# ECONOMIC ANALYSIS OF IMPLEMENTING RESPIRATOR PROGRAM OR VENTILATION SYSTEM IN A MANUFACTURING ENVIRONMENT

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**Abstract** The techniques and methods of developing cost models for respirators are discussed. Models are developed and implemented in this study for nineteen types of respirators in two major classes (air-purifying and supplied-air) and one LEV system. One respirator model is selected for detailed discussion from among the twenty models. The technical cost method is used in constructing the cost models for each of the respirators and the LEV system. In this methodology, the costs of purchasing and using a typical respirator or LEV system are divided into two categories, variable costs and fixed costs. Variable costs consist of the cost of replaceable components and probabilistic mortality cost. Fixed cost is the annualized capital requirement plus interest cost. The criteria for estimating some of the cost elements are based on existing equations in the literature, engineering judgement and manufacturer-provided information. A technical cost model results from the integration of this information into a computerized framework. The cost models for discussion are presented in the order of increasing computational complexity. Through the economic analysis, the lowest cost type in each class of respirator is determined. The determination criteria are based on the minimum total annual cost and highest benefit cost ratio. The selected lowest cost respirators are compored with the LEV system from the economic standpoint to reveal the cost optimal alternative.

**Key Words** Economic Analysis, Respirator, Ventilation System

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## 1. INTRODUCTION

Using a new product in a manufacturing setting to increase the efficiency of employees and reduce the health hazards of the work environment engenders to a wide range of uncertain engineering and economic consequences. while considerable talent can be brought to bear on the engineering issues, many economic questions remain. This problem of dealing with the economic questions is particularly important when the new product is not fully studied from an economic aspect since economic analysis is a key issue in selecting competitive alternatives. A need for a detailed study of the competing alternatives is obvious. Therefore, a detailed and comprehensive economic model for each alternative needs to be developed to address the issue of capital cost of the product and its replaceable component costs during its recommended life cycle and the probabilistic cost of personal injury given the characteristics of the product and the injurious substance. When such a model is developed, it will assist the user to select the most economical alternative, i.e. that one which has the lowest total annual operating and capital cost, but which performs the task at a given level of personal injury risk.

Technical cost modeling is an extension of an engineering feasibility study with particular emphasis on capturing the cost implications of implementing a new product in a manufacturing environment. Because of their parameterized structure, technical cost models can readily be tailored to a wide range of operating conditions. This simplifies the economic analysis of technological changes. Furthermore, these models are flexible and allow users to implement the model to their own cost estimating environment. Once modified, the cost model can be used to explore, in detail, the costs of two different products competing for a particular application. Using technical cost models, the economic costs of implementing and maintaining a respiratory protection program or a ventilation system can be investigated without extensive expenditure of capital and time. Technical cost models can be used to estimate the economic cost of implementing the use of respirator or ventilation systems. They can also be used to establish a direct comparison of economic costs of these alternatives and to identify limiting parameters of the competing approaches.

In this study, a detailed cost estimating model for two major classes of respirators, air-purifying and supplied air, and the local exhaust ventilation (LEV) system was developed. Each model incorporates unit purchase, operating, administrating, medical check-up, fit testing, training and probabilistic fatality and uncertainty costs. Each of these cost components has detailed elements which enable the model to address the costs and expenses that occur during the life of a particular respirator or LEV system.

The use of respiratory protection versus ventilation controls is governed by the rules of the Occupational Safety and Health Administration (OSHA), specifically Federal Register part 1910. 134[1]. Subpart 1910. 134 Clearly states that when feasible, engineering controls shall be used instead of respiratory protection equipment (RPE). One such engineering control is the use of ventilation. In this instance, OSHA generally interprets feasibility to include both technical and economic feasibility. The proposed study examines and illustrates the techniques of an engineering cost and feasibility study through a description of the costs involved in implementing respirator or ventilation exposure control systems in a workplace environment. The cost models developed will provide direct economic cost data to address the issue of feasibility and cost comparison. One technical cost model, Disposable Particulate-Removing Air-Purifying Respirator (DPRAPR), is separately described in the up-coming sections. This model was selected from among the sixteen that were developed over the course of this study.

**1.1 Background** Cost models built using the electronic spreadsheet approach allow for cost estimates based on alternative sets of assumptions. The cost model can be used to assess the potential feasibility of different types of equipment and processes for a given application. The user-interactive computerized nature of the cost model is particularly suitable for examining different equipment alternatives and for estimating how the potential use of alternative equipment can effect the cost.

Despite the method used to estimate the potential manufacturing costs, the final system selection should be a compromise between performance and economics. Factors to cosider are the user's requirements, which depend on the nature and characteristics of the contaminants, initial costs, service life cost, operating costs. and the cost associated with the risk due to the use of specific respirators or LEV systems. Any of these factors can alter the choice. However, when the choice is between apparently equal alternatives in terms of the cost, the system with the lowest life cycle cost is the best choice. Therefore, once all the costs and benefits have been identified and enumerated, the next step is to compare them using an appropriate engineering economy method.

In the reviewed literature related to respiratory protective and local exhaust ventilation systems, no model is cited which considers the cost of acquiring and operating this equipment. The model developed in this study appears to be unique in its consideration of the probabilistic cost of personal injury given the device effectiveness and characteristics of the injurious substances The possibility that such a cost model exists in the private sector cannot be ruled out, However, the lack of evidence of a precedent supports the previous statement of uniqueness of this cost model.

## 2. INDUSTRIAL RESPIRATORS

Respirators are devices used to protect the wearer from hazardous airborne contaminants and oxygen deficient atmospheres. The types of respirators used in different workplace environments are governed by the chemical and physical properties of the hazards existing in those environments. The National Institute for Occupational Safety and Health (NIOSH) routinely makes recommendations regarding the use of respirators for workers exposed to workplace environments that contain hazardous concentrations of airborne contaminants and/or oxygen deficient atmospheres. Such recommendations are made only when effective engineering control methods (ventilation systems) are not technically feasible, when these ventilation systems are used alone, and they are not completely effective, while controls are being installed or repaired, or when emergency and other temporary situations arise.

**2.1 Selection of Respiratory Protective Equipment** Respiratory protective devices vary in design, application and protective capability. The user must, therefore, assess the respiratory hazard and understand the specific uses and limitations of available equipment to assure proper selection. Respiratory protective devices fall into two main functional classes: (1) air-purifying and (2) supplied air following BERP [5]. Figures 1 and 2 illustrate these classifications and their subclasses.

**2.2 Design of Respiratory Equipment and LEV System Risk Model** The risk involved in the implementation of a respiratory protection program include: (1) imperfections in the measurement of effectiveness; (2) misuse of equipment (improper fit, improper use, etc.);

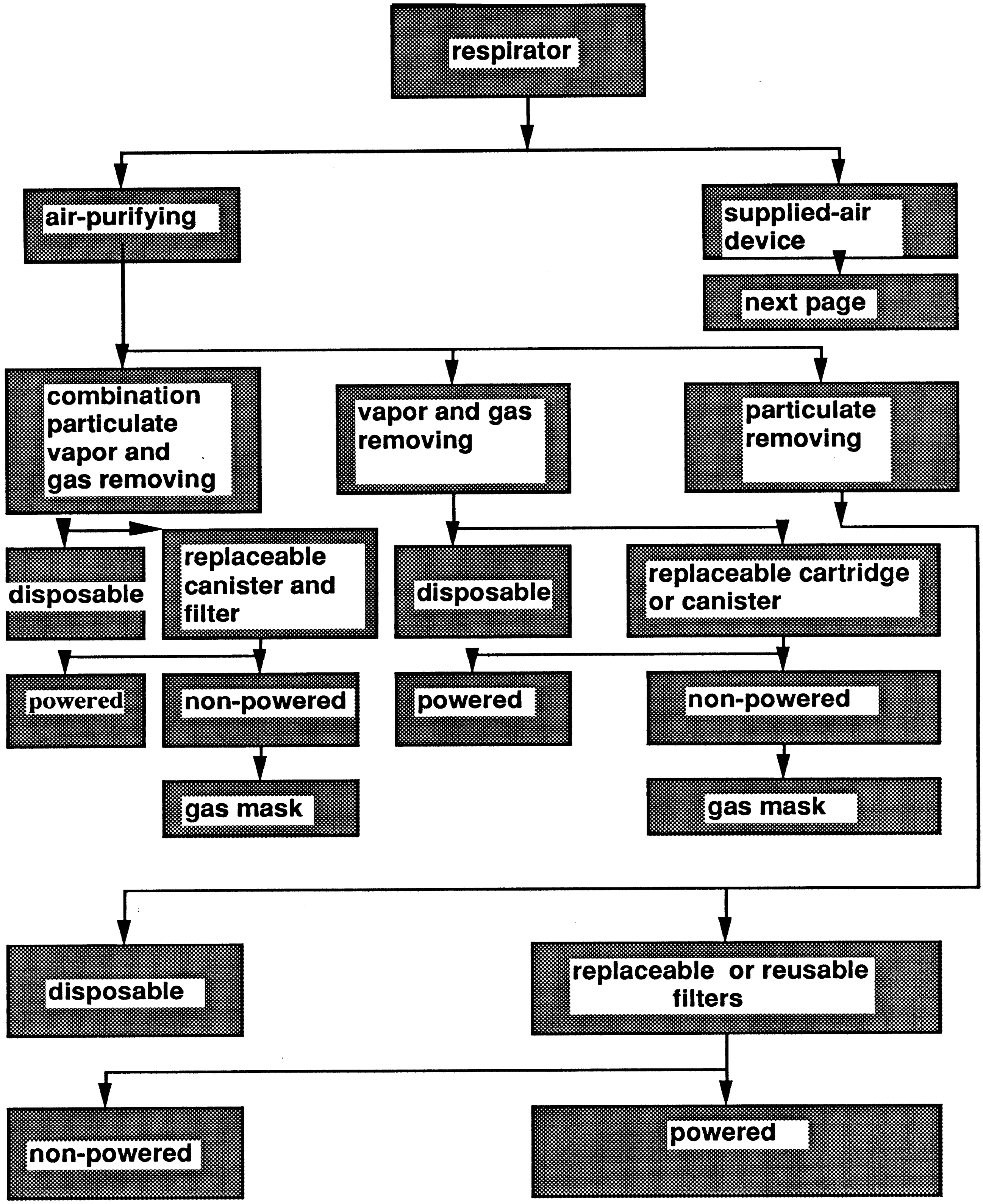


**Figure 1**. Classification and subclasses of respirators.

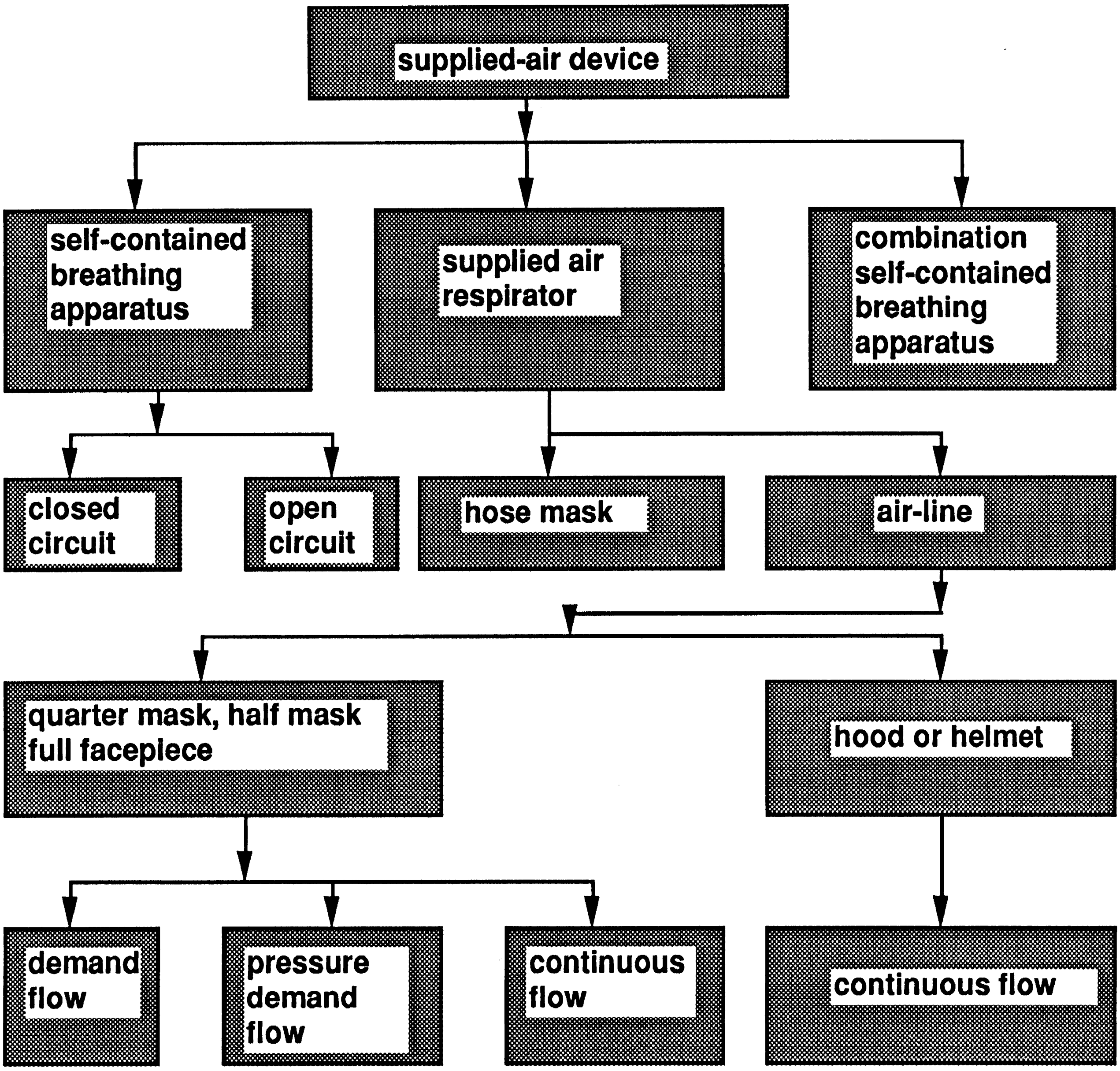


**Figure 2**. Classification and subclasses of respirators.

(3) injuries arising from the unequal response of individuals to given exposure doses; and (4) difficulty in assessing the value of injuries that might occur.

The method developed in this study is designed to take into account the probability of injury due to exposure to different levels of contaminants resulting from respirator or LEV system ineffectiveness. The minimum "effectiveness rating" for respiratory protection equipment allowed under OSHA regulations is 80%. For The purposes of this study, the range of effectiveness rating was limited to 80-99.5% to accommodate OSHA regulations while still maintaining economic feasibility (e.g. very highly effective and costly equipment were not considered). The effectiveness ratings in column 1, Table 1, were selected, and the penetration rates are calculated by using formula 1-(effectiveness rating). In practice, the values of respiratory penetration rates can be estimated from workplace protection factor studies, quantitative fit testing or laboratory bench testing. Using these estimates of penetration, the effectiveness rating of each respirator can be calculated. The penetration rates are multiplied by an arbitrary safety factor of 5 in order to represent worst case exposure, and the resulting values are tabulated in column 3. The "probability of injury" values are determined using a dose response relationship curve. The model is designed to accept "Cost of injury" values which vary with the level of exposure and the resulting severity of the injury. However, due to the lack of itemized cost data for varying exposure rates, the average cost of injury in each of three cases studied is used to represent the "Cost of injury" in this analysis. The average costs for different types of respiratory diseases are tabulated in Table 2, information provided by the State of New York WCB [6]. The expected cost of injury is the product of the cost of injury and probability of injury. These values are implemented in the model under variable costs of using the respirator equipment or LEV systems.

## 3. ECONOMIC MODEL

The first step in describing an economic model is to divide the object of interest into the components that must be used, consumed or replaced during the life of the product, as well as the cost components associated with the risk of equipment failure and resulting injury. This process fundamentally illustrates the steps necessary to study a given product for cost breakdown. The disposable respirator cost component flow sheet shown in Figure 3 provides a clear conceptualization of the costs occured during a year's use of a disposable respirator in a Respiratory protection Equipment Program (RPEP). The cost breakdown flow sheet provides a clear visualization of the detailed components of the (RPEP) which are required in order for the RPEP to exist and function over time. The spreadsheet is divided into sections which include:

1. Cost of purchasing the product.
2. Input factors (such as how many times a certain component needs be replaced) in an "Established Service Life of the Product".
3. Costs associated with training, fit testing, and medical check-ups.
4. A framework to estimate the probabilistic cost of injury and mortality with respect to the use of a specific brand of respirator or LEV system.

This segmentation is used to clearly define which variables are exogenous and which are endogenous to the model. Figure 3 is an example of a disposable, air-purifying respirator cost breakdown format, which illustrates part of the spreadsheet cost model.

The technical cost modeling method uses an approach in which each of the elements that contributes to the total annual cost is estimated individually. These individual estimates are derived from a study of a particular respirator or LEV system and from clearly defined and verifiable economic assumptions. The technical cost approach reduces the complex problem of cost analysis to a series of simpler estimating problems and brings engineering expertise, rather than intuition, to bear on solving these problems. In dividing cost into its

**TABLE 1. The Risk Assessment for Various Exposure Rates.**

| Effectiveness rating | Penetration rate | Safety factor penetration rate times (5) | Probability of injury | Cost of injury ($) | Expected cost of injury ($) |
|---|---|---|---|---|---|
| 99.5% | 0.005 | 0.025 | p1 | (x1) | p1(x1) |
| 99% | 0.010 | 0.050 | p2 | (x2) | p2(x2) |
| 98% | 0.020 | 0.100 | p3 | (x3) | p3(x3) |
| 97% | 0.030 | 0.150 | p4 | (x4) | p4(x4) |
| 96% | 0.040 | 0.200 | p5 | (x5) | p5(x5) |
| 95% | 0.050 | 0.250 | p6 | (x6) | p6(x6) |
| 94% | 0.060 | 0.300 | p7 | (x7) | p7(x7) |
| 93% | 0.070 | 0.350 | p8 | (x8) | p8(x8) |
| 92% | 0.080 | 0.400 | p9 | (x9) | p9(x9) |
| 91% | 0.090 | 0.450 | p10 | (x10) | p10(x10) |
| 90% | 0.100 | 0.500 | p11 | (x11) | p11(x11) |
| 89% | 0.110 | 0.550 | p12 | (x12) | p12(x12) |
| 88% | 0.120 | 0.600 | p13 | (x13) | p13(x13) |
| 87% | 0.130 | 0.650 | p14 | (x14) | p14(x14) |
| 86% | 0.140 | 0.700 | p15 | (x15) | p15(x15) |
| 85% | 0.150 | 0.750 | p16 | (x16) | p16(x16) |
| 84% | 0.160 | 0.800 | p17 | (x17) | p17(x17) |
| 83% | 0.170 | 0.850 | p18 | (x18) | p18(x18) |
| 82% | 0.180 | 0.900 | p19 | (x19) | p19(x19) |
| 81% | 0.190 | 0.950 | p20 | (x20) | p20(x20) |
| 80% | 0.200 | 1.000 | p21 | (x21) | p21(x21) |

* : For numerical values refer to Table 2.
1: probability of prevalence of a particular disease with respect to exposure level.

**TABLE 2. Occupational Diseases and Their Average Cost (1988).**

| Occupational disease | Number of cases | Compensation average amount per case ($) |
|---|---|---|
| All ocoupational diseases | 1.801 | 16.258 |
| Dupuytren.s contractor | 7 | 14.061 |
| Gengllons. Cysts | 34 | 3,495 |
| Effect if changes in | | |
| Atmospheric Pressure | 5 | 32,698 |
| Aero-otitis Media | 2 | 69,420 |
| Compressed air illness | 3 | 8,214 |
| | | |
| Miners Diseases | 2 | 8,214 |
| Respiratory system conditions | 55 | 52,389 |
| Upper Respiratory | 8 | 61,138 |
| Lower Respiratory | 41 | 47,071 |
| Respiratory system conditions | | |
| (Nontoxic). Uns. | 6 | 77,065 |
| | | |
| Pneumoconiosis | 110 | 95,850 |
| Aluminosis | 1 | 198,960 |
| Asbestosis | 37 | 92,767 |
| Siderosis | 1 | 50,681 |
| Silicosis | 44 | 110,751 |
| Berylliosis.N.E.C | 1 | 98,889 |
| Pneumoncooniosis with | | |

Source : State of New York Workers Compensation Board [11].

Disposable air-purifying particulate-removing respirator cost breakdown layout

Respirator Manufacturer (MFG) :
Respirator Purchase cost per unit ($)

**SERVICE LIFE COST**

. User estimated respirator useful life (hrs)
. Number of hours respirator used per day (hrs./day)
. Number of days respirator used per week (days/week)
*Number of hours respirator used per year (hrs/year)
*Number of respirators required per year (number)
* Annual respirator purchase cost ($)

**TRAINING COST**

.Personnel cost for training ($)
.Training equipment cost ($)
*Annual estimated respirator training cost ($)
.Respiratory protection equipment program administrator's cost ($)

**FIT TESTING COST**

.Fit test equipment cost ($)
.Fit test material cost ($)
.Fit test personnel cost ($)
.Annual respirator estimated fit testing cost ($)

**MEDICAL CHECK UP COST**

.Number of medical check-ups per year (number)
.Cost for each medical check-up ($)
*Annual medical check-up cost ($)

**RISK ASSESSMENT COST**

.Respirator probability of ineffectiveness from (Table 2.2) is:
.Cost of injury due to respirator ineffectiveness ($)
*Annual respirator ineffectiveness expected cost ($)

**FURTHER ANALYSIS**

.....................................
.....................................
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.....................................
*Annual cost of further analysis ($)

TOTAL ANNUAL OPERATING COST OF MODEL $
INVESTED CAPITAL $

**Figure 3**. Illustration of cost model layout for (DPRAPR) model.
(*) Values generated as output of the model (endogenous). (.) Input parameters (exogenous).

contributing elements, a distinction is made between cost elements that depend upon the number of components replaced annually, and those that do not in most instances, some components of respirators are not replaced instead, they are used until they are unreliable to perform in a given contaminated environment. Such an example is the air-purifying element of positive types of air-purifying respirators. Models similar to Figure 3 will be developed to conduct economic analysis for different types of supplied-air device respirators. This procedure will continue for different classes of air-purifying respirators to determine the costs for their different types. Also, a similar analysis will be conducted for the local exhaust ventilation system. Finally, each class of respirator costs will be compared to the costs of a local exhaust ventilation system. The economic savings due to the use of the cost optimal alternative will be given. The inputs for the model are by no means fixed. Due to the user interactive nature of the model, prices can be varied and the entire spreadsheet can be recalculated if a different value is used for example, a filter may be available in two grades with different prices. The user has the option of calculating the costs associated with one price, and then recalculating them using the other price.

### 3.1 Model Overview

The preceding sections have outlined the underlying principles of technical cost analysis, and should not be considered a complete picture of cost modeling The Key principles of technical cost analysis follow:

1. The costs associated with specific respirators are listed under unified section headings such as "Replaceable Components Cost," "Fit Testing Cost," "Training Cost", "Medical Check up Cost," and "Associated Risk Cost" in all RPEP cost models.
2. The total cost of a particular model is made up of many contributing elements that can be classified under unified classes in all respiratory protection or LEV system cost models.
3. Each cost element under the unified classes can be analyzed further to establish the cost factors and the nature of the relationships that effect its values in the model.
4. The total cost for each model can be estimated from the sum of the unified section outputs. A detailed explanation will be provided later in this paper.

One advantage of the approach to cost modeling described on the preceding page is that it not only provides estimates of the total cost, but also it provides a breakdown of the cost of each contributing element including the expected cost of injury due to respirator or LEV system ineffectiveness. This information can be used for cost reduction, or it can be used to perform sensitivity analysis.

One disadvantage of this approach is that it is time consuming to generate cost estimates in this manner, and the complexity of generating these estimates can lead to mistakes. While developing a computer program for performing elemental cost analysis is still time consuming and complicated, once the program is developed, it can be used to generate the estimates both rapidly and accurately.

The author has developed macro-driven computer programs for estimating the usage costs of nineteen respirators and one local exhaust ventilation system. The models are developed for commonly used respirators in two major classes: air-purifying respirators and supplied air-respirators. The air-puritying respirator cost models are developed under three classes: Particulate Removing (PR), Vapor and Gas Removing (VGR), and Combination Particulate Vapor and Gas (CPVG).

Particulate Removing (PR) respirator cost models are developed for disposable respirators and for replaceable or reusable PR filters. The replaceable or reusable PR filter cost models are implemented. for non-powered and powered versions.

Vapor and Gas Removing (VGR) respirator cost models are developed and implemented for disposable VGR respirators, replaceable VGR cartridges or VGR canister types.

Replaceable VGR cartridge or canister type cost models are further configured as powered or non-powered versions. The non-powered version cost model is further classified as a gas mask respirator.

Combination Particulate Vapor and Gas (CPVG) respirator cost models are designed for CPVG disposable and CPVG canisters and filters. Replaceable CPVG canister and filter cost models are further developed for power and non-powered version. Under this class of respirators, the non-powered version includes the gas mask respirator.

Supplied-air respirators are manufactured in three classes: Supplied-Air Respirators (SAR), Self-Contained Breathing Apparatus (SCBA), and Combination Self Contained Breathing Apparatus (SAR/SCBA). Supplied Air Respirators are further classified as hose mask and air-lines. Self-contained breathing apparatus are classified as closed circuit and open circuit.

The aim of this work is to use the developed models for real world applications; therefore, in the SAR category the cost models are developed for those respirator classes which are routinely used, such as the air-line respirator class. Air-line respirator class cost models are developed for demand flow, pressure demand flow, and continuous flow. This model is further extended for hood/helmet type continuous flow respirators. Figure 4 illustrates the portion of the cost models menus which is used as a control mechanism for selecting the desired models for analysis.

**3.2 Model Inputs** The inputs to the respirator models form the basis for the cost estimation, the economic environment, and the technical nature of the respiratory equipment modeling process. the values for these inputs are either provied by the product manufacturer or by the industry. Each parameter can reasonably be expected to vary within a certain range; however, the default values provide average general accuracy. The input parameters define the cost of using a particular respirator. The procedure for estimating cost can be reduced to estimating these parameters. If they are estimated accurately, so will the cost of the components be.

**3.3 Results and Conclusions** The cost model for a Respiratory Protection Equipment Program (RPEP) and a LEV system was developed. The cost of these models is divided into two categories, variable costs and fixed costs. Each of these categories is the sum of the cost element(s) for which the cost is estimated or provided by the manufacturer. The final output data are arranged in tabular format for each brand and type of respirator and the LEV system for decision making purpose.

The input data used in the following case studies are either taken from the product manufacture's recently published price list or obtained from local manufactures. In some situations due to unavailability of data, the inputs were estimated and for the validity of estimated data, the appropriate experts were consulted. Despite all efforts to provide accurate data to support the validity of the developed model, one hundred percent accuracy could not be achieved. For example, in

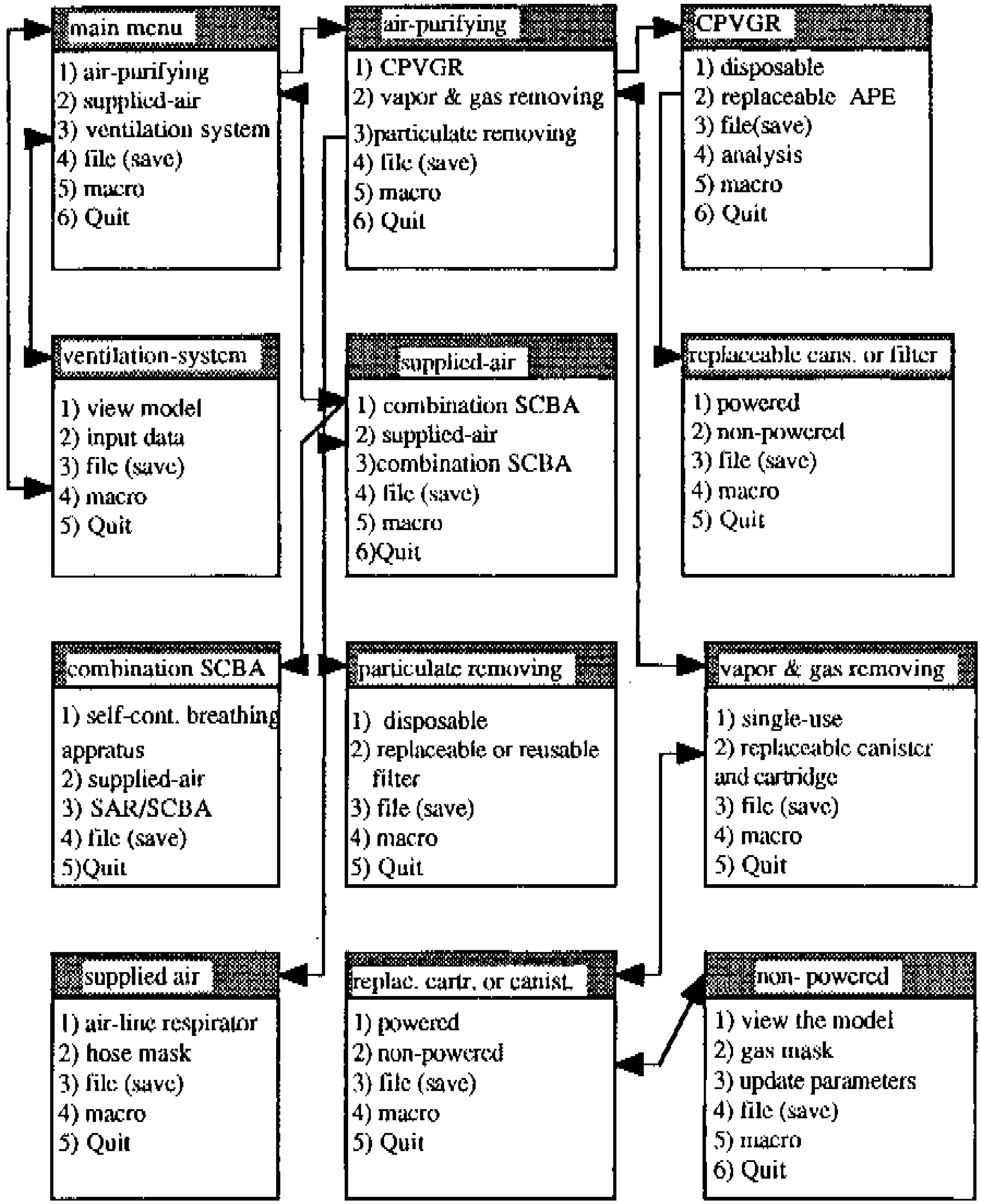


**Figure 4**. Illustration of part of the cost model menus.

the case of the useful life of the replaceable respirator facepiece, which assumed to be one thousand working hours, this assumptions could not be completely accurate for all workplace condition since the dependency of this component on the specific workplace condition could lead to variations in the useful life of that component.

In this study, the emphasis is on the methodology and its completeness in capturing the costs of the acquisition, use, and quantification of the risks of personal injury due to the use of respiratory equipments and LEV system ineffectiveness. The accuracy of the models' outputs totally depends on the user's experience in providing reliable input data.

The annual cost saving per employee due to the use of a less expensive system either LEV or respirator, is determined. This value indicates that the largest savings in annual cost per employee is achieved with use of the LEV system for VGR contaminant control.

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