1970.

will permit costs to be estimated rapidly and accurately either at the dwelling unit level or at the program level. These applications are explored in more detail in Chapter 5.

2. DESCRIPTION OF PHASE II EHEP

2.1 SITE SELECTION

The selection of a candidate city 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 hazard 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. Thus, the interest and willingness of local housing authorities as well as HUD regional offices to participate in EHEP had to be assessed. Lead poisoning incidence data for cities were then reviewed to determine the frequency with which elevated blood lead levels were reported. This approach was taken since it was hypothesized that the incidence of lead poisoning would provide an indication of the number of dwelling units which contain high levels of lead in paint. 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.

A preliminary review of available data for cities indicated that Boston, Massachusetts had a relatively high incidence of children with elevated blood lead levels. Further investigations of census tract data showed that Boston also has a varied stock of housing types which are deemed likely to contain hazardous levels of LBP. Another important reason for selecting Boston was that it had an existing lead paint hazard abatement program. Thus, it was possible to work closely with health officials and housing officials to select the areas of the city for surveys and to facilitate the survey process. Another result of the city's lead paint abatement program was that there were a large number of contractors experienced in deleading operations. Boston also had a large stock of HUD acquired properties which were available for use in the program.

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.

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, a rigorous experimental design was required to identify how many dwelling units were needed to measure variations in costs associated with a given attribute or combination of attributes, such as substrate condition or occupancy status. The reliability of statistical comparisons is enhnaced when constraints are placed on variables such as the geographical distribution of the dwelling units and the maximum and minimum surface which can be deleaded. The constraints placed on observations made during Phase II of EHEP were designed to reflect (1) the values which are expected to be encountered in practice, and (2) the desire to maintain a high degree of comparability within the data base.[1] This was accomplished through the use of surface abatement criteria which set guidelines on the amount of abatement work which could take place. These criteria[2] provided guidelines not only on the optimum level of abatement work but also on the minimum and maximum levels of abatement work for inclusion in the analysis. Dwelling units which did not meet one or more of the abatement criteria were dropped from the sample. The surface abatement criteria used in Phase II of EHEP are shown in Table 2.1.

TABLE 2.1

SURFACE ABATEMENT CRITERIA

System	Optimum Surface	Minimum Surface	Maximum Surface
Walls[a]	500 s.f.	400 s.f.	700 s.f.
Door/Frame	3 each	3 each	5 each
Window/Frame	5 each	5 each	9 each
Trim[b]	50 l.f.	50 l.f.	100 l.f.

[a] Surface measures are in square feet (s.f.).

[b] Surface measures are in linear feet (l.f.).

[1] Another reason for placing constraints on the values of key variables was to make the data base generated in Phase II of EHEP compatible with that generated in Phase I. This facilitated validation of the Phase II cost models against the Phase I data base.

[2] It should be noted that in the absence of such criteria, the ability to estimate abatement costs is unnecessarily complicated. In fact, if relevant constraints are removed, the potential sources of variation increase rapidly and may confound the data so that the confidence with which statistical tests can be applied and considered relevant is significantly reduced.

The contract management firm, the Boeing Aerospace Company, while working in close coordination with the HUD regional office, established a pool of dwelling units which could be surveyed for the presence of LBP.[1]

Two three-man teams were then assembled to conduct the survey. Each team was equipped with a portable x-ray fluorescent (XRF) lead analyzer with which lead level readings were taken and recorded. The physical measurements of the dwelling unit and any other important attributes were also taken and recorded at that time. If the dwelling unit was found to meet the surface abatement criteria, it was put in a reserve pool until specific abatement techniques could be assigned. In all, 119 dwelling units were surveyed. Of these, LBP hazard abatement operations were carried out in 71. All dwelling units inspected were from HUD's stock of acquired properties.

2.3 ABATEMENT TECHNIQUE SELECTION

The experimental abatement techniques tested in Phase II of EHEP were selected on the basis of recommendations which resulted from an extensive laboratory testing program conducted at the National Bureau of Standards.[2]

Construction experience indicates that the effective abatement of LBP may be accomplished through (1) paint removal, (2) component replacement,[3] and (3) installation of barrier materials. The method actually used will depend upon the building component to be deleaded.

To facilitate the discussion of the individual abatement techniques and their applications, building components may be conveniently grouped into

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[1] A lead content of 2.0 mg/cm^2 or more was used as the criteria for inclusion in the sample due to potential measurement inaccuracies of the lead detection instruments at lead levels below 2.0 mg/cm^2.

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

[3] Component replacement was not used in Phase II of EHEP due to its excessive cost. This method was used in Phase I of EHEP and was found to be appropriate only in cases where the component was severely damaged or deteriorated. The cost estimation procedures presented in in Section 3.3.5 for component replacement are based on Phase I EHEP cost information and are patterned after those procedures presented in Robert E. Chapman, Economic Analysis of Lead Paint Abatement Methods: Phase I, National Bureau of Standards, Technical Note 922, September 1976.

two categories: (1) planar surfaces (walls and ceilings), and (2) trim (doors and frames, windows and frames, baseboards, and other miscellaneous trim surfaces). A breakdown of the abatement methods used in Phase II of EHEP into specific techniques and the building components applicable to those techniques is given in Table 2.2. A brief summary of the abatement techniques used in both phases of EHEP is given in Appendix B of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations. Detailed requirements for the preparation, installation and finishing work as well as construction specifications of the individual abatement techniques used in Phase I of EHEP may be found in the two reports by Boone et al.[1]

TABLE 2.2

ABATEMENT TECHNIQUES USED IN PHASE II OF EHEP

Method	Technique	Applicable Building Component
Barrier Materials	Gypsum Wallboard	Walls
	Plywood Paneling	Walls
	Cementitious Coating	Walls
	Cement-Coated Fiberglass	Walls
	Veneer Plaster	Walls
	Vinyl-Coated Fabric	Walls
Paint Removal	Electric Heat Gun	All Trim Components
	Infra-Red Heating Device	All Trim Components (Used in Unoccupied Units Only)
	Solvent Stripping	All Trim Components
	Hand Scraping	All Trim Components

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[1] 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.

Nine of the ten LBP abatement techniques used in Phase II of EHEP were also used in Phase I. In all, there were 17 abatement techniques used in Phase I of EHEP. Eight were dropped because of excess cost, potential fire hazards, logistical problems, or similarities with other techniques that were used in Phase II of EHEP.

This replication should be emphasized in that it facilitates the identification and 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 work.

2.4 FORMAT AND METHODOLOGY FOR COST DATA COLLECTION

Once an available pool of dwelling units had been established, the individual abatement techniques were assigned to the stock of dwelling units. The dwelling units were then grouped together into contract packages. The contract packages consisted of either two or four dwelling units. They were designed so that the number of different abatement techniques used in any one contract was kept to a minimum. Emphasis was also placed on locating all dwelling units in the same contract in as small an area as possible.

Explicit in the cost experiment was that expected abatement costs for two different ownership categories be analyzed. The two ownership categories analyzed were (1) "privately owned"[1] dwelling units and (2) "acquired properties"[2] owned by HUD. In both cases the dwelling units were owned by HUD. However, the approach taken in soliciting bids from contractors differed between the two categories.

For the cases involving the "privately owned" dwelling units, a representative from the contract management firm posed as a landlord who was anticipating deleading work in some of their rental properties. The representative met with contractors and provided information on the type of dwelling unit, its location, the scope of the work and what abatement techniques were to be used. Bids were then solicited from the contractors.

For the cases involving the "acquired-properties" owned by HUD, the contract management firm provided technical scopes of work and technical specifications for each dwelling unit in the contract package. HUD then used its approved list of contractors, from which ten were selected for bid solicitation. As under HUD normal practice, performance and payment bonds, as well as Davis-Bacon wages, were required

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[1] Thirty-six dwelling units were deleaded in the "privately owned" category.

[2] Thirty-five dwelling units were deleaded in the "acquired-property" category.

for all contracts in excess of $2000.[1] Since some of the deleading contractors who were low bidders, but bid over $2000, were unfamiliar with obtaining performance and payment bonds, excessive delays resulted. In several cases the contract award had to be withdrawn and given to the next lowest bidder.

The contract management firm negotiated a price for recording all of the contractor's direct costs for both the "privately owned" and "acquired property" cases after the abatement contracts had been awarded. It should be noted that the direct costs to the contractor are generally less than the bid price. Direct costs represent the basic costs to the abatement contractor of labor, materials, and any special equipment, whereas the bid price includes a markup for overhead and profit.

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 used to collect information about the contract, the address of the dwelling unit, the time elapsed between the start and finish of the abatement work, the substrate condition, the surface deleaded, and the abatement techniques used. This format was chosen because it facilitates access to cost and other data for indepth analysis. The form is divided so that both direct labor use and material and equipment use can be identified for each sequence in the abatement process. Information on labor includes skill, hours expended, and hourly rate. Information on materials and equipment includes the type (e.g., gypsum wallboard), unit size (e.g., 4' x 8' x 1/2"), quantity, unit cost, and equipment purchase or rental price.

The type of abatement work being performed (i.e., the sequence in the process) is divided into seven basic tasks including preparation, repair, installation or paint removal, and finish painting. The type of work being done also took into consideration such tasks as cleanup and waste disposal, down-time (e.g., lock-outs), and other activities (e.g., transportation to and from the job site). Thus, the form improved the efficiency with which data on each technique could be collected. It also aided in the identification of those portions of the abatement process which were major sources of variations in direct costs.

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 Phase II and Phase I of EHEP. This resulted from a desire to improve both the efficiency and accuracy with which cost figures were reported.

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[1] Those contracts which were under $2000 were issued under purchase orders and had no requirement for bonds or Davis-Bacon wage rates.

FIGURE 2.1 DWELLING UNIT COST DATA FORM

Contract No.__________ Address ______________________________

Date Started__________ Date Finished__________ Substrate Condition ☐ Sound ☐ Unsound

Surface Deleaded____________________________ Abatement Method Used ____________________________

	DIRECT LABOR USE			MATERIALS & EQUIPMENT USE				
Type of Work	Labor Skill	Hours	Rate	Materials/Equipment Type	Unit Size	Quantity	Unit Cost	Equipment
Preparation								
Repair								
Installation or Paint Removal								
Finish Painting								
Clean-up Waste Disposal								
Down-Time								
Other								

In Phase II of EHEP, costs were reported to the contract management firm on a daily basis. This was accomplished by having a representative of the contract management firm visit the job site daily, check the work progress, and record the figures for labor, material, and equipment usage.[1] A great deal of confidence can therefore be placed in the accuracy of the data reported. Furthermore, contracts were kept smaller than in Phase I of EHEP so that more control could be exercised over data collection as well as give more contractors an opportunity to bid on the limited number of dwelling units.

In Phase I of EHEP the collection of cost data differed between Washington and Atlanta. This was largely due to the problems experienced in the Washington portion of the program.

In Washington, cost data was collected after all abatement work was completed. Unfortunately, the length of time between the start and 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 variation in wage rates, material costs, equipment costs, and productivity was experienced than would be expected with more than one contractor.

The major changes in cost data collection between Washington and Atlanta involved the reduction of the size of the contract packages and the 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 had 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. RESULTS OF COST DATA ANALYSIS

The cost data collected in Phase II of EHEP show a rather wide variation. For example, the direct cost per square foot for cementitious coating runs from \$0.22 per square foot to \$1.34 per square foot; gypsum wallboard, a material which is widely used, ranged from \$0.35 per square foot to \$1.20 per square foot. Sample data of this sort is usually summarized by computing average values. Summarizing the Phase II EHEP cost data by computing average values is quite straightforward, and it provides a means of comparing the costs of the different abatement techniques.

Table 3.1 presents the average direct cost per square foot for the techniques which were used to abate the LBP hazard on walls (barrier materials). Additionally, Table 3.1 presents an estimate of a confidence

[1] If any work stoppage resulted from the visit of the representative of the contract management firm, it was logged on the Dwelling Unit Cost Data Form.

interval about these average figures.[1] These figures are preceded by ±; this means that the reported average figure plus or minus the number in the second column represents the interval within which we can safely say that average costs[2] will fall. In the case of gypsum wallboard, based on data collected from 13 dwellings units, the average direct cost per square foot will reliably fall between 65 cents and 93 cents per square foot (the average of 78 cents per square foot ± 15 cents). Cement coated fiberglass on the average, costs 18 cents more per square foot than gypsum wallboard (see Table 3.1). However, because the confidence interval for cement-coated fiberglass (between $0.82 and $1.10) overlaps that of gypsum wallboard, one cannot say with very much certainty that gypsum wallboard is less costly. Care must be excercised in drawing conclusions based on averages of data.

TABLE 3.1

AVERAGE DIRECT COST PER SQUARE FOOT FOR APPLYING BARRIER MATERIALS

Abatement Method	Average Direct Cost per Square Foot ($)	Width of Confidence Band Around the Average ($)
Gypsum Wallboard	0.78	± 0.15
Plywood Paneling	1.04	± 0.14
Cementitious Coating	0.79	± 0.20
Veneer Plaster	0.82	± 0.22
Cement-Coated Fiberglass	0.96	± 0.14
Vinyl-Coated Fabric	1.19	± 0.41

[1] A confidence interval shows the width of the band of uncertainty which surrounds the estimated average cost figures in Table 3.1.

[2] The average cost figure used here is the average of abatement costs in many dwelling units. Abatement costs in a particular dwelling unit may therefore be well above or well below this average cost figure.

In many cases it may be quite satisfactory to use the reported average figures as a basis for estimating the costs of abating the LBP hazard. However, additional problems exist with the use of average figures. How does one modify the costs experienced in Boston for gypsum wallboard to reflect the labor market conditions of, say, Columbus, Ohio? In other words, if the data is to be useful it must include a procedure, or method, which will allow for conditions different from those experienced in Boston to enter into the calculation of predicted costs.

Deriving a method of cost estimation which is based on real world experience and which allows local conditions to register their influence on deleading costs is a difficult problem of statistical measurement. The core conceptual premise which enables this to be achieved is the assumption that costs are dependent on (i.e., are made to vary by) a small handful of identifiable key factors. In other words, changing the values of the key factors will cause changes to occur in the average direct costs. The problems involved in statistical measurement require us to identify those key factors and then to measure their impact on costs. Economic theory and engineering practice help identify a list of candidate key factors for each abatement technique. Statistical analysis provides the tools for measuring the relative importance (or unimportance) of the candidate key factors. Using such an approach considerably lowers the level of uncertainty. It was mentioned above that the range of reliability for gypsum wallboard was 78 cents $\pm$ 15 cents. After introducing five key factors as causal agents in explaining the cost per square foot of gypsum wallboard, the confidence interval of prediction about the average has been reduced to $\pm$ 7 cents. This represents a 53 percent reduction in the possible error of estimation that would be made if we relied only upon the simple average figure.

In this chapter, after reviewing our definitions of costs, we shall discuss the cost models for each technique for deleading walls and for deleading trim. An explanation of the variations in painting costs will then be presented. Finally, at the end of this chapter, we shall summarize the results of our data analysis.[1] For readers wishing to pursue the more technical details of estimation, a short theoretical discussion is provided in Appendix C of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

3.1 THE COST CONCEPTS

In this report the definitions of costs being used are fairly conventional. However, to insure understanding, it is necessary to define the terms which will be used throughout the report. For any particular

[1] This chapter does not attempt to explain in any detail how to use these cost models to estimate costs. Applications of the material presented in this chapter are presented in Chapter 5. This chapter and Chapter 4 form the basis for the procedures discussed in Chapter 5.

lead paint abatement task, say deleading 360 gross square feet in a bedroom with gypsum wallboard, a contractor will experience a total cost of undertaking that particular task. The total cost will include payments to labor, payments for material, and any overhead costs that should in principle be assigned to that task. The difference between the bid price, i.e., the contract amount for which the contractor agreed to do the work, and the total labor, materials, and overhead costs represents the contractor's pretax profits.

Those costs that the contractor would not incur if he had not undertaken the specific job (i.e., certain labor, material and other job specific costs) are called direct costs or variable costs.[2] Those costs that the contractor or firm would incur regardless of whether the firm undertook a specific job (i.e., certain rental payments, debt service payments, payments for equipment, payments for clerical and secretarial labor, and payments for management) are lumped in the category of overhead costs.

The amount of overhead costs and profits which accrue to any specific job are a function of many factors over and above a particular job. Since these factors may be separated from those which are related to a specific technique, they will be dealt with in Chapter 4. Our focus in this chapter will therefore be on the direct costs of the alternative abatement techniques.

Direct cost can be discussed either in total terms or in per unit terms. If we divide the total direct costs of deleading 360 square feet of bedroom wall area with gypsum wallboard by the number of square feet, we are then discussing direct costs per square foot (i.e., per unit direct cost). In this report our discussions of costs are presented on a per unit basis. Note that per unit direct cost is always equal by definition to the sum of per unit labor costs, per unit material costs, and any per unit special equipment costs.

Also of interest is the size of the markup factor. Total costs per unit (the sum of per unit direct costs and the overhead and profit residual per unit) divided by per unit direct costs yields the markup factor.

The product of per unit direct cost, times the markup factor, times the number of units, e.g., square feet of wall area or linear feet of trim, will yield the total cost of a particular deleading job.

Finally, it should be carefully noted that in all our discussions of direct costs we separate the direct costs for finish painting from those for installing the abatement technqiue. Some abatement techniques, e.g., plywood paneling, need not be painted. Some may or may not be painted, e.g., cementitious coating. Some require painting, e.g., gypsum wallboard. By keeping the two cost figures separate, we are

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[1] "Direct" and "variable" can be used synonymously. In this report we shall use "direct."

insuring that variations in painting costs are not interpreted as causing variations in the installation cost for a particular abatement technique.

3.2 TECHNIQUES FOR LBP HAZARD ABATEMENT ON WALLS

In Phase II of EHEP, data was collected on six techniques for covering the LBP on walls. Four methods of paint removal on doors and frames, windows and frames, and baseboards were also tested. In this section we shall present the results of our cost analysis for the six techniques for deleading walls: gypsum wallboard, plywood paneling, cementitious coating, veneer plaster, cement-coated fiberglass, and vinyl-coated fabric.

In Section 3.3 we shall present the results of our cost analysis for the trim methods.

For each technique the key factors affecting direct costs are identified. An indication of whether direct costs rise or fall as the value of the key factor is increased is also presented.[1] For those readers who wish to calculate abatement technique costs by hand, rather than use the computer program presented in Chapter 5, a separate set of tables and worksheets is provided. These tables include statistical estimates of the weighting factors associated with each key factor. The weighting factor tells us what quantitative impact a unit change in the value of the associated key factor has on per unit direct cost. The methodology for performing LBP abatement cost estimates by hand is described in Appendix E of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations. Statistical estimates of the weighting factors are found in Appendix C.3 of the same report.

3.2.1 Gypsum Wallboard

The results of our data analysis indicate that the per unit direct cost of gypsum wallboard will:

- o fall as job size[2] increases;
- o increase with higher wage rates and material prices; and
- o be more sensitive to increases in material prices than to increases in wage rates.

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[1] A 10 percent level of significance is assumed in the discussion which follows.

[2] Job size is defined here as the square feet of wall area deleaded. For paint removal methods, i.e., for trim surfaces, it is defined as the linear feet of trim from which LBP was removed.

3.2.2 Plywood Paneling

The direct costs of plywood paneling will:

- o increase with higher wages and material costs per square foot;
- o increase with larger job sizes;[1] and
- o be sensitive to management competence and experience.[2]

Separate estimates were made of the factors influencing material costs per unit. Here it was found that material costs will:

- o increase with higher sheet prices for paneling;
- o increase if the wall surfaces are in an unsound[3] condition; and
- o fall with higher wage rates, because they proxy higher skills.

3.2.3 Cementitious Coating and Veneer Plaster

The cost data for these two methods of deleading walls were combined into one analytical unit.[4] It was found that direct costs per square foot will:

- o rise when either wage rates or material prices rise;

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[1] The impact of this factor is less certain than for wage rates or material prices since it is significant only at the 20 percent level.

[2] The impact of experience (familiarity) is less certain than for wage rates, material prices, or management competence since it is significant only at the 20 percent level.

[3] An unsound wall is defined as any wall which exhibits one or more of the following characteristics: (1) crumbling plaster, (2) bulging, (3) efflorescence, (4) declamation from lath or structural members, and (5) holes greater than four inches in diameter. If none of these five characteristics are present, then the wall is defined as sound.

[4] This combination was necessary because separate cost analyses of each technique were not successful due to the lack of a sufficient number of observations. Since both techniques are coatings with similar product characteristics, and since there was no statistically significant difference in their average direct cost per square foot (only 3 cents in realized cost), it was decided to analyze their cost characteristics jointly. Although some prior objections could be advanced for combining these data sets, the accuracy of the estimated results in predicting the experienced costs of each of these techniques justified the merger of the data sets.

- o fall with larger job sizes;[1]

- o increase if the removal of wallpaper is necessary; and

- o be significantly lower per square foot if cementitious coating is used rather than veneer plaster, everything else held equal.[2]

Separate estimates were made for the material costs of these techniques. It was found that material costs will:

- o be sensitive to room dimensions and configurations;

- o be increased by poor wall conditions;

- o be lower for veneer plaster than for cementitious coating.

3.2.4 Vinyl-Coated Fabric

In our previous discussions of barrier materials for LBP abatement, our primary focus has been on explaining variations in direct cost per square foot. For vinyl-coated fabric and, as we shall see later, for cement-coated fiberglass, our statistical measurements of costs follow a slightly different sequence. This is because suitable results for direct costs could not be immediately obtained. Instead it was necessary to first develop statistical measurements of the key factors which explained labor productivity. These measures can than be used to find labor cost per square foot. Next it was necessary to develop statistical measurements of the key factors which determined material cost per square foot. The sum of labor and material cost per square foot is equal to the direct cost per square foot.

The calculation, or prediction, of direct costs per square foot thus involves five steps:

(1) The determination of the average wage rate;

(2) The determination of the expected productivity of labor;

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[1] The impact of this factor is less certain than for wage rates or material prices since it is significant only at the 20 percent level.

[2] The above statement should be very carefully qualified. The significant difference is a reflection of the fact that material prices for cementitious coating tend to be higher than those for veneer plaster. It does not necessarily imply that significant differences in per unit direct costs exist per se. Since per unit direct cost is very sensitive to small changes in material prices, an allowance had to be made for cases involving veneer plaster.

(3) The division of the wage rate by labor's productivity to determine labor cost per square foot;

(4) The determination of material cost per square foot; and

(5) The summing of labor cost with material cost to determine direct cost per square foot.

It was found that the productivity of labor in the installation of vinyl-coated fabric will:

- o decrease if wainscotting requires removal;
- o be higher for larger jobs and jobs which involve less cutting and trimming of the material;[1] and
- o increase with higher paid labor.[2]

Material costs per square foot will increase with higher prices per square yard of vinyl-coated fabric and by the requirement that wainscotting be removed.

3.2.5 Cement-Coated Fiberglass

Labor's productivity in the installation of cement-coated fiberglass will be:

- o raised when the ratio of net-to-gross square feet is lowered;[3]
- o lowered by wainscotting removal;

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[1] Two key factors are involved in the above statement. The first, job size, is significant at the 10 percent level. The second, a proxy for the amount of cutting and trimming of material, is significant only at the 30 percent level.

[2] The impact of higher wage rates on productivity is less certain than job size or the removal of wainscotting since it is significant only at the 20 percent level.

[3] The gross square feet of wall area is defined as the total wall area including openings for windows, doors, and cabinets. It is equal to the perimeter of the room times the ceiling height. The net square feet of wall area is defined as the wall area remaining after the area for all openings, such as doors, windows and cabinets has been subtracted from the gross square feet of wall area. For a detailed discussion of this result, see Appendix D in the companion report <u>Lead Paint Abatement Costs: Some Technical and Theoretical Considerations</u>.

° raised in unoccupied units; and

o lowered by unsound substrates.[1]

Material costs per square foot increase with higher net square feet to gross square feet ratios and with higher labor costs per square foot.

3.3 TECHNIQUES FOR LBP HAZARD ABATEMENT ON TRIM

Identifying low cost and effective methods of deleading LBP found on windows, doors, baseboards and other trim surfaces is as important as identifying cost effective methods of deleading walls. Trim surfaces cannot be considered any less accessible to the pica child than wall surfaces. In addition, trim surfaces contain higher quantities of lead than do wall surfaces.

> Trim surfaces exhibit substantially higher lead levels than do walls, for all indicated combinations of occupancy class, room type, and age category.[2]

Four methods of removing LBP from trim surfaces were tested in the Boston phase of EHEP. Two additional methods were tested in Atlanta. In this section we present the cost characteristics of five of these six methods:[3] the infra-red heating device, solvent stripping, the heat gun, hand scraping, and component replacement.

Note that in Table 3.2, which presents the average direct costs per linear foot of paint removal, the estimates of the width of the confidence intervals about these average figures are quite large.[4] Recall that these figures, preceded by a ± sign, represent the interval within which we can safely say that average costs[5] will fall. Using the costs

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[1] The impact of substrate condition on productivity is less certain than the other key factors since it is significant only at the 30 percent level.

[2] Douglas R. Shier and William G. Hall, Analysis of Housing Data Collected in a Lead Based Paint Survey in Pittsburgh, Pennsylvania Part I, National Bureau of Standards, Interagency Report 77-1250, March 1977, p. 43.

[3] The sixth method, the diptank, is described in Appendix B of Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

[4] A confidence interval shows the width of the band of uncertainty which surrounds the estimated average cost figures in Table 3.2.

[5] The averge cost figure used here is the average of abatement costs in many dwelling units. Abatement costs in a particular dwelling unit may therefore be well above or well below this average cost figure.

TABLE 3.2

AVERAGE DIRECT COST PER LINEAR FOOT FOR PAINT REMOVAL

Abatement Method and Surface Type	Average Direct Cost per Linear Foot ($)	Width of Confidence Band Around the Average ($)
Heat Gun		
Doors	1.64	± 0.87
Windows	2.20	± 0.89
Trim	0.57	± 0.19
Infra-Red		
Doors	1.93	± 1.43
Windows	2.27	± 1.24
Trim	0.54	± 0.80
Hand Scraping		
Doors	2.53	± 1.01
Windows	2.23	± 1.15
Trim	0.81	± 0.53
Solvent Stripping		
Doors	3.80	± 1.18
Windows	3.44	± 1.24
Trim	1.26	± 0.79

for the electric heat gun to remove LBP from doors based on data collected in nine dwelling units as an illustration, we can see that the average direct cost per linear foot will reliably fall between \$0.77 and \$2.51 (the average of \$1.64 per linear foot ± 87 cents). The magnitude of the variations in per unit direct costs for the electric heat gun are large but are also indicative of those of the three other paint removal methods. Keeping this in mind, we may now go on to see how the use of the key factor method permits us to reduce the width of the band of uncertainty about per unit direct cost to an acceptable level.[1]

3.3.1 Electric Heat Gun

Direct costs per linear foot were analyzed for the electric heat gun method of paint removal. The direct costs of using the heat gun to remove LBP from door and window surfaces were combined into one analytical unit while the direct costs of using the heat gun to remove LBP from baseboard trim was made a separate analytical unit. Our analysis indicates that the direct cost of paint removal using the electric heat gun will:

- o fall with larger job sizes;
- o rise with higher wage rates;
- o be higher if non-woodworking contractors perform the work; and
- o be lower for doors than for windows and are lowest for baseboard trim.

3.3.2 Hand Scraping

The direct cost of removing paint by hand scraping is sensitive to two variables. Direct costs will:

- o rise as the wage rate increases; and
- o fall as the number of linear feet deleaded is increased.[2]

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[1] A 10 percent level of significance is assumed in the discussion which follows.

[2] The impact of job size on direct costs is less certain than wage rates since it is significant only at the 20 percent level.

3.3.3 Infra-Red Heating Device[1]

For the infra-red heating device we found that an analysis of labor cost per linear foot rather than direct cost per linear foot gave us much more reliable measures of the underlying key factors. Material costs represent a small and relatively constant proportion of direct costs per linear foot for this method. Furthermore, the fraction of direct costs per linear foot associated with labor costs was also relatively constant. Therefore, it was decided to factor up labor costs by that fraction in order to determine direct costs per linear foot.

Two key factors each for windows, doors and baseboard trim determine per unit labor costs for this technique. The wage rate has, as one would expect, a strong and very reliably measured impact on labor costs. Job size expresses itself as a key factor in an unusual manner. Rather than appearing simply as a measure of linear feet, job size is the product of two physical measurements -- linear feet multiplied by the XRF reading, the lead content in the paint film covering the trim surface. Labor costs per linear foot fall as the product of this key factor increases. Neither linear feet nor XRF readings by themselves show up as measurable key factors affecting labor costs per unit. This compound factor probably measures the joint effects of job size and difficulty of removal of the paint. Paint technologists have speculated that the XRF readings (lead content of the paint) may be related to the strength of the bond between the paint film and the substrate in this way. As paint films become very old, they suffer significant loss of bond strength. The older paints encountered in housing quite likely have a significantly higher lead content than newer paints. Thus, in general, the paints with high lead levels, being older, should be more easily and quickly removed.

3.3.4 Solvent-Based Paint Remover

The labor costs per linear foot for this technique respond to the same key factors that affect the costs of removing paint with an infra-red heating device. It was found that labor costs will:

- o rise with wage rate increases;
- o fall as the product of the XRF reading and linear feet rises, and;
- o be lower for baseboard trim than for windows and doors.

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[1] The infra-red heating device was used only in unoccupied dwelling units in Phase II of EHEP because it produced smoke which may have contained lead fumes.

3.3.5 Component Replacement

The per unit (i.e., per door, per door frame, or per window and frame) direct cost of component replacement[1] is primarily sensitive to two key factors:

- o the wage rate; and
- o the price per unit of the component.

3.4 FINISH PAINTING

In the introduction of this chapter we stated that painting costs were not included in our analysis of the direct costs for the various techniques. This was done in order to keep variations in painting costs from falsely influencing the cost data for the installation of barrier materials or paint removal methods. It was found that wall painting costs will:

- ° fall with larger job sizes;
- ° rise when either wage rates or material prices rise; and
- ° rise when the ratio of net-to-gross square feet rises.

It was found that painting costs for doors and frames and windows and frames will:

- ° fall with larger job sizes; and
- ° rise when either wage rates or material prices rise.

Baseboard painting costs were found to be sensitive only to changes in wage rates. In particular, baseboard painting costs will rise as wage rates rise.

3.5 SUMMARY OF COST DATA ANALYSIS

This chapter has presented our attempts to identify and measure the impacts that relative changes in the value of key factors have on

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[1] Component replacement was not used in Phase II of EHEP due to its excessive cost. This method was used in Phase I of EHEP and was found to be appropriate only in cases where the component was severely damaged or deteriorated. The cost estimation procedures presented in Section 3.3.5 for component replacement are based on Phase I EHEP cost information and are patterned after those procedures presented in Robert E. Chapman, Economic Analysis of Lead Paint Abatement Methods: Phase I, National Bureau of Standards, Technical Note 922, September 1976.

direct costs. The salient result of our statistical analysis has been the measurement of the role played by job size (square feet or linear feet) in the determination of costs. For all of the techniques, except component replacement, job size in some form is an important key factor.

This result may seem surprising to some because of the relatively small sizes of the jobs that were undertaken in each dwelling unit. Furthermore, it should be noted that in nine of the ten techniques analyzed, increasing job size causes costs per unit to fall. From a cost effectiveness point of view, this implies that it will be less expensive to delead 1,000 square feet of wall area in one dwelling unit than deleading 500 square feet of wall area in each of two dwelling units.

In all of the wall models the wage rate and material cost and/or prices are statistically significant key factors. In all of the trim models wage rates are significant key factors. These results are in full accord with our hypothesized expectations. The structure of the Phase II experimental design[1] emphasized isolating the effect of substrate condition. For all of the wall models, except gypsum wallboard, poor substrate condition was found to add significantly to direct cost per square foot.

It also bears pointing out, that even though LBP abatement operations are conducted in an environment which contains many unknowns and unpredictable events, it is possible to explain the level and behavior of costs with a relatively small handful of key factors. Using the key factor approach to estimate, i.e., predict costs, will result in much more accurate predictions than those based on averages of historical data.

It was stressed in the introduction of this chapter that caution must be exercised when making use of average figures. The selection of one technique on the basis of its average cost for deleading walls or trim (as is done in some cities) and its uniform application in every dwelling unit may not be cost effective.

Tables 3.3 and 3.4 summarize the cost data that was collected in the Boston phase of EHEP. If our qualifications are remembered, these tables should provide a useful portrayal of the structure of costs for each of the different abatement techniques.

4. GENERALIZATION OF EHEP COST MODELS

In order to effectively use the information on direct costs presented in Chapter 3, two additional steps must be taken. First, we must know how direct costs are associated with total cost, so that an estimate of the contractor's bid price can be made. Second, we must be able to generalize our conclusions about direct costs to programs outside the

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[1] See Section 4.2.1.1 of this report.

TABLE 3.3

SUMMARY ANALYSIS OF DIRECT COSTS PER SQUARE FOOT[a] FOR APPLYING BARRIER MATERIALS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Abatement Technique	Number of Observations[b]	Installation Cost per Square Foot	Painting Cost per Square Foot	Installation Plus Painting Cost (4)=(2)+(3)	Labor Cost Per Square Foot	Material Cost per Square Foot	Labor Cost as a Percent of Total (7)=(5)/(2)x100	Range of Direct Cost Per Square Foot
Cementitious Coating	10	0.79	---	0.79	0.60	0.19	76%	0.22-1.34
Plaster Veneer	10	0.82	0.23	1.05	0.68	0.15	84%	0.35-1.47
Gypsum Wallboard	13	0.78	0.24	1.02	0.61	0.17	78%	0.25-1.20
Cement Coated Fiberglass	9	0.96	---	0.96	0.52	0.44	54%	0.66-1.19
Plywood Paneling	14	1.04	---	1.04	0.67	0.37	64%	0.77-1.69
Vinyl Coated Fabric	8	1.19	---	1.19	0.68	0.51	57%	0.84-1.84

[a] Per gross square foot.

[b] Number of observations used to estimate the key factors for this abatement technique in Phase II.

TABLE 3.4

SUMMARY ANALYSIS OF DIRECT COSTS PER LINEAR FOOT FOR PAINT REMOVAL[a]

	Doors & Frames			Windows & Frames			Baseboard Trim		
Technique	Number of Observations	Total Direct Cost	Labor Cost %	Number of Observations	Total Direct Cost	Labor Cost %	Number of Observations	Total Direct Cost	Labor Cost %
Heat Gun	9	1.64	93	9	2.20	97	8	0.57	95
Infrared	4	1.93	92	4	2.27	89	3	0.54	80
Hand Scraping	1	2.53	95	6	2.23	95	6	0.81	96
Solvent Strip	8	3.80	88	8	3.44	88	6	1.26	82
Replacement[b]	26	219.64	64	5	125.79	58	-	--	-

[a] Excluding painting

[b] Based on Phase I data collected in Atlanta, Georgia. Replacement costs are per unit.

context of EHEP. In other words, we must be satisfied that the statistical measurements made in Boston, Massachusetts under Phase II of EHEP will also be valid in Chicago, Illinois or Coos Bay, Oregon. These two topics are the subject of this chapter.

4.1 MARKUP AND ITS DETERMINANTS

Every buyer of LBP abatement services is presented with a total cost figure from the abatement contractor which is referred to as the bid price. The bid price includes not only the contractor's anticipated direct costs (labor, materials, and equipment) associated with doing the job, but also a contribution to overhead and a residual which may be referred to as profit. If the buyer agrees to the contractor's bid price, then after the job has been completed the difference between the bid price and direct costs will be the the contractor's overhead and profit. The ratio of bid price (total cost) to direct cost represents the markup ratio. This relationship may be expressed by the following simple identity:

$$\text{BID PRICE} = \text{MARKUP RATIO} \times \text{DIRECT COST} \qquad 4.1$$

In Chapter 3, a means of determining direct cost was presented. In this section we shall see how certain job specific factors combine to produce an expected markup ratio.

It is important to point out here that, if the decision is made to operate in a cost plus fixed fee contracting mode, direct costs may be factored up by the agreed upon fixed fee rate to arrive at total costs. The decision-maker faced with a large amount of abatement work thus might want to weigh the advantages of the cost plus fixed fee contracting mode against those of the bid price. In general it would be expected that abatement contractors would prefer to operate in a cost plus fixed fee mode since uncertainties due to varying housing conditions are shifted from the contractor to the buyer of his services. This would probably stimulate more competition among abatement contractors for the contracts being let. On the other hand, the buyer loses a certain amount of fiscal control in going from the relatively firm figure represented by the bid price to the cost plus fixed fee arrangement.

The Phase II EHEP data used to analyze markup involved 19 separate contracts[1] and 58 dwelling units. About 28,000 net square feet of wall area had barrier materials applied, and LBP was removed from over 3200 linear feet of trim. The total bid price of these 19 contracts was $63,784. This was 17.6 percent higher than the actually experienced direct costs

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[1] Although 24 contracts were let during Phase II of EHEP, five contracts were excluded from the data base used to analyze markup. Four contracts involving two contractors were excluded because their data was proven to be unreliable. The fifth contract was eliminated because the building was seriously damaged in a fire.

(i.e., the average markup ratio was 1.176). The actual markup ratio on the 19 individual contracts ranged from 0.94 to 1.49.

Three key factors were found to explain 77.3 percent of the variations in the markup ratio. From the results of our analysis, the following can be inferred:

- o increasing the net square feet of wall area to be deleaded tends to lower the markup ratio;
- o increasing the number of linear feet of paint removal raises the markup ratio; and
- o contracts using abatement techniques with which the contractors are familiar (e.g., gypsum wallboard or plywood paneling) are subject to markup discounts.

4.2 VALIDATION

The findings of this empirical study can be generalized to cities other than Boston and to times other than 1976. This conclusion is based on several considerations. First, the key factors associated with each technique will reflect important differences which exist between regions. Second, EHEP has been structured so as to facilitate the generalization of its results.

Four major research tasks have been built into EHEP to insure that its results can be generalized. Three of these tasks relate to the internal validity and consistancy of the experiment. The fourth task relates to a test of the ability of the EHEP Phase II models to predict direct costs for different regions and times. This task is one test of EHEP's external validity. In this section we shall assess the results of Phase II of EHEP both in terms of its internal validity and in terms of its external validity.

Certain portions of the discussion which follows are of a more technical nature than in previous sections. Therefore, the reader who is primarily interested in applying the cost estimation procedure presented in Chapter 3 is directed to Chapter 5.

4.2.1 Internal Validity

If empirical findings are to be useful for prediction (i.e., if they are to be externally valid), they first must be internally valid. Three dimensions comprise the elements of internal validity:

(1) the experimental design;

(2) the data collection procedures; and

(3) the degree of reliability and accuracy within the data set.

Each of these three dimensions will now be discussed to show how the experiment was constructed, how it was controlled, and why its results exhibit a high degree of internal validity.

4.2.1.1 Experimental Design

To insure internal validity, an experiment must be designed so that a degree of control is introduced over the various factors that affect the outcome of the experiment. This is necessary in order to identify the main causative factors.

The collection of meaningful cost information from the dwelling units selected for LBP abatement hinged on an experimental design capable of identifying and measuring those factors which cause variations in abatement technique cost. Of crucial importance in the measurement of variations in abatement technique costs is the ability to identify the ways in which variations in the individual abatement technique's costs are introduced. In order to be able to identify the sources of variation in costs, it was necessary to specify where the data were to be collected in terms of occupancy status of the dwelling unit, the condition of the substrate, the functional uses of the rooms, the ownership charcteristics of the dwelling units, and how the abatement techniques were to be assigned to dwelling units.

The experimental design is described in part by referring Table 4.1, which shows the structure of the experiment for making cost comparisons among trim abatement techniques.

TABLE 4.1

EXPERIMENTAL DESIGN FOR THE TRIM EXPERIMENT

Occupied				Unoccupied			
Abatement Technique				Abatement Technique			
A	B	C	D	A	B	C	D
5	0	5	5	5	5	5	5

Table 4.1 is divided into two parts; one part for occupied dwelling units and one part for unoccupied dwelling units. The columns (letters A through D) identify the specific abatement technique. The number under each letter specifies the number of dwelling units the experiment requires for that technique. For example, if the dwelling unit is occupied, and abatement technique A is used to remove paint from all trim surfaces, then five dwelling units were required. Note that each cell but one[1] in Table 4.1 has the same number of observations.

The complete experimental design consisted of three separate tests to measure variations in costs as a function of abatement technique, occupancy status and surface type or condition. This third test category was further divided into three parts. These parts were concerned with assessing the variation in relative costs as a function of (1) wet or dry rooms,[2] (2) sound or unsound[3] wall surfaces, and (3) trim surfaces. The overall experimental design is shown in Table 4.2. Note that the numbers in each cell of Table 4.2 are divided into two parts by a slash. The desired number of observations comes before the slash. The actual number of observations is shown after the slash. The fact that the desired number of observation is not always equal to the actual number of observations is a reflection of the complexity of controlling an experiment of this size. (Recall that the complexity of the experiment has already been significantly reduced as a result of providing surface abatement criteria.)[4] An additional problem resulted in that no abatement work was undertaken in any of the local housing authority's stock of dwelling units. This portion of the program was abandoned due to the difficulty experienced in finding lead levels[5] which were comparable to those in HUD acquired properties. An important part of the Phase II EHEP experimental design was the assignment of abatement techniques to the stock of dwelling units. A procedure was developed so

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[1] Technique B, the infra-red heating device, was not used in occupied dwelling units because it produced smoke which may have contained leaded fumes.

[2] Wet rooms refer to bathrooms and kitchens; all other rooms were assumed to be dry.

[3] An unsound wall is defined as any wall which exhibits one or more of the following characteristics: (1) crumbling plaster, (2) bulging, (3) efflorescence, (4) declamation from lath or structural members, and (5) holes greater than four inches in diameter. If none of these five characteristics are present, then the wall is defined as sound.

[4] The surface abatement criteria used in Phase II of EHEP were discussed in Section 2.2.

[5] The same criteria for lead content, 2.0 mg/cm^2 or more, was used in screening dwelling units owned by the local housing authority as was used in screening the HUD acquired properties.

TABLE 4.2

EXPERIMENTAL DESIGN FOR PHASE II OF EHEP

Building		Occupied						Unoccupied					
Component		A	B	C	D	E	F	A	B	C	D	E	F
Walls[a]	(wet)	5/4	5/7					5/5	5/5				
	(dry)	5/4	5/3					5/3	5/2				
	(sound)	5/4	5/7	5/5	5/5	5/4	5/4	5/4	5/3	5/2	5/2	5/2	5/3
	(unsound)	5/4	5/3	5/3	5/2	5/2	5/3	5/4	5/4	5/3	5/4	5/5	5/1
Trim[b]		5/6	0/0	5/3	5/4			5/3	5/3	5/4	5/3		

[a] Techniques for LBP Hazard Abatement on Walls

A = Gypsum Wallboard
B = Plywood Paneling
C = Cementitious Coating
D = Cement-Coated Fiberglass
E = Veneer Plaster
F = Vinyl-Coated Fabric

[b] Techniques for LBP Hazard Abatement on Trim (Doors & Frames, Windows & Frames, and Miscellaneous Trim)

A = Electric Heat Gun
B = Infra-Red Heating Device
C = Solvent-Based Paint Remover
D = Hand Scraping and Sanding

that the assignment of abatement techniques to the stock of dwelling units was a random process. This minimized the changes of systematic bias entering into the experiment.

The assignment of the abatement techniques to the stock of dwelling units may now be explained by referring once again to Table 4.1. To begin with, a dwelling unit is selected from those which satisfied the surface abatement criteria and the criteria for lead content. Assuming this dwelling unit is unoccupied, it has an equal chance of being assigned to each of the four trim abatement techniques. To determine which abatement technique to which it is assigned a random number is drawn. (Picking a random number is analagous to flipping a coin or rolling a die.) The random number is selected in such a way that it may be characterized as a proportion between zero and one. Similarly, the four abatement techniques may be characterized by ranges of proportions between zero and one. For example, Technique A is characterized by all proportions between 0 and 1/4, B by all proportions between 1/4 and 1/2, C by all proportions between 1/2 and 3/4, D by all proportions between 3/4 and 1. If the random number indicates that the proportion is 3/10, then this corresponds to the range of values assigned to Technique B. Thus Technique B is assigned to that dwelling unit. There are now only four observations required to fill the cell unoccupied -- Technique B. Similarly, there are only 19 more observations needed to complete the trim experiment in unoccupied dwelling units. The proportions are now recalculated for each of the four trim abatement techiques. Technique A is now characterized by all proportions between 0 and 5/19, B by all proportions between 5/19 and 9/19, C by all proportions between 9/19 and 14/19, and D by all proportions between 14/19 and 1. The process is continued until all cells have been filled. A similar procedure was used to assign abatement techniques to dwelling units with walls requiring deleading work. For those readers who are interested in the decision model used in Phase II of EHEP, a mathematical discussion is provided in Appendix C of the companion report Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

4.2.1.2 Data Collection Procedure

Measurement errors pose serious problems to the internal validity of an experiment. For example, the statistical analysis of data with serious measurement errors involving the key factors requires the use of complicated statistical procedures. As a consequence, very strong assumptions about the nature of the measurement errors must be made. Thus the administration of the experiment and the actual collection and recording of the data is an important element affecting the internal validity of the experiment.

The collection of the data in the field was under the direction of a team from the Special Projects Group of the Boeing Aerospace Company.

The project manager and the project engineer from Boeing[1] are both experts in the fields of remodeling construction. With their extensive background in the administration of construction contracts, they were able to effectively monitor and record accurately the field collected data. In Phase II of EHEP, costs were reported to the Boeing representatives on a daily basis. This was accomplished by having a representative of the contract management firm visit the job site daily, check the work progress, and record the figures for labor, material, and equipment usage. A great deal of confidence can therefore be placed in the accuracy of the data reported. Smaller contracts in Phase II than in Phase I of EHEP also permitted more control to be exercised over data collection. Smaller contracts also stimulated more competition since it gave more contractors an opportunity to bid on the limited number of dwelling units.

4.2.1.3 Internal Reliability and Accuracy

Probably the best check of an experiment's internal validity is provided by the quality of the experiment's statistical measurements. Realiable and accurate statistical measurements will result when the experiment has successfully identified the basic structure of the process being analyzed and has developed procedures which accurately quantify the factors which interplay to cause variations in the process being studied. Tests of the reliability of statistical measurements involve, in some form or other, asking "how well do the statistical measures explain the data set from which they were derived?" Three major tests have been used to examine the EHEP results. First, a descriptive statistic, the average absolute percentage error, was used. Second, a statistic relating the overall ability of the model to explain the variations that occurred in the dependent variable was computed. Third, an indicator of the relative (statistical) importance of each of the key factors was calculated. With regard to these three statistics and their values, it is possible to assert that EHEP Phase II results exhibit a high degree degree of internal validity.

The Average Absolute Percentage Error

The Average Absolute Percentage Error is a descriptive statistic that measures how close, in percentage terms, that predicted (estimated) costs come to actual (experienced) costs. It is analagous to the cost estimator's concept of "percent error in the estimate."

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[1] The project manager heading EHEP administration was Lee Gaylor of the Special Project group, Logistics Support and Services Division, Boeing Aerospace Company. The project engineer, Ben Brown, was responsible for field management of EHEP. Close cooperation existed between HUD, Boeing and NBS.

As an example, let us look at a particular case involving gypsum wallboard. In one dwelling unit in the Dorchester Section of Boston, a contract was awarded to a contractor which involved the installation of 327 net square feet of gyspum wallboard in a living room. The wage rates and crew composition dictated a $10.26 per hour average wage rate. The contractor paid $2.40 per sheet for wallboard. Using these key factors results in a predicted direct cost of $1.01 per square foot. This predicted value compares with the actually experienced value of 92 cents per square foot. The error that results is 9 cents per square foot, and amounts to 9.8 percent of the actual value.

For each of the 13 dwelling units where gypsum wallboard was installed, we have computed the error that results when the key factor method of cost estimation was used. Summing the absolute values of these errors and dividing the sum of the absolute errors by the sum of the actual values yields a measure referred to as the "Average Absolute Percentage Error" (AAPE). In the case of gypsum wallboard, the average absolute error associated with the use of the key factor method of estimating the direct costs of gypsum wallboard is 8.8 percent. Table 4.3 presents the average absolute errors associated with the predictions of direct cost per unit presented in Section 3.2.1 through 3.2.5 of this report. The median of the AAPE's for the six wall techniques is 6.7 percent.

The average absolute error percentages associated with trim's key factors ranged from a low of 5.4 percent for the heat gun (doors and windows) to a high of 32.7 percent for hand scraping (baseboards only). The median error percentage was 15 percent. The error percentages for trim methods were higher than for wall methods for three reasons. First, linear foot measurements are not as reliable as square feet measurements for job size. This is because trim varies not only in length, but also in width and in degree of ornateness. These two characteristics were not measured. As such, an element of inherent variability is introduced in our measures of direct cost. Second, because of the fundamental simplicity of the trim methods, the number of candidate key factors and consequently the number of utilized key factors are fewer than for the wall techniques. Third, the total labor hours devoted to deleading trim in a dwelling unit were substantially less than total labor hours involved in applying barrier materials to walls. (As few as four labor hours were spent deleading trim in one dwelling unit). Small errors of measurements or rounding in the recording process would therefore produce greater impacts on measured per unit costs for trim methods in comparison to wall methods.

The average absolute percentage error associated with using the key factor approach to project the markups in the Boston data is 5.1 percent. If the average markup of 1.176 was used uniformly in every contract, the resulting error would be almost twice as large as the error associated with predicting markups using the key factor method.

The Coefficient of Determination

TABLE 4.3

AVERAGE ABSOLUTE ERRORS AS A PERCENTAGE OF ACTUAL DIRECT COST FOR BARRIER MATERIALS

Technique	Average Absolute Percentage Errors
Gypsum Wallboard	8.8
Plywood Paneling	5.6
Cementitious Coating	5.1
Veneer Plaster	11.5
Vinyl-Coated Fabric	6.1
Cement-Coated Fiberglass	7.7

Another statistic which is widely used to evaluate the quality of statistical measurements is the coefficient of determination. This statistic measures the ratio of the explained or predicted variation in a set of sample data to the total or actual variation in the data. This statistic can vary between 0 (the model does nothing to help explain the variation in the dependent variable) and 1 (all variations are explained by the model). The lowest coefficient of determination for the barrier techniques is 0.66 while the highest is 0.96.

Although the trim methods of cost estimation did not perform as well as the wall methods of cost estimation in terms of error percentages, they did as well in terms of their ability to explain the inherent variation in the trim sample data. The median value of the trim techniques coefficient of determination was 0.85 with all of the estimated coefficients of determination for the trim methods being over 0.79. This is a very encouraging result. The coefficient of determination for the estimated markup relationship is 0.77.

Significance[1] of the Statistical Measurements

[1] A 5 percent level of significance is assumed in the discussion which follows.

Lastly, another way of evaluating these statistical measurements involve examining the significance of our measurements of the individual impacts of each of the key factors. In the analysis of barrier materials presented in Chapter 3, there are 43 key factors identified. Twenty-nine (67%) of these key factors are statistically significant. In terms of the significance of the statistical measurements of the impacts of the key factors for the trim techniques, 25 of the 35 statistical measurements (71%) are statistically significant. All of the key factors for the markup relationship are statistically significant.

4.2.2 External Validity

The cost data generated in the Atlanta portion of Phase I of EHEP was used to test the ability of the Boston results to predict costs in a different city at a different time. The accuracy of the key factor method in estimating (i.e., predicting) direct costs in Atlanta provides an indication of the level of confidence which we can have in its external validity. In addition to assessing the predictive accuracy of the key factor method, it would also be useful to know if in fact the EHEP procedure does better than a "naive"[1] or less complicated method of prediction. Furthermore, it would be useful to know how much better in numerical terms our predictive mechanism does relative to such a "naive" method. To illustrate this point we may draw on an analogy to a betting system. Assume that one has developed a method for predicting the expected point difference in professional football games. It would be useful here to know how close (in percentage terms) this method came to predicting the actual point spread over some sample of games. Furthermore, since the method of prediction may be costly to implement, it would be useful to know what improvement this system offers relative to a "naive" system. The "naive" system could be predicting a future point spread on the basis of the point spread in the last game played between two teams. Atlanta data provides us with an opportunity to make such tests.

An estimate of the EHEP procedures' accuracy is provided by calculating the Average Absolute Percentage Error (AAPE) associated with predicting direct costs per dwelling unit in Atlanta when compared to the direct costs per dwelling unit actually experienced. In order to perform this test, the key factor models were used to predict direct costs for each of the deleading tasks required in a sample of Atlanta dwelling units. The predicted costs of these tasks were summed to obtain a predicted

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[1] One naive method of cost estimation is to use historical cost figures that are adjusted to reflect differences in time and location.

total direct cost for that particular dwelling unit. Table 4.4 lists in the third column the predicted dwelling unit costs for nine dwelling units.[1]

The first column of Table 4.4 lists the techniques used in a particular dwelling unit. Column two reports actual direct costs. The magnitude of the error (predicted value minus actual value) is reported in the fourth column. This number divided by the actual value yields the percentage error. Summing the absolute values of these errors and dividing by the number of observations yields 8.4 percent. This means that the average absolute percentage error associated with the use of the EHEP models in predicting direct costs at the dwelling unit level in Atlanta is 8.4 percent. When the sum over the nine units of the predicted dwelling unit cost (column 3) is divided by the sum of the actual reported costs (column 2), this error is reduced to 3.8 percent. (Notice that the estimated total is below that of the direct costs actually experienced.) Earlier in this section we stated that it would be useful to compare the EHEP procedure to a "naive" method of forecasting costs. This requires a more complete definition of a "naive" method. For the purposes of this comparison we assumed as our naive method the following: that per unit predicted costs for a subtask be based on the simple adjusted averages reported in Tables 3.3 and 3.4.[2]

This assumes, "naively," that Atlanta will be like Boston on the average with respect to the direct costs of deleading.

Based on a procedure developed by Henri Thiel,[3] the following assertion can be made: Using EHEP key factor models to predict direct costs per

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1 The nine dwelling units used in the assessment of the Phase II EHEP cost models represent approximately 11 percent of the total population of dwelling units deleaded in the Atlanta portion of Phase I of EHEP. Several criteria were used to select candidates for inclusion in the assessment of the Phase II EHEP cost models. These criteria included: (1) similarity with a technique used in Phase II; (2) the dwelling unit contained both trim and wall work; (3) the observations were independent. Dwelling units which satisfied these criteria were then selected at random for the validation exercise.

2 The average per unit labor and material costs experienced in Boston were deflated by relative price indicies (Atlanta relative to Boston). The indicies, based on city cost indicies for labor and materials found in <u>Building Construction Cost Data 1975 and 1977</u>, R. S. Means, editor, were used to adjust the Boston data to reflect the differences in labor market and material market conditions that existed between Atlanta in January of 1975 and Boston in May of 1976.

3 Thiel, Henri, <u>Applied Economic Forecasting</u> North-Holland Publishing Company, Amsterdam (1966), pp. 15-36.

TABLE 4.4

ESTIMATING LBP ABATEMENT COSTS IN ATLANTA, GEORGIA
USING THE PHASE II EHEP COST MODELS

Methods Used in the Dwelling Unit (1) Wall	Trim	Actual[a] Dwelling Unit Direct Cost (2)	Predicted[a] Dwelling Unit Direct Cost (3)	Error[a] Predicted Minus Actual Direct Cost (4)	Percent Error (5)
Gypsum + Painting	Heat Gun + Painting	500.68	529.86	29.18	5.8
Melamine	Solvent + Painting	1059.61	1172.73	113.12	10.7
Veneer Plaster + Painting	Replacement Solvent + Painting	775.94	758.39	-17.55	-2.3
Gypsum + Painting	Replacement Heat Gun + Painting	662.52	684.95	22.43	3.4
Gypsum + Painting	Replacement + Painting	687.35	633.95	-53.4	-7.8
Filled Paint + Painting	Solvent + Painting	444.87	466.41	21.54	4.6
Gypsum + Painting	Replacement Solvent + Painting	1558.11	1323.83	-234.28	-15.0
Veneer Plaster + Painting	Replacement Heat Gun + Painting	501.88	422.24	-79.64	-15.9
Filled Paint	Solvent + Painting	636.06	571.72	-64.34	-10.1

[a]Entries are in dollars per dwelling unit.

dwelling unit reduces the root mean squared error to only 24.3 percent of that which would result if the "naive adjusted average" method was used to predict direct costs per dwelling unit. That is, the "naive adjusted average" method resulted in root mean squared errors that were approximately four times as large as those experienced with the key factor method.

It is our belief that both the predictive accuracy of the EHEP results in Atlanta and its performance relative to a "naive" method suggest that the key factor approach should prove externally reliable in its application to other cities in future periods.

5. APPLICATIONS OF THE EHEP COST MODELS

Thus far we have seen EHEP described, how cost models based on data collected in Phase II of EHEP were developed, and how the results of these models were tested against the data collected in Phase I of EHEP. The purpose of this chapter is to show how the cost models presented in Chapters 3 and 4 can be used to calculate abatement costs for specific needs. Two specific cases which we shall deal with are:

(1) forecasting abatement costs for an individual dwelling unit; and

(2) forecasting abatement costs for a major program.

In the final section of this chapter a computer program will be described which permits these abatement costs to be calculated.

5.1 DETERMINING DATA NEEDS

The first step in applying the EHEP cost models involves determining the minimum data requirements to exercise the models. Through experience gained in EHEP, we have found that data needs can be divided into three basic categories. These categories are:

(1) data on the dwelling unit;

(2) data on wage rates; and

(3) data on material prices.

These three categories reflect job specific requirements as well as prevailing supply and demand conditions in the labor and product markets. (Within each category there may be some variation in the amount of data required to exercise the models for different abatement techniques due to differences in the key factors affecting technique cost.)

These data requirements may be viewed as "excessive" by some. The greater flexibiliy and increased accuracy gained through the key factors approach, however, will make the extra effort worthwhile. We are now ready to examine the type of data associated with each of the three categories.

Dwelling unit specific data may be divided into two basic types: those concerned with the deleading of walls and ceilings, and those concerned with the deleading of trim surfaces. Specific dwelling unit data which are needed to perform deleading cost estimates for wall areas include:

- the gross square feet of wall area;[1]
- the net square feet of wall area;[2]
- the square feet of ceiling; and
- if the wall is in an unsound condition; or if cabinet work, pantry work, or wallpaper stripping is to take place.

Dwelling unit data required to perform deleading cost estimates for trim surfaces include:

- window sill height and width;
- the number of windows and frames requiring deleading;
- the number of doors and frames requiring deleading;
- the height to which deleading will take place;[3]
- the linear feet of miscellaneous trim requiring deleading; and
- the number and type of units requiring replacement.

Data on wage rates include the hourly wage for laborers, carpenters, apprentice carpenters, painters, wallpaper hangers, and plasterers. The data on material prices needed for the wall techniques are the purchase prices per square foot of barrier materials. No data on material prices are needed for the paint removal methods.

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[1] The gross square feet of wall area is defined as the total wall area including openings for windows, doors, and cabinets. It is equal to the perimeter of the room times the ceiling height.

[2] The net square feet of wall area is defined as the wall area remaining after the area for all openings, such as doors, windows and cabinets has been subtracted from the gross square feet of wall area.

[3] Experience in EHEP has shown that there is a considerable amount of variation in the height to which LBP is removed. For example, in Washington, D.C., LBP was removed to a height of five feet; in Atlanta and Boston LBP was removed only to a height of four feet.

5.2 OBTAINING THE NECESSARY DATA

Once all of the factors needed to make the desired cost estimate have been identified, it is possible to map out a strategy for systematically and efficiently measuring their values.

One major source of data which should not be overlooked is the dwelling unit survey. Surveys are almost always conducted at the start of an abatement program to determine the incidence of LBP in housing. Published information on conducting an LBP survey provides us with valuable insight into how the survey can complement the cost estimation effort.[1] The importance of collecting data at this time can not be overstressed since it permits very detailed information on specific characteristics of the dwelling unit to be documented at little or no extra expense to the overall program. Experience gained during EHEP indicated that a three man team could rapidly survey a dwelling unit and make measurements which greatly enhanced the quality and accuracy of the cost estimates.[2] One exercise which was particularly useful was the preparation of a floor plan for the dwelling unit being surveyed (see Diagram 5.1). It was found that using a piece of graph paper helped the team member sketch the floor plan accurately. One of the other team members then assisted the artist in measuring the size of the rooms, the height of the ceiling, the size and location of all doors and windows, window sill height and information on cabinets. It was found that these elements could easily be placed on the floor plan using the standard architectural notations. Another benefit of the LBP survey is that it helps to identify potential problem areas, such as, unsound substrates, deteriorated trim or nonfunctional doors or windows. Careful documentation of this information during the survey permits an estimate of the required repairs and component replacements to be made.

The "job specific" information collected during the dwelling unit survey is a valuable tool in the key factors approach to LBP abatement cost estimation. However, it does not provide all of the data necessary to make the estimate. Information on the prevailing wage rates and material prices mentioned earlier must also be obtained. Fortunately, this information can be based on costs experienced in the past. Most municipal officials and building owners have had experiences in remodeling. These figures can be used as a basis for estimating wage rates and material

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[1] A detailed description of the organization and implementation phases of a dwelling unit survey is given in William G. Hall and Lillian T. Slovic, Survey Manual for Estimating the Incidence of Lead Paint in Housing, National Bureau of Standards, Technical Note 921, September 1976.

[2] It is anticipated that the members of the survey team can learn enough about what to look for during the survey as part of the inspector training period described in William G. Hall and Lillian T. Slovic, Survey Manual for Estimating the Incidence of Lead Paint in Housing.

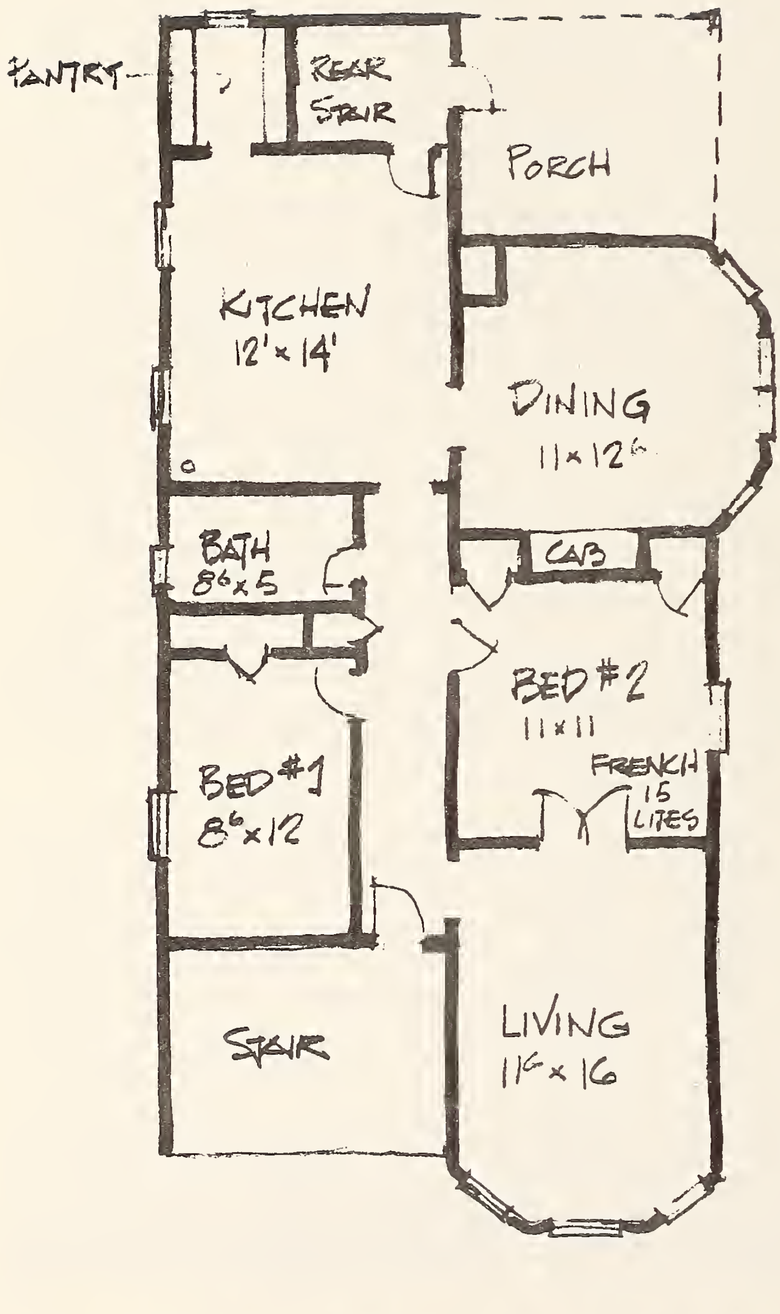

DIAGRAM 5.1 SAMPLE FLOOR PLAN

prices. (More up-to-date figures on material prices can usually be obtained from local building supply firms.) Furthermore, these factors should remain constant for many dwelling units.

5.3 FORECASTING LEAD PAINT ABATEMENT COSTS

It was mentioned in Section 5.2 that a survey for determining the incidence of LBP in the housing stock was a valuable source of information for making cost estimates. We shall now explore this topic in more depth, with a special emphasis on how the survey results can aid policy makers and municipal officials in forecasting the costs of the overall program as well as for individual dwelling units and contracts. We shall first focus on how this information simplifies the task of making program cost estimates.

There exists within most urban areas a varied stock of housing. This point has been underscored in previous housing surveys.[1,2,3] In particular, these surveys have shown that differing amounts of LBP are found in different types and ages of housing. Therefore, in order to establish a credible baseline cost estimate, it seems reasonable that forecasts for budgeting, scheduling and other programmatic purposes should take these differences into consideration as much as possible.

Probably the most important step is to divide the housing stock into several well defined types. For example, the following housing types might be used: multifamily low rise, multifamily high rise, single family attached, single family detached one story, single family detached two or more stories. Associated with each housing types would then be an age group. Commonly used age groups are: Pre 1940, 1940 to 1960, and 1960 to the present. All dwelling units could therefore be grouped into one of these 15 type/age categories. As the survey progresses, information collected on individual dwelling units can be used to establish estimates (averages) of the expected amounts of deleading work to take place in any dwelling unit by category (i.e., type and age). These "statistical" dwelling units can then be used to generate baseline cost estimates for the program. For example, if there were 2000 pre 1940 single family attached dwelling units and the expected bid price for

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[1] Selma J. Mushkin and Ralph Freiden, Lead Poisoning in Children: The Problem in D.C. and Preventative Steps, Public Services Laboratory, Georgetown University, Washington, D.C., 1971.

[2] William Hall, T. Ayres, and D. Doxey, Survey Plans and Data Collection and Analysis Methodologies: Results of Pre-Survey for the Magnitude and Extent of Lead-Based Paint Hazard in Housing, National Bureau of Standards, Interagency Report 74-426, January 1974.

[3] Douglas R. Shier and William Hall, Analysis of Housing Data Collected in Lead-Based Paint Survey in Pittsburgh, Pennsylvania: Part I, National Bureau of Standards, Interagency Report 77-1250, May 1977.

deleading the "statistical" pre 1940 single family attached dwelling unit was $1250, then $2.5 million would be a good indicator of the expected costs for that portion of the program. The use of "statistical" dwelling units to produce baseline program cost estimates should give program administrators, and other public officials, some insight into the magnitude of the anticipated program, as well as facilitate the scheduling of the actual deleading work. These estimates should also provide the community with a means of gauging the impact that the program will have on the community and, to some extent, the local housing market.

However, when dealing with contract cost estimates, it is important to point out that although the use of "statistical" dwelling units for forecasting overall program costs is desirable, it is not satisfactory for estimating the costs of a "particular" dwelling unit. This stems from the fact that by grouping large numbers of dwelling units into characteristic (type and age) categories, we are able to nullify some of the adverse effects that variations in the expected amount of deleading work cause. On the other hand, when we deal with individual dwelling units, we wish to take into account these variations so that we can more effectively measure changes in costs and hence identify that technique which is least costly. From a statistical viewpoint, the use of dwelling unit specific data is necessary because we are no longer working with large numbers of observations so that any variations in the level of deleading activities which affect costs will probably not cancel out each other. What this means is that different programmatic needs will require similar but slightly different sets of information. Therefore, in an attempt to reduce the additional work caused by these input requirements, a procedure which is both quick and easy-to-use is needed.

Two procedures were developed through Phase II of EHEP to meet both of these programmatic needs. The first procedure uses a computer program written in the BASIC language which can be referenced through the Federal Agencies' Computer Time-Sharing System (FACTS)[1] library of programs. The FACTS library is part of the Remote Access Multi-User System (RAMUS), a nationwide interactive time-sharing computer and telecommunications network developed and operated by the General Services Administration (GSA). The RAMUS and FACTS systems are available to <u>all</u> Federal agencies and their authorized contractors. The second procedure is aimed at those program offices which do not have access to a computer time-sharing system. This hand calculation procedure uses worksheets, cost equations,

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[1] For a detailed description of FACTS, see <u>Users' Manual for the Federal Agencies' Computer Time-Sharing System</u>, National Research Council, Building Research Advisory Board, Federal Construction Council, Technical Report 68, 1976.

and a schematic diagram, for estimating costs and identifying those techniques which are least costly.[1] In this report, we shall focus on the first procedure.

As a first step in seeing what the program does and how to use it, we shall refer to Diagram 5.2. Diagram 5.2 is a flowchart of the computer program; it shows the basic input requirements, the sequence in which calculations take place, and the program outputs. Table 5.1 summarizes the input data requirements which were discussed in Sections 5.1 and 5.2. Notice that with the exception of dwelling unit specific data, the input data requirements are the same for estimating costs at the program level and for estimating costs at the contract level. Therefore, only after the user has already input the required data on wage rates and material costs will the computer ask the use if they wish to estimate costs at the program or contract level. If they wish baseline program costs, then they shall enter a 1 in response to the computer's question; if contract costs estimates are desired, then a 0 should be entered.

Suppose the user enters a 1 in block A (see Diagram 5.2), indicating that they wish a program cost estimate. The computer will then request information (see Table 5.1) on the "statistical" dwelling unit. Once all data have been entered, the computer calculates the direct costs for each wall and trim technique based on the representative ("statistical") values of the key factors. These direct cost figures are then averaged. A markup ratio based on the representative values of the key factors is also calculated. (The markup ratio assumes that, on the average, three dwelling units will be in each contract.) The markup ratio is then used to calculate the total cost (i.e., the sum of direct costs, overhead costs, and profit) of deleading the "statistical" dwelling unit. The user may then use this figure to determine the costs of that portion of the deleading program. Once the cost information has been printed out, the user has the option of either stopping or performing cost estimates for other categories (building type/age).

In the event that the user wished to make contract cost estimates, the computer program would operate in a slightly different manner. However, before explaining this section of the flowchart, it is important to recognize several constraints. First, the user should place the dwelling units into groups of from one to ten dwelling units.[2] Second, all

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[1] Details of the hand calculation procedure are given in the companion report, Lead Paint Abatement Costs: Some Technical and Theoretical Considerations.

[2] The computer will not accept information on more than ten dwelling units at any one time. Thus if 50 dwelling units required deleading, at least five groups of ten dwelling units would have to be formed. Generally speaking, eight dwelling units is a good number to work with at any one time.

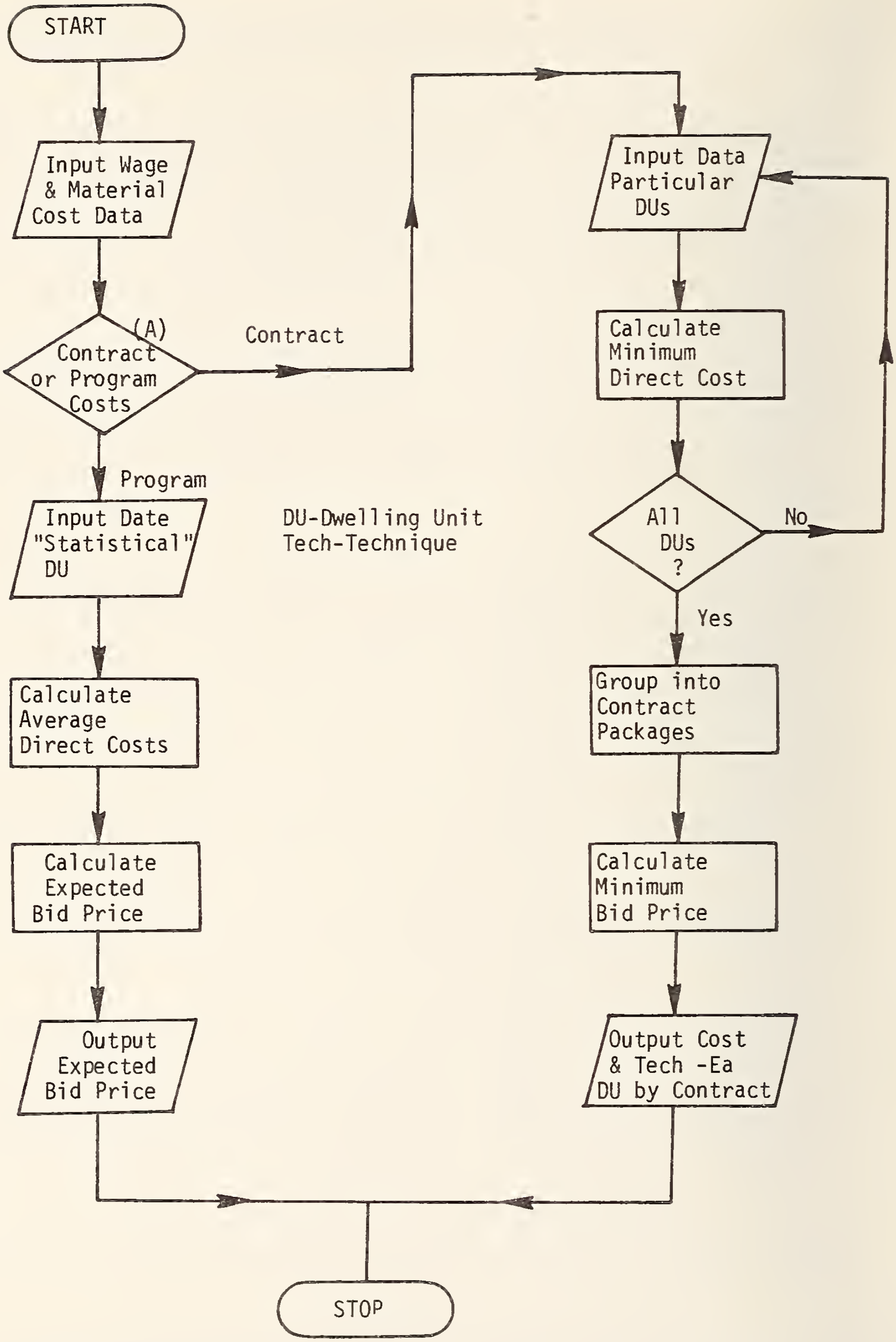

DIAGRAM 5.2

FLOWCHART FOR COMPUTER TIME-SHARING PROGRAM

TABLE 5.1

INPUT DATA REQUIREMENTS

Data Requirement	Nature of Data as a Function of the Type of Cost Estimate Desired: Program	Contract
Wage	Average Hourly Wage Rate	Average Hourly Wage Rate
Carpenter	"	"
Painter	"	"
Plasterer	"	"
Paper Hanger	"	"
Apprentice Carpenter	"	"
Laborer	"	"
Material		
Gypsum Wallboard	Price per 4' x 8' Sheet	Price per 4' x 8' Sheet
Plywood Paneling	"	"
Vinyl-Coated Fabric	Price per Square Yard	Price per Square Yard
Flat Latex Wall Paint	Price per Gallon	Price per Gallon
Semi-Gloss Enamel (Oil Base)	Price per Gallon	Price per Gallon
If Needed:		
Unfinished Door	Price for One, New	Price for One, New
Unfinished Door Frame	"	"
Unfinished Window and Frame	Price for Both, New	Price for Both, New
Dwelling Unit	Based on "Statistical" Dwelling Unit	Observed Value in the Particular Dwelling Unit
Gross Sq. Ft. of Wall Area	Square Feet	Square Feet
Linear Ft. of Doors and Frames	Linear Feet	Linear Feet
Linear Ft. of Windows and Frames	"	"
Linear Ft. of Miscellaneous Trim	"	"
Occupancy	Percent Occupied	1 If Occupied 0 If Unoccupied
Wainscotting	Percent of Wall Area	Percent of Wall Area
Substrate Condition	Percent Unsound	1 If Poor 0 If Satisfactory or Better
Pantry Work	Percent Needing It	1 If Needed 0 If Not
Wallpaper on Walls	Percent Having > 2 Layers	1 If 3 or More Layers 0 If 2 or Less
If Needed:		
Number of Doors to Replace	Number	Number
Number of Door Frames to Replace	"	"
Number of Windows and Frames To Replace	"	"
Address	DU/Age Category	Address as Specified
XRF Reading	Average or Separate for Each Trim Type	Average or Separate for Each Trim Type

dwelling units within a group should be relatively close to each other so that the distance between dwelling units will not enter as a complicating factor in making up contract packages.[1]

Let us now return to the flowchart. In response to the computer's question in block A, a 0 is entered, indicating that contract cost estimates are desired. (Recall from the previous discussion that information on wage rates and material prices would have been entered prior to reaching block A.) The computer then asks for how many dwelling units the user will be inputting data. Suppose the user has eight dwelling units for which he wants cost estimates. The computer first requests information on all the dwelling unit specific key factors listed in Table 5.1 for dwelling unit number one. The cost of each abatement technique is then calculated and the one which minimizes direct costs is identified. (This procedure is followed for both wall and trim surfaces.) The computer then returns to the user and requests information on the second dwelling unit.

This input loop continues until all data regarding specific dwelling units have been input. As a next step, the computer groups the dwelling units into "preliminary" contract packages based on the values of the key factors factors and other decision criteria implicit in the program (e.g., technique familiarity and occupancy status). The objective here is to reduce the expected markup ratio to as small a number as possible. The computer program then tests to see if the sum of the expected bid prices for the "preliminary" contract packages can be reduced by removing a dwelling unit from one contract package and placing it in another. Once this search routine finds that no further reductions in the overall bid price can be achieved, the dwelling units are assigned to contract packages and the program enters the output routine. The output routine first prints the least-cost technique for both wall and trim surfaces for each dwelling unit and gives expected cost. This is done for each contract. For example, the first contract might have dwelling units number 1, 3 and 7; the second dwelling units 2 and 8; and the third dwelling units 4, 5 and 6. The expected markup ratio for each contract is also given in order to facilitate policy analysis by program decision makers. This information is useful for policy analysis because if markup ratios are consistently high, it may be possible to achieve a reduction in program costs by operating in a cost plus fixed fee contracting mode.

The discussion in this section has been aimed at explaining what tasks the computer program performs and how it accomplishes these tasks. In terms of using the program and how will be given in this section. The reader wishing more details on running the program is referred to Appendix A. The discussion here is limited to those details concerned

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[1] This approach was taken since it permits the computer to assign the dwelling units to contract packages in such a way that the sum of the expected bid prices for the contracts is minimized.

with establishing a computer account and identifying office terminal needs.

Before the computer program can be referenced, the agency (or authorized contractor) must subscribe to the RAMUS service. An agency or authorized contractor wishing to subscribe to the RAMUS service should initiate the administrative procedure by writing to:

Agency Services Coordination Division
ADTS, GSA
1776 Peachtree Street, N.W.
Atlanta, Georgia 30309

This letter should include the following information:

1. The date the agency wishes to begin RAMUS service;
2. The number and type of terminals which will be used;
3. The average number of hours per day of terminal connect time;
4. The estimated program storage requirements;
5. The name, address, and telephone number of the agency, the person to be contacted for information pertaining to RAMUS usage; and
6. The billing address and appropriate fund citation.

Item number 2 in the list above requests information about the type of office terminal to be used. In order to use RAMUS, the terminal should be either the Automatic Send/Receive Model 33 or 35 Teletypewriter, or any fully compatible equipment. The office terminal communicates with RAMUS by means of a telephone (voice grade) circuit; either FTS, WATS, or leased lines may be used. Once the user has received an identification code and password, they enter the FACTS library via RAMUS. (This procedure is analogous to checking a book out of a library and using the information in the book to solve a particular problem.) Details, including sample computer runs, of how the user establishes a file and references it in order to run their program are given in Apendix A.

6. SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 SUMMARY

The potential of lead poisoning through the ingestion of lead-based paint (LBP) chips is a threat to the health and well-being of young children. The potential and the magnitude of the problem have stimulated public and private interest in eliminating the hazards of LBP from the nation's housing. A method of estimating the costs of LBP abatement is required to insure that the resources devoted to eliminating the hazards of LBP will be used efficiently. A major goal of the Experimental Hazard Elimination Program (EHEP) was to produce such a method.

Based on results from EHEP, this study develops and validates a series of cost models for the estimation of the direct costs of LBP abatement. A cost model for predicting the contractor's markup for overhead and profit is also developed. Direct costs were analyzed at the dwelling unit level by building component (walls, doors and frames, windows and frames, and miscellaneous trim) and by abatement technique. They were compared on the basis of per unit direct cost (i.e., the direct cost per square foot, per linear foot, or per item). Each abatement technique was then analyzed statistically so that the key factors which accounted for variations in per unit direct cost could be identified. Estimates of the relative impact that the key factors had on per unit direct costs were then developed. The key factors and the weighting factors were then combined in such a way that the resulting cost models permitted the prediction of the per unit direct cost for each abatement technique.

To provide a measure of the confidence with which the EHEP cost models can be used, a statistical estimate of how complete the model is at explaining variations in per unit direct cost and the markup ratio was presented. These statistics took on values which ranged from 0.66 to 0.91 for the twelve separately estimated cost models; the average value was 0.81. That is, on the average, 81 percent of the variation in per unit direct cost was explained by a linear cost model. It should be noted that the estimate of how complete the model was at explaining variations in per unit direct cost exceeded 0.80 for nine of the twelve models. The results of the cost models were then tested against an independent set of data. This validation procedure was undertaken to test the adequacy of the cost models to predict abatement costs in another city at a different point in time. The results of the validation procedure were encouraging, underscoring the advantages of the key factor approach over a simple average. With these considerations in mind, it seems likely that most of the cost models developed in this study provide a reliable procedure for estimating the costs of LBP abatement. Finally, through validation it was found that most of the cost models developed in this study are of general enough nature that they have captured potential differences in per unit direct cost due to regional effects.

Guidelines for using the EHEP cost models as a management tool were discussed. A computer program written in the BASIC language was developed which permitted decision makers to make cost estimates via a time-sharing terminal. Specific applications of the computerized cost models in estimating the least-cost combination of abatement techniques for a contract package of one or more dwelling units were explored as were potential applications of the procedure as a policy tool for making baseline estimates for planned or on-going programs.

6.2 RECOMMENDATIONS FOR FURTHER RESEARCH

In order to expand the cost models developed in this study to include future expenditures, to determine the optimal level of LBP hazard abatement, 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.

It was noted earlier that the hazard abatement quality of a barrier material was a function of how well it prevented access to the LBP which remained beneath. The durability of the product is therefore an important factor which should be considered in its use. However, due to the lack of information on the durability of the various barrier materials, it was not possible to assess the effect that future repair costs would have on the choice of the least costly barrier material. The impact that future costs, which are not always seen with certainty, can have on investment decisions has been demonstrated in other studies.[1] Since it is unlikely that the failure of a barrier material can be known with certainity, it appears that, at least at the program level, some allowance for future costs due to technique failure should be made.

It was shown in the introduction of this report that there are environmental sources of lead capable of causing lead poisoning other than LBP. This study in its analysis of deleading costs has not focused on the benefits which would result from these deleading operations. The establishment of what benefits are associated with LBP abatement and their quantification is essential to the identification of the optimal level of protection against LBP poisoning and the optimal combination of LBP abatement techniques. Furthermore, it is important to recognize that the estimation of total project benefits may also be used as a policy tool in the development of alternative LBP abatement strategies at the national or city level. Developing such estimates in future research will reduce the probability of pursuing an LBP abatement strategy which wastes either scarce tax dollars or irreplaceable human resources.

It is important that the material presented in this report be placed in the hands of municipal officials and building owners. A simplified guidebook to LBP abatement which focuses on the cost estimation procedure would seem most appropriate. This guide could include the additional research topics discussed above so that the most efficient allocation of funds could be achieved.

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.

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[1] Donovan Young and Luis Contreras, "Expected Present Worths of Cash Flows Under Uncertain Timing," The Engineering Economist, Volume 20, Number 4, Summer 1975.

Finally, the success that this procedure has had in estimating the costs of LBP abatement indicates that a similar aproach may be very useful in estimating the costs of housing rehabilitation. The current lack of cost information in the housing rehabilitation industry may be a deterrant to investments in the rehabilitation of central city housing. Should reliable cost information be made available to municipal officials and potential homeowners, a more meaningful and comprehensive approach to housing conservation might be possible.

7. REFERENCES

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APPENDIX A:

HOW TO USE THE COMPUTERIZED COST ESTIMATION PROCEDURE

In Section 5.3, background information was given that identified the inputs required to use the computerized cost estimation procedure. Recall that these inputs were in part a function of whether the costs desired were for policy analysis or for contract cost estimation. To make efficient use of the time saving potential that the computerized cost estimation procedure offers, some planning on the part of the individual(s) using the program will be necessary. For example, to do program cost estimates, a table similar to Table A.1 would be useful. Table A.1 shows the number of dwelling units in each type/age category. Each category can then be broken down into data on the "statistical" dwelling unit. Diagram A.1 shows how a simplified worksheet can be used to record data on wages and material costs.[1] (Recall that the same information on wages and material prices can be used for both program analysis and contract cost estimation.) In entering dwelling unit specific data, a worksheet similar to that shown in Diagram A.2 was found to be very efficient. (Diagram A.2 illustrates such a breakdown for single family attached dwellng units.) If these basic guidelines are followed for keeping input data at hand, the cost estimation work should proceed both smoothly and rapidly.

We are now ready to see how, through the FACTS library of programs, a user file can be established. Once you have established your file, it is then possible to run your program without going through the FACTS executive system. (Recall that establishing a file is like checking out a book from a library. You use it until your need is satisfied and then return it.)

As a first step, the user must call RAMUS. (The telephone number by which you can reach RAMUS will be provided when you establish your subscription to the service.) When you reach RAMUS, the computer will request your user ID, your secret password, and the type and name of

---

[1] When entering data into the computer program, it is not necessary to use a dollar, ($) sign. Thus, if the wage rate for a carpenter was $9.00 per hour the proper input would be 9.00 or 9. The same argument holds for material prices, e.g., 2.50 <u>not</u> $2.50.

the program you wish to use.[1] A sample of the type of information requested is shown below. Notice that the computer prints over your password so that it can not be deciphered and used by someone else.

```
GSA 440 TIME-SHARING SYSTEM 1 ON AT - 11:23 PN:04 TTY:60

12/12/77.

USER ID-- __ __ __ __

PASSWORD? __ __ __ __ __
```

TYPE OLD OR NEW: OLD:FACTS***

The computer is now ready to run FACTS. In response to the computer's READY signal, please type RUNNH. The computer will then ask what level of prompting you wish; in response to the ***?, enter HE as in the sample below.

```
READY
RUNNH

FACTS RESPONSING. INDICATE LEVEL OF PROMPTING AT ***? PROMPT
ENTER TO GET
_____ ______

 AB  ABBREVIATED PROMPTING
 FL  FULL PROMPTING
 HE  FULL PROMPTING + SYSTEM EXPLANATION
```

---

[1] At the end of each statement, e.g., B310, you must press the non-printing carriage return character. This tells the computer to proceed. If you make a mistake, e.g., typing B315 instead of B310, you can correct by using the character ←. To change B315 to B310, you would type ← once and then 0. The line would then look like B315←0. In the event that you do not have enough space to make corrections using the character ←, you can press the escape key (ESC). This action will cause the input for that line in the computer program to be repeated a second time. If you get in a real bind, hit the BREAK character. This disconnects you from RAMUS.

TABLE A.1

NUMBER OF DWELLING UNITS BY TYPE/AGE CATEGORY

DWELLING UNIT TYPE	DWELLING UNIT AGE		
	PRE 1940	1940-1960	POST 1960
MULTIFAMILY LOW RISE			
MULTIFAMILY HIGH RISE			
SINGLE FAMILY ATTACHED			
SINGLE FAMILY DETACHED ONE STORY			
SINGLE FAMILY DETACHED TWO OR MORE STORIES			

DIAGRAM A.1 WAGE AND MATERIAL PRICE DATA

AVERAGE HOURLY
WAGE RATE

CARPENTER	________
PAINTER	________
PLASTERER	________
PAPER HANGER	________
APPRENTICE CARPENTER	________
LABORER	________

MATERIAL PRICES

GYPSUM WALLBOARD - (4' x 8' sheet)	________
PLYWOOD PANELING - (4' x 8' sheet)	________
VINYL-COATED FABRIC - (SQUARE YARD)	________
FLAT LATEX WALL PAINT - (GALLON)	________
SEMI-GLOSS ENAMEL (OIL BASE)-(GALLON)	________

IF NEEDED

UNFINISHED DOOR - (NEW-EACH)	________
UNFINISHED DOOR FRAME - (NEW-EACH)	________
UNFINISHED WINDOW AND FRAME - (NEW-EACH)	________

DIAGRAM A.2 DWELLING UNIT DATA FORM[a]

DU/AGE CATEGORY PRE 40 SINGLE FAMILY ATTACHED

WALL AREA - (GROSS SQUARE FEET) ____________________

DOORS AND FRAMES-(LINEAR FEET) ____________________

WINDOWS AND FRAMES-(LINEAR FEET) ____________________

MISCELLANEOUS TRIM-(LINEAR FEET) ____________________

OCCUPANCY-(PERCENT OCCUPIED) ____________________

WAINSCOTTING-(PERCENT WALL AREA) ____________________

SUBSTRATE CONDITION-(PERCENT UNSOUND) ____________________

PANTRY WORK-(PRECENT NEEDING IT) ____________________

WALLPAPER REMOVAL-(PERCENT HAVING $\geq$ 2 LAYERS) ____________________

XRF READINGS - (DOORS) ____________________

XRF READINGS-(WINDOWS) ____________________

XRF READINGS-(MISCELLANEOUS) ____________________

IF NEEDED

REPLACEMENT DOORS-(NUMBER) ____________________

REPLACEMENT DOOR FRAMES-(NUMBER) ____________________

REPLACEMENT WINDOWS AND FRAMES-(NUMBER) ____________________

---

[a] For making cost estimates at the program level.

***? HE

The computer will then print the following details on FACTS.

FACTS CONSISTS OF AN EXECUTIVE SYSTEM AND A LIBRARY OF FULLY TESTED ENGINEERING AND SCIENTIFIC COMPUTER PROGRAMS.

THE FACTS EXECUTIVE SYSTEM ALLOWS THE USER TO FULLY UTILIZE THE FACTS LIBRARY OF ENGINEERING AND SCIENTIFIC COMPUTER PROGRAMS BY (1) PROVIDING LIBRARY VISIBILITY, (2) CONSTRUCTING COMMANDS PROGRAMS FOR THE USER WHICH TAKE CARE OF ALL SYSTEM DETAILS THAT ARE NECESSARY FOR SETTING UP AND RUNNING FACTS PROGRAMS AND (3) PROVIDING USER LIBRARY MANAGEMENT. THESE FUNCTIONS ARE ACCOMPLISHED WITHIN SUBLEVELS OF THE EXECUTIVE SYSTEM. SUBLEVEL STATUS IS ACHIEVED THROUGH THE USE OF COMMANDS GIVEN TO THE COMPUTER IN RESPONSE TO THE ***? PROMPT PRINTED IN THE EXECUTIVE SYSTEM COMMAND LEVEL. THE THREE PRINCIPAL FUNCTIONS OF THE FACTS EXECUTIVE SYSTEM ARE AS FOLLOWS:

(1) LIBRARY VISIBILITY IS ACHIEVED THROUGH THE LIST AND BRIEF SUBLEVELS

/LIST SUBLEVEL/-PROVIDES A LIST OF COMPUTER PROGRAMS CURRENTLY AVAILABLE IN THE FACTS LIBRARY. THE FACTS LIBRARY, WHICH IS CONSTANTLY EXPANDING, IS DIVIDED INTO SUBAREAS THAT ARE IDENTIFIED BY EITHER A SINGLE ALPHABET LETTER OR BY A LETTER AND A NUMBER. A LIST OF THE SUBAREAS AND THE NUMBER OF FACTS PROGRAMS IN EACH SUBAREA IS AVAILABLE AS AN OPTION WITHIN THE LIST SUBLEVELS OF THE EXECUTIVE SYSTEM.

/BRIEF SUBLEVEL/-PROVIDES A SHORT DESCRIPTION OF THE CAPABILITIES AND DATA REQUIREMENTS FOR EACH PROGRAM IN THE FACTS LIBRARY.

(2)CONSTRUCTION OF COMMANDS PROGRAMS IS ACHIEVED THROUGH THE CONSTRUCT SUBLEVEL.

/CONSTRUCT SUBLEVEL/-FOR EACH FACTS LIBRARY PROGRAM THAT THE USER WANTS TO RUN, THE COMPUTER CREATES A SMALL COMMANDS PROGRAM TO HANDLE ALL THE DETAILS REQUIRED TO MAKE THE PROGRAM OPERATIONAL. THIS SMALL PROGRAM IS STORED IN THE USERS OWN LIBRARY BY THE COMPUTER AND ITS NAME RECORDED IN A DIRECTORY FILE THAT THE COMPUTER GENERATES FOR THE USER THE FIRST TIME IT CREATES A COMMANDS PROGRAM FOR HIM. EACH TIME THE USER CREATES ANOTHER COMMANDS PROGRAM IT IS ALSO STORED IN HIS LIBRARY AND ITS NAME IS ADDED TO HIS DIRECTORY FILE. THUS, THE USERS DIRECTORY FILE CONTAINS A CURRENT LIST OF THE COMMANDS PROGRAMS THAT ARE IN HIS LIBRARY. COMMANDS PROGRAMS ARE CREATED BY THE FACTS EXECUTIVE SYSTEM BUT THEY ARE RUN UNDER RAMUS IN THE SAME MANNER AS ANY OTHER COMPUTER PROGRAM ON THE RAMUS SYSTEM. A COMMANDS PROGRAM, ONCE GENERATED, CAN BE USED OVER AND OVER AGAIN WITHOUT RETURNING TO THE FACTS EXECUTIVE SYSTEM.

(3)MANAGEMENT OF THE USERS LIBRARY OF COMMANDS PROGRAMS IS HANDLED THROUGH THE DELETE, DIRECTORY AND MESSAGE SUBLEVELS.

/DELETE SUBLEVEL/-PROVIDES THE MECHANISM FOR LISTING THE CONTENT OF THE USERS DIRECTORY FILE(S) AND FOR DELETING COMMANDS PROGRAMS FROM HIS LIBRARY. THE NAMES OF DELETED COMMANDS PROGRAMS ARE REMOVED FROM THE USERS DIRECTORY FILE. THUS, THE DIRECTORY IS ALWAYS CURRENT.

/DIRECTORY SUBLEVEL/-ALLOWS THE USER TO LIST THE CONTENT OF HIS DIRECTORY FILE(S).

/MESSAGE SUBLEVEL/-ALLOWS THE USER TO MAKE COMMENTS ON FACTS DURING THE ACTUAL USE OF THE SYSTEM. MESSAGES ARE REVIEWED AT FREQUENT INTERVALS AND THE USER IS NORMALLY CONTACTED IF ADDITIONAL INFORMATION IS REQUIRED.
NOTE: COMMANDS AND RESPONSES SHOULD BE ENTERED ONLY IN RESPONSE TO PROMPTS: OTHERWISE IT CONFUSES THE COMPUTER. ALSO, THINK BEFORE YOU RESPOND TO A COMPUTER PROMPT, A LITTLE THOUGHT WILL PAY-OFF.

THE FACTS LIBRARY CONSISTS OF A NUMBER OF FULLY TESTED ENGINEERING AND SCIENTIFIC COMPUTER PROGRAMS. THESE PROGRAMS ARE REALLY SUBROUTINES AND EACH CONTAINS A PREAMBLE WHICH DEFINES THE PURPOSE OF THE PROGRAM, THE DATA REQUIRED TO MAKE IT OPERATIONAL AND OTHER INFORMATION NECESSARY FOR ITS EFFICIENT OPERATION. SINCE THESE PROGRAMS ARE SUBROUTINES, THEY MAY BE LINKED TOGETHER FOR SOLVING EXTREMELY COMPLEX PROBLEMS WHERE A MULTIPLICITY OF OPERATIONS ARE REQUIRED. THE FACTS EXECUTIVE SYSTEM CAN READ AND INTERPRET THE CONTENT OF THE PREAMBLE OF FACTS PROGRAMS AND FROM THIS ANALYSIS, CREATE A COMMANDS PROGRAM CONTAINING THE ELEMENTS THAT ARE NECESSARY FOR MAKING THE FACTS SUBROUTINE FULLY OPERATIONAL.

YOU ARE NOW AT COMMAND LEVEL (PROMPT SYMBOL***).
ENTER NEXT FACTS COMMAND AT ***? PROMPT.

VALID COMMANDS	ACCEPTABLE ABBREVIATION	PROMPT SYMBOL	COMMAND ACTION
ABBREVIATE	AB	***	PRINT ABBREVIATED PROMPTING
BRIEF	BR	$$$	PRINT BRIEF DESCRIPTION OF PROGRAMS
CONSTRUCT	CO	+++	CONSTRUCT COMMANDS PROGRAMS
DELETE	DE	%%%	DELETE COMMANDS PROGRAMS
DIRECTORY	DI	&&&	LIST OF PROGRAMS IN USER'S DIRECTORY
FULL	FL	***	PRINT FULL PROMPTING
HELP	HE	@@@	PRINT FACTS SYSTEM DETAILS
LIST	LI	###	LIST OF FACTS PROGRAMS
MESSAGE	ME	↑↑↑	MAKE SYSTEM COMMENTS
RAMUS	RA	<<<	PRINT RAMUS SYSTEM DETAILS
STOP	STOP		RETURNS USER TO RAMUS SYSTEM

In respose to the ***? question, please enter RA. This will tell the computer to print the following details on RAMUS.

***? RA

<<<

ALL PROGRAMS, INCLUDING THE FACTS EXECUTIVE SYSTEM, ARE RUN UNDER THE CONTROL OF RAMUS (REMOTE ACCESS MULTI-USER SYSTEM). IN ORDER TO RUN A COMMANDS PROGRAM DEVELOPED WITHIN FACTS, THE USER MUST EXIT TO RAMUS. THIS CAN BE DONE AT ANY TIME BY TYPING AN S AND THEN HITTING A CARRIAGE RETURN OR WHEN AT COMMAND LEVEL THE USER MAY TYPE STOP. AT RAMUS LEVEL THE USER MAY RUN ANY PROGRAM BY TYPING "RUN OPTION: PROGRAM NAME" FOR EXAMPLE, IF THE USER WANTED TO RUN A COMMANDS PROGRAM NAMED RLR01 AND ITS RUN OPTION IS RUN, THE USER WOULD TYPE RUN: RLR01 AND THEN HIT A CARRIAGE RETURN. (FOR GREATER DETAIL OF THE RAMUS SYSTEM AND ITS OPTIONS, THE USER MUST OBTAIN A COPY OF THE OPERATING SYSTEM MANUAL THROUGH GSA).

YOU ARE NOW AT COMMAND LEVEL (PROMPT SYMBOL***).
ENTER NEXT FACTS COMMAND AT ***? PROMPT.

VALID COMMANDS	ACCEPTABLE ABBREVIATION	PROMPT SYMBOL	COMMAND ACTION
ABBREVIATE	AB	***	PRINT ABBREVIATED PROMPTING
BRIEF	BR	$$$	PRINT BRIEF DESCRIPTION OF PROGRAMS
CONSTRUCT	CO	+++	CONSTRUCT COMMANDS PROGRAMS
DELETE	DE	%%%	DELETE COMMANDS PROGRAMS
DIRECTORY	DI	&&&	LIST OF PROGRAMS IN USER'S DIRECTORY
FULL	FL	***	PRINT FULL PROMPTING
HELP	HE	@@@	PRINT FACTS SYSTEM DETAILS
LIST	LI	###	LIST OF FACTS PROGRAMS
MESSAGE	ME	↑↑↑	MAKE SYSTEM COMMENTS
RAMUS	RA	<<<	PRINT RAMUS SYSTEM DETAILS
STOP	STOP		RETURNS USER TO RAMUS SYSTEM

In response to ***?, please type LI; this will get you to the LIST level of FACTS. When the computer prints ###?, please type *; this will tell the computer to list all the functional codes, the number of programs in each area, and a description of the functional code. Typing LI in response to the first question, and * in response to the second will cause the following output to be printed.

***? LI
YOU ARE NOW AT LIST LEVEL (PROMPT SYMBOL ###).
ENTER ONE FUNCTIONAL AREA CODE (E.G. J) IN RESPONSE TO EACH PROMPT.
ENTER AN * FOR LIST OF CODES. ENTER WORD END TO RETURN TO COMMAND LEVEL.
###?*

FUNCTIONAL AREA CODE	PROGRAMS IN AREA	DESCRIPTION
E	1	ELECTRICAL
H_1	8	HYDRAULICS-SPILLWAYS
H_2	11	HYDRUALICS-OUTLET WORKS
H_3	2	HYDRAULICS-GATES & VALUES
H_6	23	HYDRAULICS-OPEN CHANNELS
H_7	5	HYDRAULICS-SPECIAL PROBLEMS
I	4	SOILS
J	3	ECONOMICS
L	2	MECHANICAL
M	1	MATHEMATICAL
U	1	GEODESORY & SURVEYING
X	21	STRUCTURAL
Z	1	OTHER

After the computer has printed information on the functional codes, it will ask the user if a listing of individual programs is desired. Since the program on deleading costs is stored in the functional area code J, the user should enter J in response to ###. The listing will then identify J0003 as the desired program. (Note, as of the date of the printing of this publication, the computerized cost estimation program had not been placed in the FACTS library. Thus, the listing of all programs in the J, economic, functional area code is necessary to determine if J0003 is the correct FACTS program number.)

The user should then type END and BR in response to the prompting, ***?, question from the computer so that a brief of program J0003 can be obtained (see below).

```
***? BR

YOU ARE NOW AT BRIEF LEVEL (PROMPT SYMBOL $$$).
ENTER ONE PROGRAM NAME (E.G. H2010) IN RESPONSE TO EACH PROMPT.
TYPE WORK END TO RETURN TO COMMAND LEVEL.
$$$ ? J0003

  I.  DESCRIPTION

      J0003 WILL ANALYZE THE COSTS OF THE ALTERNATIVE METHODS FOR
      ELIMINATING THE LEAD PAINT HAZARD FROM A DWELLING UNIT. THE
      PROGRAM PERMITS THE USER TO INPUT SPECIFIC INFORMATION ON ANTI-
      CIPATED CONTRACT PACKAGES OF DWELLING UNITS. THE LEAST-COST
      COMBINATION OF ABATEMENT TECHNIQUES FOR EACH DWELLING UNIT IS
      IDENTIFIED. DWELLING UNITS ARE GROUPED TOGETHER INTO CONTRACT
      PACKAGES SO THAT THE SUM OF THE EXPECTED BID PRICES IS MINIMIZED.
      THE EXPECTED BID PRICE FOR EACH CONTRACT IS GIVEN. EXPECTED
      CONTRACT COSTS FOR EACH DWELLING UNIT ARE ALSO GIVEN.
```

II. LIMITATIONS

J0003 WILL HANDLE ANTICIPATED CONTRACT PACKAGES OF UP TO 10 DWELLING UNITS. DATA FOR EACH DWELLING UNIT IS ENTERED IN RESPONSE TO QUESTIONS AT RUN TIME.

III. DATA

TWO TYPES OF DATA ARE INPUT, CONTRACT SPECIFIC DATA AND DWELLING UNIT SPECIFIC DATA. INPUT DATA FOR EACH ANTICIPATED CONTRACT CONSIST OF THE FOLLOWING:

A. CONTRACT SPECIFIC DATA

WAGE	AVERAGE HOURLY WAGE RATE
CARPENTER	"
PAINTER	"
PLASTERER	"
PAPER HANGER	"
APPRENTICE CARPENTER	"
LABORER	"

MATERIAL

GYPSUM WALLBOARD	PRICE PER 4' x 8' SHEET
PLYWOOD PANELING	"
VINYL-COATED FABRIC	PRICE PER SQUARE YARD
FLAT LATEX WALL PAINT	PRICE PER GALLON
SEMI-GLOSS ENAMEL (OIL BASE)	PRICE PER GALLON

IF NEEDED:

UNFINISHED DOOR	PRICE FOR ONE, NEW
UNFINISHED DOOR FRAME	"
UNFINISHED WINDOW AND FRAME	PRICE FOR BOTH, NEW

B. DWELLING UNIT DATA

GROSS SQ. FT. OF WALL AREA	SQUARE FEET
NET SQ. FT. OF WALL AREA	"
LINEAR FT. OF DOORS AND FRAME	LINEAR FEET
LINEAR FT. OF WINDOWS & FRAMES	"
LINEAR FT. OF MISCELLANEOUS TRIM	"

OCCUPANCY PERCENT OCCUPIED OR 1 IF OCCUPIED
0 IF UNOCCUPIED

```
    WAINSCOTTING          PERCENT OF WALL AREA

                                               OR   1 IF POOR
    SUBSTRATE CONDITION   PERCENT UNSOUND           0 IF SATISFACTORY OR BETTER

    PANTRY WORK           PERCENT NEEDING IT   OR   1 IF NEEDED
                                                    0 IF NOT

    WALLPAPER ON WALLS    PERCENT HAVING > 2 LAYERS 1 IF 3 OR MORE LAYERS
                                                    0 IF NOT

  IF NEEDED:

    NUMBER OF DOORS TO REPLACE        NUMBER

    NUMBER OF DOOR FRAMES TO REPLACE    "

    NUMBER OF WINDOWS AND FRAMES        "
      TO REPLACE

    ADDRESS                          DU/AGE CATEGORY OR ADDRESS AS SPECIFIED
    XRF READINGS                     AVERAGE OR SEPARATE
                                     FOR EACH TRIM TYPE
  FINISH
  $$$? END
```

The user has now identified the computerized cost estimation program and is now ready to construct a file to store a "duplicate" of the FACTS program. To do this, type END in response to $$$, and then CO in response to the prompting, ***?, question. Study the following steps carefully. First, when the computer prints +++?, hit the nonprinting carriage return character. Second, type J0003 (if the FACTS program number for the computerized deleading program was different, please enter that number) when the computer prints +++?. Third, type FINIS. Fourth, enter three letters (for example, your initials). The FACTS executive system then automatically establishes a directory file and assigns you a program name. You should record this information where you can easily refer to it. Fifth, type END. Sixth, type STOP. These six steps <u>should</u> generate an output similar to that which follows.

```
***? CO


YOU ARE NOW AT CONSTRUCT LEVEL (PROMPT SYMBOLS +++)
ENTER DIRECTORY FILE NAME?  IF YOU DON'T HAVE ONE, HIT A CARRIAGE RETURN.
+++ ?
```

```
ENTER ONE PROGRAM NAME (E.G. H2010)  IN RESPONSE TO
EACH PROMPT.  AFTER ALL NAMES HAVE BEEN ENTERED, TYPE FINIS AFTER
SUBSEQUENT PROMPT.
+++  ? J0003

+++  ? FINIS

ENTER # CHARACTERS (E.G. YOUR INTIALS) TO BE USED AS A PREFIX
IN NAMING YOUR NEW DIRECTORY FILE.

+++  ? KAH

THE FOLLOWING PROGRAMS ARE ADDED TO YOUR DIRECTORY FILE  KAH100
                     (MON 12/12/77)

COMMANDS PROGRAM NAME FACTS PROGRAM USED RUN OPTION
      KAHOO          J0003             RUNNH

THESE PROGRAMS WILL BE SAVED UNTIL YOU DELETE THEM.  THEY CAN BE RUN AT
RAMUS LEVEL BY ENTERING RUN OPTION: COMMENTS PROGRAM NAME (E.G. RUNNH:
SRHOO).

***  ? STOP
```

The computer has now returned you to RAMUS. You may now run your program by typing OLD: (your program name) and then RUNNH <u>after</u> the computer prints READY.

```
OLD:  KAHOO
READY
RUNNH


KAHOO     13:30 ATL MON    12/12/77
WAGE RATE INFORMATION

INPUT WAGE RATE PER HOUR FOR CARPENTER
 ? 8.20
INPUT WAGE RATE PER HOUR FOR PAINTER
 ? 8.50
INPUT WAGE RATE PER HOUR FOR PLASTERER
 ? 7.70
INPUT WAGE RATE PER HOUR FOR PAPERHANGER
 ? 7.30
INPUT WAGE RATE PER HOUR FOR APPRENTICE CARPENTER
 ? 5.00
INPUT WAGE RATE PER HOUR FOR LABORER
 ? 5.50
```

```
MATERIAL PRICE INFORMATION

INPUT PRICE OF 4 FT BY 8 FT SHEET OF GYPSUM WALLBOARD
 ? 2.20
INPUT PRICE OF 4 FT BY 8 FT SHEET OF PLYWOOD PANELLING
 ? 5.90
INPUT PRICE PER SQUARE YARD OF VINYL-COATED FABRIC
 ? 4.10
INPUT PRICE PER GALLON OF LATEX FLAT WALL PAINT
 ? 6.50
INPUT PRICE PER GALLON OF SEMI-GLOSS ENAMEL (OIL BASE)
 ? 7.70
TYPE 1 IF THERE ARE ANY DOORS, DOOR FRAMES OR WINDOWS
AND FRAMES THAT NEED TO BE REPLACED, 0 IF NOT
 ? 0

IF PROGRAM COST ESTIMATES ARE DESIRED, TYPE 1, IF
CONTRACT COST ESTIMATES ARE DESIRED, TYPE 0
 ? 1

STOP FOR A MINUTE AND CHECK THE DATA YOU HAVE JUST INPUT
IF ANY ERROR WAS MADE IN ENTERING IT, YOU MAY TYPE 1
TO REPEAT INPUT STATEMENTS: IF NOT, TYPE 0 TO CONTINUE
 ? 0


                  DWELLING UNIT INFORMATION

TYPE IN AN IDENTIFYING ADDRESS OR DU TYPE FOR THIS DWELLING UNIT
 ? PRE 40 SINGLE
FOR POLICY ESTIMATES INPUT AVERAGES FOR SQUARE FEET, LINEAR FEET,
XRF, ETC.: AND PERCENTAGE OF SAMPLE NEEDED FOR THOSE VARIABLES
REQUIRING A 1 OR Ø
INPUT GROSS SQUARE FEET OF WALL AREA
 ? 450
INPUT LINEAR FEET OF DOORS PLUS LINEAR FEET OF DOOR
FRAMES REQUIRING PAINT REMOVAL
 ? 33
INPUT LINEAR FEET OF WINDOWS PLUS LINEAR FEET OF
WINDOW FRAMES REQUIRING PAINT REMOVAL
 ? 30
INPUT LINEAR FEET OF MISCELLANEOUS TRIM REQUIRING
PAINT REMOVAL
 ? 110
TYPE 1 IF UNIT IS OCCUPIED, 0 IF NOT
 ? .975
INPUT PERCENT OF WALL AREA THAT IS WAINSCOATED
(TYPE AS A DECIMAL, E.G., 0.25 FOR 25 PERCENT)
 ? 0
TYPE 1 IF SUBSTRATE CONDITION IS POOR, 0 IF NOT
 ? .25
```

```
TYPE 1 IF PANTRY WORK IS NECESSARY, 0 IF NOT
 ? .10
TYPE 1 IF 3 OR MORE LAYERS OF WALLPAPER ARE ON WALLS,
0 IF NOT
 ? .05
TYPE 1 IF SEPARATE XRF READINGS ARE AVAILABLE FOR DOORS,
WINDOWS AND MISCELLANEOUS TRIM, 0 IF ONLY AN AVERAGE
IS AVAILABLE
 ? 0
INPUT AVERAGE XRF READING
 ? 3.47
STOP AND CHECK THE DATA FOR THIS DWELLING UNIT
IF THERE IS AN ERROR, TYPE 1 TO REPEAT INPUT STATEMENTS
IF NOT, TYPE 0
 ? 0

                              PRE 40 SINGLE

WALL COST        TRIM COST        TOTAL COST        MARKUP RATIO
 597.572          209.972          807.545           1.31

IF YOU WISH TO DO MORE COST ESTIMATES TYPE 1, IF NOT TYPE 0
 ? 0

RUNNING TIME:   13.7 SECS   I/O TIME:   50.3 SECS

READY
BYE
OFF AT 14:20
```

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15. SUPPLEMENTARY NOTES

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 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 Boston, Massachusetts. The major focus of the program was on the collection of data on the direct costs of labor, materials and special equipment associated with these abatement techniques. Data were also collected on contractors' bids so that markup ratios could be calculated.

This report provides an overview of the statistical analysis of these direct cost data by abatement technique and building component (i.e., walls, doors and frames, windows and frames, and miscellaneous trim). An overview of the statistical analysis of the markup ratio is also included. Cost models are developed for each abatement technique which identify the key factors which affect direct cost and markup. Guidelines are given so that these models can be used by municipal officials and building owners to estimate deleading costs as well as provide input to policy evaluation and formulation.

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)*

Abatement; building economics; building materials; economic analysis; housing; lead-based paint; lead poisoning

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