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16. ABSTRACT The report discusses an EPA investigation of techniques to improve methods for estimating volatile organic compound (VOC) emissions from area sources. Using the automobile refinishing industry for a detailed area source case study, an emission estimation method is being developed that uses advanced computational techniques and updated, comprehensive, emissions-related information. New computational techniques contributing to the estimation method are fuzzy logic, neural networks, and genetic algorithms. This method development requires a thorough characterization of the area sources, an analysis of current emission estimation methods, the development and execution of a nationwide industry activity survey, and a compilation and analysis of the survey results and other explanatory variables. Results will be captured in a personal-computer-based emissions estimation system called VOCEES (VOC Emissions Estimation System). VOCEES has been developed as a dual-use tool that prepares VOC emissions inventories and analyzes the impact of many factors on emissions. This methodology can be easily extended to other area sources.

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| Emission | Volatility | Stationary Sources | 14G | 20M |
| Estimating | Painting | Computational Intelligence | | 13H |
| Artificial Intelligence | Automobiles | | | 13F |
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# FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

## Abstract

The Environmental Protection Agency is investigating techniques to improve methods for estimating volatile organic compound (VOC) emissions from area sources. Using the automobile refinishing industry for a detailed area source case study, an emission estimation method is being developed that uses advanced computational techniques and updated, comprehensive, emissions-related information. New computational techniques contributing to the estimation method are fuzzy logic, neural networks, and genetic algorithms. This method development requires a thorough characterization of the area sources, an analysis of current emission estimation methods, the development and execution of a nationwide industry activity survey, and a compilation and analysis of the survey results and other explanatory variables. Results will be captured in a personal-computer-based emissions estimation system called VOCEES (VOC Emissions Estimation System). VOCEES has been developed as a dual-use tool that prepares VOC emissions inventories and analyzes the impact of numerous factors on emissions. This methodology can easily be extended to other area sources.

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Sincere thanks are extended to P. Jeff Chappell, Project Officer, EPA/AEERL, who conceived and directed the methodology development using computational intelligence, inferential techniques, and a new broad set of continuously updated databases.

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# 1. INTRODUCTION

Under the 1990 Clean Air Act Amendments, state air pollution control agencies are required to prepare and maintain emission inventories for carbon monoxide (CO) and precursors to ozone ($O_3$). Ozone is photochemically produced in the atmosphere when volatile organic compounds (VOCs) are mixed with CO and oxides of nitrogen ($NO_x$) in the presence of sunlight. The role of the emission inventory is to identify the types of emission sources present in an area, the amount of each pollutant emitted by each type of source, and any emission control devices being employed. In developing these inventories, the state agencies may either use emission estimation methods endorsed and provided by the U.S. Environmental Protection Agency (EPA) or their own methods. New methods of estimation are sought which will be more accurate, efficient, and cost effective than current methods. Results of this work will either validate existing area source emission estimation methods or recommend improved methods. The EPA Air and Energy Engineering Research Laboratory (AEERL) has directed this research effort.

Stationary sources of pollutant emissions are designated as either point sources or area sources. Whereas point sources are inventoried on an individual basis, area sources are processes, activities, or businesses that are too small or too numerous to be practically tracked as individual emission sources. The distinction between point and area sources is an annual emissions threshold, such as 10 tons (907 kg) of volatile organic compounds (VOCs) per year per source.

The required components of an emission estimation methodology are: (1) calculation of the emission estimates; (2) temporal and spatial allocation of the emissions; (3) validation of the emission estimates, and (4) speciation of the emissions. This project concentrates on the first three components. Tools are available from EPA that can be used to develop a VOC inventory grouped into reactivity classes suitable for modeling (VOC/PM, 1990). The criteria established for this research effort include: reasonable accuracy and cost; dynamic and robust behavior; use of readily available information; and ease of use.

There are two primary reasons to improve existing emission estimation methods: (1) the current emission estimation methods require further development to improve accuracy and ease of use; and (2) innovative tools have emerged which may contribute significantly to improving estimation methods. Among the issues and uncertainties are:

- Most solvents used by any one solvent area source category are also used by other industries. This prevents use of solvent manufacturer production figures alone for estimating emissions from one solvent source category.

- There are many very different solvent area sources categories. Therefore, reasonably accurate emission estimates require area source category-specific estimation methods.
- Current methods endorse the use of data sources whose published data are from 2 to 5 years old and may misrepresent a significant segment of the area source industry. Federal information derived from business payroll records often provides no record of very small businesses. Also, data at the county level for certain Standard Industrial Classification (SIC) codes are often not disclosed.
- Current methods do not consider the dynamic factors that impact area sources such as local economics, changing technology, and regulatory influence. Nor do they consider human behavior and consumption patterns.

New technologies, such as innovative computational techniques, offer the opportunity to improve existing methods. This project investigates the appropriateness of applying advanced, inference-based computational intelligence techniques, such as neural networks, fuzzy logic, and genetic algorithms, to emissions estimation. These techniques make it possible to determine and use relationships between two domains (*e.g.*, industry variables and emission levels), and to augment or supplant traditional mathematical models. Also, since all emissions have a geographic component in that each emission has a source, it is helpful to capture and represent emissions-related data using a geographic information system (GIS).

This research is based on three essential directives to ensure an innovative and improved emission estimation method. The directives are:

1) Focus
The research concentrates on a case study of a single area source, automobile refinishing, in order to demonstrate the feasibility of developing an improved method for deriving VOC emission estimates from area sources. Automobile refinishing was chosen as representative of VOC emitting sources based on three criteria: relative environmental significance, national prevalence, and an accessible information base representative of such sources. The new method of source evaluation and emission estimation can be extended to many other area sources.

2) Product Development
The project goal is to produce a prototype, personal computer-based, user-interactive system and database that allows a novice, personal computer (PC) user to estimate VOC emissions from automobile refinishing at the county level, anywhere in the United States. MapInfo, Inc.'s *MapInfo* software has been used as both the interface and database management system. *MapInfo*'s

generic interface was customized using *MapBasic*, a BASIC language compiler, to provide an interface specific to emissions estimation.

3) Innovation and Improvement

The project plan incorporates several new or expanded features for emissions estimation. These are listed in Table 1-1.

**Table 1-1. Project Initiatives for New Method Development**

| INITIATIVE | DESCRIPTION |
|---|---|
| **Annual updating** | The method will use information and logic that is continuously reviewed and revised. |
| **Improved validation** | New validation activities include: (a) preparation of the most thorough nationwide survey of the automobile refinishing industry (*i.e.*, auto refinishing shops) to date. The survey will obtain industry answers about activity levels (*e.g.*, number and types of employees or repair jobs), solvent usage, and emission control. In addition, extensive product distribution data have been requested from all major automotive paint manufacturers; (b) selective sampling and chemical analysis of local sources has been designed to establish actual mass rates of shop emissions; and (c) literature review and consulting with experts to provide new insight into major influences on emissions. |
| **Intensive area source characterization** | Characterization includes main industry variables influencing emission levels. In addition to the national survey, the research team has held meetings with shop managers and industry consultants, attended national conferences, contacted associations, and analyzed the literature. |
| **More extensive data** | Data analysis will extend down to the county level. Data from federal and state agencies, trade associations, and industry sources have significantly increased the EPA information base related to this area source. |
| **Improved data recovery and structuring** | One result is a systematic and efficient approach for using information, emphasizing data sources which are regularly updated (*e.g.*, annually) and which are readily accessible at minimal cost to EPA and state agencies. |
| **Improved data correlations** | This involves applying statistics, for prescreening of the best data relationships. |
| **Application of imprecise information and expert opinion** | Such "artificial intelligence" techniques as fuzzy logic, genetic algorithms, and rule-based expert systems can augment the use of pertinent information which had been neglected to this point. |
| **Regulatory policy consideration** | The method incorporates regulatory influence on emissions at local, state and national levels. |
| **Alternate methods review** | Methods (used by States) other than the standard EPA guidelines and emission factors have been examined. |

## 2. COMPLETED METHOD DEVELOPMENT PROCESS

The area source emissions estimation method development process involves:

1) area source characterization, examining materials balances, process operations and controls, and economic influences,
2) review of current emissions estimation methods,
3) database development, including retrieval and screening of the best accessible data correlating with area source characteristics and emissions,
4) selection of analytical methods (the "tool set"), for calculating or inferring final emissions levels and their distributions,
5) system configuration for data input computation and reporting, and
6) validation of results (for this case study, emphasizing a national survey of automobile refinishing shops).

These main elements are necessary for essentially all area source emissions estimation improvements, although specific techniques can vary. Steps 1) and 2) are essentially complete, steps 3) to 5) are near completion, and a plan for step 6) (covered in Section 3) is complete. The completed portions of the method development are discussed in the following.

## 2.1 Area Source Characterization

A detailed characterization of the automobile refinishing industry was conducted in order to fully consider the issues and variables associated with the industry's VOC emissions. Table 2-1 lists some of the contacts and companies which make up this $23 billion per year industry.

**Table 2-1. Contacts, Organizations, and Information Sources for the Automobile Refinishing Industry.**

| Data Sources | Examples |
|---|---|
| Organizations | National Paint and Coatings Association (NPCA), Automotive Service Association (ASA), Automotive Service Industry Association (ASIA), Inter-Industry Conference on Auto Collision Repair (I-CAR), Society of Collision Repair Specialists (SCRS), Motor & Equipment Manufacturers Association (MEMA) |
| Paint Manufacturers | BASF, E.I. DuPont de Nemours & Co., Nason Automotive Finishes, PPG Industries, The Sherwin-Williams Co., Sikkens/AKZO Coatings, ICI Autocolor, American Standox, Inc., and Spies Hecher, Inc. |
| Associated Industries | Binks Manufacturing Company, Herkules Equipment Corporation, Safety-Kleen Corporation, 3M Automotive Trades Division |
| Publications | I-CAR Technical Manuals, Mitchell Manuals, Chilton's Manuals, Body Shop Business, Body Shop Tool & Equipment News, Automotive Body Repair News, Motor, and local trade publications (*e.g.*, Hammer and Dolly, Midwest Autobody Magazine, Alabama Automotive Business) |
| Body Shops | An estimated 65,000 shops in 1993. A nationwide survey of 5900 body shops has been proposed to obtain data for both method development and validation. |
| Consultants | CCC Information Services, CARSTAR Automotive, Inc., AutoChex, Inc., Mitchell-ADP Xchange (MAX), and individual industry consultants |
| Conference | Attended 1992 National Autobody Congress and Exposition (NACE). At NACE, numerous contacts were made with industry representatives and consultants. NACE also provided a more complete understanding of the scope and magnitude of the industry. |

According to industry representatives, the impact of technological and regulatory changes, along with economic factors, has provoked a steady decrease in the number of body shops nationwide over the past twenty years. While there may have been as many as 125,000 body shops in 1975 (Athey, 1988), there are presently estimated to be 63,000 body shops in operation. Compared with an estimated 83,000 (Athey, 1988) shops in 1988, and including estimates from industry experts that there will be half that number by 1997 (and only 25,000 by the year 2000), a nearly linear decrease in body shops with time is projected, as shown in Figure 2-1.

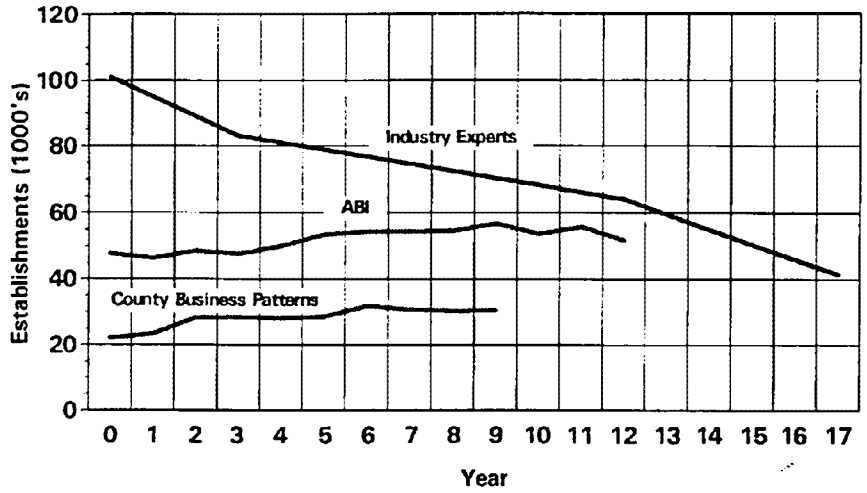


**Figure 2-1. National Trends in the Number of Body Shops**

However, Figure 2-1 also shows that numbers from County Business Patterns from 1975 to 1989 (County, Annual) contradict the drastic drop-off over the past 17 years. While EPA recommends using County Business Patterns for making emissions estimates, industry estimates seem more realistic. Data obtained from American Business Information (ABI) computer files shows a nearly flat growth trend from 1981 to 1993, but agrees much more closely with industry experts on the current number of shops.

Several trends drive the market. For example, although the number of U.S. cars on the road increases each year (growing well ahead of the population curve), that growth is not reflected in the number of accidents that take place because of improved vehicle safety and more stringent enforcement of traffic laws (*e.g.*, against drunk driving). Manufacturers' finishes have also become more corrosion resistant. More efficient paint spray guns mean less paint is wasted, again lowering consumption per paint job. Overall, these opposing changes have tended to stagnate the volume of refinishing over the past decade. As cars become smaller, there is less surface area to paint per accident, which lowers paint consumption. Such trends have tended to stagnate the volume of refinishing over the past decade.

Beyond the number of body shops which can be captured through industry surveys, County Business Patterns, and the Yellow Pages as represented by ABI, there exist many unlicensed "backyard" shops. Industry experts estimate that the number of these shops has grown as increased regulatory costs and economic conditions have reduced the number of licensed body shops. Estimates indicate that these shops may represent an additional 25-40% more body shops than the number which are on record. These "unseen shops" are potentially a large source of VOC emissions since their control technology is more likely to be primitive and

they are more likely to disregard laws and regulations. Figure 2-2 shows the preponderance (45%) of shops employing only 1-2 people.

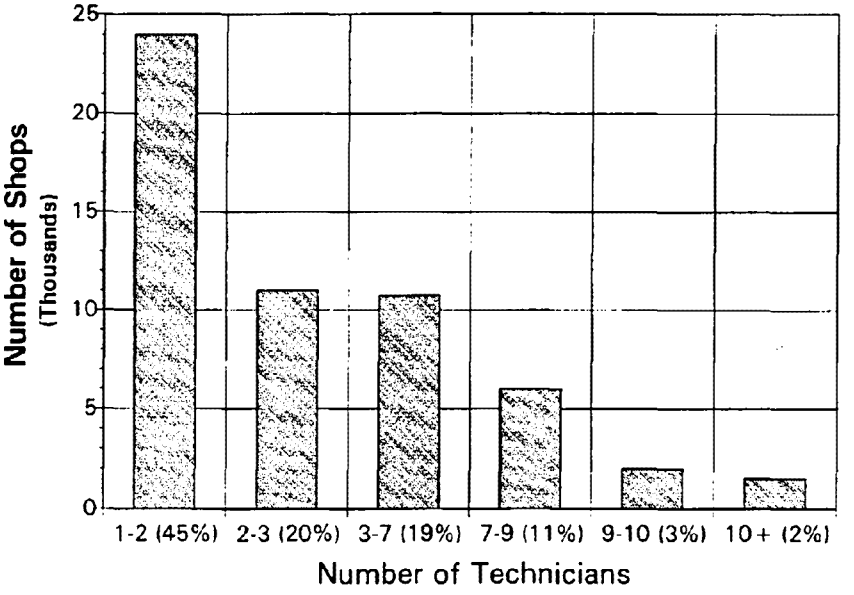


**Figure 2-2. Body Shop Size Distribution by Number of Employees**

### 2.1.1 Refinishing Procedures

While there may be minor differences from shop to shop, the procedure for refinishing an automobile can usually be thought of as a four-step process. These four steps are: 1) vehicle preparation, 2) vehicle priming, 3) topcoat application, and 4) equipment cleanup. The vehicle preparation consists of cleaning followed by a solvent-based compound to remove grease, wax, and other contaminants. These compounds are usually made entirely of VOC's and contain solvents such as toluene and xylene.

Priming creates and makes up for deficiencies in the present finish or the underlying surface. Materials used include primer-surfacers (nitrocellulose lacquer, acrylic lacquer, and alkyd enamel). Solvents are prevalent in topcoats because of the need to properly blend a repair with the surrounding finish (blending requires the application of successively thinner coats, and more solvents). The materials used in topcoats can be divided into lacquers, enamels, and polyurethanes. Their relative usage in today's market is 34%, 54%, and 12%, respectively.

When cars are manufactured, the paint is applied by machine and baked in an oven. This is a relatively simple process since the car is essentially a metal frame

at the time. This process has enabled manufacturers to use more polyurethanes because cyanates in the polyurethane are not a direct hazard to employees. Auto refinishers, however, cannot use high temperatures to cure their finishes since this would ruin the interiors, plastic, and electronics present. They must use different materials and techniques from the manufacturers while reproducing the same finish. Drying time becomes important to a refinisher because shorter drying times reduce contamination from dust and dirt and more cars can be finished in a given time. Drying time is even more important for metallic paints.

According to the National Paint and Coatings Association (Connolly, 1990), over 36 million gallons of coatings (topcoats and primers) were sold in the U.S. in 1989. That number has remained basically constant over the past ten years. Coatings can generally be categorized as two major types: solvent-based coatings (which contain VOCs), and water-borne coatings.

*Solvent-Based Coatings*

Solvent-based coatings are by far the most common in automobile refinishing. These coatings can be divided into groups that cure by three different methods: crosslinking (two-component epoxies and urethanes, and baked acrylic and alkyd enamels), noncrosslinking (thermoplastic acrylics and vinyls, and cellulosic lacquers), and drying (some alkyds) (Connolly, 1990).

Solvent-based materials can also be divided into lacquers, enamels, and urethanes. Lacquers were the first materials used for automotive refinishing. Lacquer paints rely completely on solvent evaporation to transfer pigments and therefore are have high solvent and VOC content. They are usually based on acrylic resins and, in some cases, acrylics modified with nitrocellulose. Enamel use by manufacturers began in the 1950's and by the refinishing industry in the 1960's. Enamels can be divided further into two categories, acrylic enamels and alkyd enamels, which provide different appearance and durability characteristics. Enamels still rely predominantly on solvent evaporation to provide pigment transfer and adhesion, but also use chemical linkages formed during the curing process. Since they rely less on solvent evaporation, they usually contain less VOCs than lacquers. Urethanes are the newest materials used by automotive refinishers. They rely more on chemical processes to form the bonds necessary for adhesion and therefore potentially contain less VOCs than either lacquers or enamels. While this makes them more attractive environmentally, they also contain isocyanates which are potentially hazardous to the people applying the coatings.

*Water-Borne Coatings*

Water-borne coatings can be divided into four groups: emulsions, latexes, water solubles, and colloidal dispersions (Connolly, 1990). In emulsions and latexes, the principal film resin is in a fully polymerized state and is suspended in the water by the addition of a dispersing agent. These polymers are made by emulsion polymerization. The resins used in water soluble and colloidal dispersions systems have relatively low molecular weights and undergo further cross linking or polymerizations during the curing stage. This category includes all electrocoat systems.

Water-borne coatings are only now becoming popular in the refinishing industry. While car manufacturers have used them for years as undercoats and primers, their long drying times have precluded their use by refinishers. Advances in technology still have not been able to provide a suitable topcoat formulation which will replace conventional topcoats in the near future.

*Future Trends*

Automobile original equipment manufacturers (OEMs), dictate the changes in styling demands, increases in finish durability, and new multi-component substrates. New paint styling will come in the form of specialty pigments and the use of colored aluminum and colored micas in paint formulations. OEMs are beginning to use tinted clearcoats, more tricoats, and super-smooth clearcoats that the refinishers must be prepared to match. Increased corrosion resistance will come through improvements in electro-deposition. Resistance to environmental deposits will come through the use of fluorinated clearcoats (which, since they are so durable and long-lasting, present a problem of proper disposal). There will also be improvements made in resistance to sunlight (UV stability). Expanding use of treated steel and advanced alloys, aluminum, plastics, and composites means most refinishers must address the proper coating of plastics and composites (plastics are especially sensitive to solvents, which break down their chemical structure).

The consequences of the changes which are taking place will be seen in four areas: 1) larger shops will be necessary to maintain profitability and keep pace with technology, 2) coatings will carry a higher apparent cost because of their chemical makeup, 3) new finishes will become more and more durable, and 4) more training will be necessary to keep up with advances and changes.

### 2.1.2 Environmental Concerns and Controls

Refinishing regulation and industrial controls can be divided into two components -- environment and health. Environmental regulations primarily concern volatile organic compounds (VOCs). Most regulations require the

reduction of VOCs through either the use of reduced VOC coatings or the control of vent emissions. While automobiles themselves are the largest source of VOCs, the refinishing of these autos accounts for only 3% of VOC emissions. The three main approaches to control are 1) use of lower-VOC coatings, 2) use of enclosed cleaning devices, and 3) increase of paint (to surface) transfer efficiency. There is also a movement to require licenses to purchase coatings. This movement is intended to allow coatings only to be sold to "legitimate" body shops and not non-compliant, "backyard" shops.

Paint manufacturers have met some State requirements through the development of low-VOC coatings and waterborne coatings. Low-VOC coatings have forced the industry away from lacquer and enamel coatings and toward urethanes.

Typical VOC contents range from 4.8 lbs/gal for acrylic urethanes to 6.8 lbs/gal for acrylic lacquers. New laws in Southern California in 1995 will limit topcoat VOCs to 3.5 lb/gal, primer/surfacer VOCs to 2.1 lb/gal, primer/sealers to 3.5 lb/gal, and basecoat/clearcoat combinations to 4.5 lb/gal and less. Ultimately these regulations will require primers with 2.1 lb VOC/gal and basecoat/clearcoats with 3.5 lb VOC/gal. For the primers, this means the industry will be turning towards water-borne products and some very-high-solids solvent-based products. Basecoats will also became water-borne, while clearcoats will consist of water-borne and 2-pack urethanes. Binders used in these products will move towards resins (isocyanates in particular) trapped in a water thinner.

The move to low-VOC coatings will result in 1) better application conditions (*i.e.*, better airflow, better temperature control), 2) improved curing techniques (*i.e.*, use of downdraft booths and infrared heaters), 3) more training for painters and jobbers, and 4) reductions in VOCs through increased paint transfer efficiency (TE) from spray gun to car surface. While conventional spray guns have TEs of 25-50%, high TE guns are in the 50-75% range. Most high TE guns are high volume, low pressure (HVLP) guns. While first generation HVLP guns generally gave poor performance, current models produce acceptable results.

Equipment cleaning is a significant contributor of VOC emissions. An increasing number of body shops use special cleaning stations to remove coatings from their spray guns and to allow reuse of solvents in cleaning, lowering emissions.

Another method of reducing VOC emissions is the addition of control technology on paint spray booths. The main purpose of a spray booth is to provide a safe and clean environment, and is not necessarily to trap emissions. Booth exhaust fumes can be controlled by 1) thermal incineration, 2) catalytic incineration, and 3) carbon adsorption. Thermal incineration co-fires a fuel with the exhaust from the

booth stacks to destroy VOCs. Destruction efficiency is limited only by the cost of fuel. Catalytic incineration uses a catalyst to create the oxidation reaction at a lower temperature than thermal incineration (approximately 900 °F compared to 1800 °F) and has a destruction efficiency nearly as high with much less fuel. In carbon adsorption, the exhaust stream is passed through an activated carbon bed where the carbon particles adsorb VOCs. Care must be taken to properly maintain the bed and prevent saturation.

Besides the controls described, other body shop operations can be better managed to reduce emissions. For example, control techniques include tight fitting containers, reducing spills, rigid inventory control, tracking worker use rates, mixing paint to need, providing operator training, proper cleanup methods, and solvent recycling with in-house equipment or by lease agreements.

Health issues are a major concern within the industry. Isocyanates are quite hazardous when improperly handled. At the Saturn automobile manufacturing facility, for example, when urethane coatings are being applied, workers are not allowed to enter the paint booths. If they do enter, the paint machines automatically shut down. In addition to isocyanates, heavy metals such as lead and chromate are being phased out. Some sacrifices have been made, especially in coating corrosion resistance. Manufacturers are not barred from putting most compounds in paints (they only need to label them properly), but mainly provide their own motivation for excluding hazardous materials.

## 2.2 Review of Current Estimation Methods

Most EPA-endorsed methods for estimating solvent emissions from area sources have been derived from a methodology developed as part of the National Emissions Data System (NEDS) (Myers, 1975). This methodology determines national solvent emissions through material balance. Solvent use by an area source is typically correlated with population or employment in a particular SIC to create an *activity level* or *activity factor* (*e.g.*, lbs. solvent/person). Activity levels are combine with *emission factors* (solvent emitted/solvent used), which are based on source-specific emission measurements to determine emissions by states and counties. Emission factors are "developed from only a limited sampling of the emissions source population for any given category, and the values reported are an average of those limited samples and may not be statistically representative of the population" (Rethinking, 1991).[1] The EPA recommended emission factor for auto refinishing is 2000 lb. emission/ton solvent used, or 1. The NEDS area source emission estimation method has been used in several emission inventory efforts. These efforts include the 1985 National Acid Precipitation Assessment Program (NAPAP) emissions inventory prepared by EPA (Demmy, 1988), the Regional Ozone Modeling for Northeast Transport (ROMNET), and the Area and Mobile Source (AMS) Subsystem of the Aerometric Information Retrieval System (AIRS) (Aerometric, 1992), which is planned to replace NEDS while using similar estimating techniques.

There have also been detailed studies performed on individual area sources in order to provide guidance on area source emission control technology. Methods for estimating emissions are often included in these studies. A 1988 study of VOC emissions from automobile refinishing area sources uses a rather complex calculation dependent upon the final thickness of applied coatings, in thousandths of an inch, while categorizing the entire industry into three types of establishment -- small, medium and volume shops (Athey, 1988). This approach has been criticized as being inappropriate for an industry which has a large variance in operating characteristics (National, Nov. 1991).

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1 The Emission Factor Rating (A through E, with A being the best) is a qualitative rating which "reflects the quality and the amount of data on which the factors are based". (Compilation, 1985) Factors based on many observations or on more widely accepted test procedures are assigned higher rankings (*e.g.*, an A rating means that 10 or more tests were conducted at different plants using a single valid reference measurement method or equivalent technique). EPA also states that, "at most, a rating should be considered an indicator of the accuracy and precision of a given factor used to estimate emissions from a large number of sources." (Compilation, 1985; Joyner, 1991)

The basic approach in estimating emissions is by a simple calculation:

***Emissions = Activity level x Emission factor x [1-(CE x RE x RP)]***

where: CE = Control efficiency percent/100
RE = Rule effectiveness percent/100
RP = Rule penetration percent/100

CE is related to control technology, (*e.g.*, carbon filtration of VOCs from auto refinishing paint booths.) RE is an adjustment to reflect that air pollution rules are not able to assure full compliance with regulatory requirements at all times. RP is a measure of the extent to which a rule applies to a source category. EPA's guidance stipulates use of a default value of 0.80 for RE unless data can be collected to determine a "true" value. RP is calculated as a ratio of the controlled emissions covered by a regulation applicable to a category to the total uncontrolled emission for a category. The RP term may be appropriate to deal with "backyard shops" engaging in auto refinishing. If such operations are not subject to air pollution rules, estimates of uncontrolled emissions are needed to estimate RP. This requires being able to account for emissions both from licensed operations and backyard shops. RE and RP are of no concern of CE = 0, or if there are no applicable regulations for a category. However, in more and more areas rules will apply, so area source methods need to address RE and RP.

This study on improved estimation methods is focused almost entirely on improved activity levels. Industry characterization, and most importantly a future national survey, can also produce better evaluations for CE, RE, and RP.

Activity levels can be found in a number of EPA references. Table 2-2 contains activity factors for automobile refinishing from *AP-42 Compilation of Air Pollutant Emission Factors* (Compilation, 1985) and its Supplement D (Joyner, 1991), the EPA State Implementation Plan (SIP) guidance document (Procedures, 1991), and AIRS/AMS (Kimbrough, 1992)(Aerometric, 1992). In analyzing these data, it can be noted that:

- The AP-42 activity levels and National VOC emissions did not change for more than ten years. They may not have changed since the AP-42 was first published in 1968.
- The SIP guidance document's *per capita* activity level is 21% greater than that of the AP-42 document, while the *per employee* activity level is 48% less than that of the AP-42 document.

**Table 2-2. Recommended Emission Factors for the Automobile Refinishing Area Source**

| Reference | National VOC emissions (tons per year) | VOC emission factors (pounds/year) | | U.S. population (millions) | SIC code | Number of U.S. automobile refinishing employees | Year derived |
|---|---|---|---|---|---|---|---|
| | | Per capita | Per employee | | | | |
| AP-42 (Compilation, 1985) | 199,000 | 1.9 | 5200 | 209.5 (est'd) | | 76,500 (est'd) | 1972 (est'd) |
| AP-42 Supplement D (Joyner, 1991) | 199,000 | 1.9 | 5200 | 209.5 (est'd) | | 76,500 (est'd) | 1972 (est'd) |
| SIP Guidance Document (Procedures, 1991) | 281,00 (est'd) | 2.3 | 3519 | 245.7 | 7532 | 163,000 (est'd) | 1989 |
| AIRS / AMS (Kimbrough, 1992) | | | 3519 | | 7535, 7532 | | |

* For *AP-42* and *AP-42, Supplement D*, data from 1972 most closely corresponds to the data given in the table.

Examples of two problems with current methods are:

1) Differences in Emission Estimates. The two activity levels (*per capita* vs. *per employees*) seldom produce the same emission estimate, as shown in the example in Figure 2-3 for 26 California counties. These discrepancies arise from the static nature of emission factors and the different characteristics of individual geographic regions.

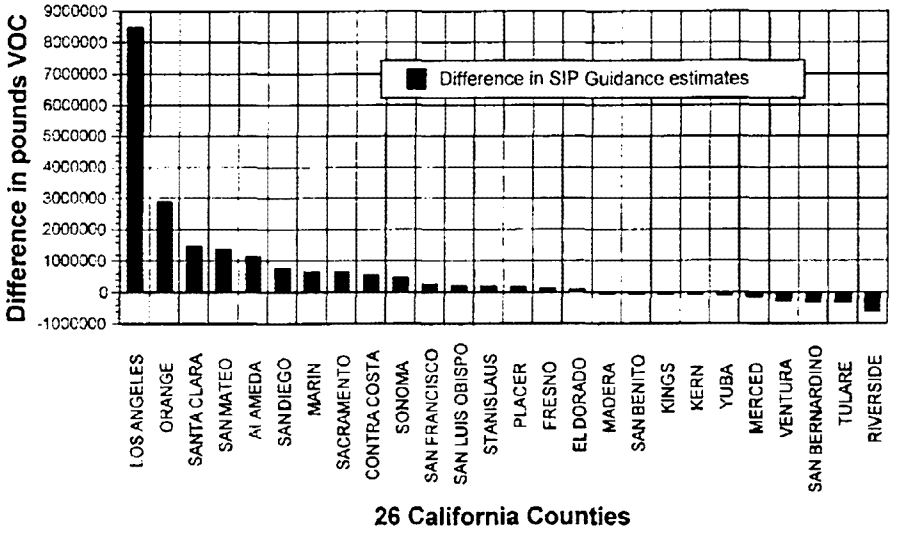



**Figure 2-3. Difference in Emission Estimates (emission estimates using per employee emissions - emission estimates using per capita emission factor)**

2) Missing Data. *County Business Patterns* (County, Annual) exercises disclosure protection for counties where revealing information may disclose details about the operations of individual businesses. For example, in 1990, Standard Industrial Classification (SIC) 7532 employment for 47 of North Carolina's 100 counties was not disclosed. An emission estimation method should utilize activity factors that are available for all areas required to compile emission inventories.

The following sections provide additional detail on past and ongoing emission inventory efforts and methods.

### 2.2.1 Emission Inventories

Some past and ongoing emission inventories efforts by EPA include the National Emissions Data System (NEDS -- still-prevalent emission estimation method), the NEDS successor -- the Aerometric Information Retrieval System (AIRS), and its Area and Mobile Source (AMS) Subsystem emission inventories.

Emission inventories are used in photochemical air-quality models which determine the emission reductions needed to achieve the desired air-quality standard, such as the National Ambient Air Quality Standard (NAAQS). EPA air-quality modeling guidelines specify the Urban Airshed Model (UAM) as the recommended model for ozone concentrations over urban areas.

*National Emissions Data System (NEDS)*

The EPA established the NEDS for sources of airborne pollutants in 1971 (Myers, 1975). NEDS summarized annual cumulative estimates of source emissions for the Clean Air Act's five criteria pollutants: particulate matter, sulfur oxides, nitrogen oxides, VOCs, and carbon monoxide by Air Quality Control Region, by state, and nationwide.

EPA has compiled emission factors for a variety of sources and activity level, reporting the results since 1968 in AP-42 Compilation of Air Pollutant Emissions Factors, for which supplements are issued regularly. However, "emission factors" currently in use are developed from only a very limited sampling of the emissions source population for any given category. The values reported are an average of those limited samples and may not be statistically representative of the emissions sources.

*National Acid Precipitation Assessment Program (NAPAP)*

The NEDS area source emissions estimation method has been used in other emission inventory efforts. The 1985 National Acid Precipitation Assessment

Program (NAPAP) emissions inventory prepared by EPA (Demmy, 1988), includes emissions from the U.S. and Canada for 1985. The U.S. emissions data were derived primarily using existing methodologies previously used by EPA (Zimmerman, 1988; Demmy, 1988). The NEDS point and area source inventory was used as a starting point for modification and refinement in the development of the 1985 inventory. The NEDS inventory development and quality assurance methods were refined under the Regional Ozone Modeling for Northeast Transport (ROMNET), but as with NAPAP, the NEDS area source solvent inventory methods remained essentially the same (work in progress, Battye, W., EC/R).

*Aerometric Information Retrieval System (AIRS) Area and Mobile Source Subsystem (AMS)*

While NEDS has historically been the computer software system the EPA has used to calculate, store, and retrieve area and mobile source emissions, EPA is in the process of designing and developing a new data subsystem. Residing in the Aerometric Information Retrieval System (AIRS), the new subsystem is called the Area and Mobile Source (AMS) Subsystem (Aerometric, 1992).

AIRS is the current computerized database management system developed by the Office of Air Quality Planning and Standards (OAQPS) to support EPA and state needs for air quality, air emissions, and air compliance data. One component of AIRS, the AIRS Facility Subsystem (AFS), replaces EPA's NEDS for storage and retrieval of point source emissions data (Aerometric, 1992).

Once fully implemented, the procedure planned to be used by AMS to generate emission estimates for area and mobile source categories for all areas of the U.S. -- nonattainment and attainment -- is similar to that used under NEDS. To some extent, these methods were previously documented in Area Source Documentation for the 1985 National Acid Precipitation Assessment Program Inventory (Demmy, 1988); however, the NAPAP report did not include certain initial data calculations. In addition, over the years, numerous changes have occurred to the sources of the data that "feed" these methodologies. The initial data calculations and source data changes can be found in (Aerometric, 1992). The most recent review of emissions computation procedures is contained in Documentation of AIRS AMS National Methodologies (Kimbrough, 1992).

While the AIRS/AMS emission estimation method is not included in the official State Implementation Plan (SIP) emission inventory guidance documents being disseminated by EPA's Office of Air Quality Planning and Standards (OAQPS), this does not preclude state and local air agencies from using this method to estimate their area source emissions.

For AIRS/AMS, the reported national consumption of each solvent is extracted from the Department of Energy's Petroleum Supply Annual (Petroleum, 1992) and International Trade Commission's (ITC) Synthetic Organic Chemicals (Synthetic, 1991). The percentage of each solvent consumed by each solvent user category is obtained from Chemical Products Synopsis (Chemical, 1990) and Chemical Profiles (Chemical, Weekly). Total employment is obtained from County Business Patterns. Point source employment is estimated using plant data from the AIRS/FS and employment data from County Business Patterns. Solvent consumption amounts used for surface coating are taken from the annual "Trends" report (National, March 1991). County population is obtained from Current Population Reports (Current, Annual).

### 2.2.2. Compilation of Air Pollutant Emission Factors

Table 2-3 contains national emissions and activity factor for VOC from Automobile Refinishing as excerpted from AP-42 Supplement D.

The numbers in Table 2-3 have been applied to determine the population and number of Automobile Refinishing (SIC 7532) employees at the time of the activity levels' derivation. After reviewing the U.S. Census data, it was concluded that AP-42 activity levels must have been derived around 1972 when the U.S. resident population was 209,284,000 (Bureau, 1992) and there were 16,237 equivalent SIC 7532 establishments with 70,121 employees (Bureau, 1972). Therefore, emission factors appropriate for 1972 are published for use in estimating VOC emissions in a September 1991 document (Joyner, 1991).

**Table 2-3. National Emissions and Activity Levels for VOC from Automobile Refinishing (Emission Factor Rating: C)[a] (Procedures, 1980; Lamason, 1981; End, 1979)**

| Emissions | Automobile Refinishing |
|---|---|
| National: | |
| Mg/year | 181,000 |
| Ton/year | 199,000 |
| Per Capita: | |
| kg/year (lb/year) | 0.84 (1.9) |
| g/day (lb/day) | 2.7 (0.006)[b] |
| Per employee: | |
| Mg/year (ton/year) | 2.3 (2.6) |
| kg/day (lb/day) | 7.4 (16.3)[b] |

[a] All non-methane organics
[b] Assumes a 6-day work week (312 days/year)

### 2.2.3 Control Techniques Guidelines (CTG)

The EPA has funded two recent studies to evaluate VOC emissions in automobile refinishing. The first document (Athey, 1988) was finished in 1988, with preparation by the Control Technology Center (CTC). As a part of this study, methods were developed to estimate VOC emissions. The method, used in a 1988 study, is based on "broad assumptions" about three model automobile refinishing shops.

The baseline nationwide VOC emissions from the motor vehicle refinishing industry (Zimmerman, 1988; Athey, 1988) are presented in Table 2-4. The 1988 Athey report recommends that state and local agencies conduct a survey of shops in their area to determine their baseline VOC emissions from automobile refinishing operations.

**Table 2-4. Baseline VOC Emissions from Automobile Refinishing by Facility Type (Athey, 1988)**

| Facility Description | Number of shops | Total tons VOC/yr. nationwide | Percent of total VOC emissions |
|---|---|---|---|
| Small shop | 33,200 | 42,200 | 15 |
| Medium shop (includes dealers) | 41,300 | 149,900 | 52 |
| Volume shop (includes franchises) | 8,600 | 95,600 | 33 |
| Total industry | 83,100 | 287,700 | 100 |

With the requirement of State Implementation Plans for reducing VOC emissions, EPA began work on a revised Control Techniques Guideline (CTG) to provide assistance for nonattainment areas. A 1991 draft of the CTG (Draft, 1991) expanded on the 1988 work to include eight model shops to estimate automobile refinishing VOC emissions in the U.S. Table 2-5 shows the results of this emissions estimation method.

**Table 2-5. Baseline VOC Emissions from Automobile Refinishing by Facility Type (Draft, 1991)**

| Model Shop | Number of Shops | Total tons VOC/yr. nationwide | Percent of total VOC emissions |
|---|---|---|---|
| A | 6,300 | 6,300 | 2.6 |
| B | 8,820 | 16,141 | 6.7 |
| C | 3,150 | 5,733 | 2.4 |
| D | 6,300 | 19,908 | 8.3 |
| E | 24,570 | 84,767 | 35.3 |
| F | 4,410 | 21,609 | 9.0 |
| G | 3,150 | 12,537 | 5.2 |
| H | 6,300 | 72,891 | 30.4 |
| Total | 63,000 | 239,886 | 100 |

The emissions estimation technique is elaborate and depends on a great many variables. In talking with automobile refinishing industry representatives, it was found that many of these parameters have much too wide a variance to be simply averaged or estimated. As an example, many auto refinishers state that the mils thickness of coatings recommended by paint manufacturers is routinely ignored in favor of applying enough paint to make the product "look right".

The "model shop" method has been criticized by both paint manufacturers and auto refinishing organizations. Industry representatives contend it is impossible to categorize body shops into types, and repair jobs into overall or partial jobs. The industry also contends that many of the average numbers used in the estimates were considerably high and did not represent realistic situations. After repeated discussions with these organizations, EPA dropped the "model shops" concept.

### 2.2.4 State Implementation Plans (SIPs)

The 1990 base year state emission inventories are being submitted to EPA Office of Air Quality and Planning Standards (OAQPS) Emission Inventory Branch (EIB). OAQPS disseminates the SIP guidance documents (not the AP-42) to state agencies for the preparation of emission inventories. Volume I (Procedures, 1991) of the SIP guidance documents contains the emission factors and formulae for calculating inventories.

Every state is required to submit their VOC emission estimation method with their estimates. Responses have fallen under four categories: "No Method", "Per Capita", "Per Employee", and "Other Method".

"No Method" means that the documentation supplied by the State agency with their estimates is insufficient for EPA to determine the estimation method used (Telephone, 1993). EPA's OAQPS Emission Inventory Branch may ask for clarification from states designated under "No Method".

The *per capita* and *per employee* methods (Lamason, 1980) use activity factors provided to the state pollution control agencies by the EPA in the SIP Guidance Document. The automobile refinishing area source emission factors are listed in Table 2-6.

**Table 2-6. Auto Refinishing Activity Factors**

| SOURCE CATEGORY | COATING USE ($10^6$ gal/yr)[a] | COATING USAGE FACTORS (gallons/year) | | VOC EMISSION FACTORS (pounds/year)[b] | | Nat'l Emissions ton/yr | Year |
|---|---|---|---|---|---|---|---|
| | | PER CAPITA | PER SIC EMPLOYEE | PER CAPITA | PER SIC EMPLOYEE | | |
| Automobile refinishing | 36 | 0.15 | 221 | 2.3 | 3519 | 241,000 | 1991 |
| AP-42 Supplement D | - | - | - | 1.9 | 5200 | 199,000 | 1991 |
| Total Industry (CTC) | - | - | - | - | - | 287,700 | 1988 |
| Total Industry (CTG) | - | - | - | - | - | 239,886 | 1991 |
| New York see Table 2-7 | 36 | - | - | 0.9 | - | 111,600 | 1990 |
| California Counties in South Coast Air Basin | - | - | - | .41 | 446 | 43,000 | 1990 |

[a] The volume and distribution of coating usage is derived from the Frost and Sullivan's *Industrial Solvents* report (Industrial, 1989) and from Stanford Research Institute's (SRI) *Chemical Economics Handbook* (Chemical, 1992).

[b] Ninety-nine percent of the organic solvents used in surface coatings are classified as VOC.

*Other Methods*

Figure 2-4 is another representation of the type of estimation discrepancies seen in Table 2-6. A national value for VOC emissions from auto refinishing has been calculated from information provided by the 7 different sources shown in the figure. The activity factor used in each case is based on population. The Auto Refinishing column represents the SIP Guidance document emission factor/activity level coefficients. The CTG represents factors from the Control Guidance Document study referenced earlier. Note that the two state studies offer the lowest estimates. They are most closely based on actual contacts with body shops within specific regions of the country. The low values for California, provided by the California Air Resources Board may reflect the impact of stringent regulation

in that state. Without further validation, it is not possible to proselytize for one method or the other.

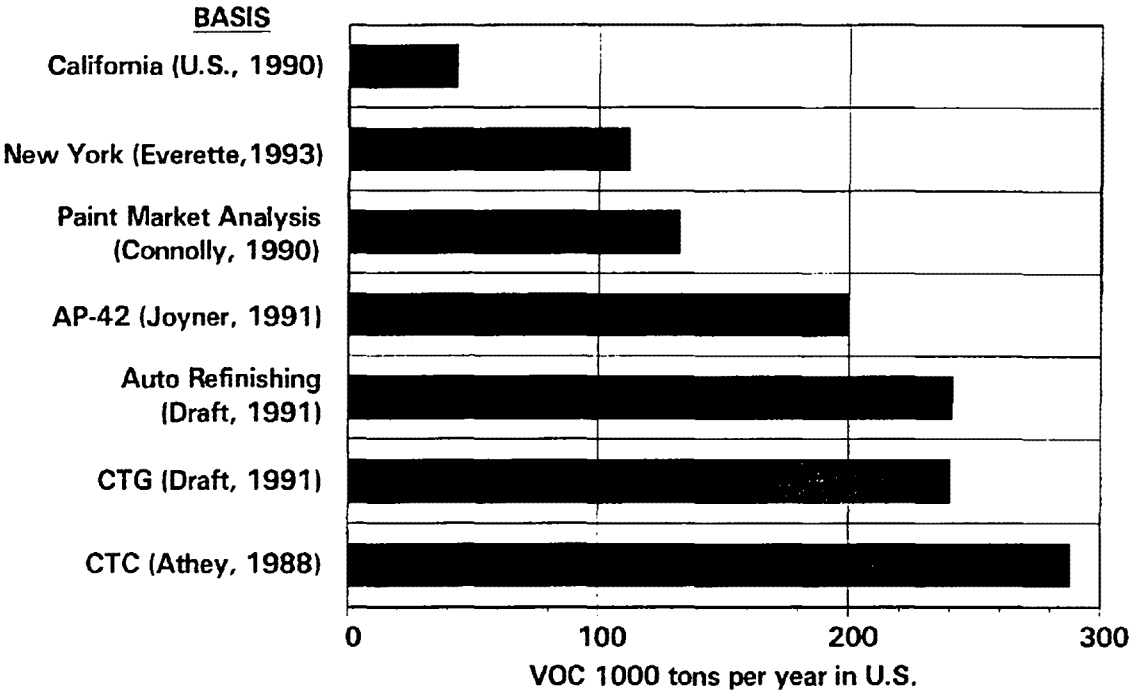



**Figure 2-4. National VOC Estimations by Different Methods**

States that chose to use an alternative VOC emission estimation method ("Other Method") are required to submit their method with their estimates. Table 2-7 contains a description of the methods used by the States of Alabama, Georgia, New York and the State of Indiana's Marion County, the only "Other Methods" submitted to date.

Although the SIP guidance document recommends use of the *per employee* factor for automobile refinishing (Lamason, 1980), as mentioned in Section 2.2, the number of automobile refinishing employees may not be available. This was the case for the State of Georgia. For the counties listing employment for SIC 7532 in the CBP, the State of Georgia used the number of accidents per county to derive an SIC 7532 employee-per-accident multiplier. Using this multiplier, Georgia extrapolated SIC 7532 employment in the counties for which the CBP invoked disclosure protection. The combined SIC 7532 employment was multiplied by the *per employee* factor to determine the State's emission inventory.

**Table 2-7. Other Emission Estimation Methods for Automobile Refinishing from State Implementation Plan (SIP) Submissions.**

| STATE | AREA | ESTIMATION METHOD |
|---|---|---|
| Alabama | Jefferson County | A 1988 survey of all body shops yielded a 308 tons/year estimate for the county. While VOC emissions for individual shops ranged from 0-33.2 tons/year, 89% of the shops emitted 4 tons or less. |
| Georgia | Nonattainment counties: Cherokee, Clayton, Cobb, Coweta, Dekalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale | For counties with number of SIC 7532 employees in CBP[e], derived number of accidents[f]/employee. From this determined number of SIC 7532 employees in each nonattainment county. Multiplied employees by 3519[d] pounds per employee-year emission factor to get annual county emissions; divided by 260 workdays per year to get county workday emissions. |
| | Attainment areas: All other counties in Georgia | Used the accidents/employee number derived above to determine the number of SIC 7532 employees. |
| Indiana | Marion County (Indianapolis) | A survey, conducted in 1987 with a 59% response rate, yielded a 141 tons VOC/year estimate for the county. A representative random sample taken in 1990 indicates that VOC emissions have not changed significantly since the 1987 survey. |
| New York | All counties except those in the New York City Metropolitan Area (NYCMA) | Derived new *per capita* emission factor from 111,600 tons VOC per US-year[a] and 247,920,500 persons per US - 0.9 lbs VOC per capita-year. |
| | NYCMA counties: Bronx, Kings, Nassau, New York, Orange[b], Queens, Richmond, Rockland, Suffolk, and Westchester | Using VOC limits on coatings[c], and rule penetration and effectiveness[d], derived VOC emissions = population*0.9 lbs VOC/person*[1-(0.19*0.53*0.8)]. |

[a] Derived from national coating usage (Industrial, 1989) and New York State's VOC/gal. limit for touch-up coatings of 6.2 lb. VOC/gal., as sprayed. (Everette, 1993)
[b] Only portions of Orange County are nonattainment
[c] 6.2 lbs VOC/gallon on partial jobs (10 $ft^2$) and 5.0 lbs. VOC/gallon on full jobs (100 $ft^2$)
[d] From SIP Guidance document (Lamason, 1980)
[e] Census Bureau's County Business Patterns (County, Annual)
[f] From Georgia Department of Public Safety accident reports

*Board Report*

In a 1991 report, the State of California Air Resources Board (CARB) estimated 1987 total organic gas (TOG) emissions from automobile refinishing to be 15,786.84 tons. These TOG estimates were updated from 1983 estimates using growth factors, which were updated from 1982 estimates using a growth factor based on the increase in vehicle registration in the United States.

California's fraction of the nationwide usage was determined by the ratio of the vehicle registration in California to the vehicle registration in the United States. Each county was apportioned its fraction of California's total by its percentage of the State's population. A 1979 composite emission factor of 5.275 pounds VOC per gallon was used to determine the TOG emission levels. It was assumed that the amount emitted was equivalent to the amount consumed.

### 2.2.5 EPA Study of Recent Methods

In a recent analysis of current methods for estimating VOC emissions from area sources, it was recommended that the best method for estimating VOC emissions from automobile refinishing is the use of a paint market analysis, updated every 4 years (Connolly, 1990), and the 1988 EPA CTC study (Zimmerman, 1988; Athey, 1988). It was also stated that "given the absence of data to discredit the employment data set or to recommend another data set, the availability of data favors the employment-based method" (work in progress, Battye, W., EC/R). Table 2-8 contains a list of variables that have been examined, with comments on the solvent use correlations, and the strengths and weaknesses of each.

The employment-based method appears to be as good as any other allocation method in the absence of other evidence. However, there is little to support the recommendation to use two national data sources whose national usage estimates disagree by over 100% (572 billion vs. 264 billion pounds of solvents per year), as seen in Table 2-9. As a result of conversations with industry representatives, the use of the paint market analysis estimates is recommended.

**Table 2-8. Automobile Refinishing Variables from Recent Review (work in progress, Battye, W., EC/R)**

| Variable | Solvent Use Correlation | Strengths | Weaknesses |
|---|---|---|---|
| Paint usage[a,b,c] | Requires average pounds VOC/gallon[d] | Accurate on national level | No State or county consumption data |
| Solvent usage[a,b] | Direct | Accurate if correlatable with multiple sources | Uncorrelatable across sources; No State or county data |
| Employees by four-digit SIC and county[e] | Requires pounds VOC/SIC 7532 employee-year | Includes number of establishments and employees and payroll by shop employment | Census does not disclose details of individual firms |
| Employees by four-digit SIC and latitude and longitude[f] | | Includes address, latitude, longitude, phone number | No other information on operations |
| Accidents | Requires pounds VOC/accident-year | Annual county data at State level[g] | Accident definition, severity, and repairs vary with regional characteristics |
| | | Annual State data at National level[h] | No county data; (same as above) |
| Fatal Accidents | Requires pounds VOC/fatal accident-year | Annual county data at State level[g] | Vehicles in fatal accident are least repairable due to damage severity |
| | | Annual State data at national level[h,i] | No county date; (same as above) |
| Receipts by four-digit SIC and county[e] | Requires pounds VOC/SIC 7532 $ receipt | Includes number of establishments and employees and payroll by shop employment | Census does not disclose details of individual firms; repair costs vary regionally |

[a] (Athey, 1988)
[b] (Connolly, 1990)
[c] (Commerce, 1987)
[d] 5.5 pounds VOC/gallon is a conservative nationwide estimate from Midwest Research Institute (MRI) study for National Paint and Coating Association (Athey, 1988).
[e] (County, annual)
[f] Computerized telephone directories
[g] State Department of Transportation
[h] National Safety Council
[i] Insurance Institute for Highway Safety

**Table 2-9. Comparison of National Paint and Solvent Usage Estimates for Automobile Refinishing**

| Automobile Refinishing Material | EPA Control Technology Center Study (Athey, 1988) | Paint Market Analysis (Connolly, 1990) |
|---|---|---|
| Paint usage ($10^6$ gallons) | 41 | 36 |
| Solvent usage ($10^6$ pounds) | 201 | 162 |
| In paint as purchased | 118 | 102 |
| Thinning solvents | 118 | 102 |
| Other solvents | 253 | -- |
| Total solvent | 572 | 264 |

### 2.2.6 Accuracy of Emissions Inventories

The accuracy and precision required of an emissions inventory is dictated by its intended use. For example, the Urban Airshed Model input data require data that have accurate and precise spatial and temporal distributions and speciations. Such requirements are quite rigorous when compared with those needed for emission trend analysis.

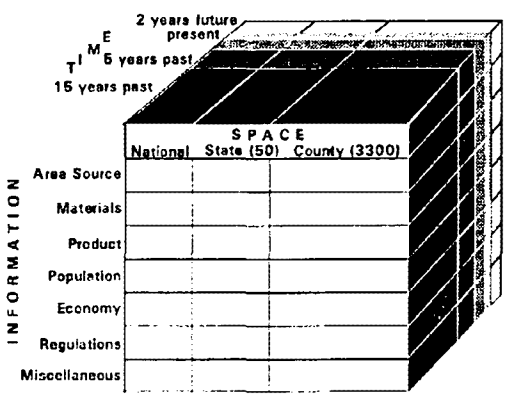
It has been stated by a National Academy of Sciences report that due to high cost and the absence of "proven measurement techniques to test the accuracy and precision of emission data" (Procedures, 1991), the uncertainty of emission inventories have only been subjectively estimated. That is, the methods used to estimate emissions have not been adequately checked by comparison with field measurements (Procedures, 1991).

Emission estimation accuracy is best addressed by acquiring actual emission data. The validation method recommended here includes a nationwide survey and several intensive surveys, the collection of nationwide materials distribution data, and site emission sampling and analysis.

## 2.3 Database Development

The success of any new method to estimate area source emissions is limited by the existence and accessibility of information. The objective is to identify data that are updated at least annually and represent county-level activity. Records should exist for at least the past five years and into the foreseeable future. The data must be statistically defensible, representative, "universal" (representative of national distributions and/or variations), and result in accurate emissions estimates. The data are then related to the primary area source variables of both a) solvent use and b) emissions. These variables may be normalized, for example, on the basis of per capita or per employee or per operation.

Figure 2-5 illustrates the information sets of interest in emissions estimation. The figure shows how the data are distributed over time and space under the method being developed. The axes also demonstrate that the data can have resolution down to the county level (or, for example, a 30x30 km grid size). Data as far back as 15 years is of interest for developing and validating the method (considering the past 15 years for major industry trends, the past five years for state/regional distribution figures and general validation, the past 2 years for detailed county level information, the past one year for detailed validation data, and the next 2 years for detailed projections).




**ASSEMBLED DATA**

For the United States: 60 variables over 12 years
For 51 states: 25 variables over 12 years
For 3126 counties: 11 variables over 22 years
For 64,524 establishments: 10 variables in 1993

**Figure 2-5. Information Sources for Emission Estimates and Data Distribution**

The database that has been assembled has both geographic, "spatial" components (*e.g.*, nation, state, county, or city) and temporal components (*e.g.*, year or month). The current data set assembled for this study includes

- 60 variables over 12 years for the United States
- 25 variables over 12 years for 51 States (including D.C.)
- 11 variables over 12 years for 3126 counties
- 10 variables for 1993 for 64,524 automobile refinishing establishments

Table 2-10 summarizes several sources and variables. Each of the variables has several dimensions.

The database development step in the method has been conducted as follows:

1) List the broadest scope of information sources containing variables that <u>might influence or correlate with</u> auto refinishing emissions.
2) Select a large subset of variables from these sources based on expert opinion (*e.g.*, from paint manufacturers, emissions experts, auto refinishing managers, statisticians) of which variables are <u>likely to influence or correlate with emissions</u>.
3) Further reduce the number of variables based on the <u>accessibility and frequency of updating</u> of the data.
4) Correlate variables with one another to show similarities in predicting trends and variables in regions of the United States, or variations from year-to-year. New variables are also correlated with those being generally applied in emissions estimation, *i.e.*, population or number of SIC employees.

The desired dependent data, area source solvent use and VOC emissions, is essentially nonexistent. Therefore, final correlations and variable selection must wait on the availability of validation data (see Section 3).

Following variables selection and final arrangement of the desired databases, the analysis and estimation system can be tailored for optimal emission predictions, but not before. Therefore, the current information remains <u>surrogate data</u> until validation is provided. Nevertheless, some interesting preliminary results and selections have come from the evaluations to date.

The <u>surrogate data</u> is summarized next (Section 2.3.1), followed by a description of data prescreening using statistical analysis (Section 2.3.2).

## Table 2-10. Major Data Items and Sources (Fatal, 1991; General, 1991; Highway, 1992)

| Source of Nationwide Data | Variable | Finest Level of Geographic Aggregation | Frequency of Update | Frequency of Measurement (est.) |
|---|---|---|---|---|
| U.S. Bureau of the Census | | | | |
| Economic Censuses | | | | |
| - By Standard Industrial Classification: | | | | |
| | Number of establishments and firms | County | Quinquennial | Quinquennial |
| | Employment | County | Quinquennial | Quinquennial |
| | Payroll | County | Quinquennial | Quinquennial |
| | Sales, receipts, or value of shipments | County | Quinquennial | Quinquennial |
| | Operating expenses | Varies by SIC | Quinquennial | Quinquennial |
| | Value added | Varies by SIC | Quinquennial | Quinquennial |
| | Net income produced | National, some SICs | Quinquennial | Quinquennial |
| | Capital expenditures | National | Quinquennial | Quinquennial |
| | Inventories | State, some SICs | Quinquennial | Quinquennial |
| | Specialization | National, SIC 2851 | Quinquennial | Quinquennial |
| County Business Patterns | | | | |
| - By Standard Industrial Classification: | | | | |
| | Number of establishments and firms | County | Annual | Annual |
| | Employment | County | Annual | Annual |
| | Payroll | County | Annual | Annual |
| Current Population Reports | | | | |
| | Median income of households | State | Annual | Few Months |
| | Percent of persons below poverty | State | Annual | Few Months |
| | Total population | County | Annual | Few Months |
| | Land area | State | Decennial | Few Months |
| Bureau of Labor Statistics | | | | |
| | Civilian labor force | State | Annual | Monthly |
| | Consumer price index | National | Monthly | Monthly |
| | Producer price index | National | Monthly | Monthly |
| Bureau of Economic Analysis | | | | |
| Regional Economic Information System | | | | |
| | Personal income | County | Annual | Monthly |
| | Disposable personal income | County | Annual | Monthly |
| | Population | County | Annual | Monthly |
| | Total wages and salaries | County | Annual | Monthly |
| | Wage and salary employment | County | Annual | Monthly |
| | Average wages per job | County | Annual | Monthly |
| | Census journey to work | County | Decennial | Decennial |
| | Gross state product | County | Annual | Monthly |
| | Full and part time employees | County | Annual | Monthly |
| | Regional economic profile | County | Annual | ? |
| | Transfer payments | County | Annual | ? |
| U.S. Department of Transportation | | | | |
| Federal Highway Administration | | | | |
| | Non-fatally injured persons | State | Annual | Monthly |
| | Public road and street mileage | State | Annual | Monthly |
| | Licensed drivers | State | Annual | Monthly |
| | Registered automobiles | State | Annual | Monthly |
| | Registered motor vehicles | State | Annual | Monthly |
| | Vehicle miles of travel | State | Annual | Monthly |
| National Highway Traffic Safety Administration | | | | |
| | Fatal accidents | State | Annual | Monthly |
| National Safety Council | | | | |
| | Motor vehicle accidents, on road | State | Annual | Monthly |
| | Motor vehicle deaths | State | Annual | Monthly |
| Insurance Information Institute | | | | |
| | Motor vehicle accidents, on and off road | State | Annual | Monthly |
| | Motor vehicle injuries | State | Annual | Monthly |
| American Chamber of Commerce Researchers Association | | | | |
| | Cost of living index | Selected MSAs | Annual | Annual |

### 2.3.1 Surrogate Data: Sources, Variables, Availability, Accuracy

The following is a description of major relevant data sources and their advantages and disadvantages.

*Census Bureau Published Data for SICs*

The level of industry emissions is likely to be proportional to the amount of business activity (*e.g.*, measured by receipts, payroll, or employees). However, identifying the amount of business activity in the automobile refinishing industry is not simple. The most complete coverage of industrial data across geographic regions of the United States is available from the Census Bureau. The Census Bureau has two programs that gather and publish data by Standard Industrial Classification (SIC) code:

1) The Economic Census collects information every five years directly from business establishments. 1987 is the most recent year for which data are available. In 1987, 3.9 million questionnaires were mailed to businesses across the country. Each business receives only one type of more than 500 industry-specific types of forms. All businesses receiving the forms are required by Title 13 of the United States Code to complete the forms and return them. The 1992 Economic Census forms will be mailed to more than 3.5 million companies in early 1993 and preliminary results will be available in 1994.

2) County Business Patterns gathers most of its data from administrative records of the Federal Government every year. The Census Bureau states that "County Business Patterns is the only series that provides annual sub-national data by two-, three-, and four-digit levels of the Standard Industrial Classification (SIC) system" (County, Annual). However, while County Business Patterns is published annually, the Economic Censuses present data addressing more specific SICs.

Census Bureau publications aggregate information by SIC for geographic regions (see Table 2-11). The information includes: (a) the number of establishments and firms, (b) the number of employees, (c) payroll, (d) sales, receipts, or value of shipments, (e) operating expenses, and (f) other categories, usually with less detail. Four SIC codes related to the automobile refinishing industry can be useful for the estimation or validation of VOC emissions:

1) 7532 - Services: Automotive top and body repair and paint shops
2) 5198 - Wholesale Trade: Paints, varnishes, and supplies
3) 2851 - Manufacturers: Paints and allied products
4) 5511 - Retail Trade: New and used car dealerships

# Table 2-11. Major Census Bureau Items by Geographic Level and Industry (Guide, 1990)

| ECONOMIC CENSUSES<br>Every 5 Years<br>2-4 year Lag-Time | Service Industries<br>Auto Bodyshops<br>SIC 7532 | Manufacturers<br>Paints & Allied Products<br>SIC 2851 | Wholesale Trade<br>Coatings Distribution<br>SIC 5198 | Retail Trade<br>Auto Dealerships<br>SIC 5511 |
|---|---|---|---|---|
| Number of Establishments and Firms | | | | |
| Establishments with payroll | N, S, M, C | N, S, M, C | N, S, M, C | N, S, M, C |
| Individual proprietorships | N, S, M, C | N, S | N | N, S, M, C |
| Partnerships | N, S, M, C | N, S | N | N, S, M, C |
| Firms | N | N, S | N | N |
| Employment | | | | |
| All employees | N, S, M, C | N, S, M, C | N, S, M, C | N, S, M, C |
| Production workers | | N, S, M, C | | |
| - Hours | | N, S, M, C | | |
| - Wages | | N, S, M, C | | |
| Employment size of establishment | N | N, S, M, C | N | N |
| Employment by principal activity | | | N | |
| Payroll | | | | |
| All employees, entire year | N, S, M, C | N, S, M, C | N, S, M, C | N, S, M, C |
| All employees, first quarter | N, S, M, C | | N, S, M, C | N, S |
| Production workers | | N, S, M, C | | |
| Supplemental labor cost | N | N, S | N | N |
| Sales, Receipts, or Value of Shipments | | | | |
| Establishments with payroll | N, S, M, C | N, S, M, C | N, S, M, C | N, S, M, C |
| Specific product, line, or type of const. | | N, S | N, (S, M) | N, S, M |
| Class of customer | | N | N | N |
| Sales size of establishment | N | N | N | N |
| Operating Expenses | | | | |
| Total | | | N, S | N |
| Cost of materials | | N, S, M, C | N | N |
| Specific materials consumed | | N | N | |
| - Quantity | | N | N | |
| - Cost | | N | N | |
| Cost of fuels | N | N, S | N | N |
| Energy consumed | | N, S | | |
| - Quantity | | N, S | | |
| - Cost | | N, S | | |
| - Cost of electricity | N | | N | N |
| Products bought or sold (resales) | | N, S | | |
| Other | | | | |
| Value added | | N, S, M, C | N | N |
| Net income produced | | | N | N |
| Capital expenditures, total | N | N, S | N | N |
| - New | N | N, S, M, C | N | N |
| Inventories (end of 1986, 1987) | | N, S | N,S | N |
| Specialization by type of manufacturing | | N | | |

| COUNTY BUSINESS PATTERNS<br>Every Year<br>2-3 Year Lag-Time | Service Industries<br>Auto Bodyshops<br>SIC 7532 | Manufacturers<br>Paints & Allied Products<br>SIC 2851 | Wholesale Trade<br>Coatings Distribution<br>SIC 5198 | Retail Trade<br>Auto Dealerships<br>SIC 5511 |
|---|---|---|---|---|
| Number of Establishments & Firms | | | | |
| Establishments with payroll | N, S, M, C | N, S | N, S, M, C | N, S, M, C |
| Employment | | | | |
| All employees | N, S, M, C | N, S | N, S, M, C | N, S, M, C |
| Employment size of establishments | N, S, M, C | N, S | N, S, M, C | N, S, M, C |
| Payroll | | | | |
| All employees, entire year | N, S, M, C | N, S | N, S, M, C | N, S, M, C |
| All employees, first quarter | N, S, M, C | N, S | N, S, M, C | N, S, M, C |

| GEOGRAPHIC LEVEL | SIC CODE |
|---|---|
| N=National | 2851 - Paints and allied products |
| S=State | 5198 - Paints, varnishes, and supplies |
| M=Metropolitan Statistical Area | 5511 - New and used car dealerships |
| C=County | 7532 - Top and body repair, paint shops |

The SIC system does not reveal the amount of business for a particular activity, such as automobile refinishing, but classifies each establishment based on its primary activity. For example, automobiles may be refinished at auto body shops, auto paint shops, or car dealerships. At the same time, establishments in the same primary SIC may engage in other activities that contribute to their total business to varying degrees. For SIC 7532, there is no way to single out what percent of the business is specifically automobile refinishing.

The Census does not include establishments with no payroll, but these small auto refinishing operations may make up 1/3 of all shops (I-CAR, 1992). Some shops may also not maintain the proper licenses or registrations to be identified by government agencies.

*Census Bureau "Microdata" for SICs*

Some detailed information collected from individual establishments, referred to as "microdata", is kept confidential by the Census Bureau. In addition, disclosure protection requires the Census Bureau to suppress numbers in published tables that might reveal an establishment's level of operations through logical inference. Disclosure often prevents publication of data in areas where a small number of firms are dominant in one industry classification.

"Microdata" can be accessed by approval and use at the Bureau's site, but the benefits are not substantial. Many area sources are service industries, rather than manufacturers, which are often classified as point sources. The Census Bureau does not collect any information about the consumption of materials such as paint or solvents by the service industry or the source of receipts by type of industrial activity. The form does, however, ask each establishment to show distribution of total receipts for labor performed, parts installed, tire services, retreading, and sales, automobile fuels and lubricants, sales of other merchandise, and all other receipts. The same form (Commerce, 1987) is sent to all establishments that are classified as "motor vehicle service shops, including tire retreading". No information can be presented that might indicate the operations of a single establishment or business in any part of the country. The "microdata" does not provide information for auto refinishing and most other area sources that is likely to provide better correlation than other, more accessible, variables.

*Census Population Data*

The Census Bureau gathers population data from households, including the number of people in the household, their relationship to one another, household income, and the number of people employed. It also includes other demographic information about the age, race, education, national origin, and citizenship of the

residents of the household. The information provided by the individual households is privileged information of the Census Bureau, just like the Economic Censuses.

The Census Bureau is the primary source of population data and its most significant population data collection effort is the Decennial Census conducted every ten years (most recently in 1990). The Census Bureau also conducts a Current Population Survey every few months to provide updates of the population. This survey only collects information from a representative sample of the United States and provides no characteristics of the population for smaller geographic regions such as counties and cities.

In this study, different measures of the population are being examined that better capture the variation in consumption of automobile refinishing for different regions of the country. Examples include the number of licensed drivers and civilian labor force.

*Product or Service Data*

The first requirement for automobile refinishing demand is the existence of an automobile, owned by a private citizen, the government, a rental car agency, or other company. Therefore, automobile sales or accident data could be related to the level of auto refinishing. However, since cars of any age may need refinishing, auto sales must be integrated over time and are difficult to relate to refinishing levels in a single year. The primary source of demand for automobile refinishing is accident damage. To help lessen the financial burden of collision repair, motorists carry collision insurance (in addition to liability insurance) on approximately 66.5% of all vehicles (Economic, 1992). However, not all accident damage is repaired. Several factors might explain why damage to a vehicle may not be repaired, including:

1) Cost of repair
2) Cost of replacement
3) Amount of damage
4) Type of damage
5) Age of car
6) Condition of vehicle before accident
7) Automobile insurance coverage
8) Financial status of owner

According to the technical report by the National Highway Traffic Safety Administration (NHTSA) (Economic, 1992), there were more than 28 million vehicles damaged in 1990. Approximately 4 million of these vehicles were damaged in accidents resulting in an injury to either the occupants of the vehicles

or a pedestrian. About 78 percent of accidents involving an injury are reported to police, while the reporting rate for property damage only vehicles is 52 percent.

Some states require motorists to report accidents if an injury is involved while other states require accidents to be reported if the property damage is expected to exceed a certain dollar amount. NHTSA reports non-fatal injuries on an annual basis, but state-supplied data may be inconsistent. NHTSA updates data by contacting the states submitting inconsistent numbers, also.

NHTSA also provides the Fatal Accident Reporting System (FARS). These data are more accurate than the measures of non-fatal injuries, but these accidents, due to their severity, are less likely to generate demand for automobile refinishing.

Additional, travel-related data have been collected that might influence the demand for automobile refinishing. These variables include the number of registered vehicles, the number of vehicle miles traveled, and the number of miles of highways.

Neither sales, accidents, nor travel data have shown the best correlation with auto refinishing (relative to other selected variables discussed later).

*General Economics Data*

Several tables with economic data are reproduced in the Statistical Abstract of the United States (Bureau, 1992). These tables come from a number of sources, including the Bureau of Economic Analysis and the Bureau of Labor Statistics. It is usually necessary to contact the agencies directly to obtain historical data or explanation of the variables included.

The Department of Commerce operates the Economic Bulletin Board (EBB) that allows access to press releases and data files using a modem. The EBB includes statistical data from the Bureau of Economic Analysis, the Bureau of the Census, the Bureau of Labor Statistics, and other Federal agencies. Some of the information provided by the EBB includes employment data, personal income statistics, price indices, major economic indicators, current business statistics, industry statistics, and regional economic statistics. The data content is provided to the EBB by different agencies.

The Regional Economic Measurement Division of the Bureau of Economic Analysis produces a CD-ROM that includes annual income and employment information covering 1969 to 1990 for states, counties, and metropolitan areas. This source has been used to verify state populations, but additional review is needed to determine what specific economic variables are available. This Regional

Economic Information System (REIS) CD-ROM is useful for accessing information at the county level.

EPA is in the process of developing an Economic Growth Analysis System (E-GAS). This is a system that uses economic growth forecasts to calculate growth factors for each of the counties in designated ozone nonattainment areas. The forecasts of economic growth that are inputs for the E-GAS model may be useful for producing forecasts of automobile refinishing business. The outputs from the E-GAS model for specific counties may also be useful, not only as a check against this study's estimates of automobile refinishing, but as possible inputs to our model. One of the major components of the E-GAS model is vehicle miles traveled.

The economic data that has been analyzed in this study is the civilian labor force data (CLF, both CLF "total" and CLF "employed") from the Bureau of Labor Statistics. This data provided good correlations with auto refinishing business activity and with estimated auto painting employees.

While there is no immediate indication that other economic data will provide the most representative variables for emissions estimation, economic data deserves further analysis.

The "economics" category was addressed last in this study, and insufficient time has been available for complete review. The best variable candidates should be cost-of-living by metropolitan area, and annual income and employment at county levels. For such major indicators as consumer price index (CPI), the values are available only on national or state levels, and the state data is not at all representative of the often significant variations in CPI from county to county. Economic data files often have gaps in both time and spatial distributions, especially for county-level data. The REIS data files appear most useful for correlation with area source validation data.

*Direct marketing information*

There has been continuing growth of direct marketing (*e.g.*, "junk" mail, telemarketing) to consumers in the U.S., accompanied by voluminous and detailed, information files on the population. The problem with direct marketing data is that it should be focused on <u>the product under consideration</u> to be useful in assessing an area source. Direct marketing almost always implies marketing of high-volume, retail consumer goods and not the products or services used or offered by most area sources. The other potentially useful direct marketing information is the demographics relating to sales of related products (*e.g.*, automobiles or refinishing paint). However, tracking auto sales rather than trends predicted by marketing data makes more sense for automobile refinishing.

The research under this study addresses marketing data by obtaining paint manufacturer information.

Direct marketing information usually includes density of a population, age, occupation, affluence, consumption patterns, and so on. Direct marketing information is not indicated to be more useful than census and business pattern data. Direct marketing requires specific information for specific addresses, but this case study does not, nor does more generic system development for emissions estimation. However, direct marketing data might relate better to such area sources as dry cleaning or printing. The emissions estimation model needs more general and area-source-specific data. Demographics data could potentially be related to types of vehicles being refinished, but relates no better to volume of VOC use than other variables.

*State Regulations*

Regulations are influencing the VOC content of paints and solvents and even the types of equipment used in shops. The actual influence of regulations on emissions can only be evaluated qualitatively. Current regulations outside of California do not impose VOC content significantly different from national averages. The limited number of pertinent state regulations confirmed by survey is summarized in Table 2-12.

**Table 2-12. Summary of State Regulations for VOC Emissions from Automobile Refinishing**

| STATE | REGULATIONS<br>(ranges of control levels; regulations vary by type of vehicle and by regions within States) |
|---|---|
| California | • VOC < 2.8 to 6.5 lb/gal (current); VOC < 2.1 to 4.5 lb/gal (1995); or 85% transfer efficiency.<br>• Require electrostatic or HVLP painting, or 65% transfer efficiency.<br>• Require closed cleanup when using organics.<br>• Cannot use more than 5% of coatings or 7 lb/gal VOC for specialty coatings.<br>• In some areas: must use equipment to control 90% of VOC (mass basis); maximum 1.67% VOC per lb of cleanup solvent; reduction of 95% VOC by weight; organic vapor pressure < 45 mmHg; must use approved spray booth. |
| New Jersey | VOC < 4.4 to 6.0 lb/gal |
| New York | VOC < 5.0 to 6.2 lb/gal |
| Texas | • VOC < 1.4 to 6.2 lb/gal<br>• Closed cleanup; recycle all wash solvents |

California has the strictest air quality regulations as exemplified by the regulations under the South Coast Air Quality Management District (SCAQMD), introduced in 1988, and the Bay Area Air Quality Management District

(BAAQMD). New Jersey's State Implementation plan was enacted in 1982, and is periodically updated. In New York, the first State Implementation Plan was prepared in 1973. It has undergone subsequent updates in 1979, 1982, 1984, and 1988. Texas first enacted specific regulations for the automobile refinishing industry in 1987, revised in 1988.

*National Regulation*

There is no present federal regulation governing VOC emissions. Work has recently been curtailed on a revision to the EPA's Control Techniques Guideline, a document intended to assist states with their SIPs. One alternative is the establishment of a national rule on the VOC contents of coatings. Paint manufacturers have thus far shown a willingness to support such a rule as long as they are given ample time to distribute present supplies and develop the new, low-VOC coatings. Eventually, the burden on manufacturers would be lighter than it is at present since there would be less variation in VOC content requirements.

*Occupational Safety and Health Regulations*

Since the mid-1980's, the Occupational Safety and Health Administration (OSHA) has required users of hazardous products (such as paints and solvents) to maintain a Material Safety Data Sheet (MSDS) on location for each toxic material used. MSDS contains information provided by the product manufacturer, such as hazardous ingredients, level of health hazard, fire and explosion, and special protection data. Users, such as auto refinishing shops, found to be in non-compliance with the law are subject to fines. Manufacturers, distributors, and retailers are required by law to provide a MSDS to the purchaser with the first shipment. Following the initial transaction, some companies elect to provide MSDS with every delivery, while others do so only upon request. MSDS do not provide any quantitative information on paint and solvent volume or geographic distribution.

OSHA also regulates ventilation spray booth design and fire hazards, such as solvent containers. However, the numerous shops and OSHA personnel limitations result in only occasional enforcement.

*Miscellaneous Data*

Other data of possible interest include weather and climate, social trends, or major national events. For instance, it has been speculated that a higher rate of accidents may occur during abnormal weather conditions, such as a snowstorm in the South. However, data provided by the University of North Carolina at Chapel Hill Highway Safety Research Center indicate that between 1986 and 1989, almost two thirds of the accidents in North Carolina occurred on clear days.

Drivers may be more cautious during inclement weather and drive less carefully on sunny days. In order to establish a correlation between weather conditions and accidents, data on precipitation, sunshine, cloudiness, and fog would have to be available for every county. A "normal weather" benchmark would also be needed to evaluate any unusual weather conditions. In North Carolina, only five metropolitan regions and the Outer Banks are covered by the National Weather Service "first-order" stations. Weather data for more than 80 of the 100 counties within the State would have to be obtained from scattered reporting site locations. Most weather information available appears to be city-specific, rather than county- or state-specific.

On average, between 80% and 90% of the repair jobs handled by auto refinishers consist of cars involved in collisions. The remaining 10%-20% consist of cars affected by corrosion, vandalism, and various other factors. Automobile corrosion is often caused by salt, either due to proximity to the ocean, or extensive use of salt on snowy roads. In order to correlate corrosion and VOC emissions, data describing the proximity of a region (*e.g.*, county seat) to saltwater, and the location and frequency of salt use on roads would be needed. This may, however, require an extensive data search to describe only a small portion of the auto refinishing business.

Other factors, such as crime and vandalism, or national political and socioeconomic trends may also be important. An example of such a trend was the OPEC oil embargo which caused a strong decline in the auto refinishing industry, along with a general economic downturn in transportation. Nationwide, increased environmental concern has also had an influence, mainly reflected in regulatory policy, as discussed. To have a measurable impact on emissions, these trends should be national rather than local. Local trends would be captured by SIP inputs.

### 2.3.2 Prescreening of Variables by Statistical Analysis

Data subsets were first selected based on availability, frequency of revision, and expert option on relation to auto refinishing emissions.

To provide working (but unvalidated) variables and data for the emission estimation method, several data subsets were further screened using regression analysis. Annual data collected at the state level have proven to be the most useful for analyzing trends and regional variations.

This working <u>surrogate database</u> organizes annual state-level data, and calculates totals for each of the 9 Census divisions and 4 Census regions of the United States. Examples of the explanatory variables in the database, along with their national totals, is shown for 1980 and 1985 to 1991 in Table 2-13. Database

completeness and availability were very important in this selection. The distribution of a single variable across the states can also be displayed over time. Table 2-14 shows data for all states in 1987. The database contains several measures of:

1) economic health (unemployment, gross State product)
2) population (resident population, civilian labor force)
3) automobile travel (vehicle miles of travel, public road and street mileage)
4) quantity of traffic (licensed drivers, motor vehicle registrations)
5) traffic accidents (accident injuries, fatal accidents, accident deaths)

Most variables were considered as independent, or explanatory. A few variables -- *i.e.*, number of auto refinishing employees, receipts for auto refinishing SIC (from CBP), and sales for the paints and allied products SIC (Census data) -- were selected as most closely representing area source activity. Using these as surrogates for solvent use, the independent variables were correlated. Scores of multivariable regression analyses have been conducted for several variables selected from statistical analysis of more than 20 original variables.

Six examples of data regressions are included in the following. The dependent variables in the examples are shown in Table 2-15. Independent variables are included with each of the tables of results for each example.

The selection procedure selects the variable that explains the greatest amount of the variation in the dependent variable. Once a variable is added to the analysis, an equation is generated, $\mathbf{Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_iX_i}$, and statistical checks are performed. The procedure may select all, some, or none of the predictor variables for the final model.

## Table 2-13. Summary of Explanatory Variables and Their National Totals

| Explanatory Variable | | | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Definition | Units | 1980 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| ACC_FTL | Fatal crashes (accidents) | number | 45,284 | 39,196 | 41,090 | 41,438 | 42,130 | 40,741 | 39,836 | 36,895 |
| ACC_NF | Non-fatally injured persons | number | 3,029,693 | 3,358,177 | 3,452,766 | 3,555,788 | 3,626,777 | 3,639,084 | 3,536,707 | 3,434,330 |
| AREA_LND | Land area | sq. miles | 3,539,289 | 3,539,289 | 3,539,289 | 3,539,289 | 3,539,289 | 3,539,289 | 3,536,346 | 3,536,346 |
| CLF_EMP | Civilian labor force, employed | thousands | 99,500 | 107,363 | 109,652 | 112,490 | 115,036 | 117,367 | 117,121 | 116,875 |
| CLF_TOT | Civilian labor force, total | thousands | 107,153 | 115,691 | 117,894 | 119,903 | 121,740 | 123,903 | 124,603 | 125,303 |
| CLF_UN | Civilian labor force, unemployed | thousands | 7,625 | 8,327 | 8,241 | 7,423 | 6,701 | 6,529 | 6,876 | 8,424 |
| DEATH_MV | Motor vehicle deaths | number | 53,476 | 46,159 | 48,140 | 48,290 | 49,391 | 45,203 | 44,419 | 41,314 |
| GSP_RPR** | Gross state product, automobile repair | 1982 dollars | 24,810 | 28,672 | 29,006 | 28,405 | 28,319 | 28,814 | 0 | 0 |
| HWY_RUR | Public road and street mileage, rural | miles | 3,331,000 | 3,171,000 | 3,178,000 | 3,163,838 | 3,131,669 | 3,122,724 | 3,122,788 | 3,139,435 |
| HWY_URB | Public road and street mileage, urban | miles | 624,000 | 691,000 | 701,000 | 710,188 | 739,474 | 753,777 | 757,363 | 749,865 |
| LIC_DRV | Licensed drivers | thousands | 145,295 | 156,868 | 159,487 | 161,818 | 162,853 | 165,555 | 167,015 | 168,995 |
| POP_RES | Resident population | thousands | 227,255 | 237,951 | 240,162 | 242,325 | 244,536 | 246,819 | 249,466 | 252,181 |
| REG_AUTO | Registered automobiles | thousands | 121,724 | 132,108 | 135,431 | 137,324 | 141,252 | 143,081 | 143,550 | 142,956 |
| REG_MV | Registered motor vehicles | thousands | 155,796 | 171,655 | 176,191 | 179,043 | 183,396 | 189,261 | 188,798 | 188,372 |
| VMT_RUR** | Vehicle miles of travel, rural | millions | 672,030 | 730,221 | 747,780 | 780,450 | 817,534 | 847,225 | 868,878 | 883,621 |
| VMT_TOT | Vehicle miles of travel, total | millions | 1,527,295 | 1,774,179 | 1,834,872 | 1,921,204 | 2,025,962 | 2,096,456 | 2,144,362 | 2,172,214 |
| VMT_URB** | Vehicle miles of travel, urban | millions | 855,265 | 1,043,958 | 1,087,092 | 1,140,754 | 1,208,428 | 1,249,231 | 1,275,484 | 1,288,593 |

# Table 2-14. Annual Summary of Explanatory Variables by State: 1987

| Region, Division, and State | 1 ACC_FTL number | 2 ACC_NF number | 3 AREA_LND sq. miles | 4 CLF_EMP thousands | 5 CLF_TOT thousands | 6 CLF_UN thousands | 7 DEATH_MV number | 8 GSP_RPR 1982 Dollars | 9 HWY_RUR miles | 10 HWY_URB miles | 11 LIC_DRV thousands | 12 POP_RES thousands | 13 REG_AUTO thousands | 14 REG_MV thousands | 15 VMT_RUR millions | 16 VMT_TOT millions | 17 VMT_URB millions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U.S., Total | 41,438 | 3,555,788 | 3,539,289 | 112,490 | 119,903 | 7,423 | 48,290 | 28,405 | 3,163,838 | 710,188 | 161,818 | 242,325 | 137,324 | 179,043 | 780,450 | 1,921,204 | 1,140,754 |
| NORTHEAST | 6,480 | 776,216 | 162,745 | 23,820 | 24,930 | 1,121 | 7,513 | 6,283 | 241,494 | 128,802 | 32,732 | 50,308 | 27,597 | 32,152 | 107,121 | 331,977 | 224,856 |
| MIDWEST | 8,867 | 884,810 | 752,093 | 27,858 | 29,845 | 1,986 | 10,647 | 6,366 | 1,139,341 | 176,427 | 39,258 | 59,027 | 34,084 | 44,332 | 211,303 | 459,571 | 248,268 |
| SOUTH | 16,834 | 1,220,635 | 873,005 | 37,819 | 40,579 | 2,756 | 19,416 | 8,616 | 1,086,408 | 266,664 | 56,173 | 83,221 | 47,384 | 64,411 | 325,013 | 713,937 | 388,924 |
| WEST | 9,257 | 674,127 | 1,751,446 | 22,993 | 24,549 | 1,560 | 10,714 | 7,140 | 696,595 | 138,295 | 33,655 | 49,769 | 28,259 | 38,148 | 137,013 | 415,719 | 278,706 |
| New England | 1,643 | 184,757 | 63,012 | 6,601 | 6,818 | 229 | 1,855 | 1,713 | 68,495 | 41,531 | 8,997 | 12,953 | 8,098 | 9,397 | 32,346 | 98,278 | 65,932 |
| Maine | 212 | 18,558 | 30,995 | 561 | 578 | 28 | 217 | 132 | 19,550 | 2,414 | 871 | 1,185 | 695 | 928 | 7,845 | 10,766 | 2,921 |
| New Hampshire | 162 | 7,872 | 8,993 | 573 | 588 | 15 | 174 | 158 | 12,220 | 2,391 | 786 | 1,054 | 688 | 874 | 5,622 | 9,167 | 3,545 |
| Vermont | 103 | 7,359 | 9,273 | 285 | 295 | 11 | 112 | 61 | 13,101 | 970 | 402 | 540 | 330 | 442 | 3,886 | 5,039 | 1,153 |
| Massachusetts | 642 | 89,519 | 7,824 | 2,987 | 3,086 | 99 | 748 | 831 | 13,203 | 20,604 | 3,944 | 5,936 | 3,393 | 3,887 | 7,929 | 42,305 | 34,376 |
| Rhode Island | 108 | 10,568 | 1,055 | 500 | 519 | 20 | 140 | 108 | 1,472 | 4,380 | 648 | 990 | 544 | 654 | 935 | 6,003 | 5,068 |
| Connecticut | 416 | 50,881 | 4,872 | 1,695 | 1,752 | 58 | 464 | 423 | 8,949 | 10,772 | 2,347 | 3,248 | 2,449 | 2,612 | 6,129 | 24,998 | 18,869 |
| Middle Atlantic | 4,837 | 591,459 | 99,733 | 17,219 | 18,112 | 892 | 5,658 | 4,570 | 172,999 | 87,271 | 23,735 | 37,355 | 19,500 | 22,755 | 74,775 | 233,699 | 158,924 |
| New York | 2,119 | 288,350 | 47,377 | 8,078 | 8,490 | 412 | 2,495 | 2,079 | 72,957 | 37,364 | 10,029 | 17,871 | 8,361 | 9,593 | 28,953 | 98,002 | 69,049 |
| New Jersey | 929 | 151,694 | 7,468 | 3,808 | 3,967 | 160 | 1,094 | 1,101 | 11,628 | 22,413 | 6,022 | 7,672 | 4,958 | 5,520 | 10,597 | 57,071 | 46,474 |
| Pennsylvania | 1,789 | 151,415 | 44,888 | 5,335 | 5,655 | 320 | 2,069 | 1,390 | 88,414 | 27,494 | 7,684 | 11,812 | 6,181 | 7,642 | 35,225 | 78,626 | 43,401 |
| East North Central | 6,163 | 682,521 | 243,961 | 19,293 | 20,780 | 1,486 | 7,354 | 4,339 | 444,583 | 121,144 | 27,806 | 41,597 | 23,852 | 29,932 | 131,686 | 314,458 | 182,772 |
| Ohio | 1,588 | 201,197 | 41,004 | 4,887 | 5,254 | 367 | 1,831 | 1,089 | 81,041 | 31,113 | 7,402 | 10,762 | 7,002 | 8,521 | 33,999 | 79,157 | 45,158 |
| Indiana | 956 | 73,497 | 35,932 | 2,577 | 2,752 | 175 | 1,127 | 594 | 73,833 | 17,702 | 3,590 | 5,474 | 2,748 | 3,708 | 21,657 | 43,643 | 21,986 |
| Illinois | 1,483 | 186,400 | 55,645 | 5,328 | 5,751 | 423 | 1,835 | 1,315 | 103,842 | 31,468 | 7,186 | 11,393 | 6,242 | 7,662 | 23,769 | 75,756 | 51,987 |
| Michigan | 1,425 | 160,509 | 56,954 | 4,159 | 4,529 | 369 | 1,730 | 921 | 91,120 | 26,683 | 6,379 | 9,189 | 5,481 | 6,945 | 31,038 | 75,706 | 44,668 |
| Wisconsin | 711 | 60,918 | 54,426 | 2,342 | 2,494 | 152 | 831 | 420 | 94,747 | 14,178 | 3,248 | 4,779 | 2,378 | 3,096 | 21,223 | 40,196 | 18,973 |
| West North Central | 2,704 | 202,289 | 508,132 | 8,565 | 9,065 | 500 | 3,293 | 2,027 | 694,758 | 55,283 | 11,452 | 17,430 | 10,232 | 14,400 | 79,617 | 145,113 | 65,496 |
| Minnesota | 466 | 42,019 | 79,548 | 2,139 | 2,261 | 122 | 601 | 532 | 118,776 | 14,067 | 2,471 | 4,236 | 2,466 | 3,172 | 16,531 | 35,167 | 18,636 |
| Iowa | 443 | 27,074 | 55,965 | 1,369 | 1,449 | 80 | 508 | 275 | 103,840 | 8,632 | 1,843 | 2,767 | 1,937 | 2,699 | 13,216 | 20,808 | 7,592 |
| Missouri | 928 | 67,750 | 68,945 | 2,426 | 2,590 | 164 | 1,085 | 634 | 104,385 | 15,297 | 3,471 | 5,057 | 2,667 | 3,712 | 20,922 | 43,379 | 22,457 |
| North Dakota | 90 | 5,119 | 69,300 | 314 | 331 | 17 | 113 | 57 | 84,496 | 1,747 | 434 | 661 | 383 | 650 | 4,175 | 5,681 | 1,506 |
| South Dakota | 107 | 6,221 | 75,952 | 340 | 355 | 15 | 156 | 65 | 71,743 | 1,726 | 485 | 696 | 410 | 674 | 4,998 | 6,426 | 1,428 |
| Nebraska | 256 | 21,917 | 76,644 | 772 | 812 | 40 | 298 | 192 | 87,445 | 4,956 | 1,069 | 1,567 | 867 | 1,305 | 8,279 | 13,091 | 4,812 |
| Kansas | 415 | 32,189 | 81,778 | 1,205 | 1,267 | 62 | 534 | 272 | 124,073 | 8,858 | 1,678 | 2,446 | 1,502 | 2,188 | 11,496 | 20,561 | 9,065 |
| South Atlantic | 8,632 | 679,712 | 266,910 | 19,591 | 20,649 | 1,056 | 9,714 | 4,457 | 387,779 | 111,771 | 28,540 | 41,625 | 25,182 | 32,835 | 156,024 | 352,504 | 196,480 |
| Delaware | 131 | 9,090 | 1,932 | 321 | 332 | 10 | 152 | 72 | 3,793 | 1,548 | 463 | 637 | 383 | 490 | 2,777 | 6,086 | 3,309 |
| Maryland | 729 | 85,265 | 9,837 | 2,303 | 2,405 | 102 | 815 | 565 | 16,129 | 11,836 | 3,009 | 4,566 | 2,719 | 3,309 | 12,293 | 36,493 | 24,200 |
| District of Columbia | 51 | 13,935 | 63 | 310 | 331 | 21 | 82 | 86 | 0 | 1,102 | 389 | 637 | 251 | 268 | 0 | 3,368 | 3,368 |
| Virginia | 906 | 80,115 | 39,704 | 2,869 | 2,996 | 126 | 1,075 | 606 | 51,631 | 14,494 | 4,053 | 5,933 | 3,614 | 4,628 | 25,093 | 54,834 | 29,741 |
| West Virginia | 418 | 27,805 | 24,119 | 669 | 750 | 81 | 503 | 99 | 32,202 | 2,971 | 1,303 | 1,858 | 821 | 1,194 | 9,896 | 13,742 | 3,846 |
| North Carolina | 1,416 | 114,674 | 48,843 | 3,130 | 3,276 | 146 | 1,577 | 613 | 74,928 | 18,306 | 4,319 | 6,405 | 3,492 | 4,870 | 29,636 | 54,600 | 24,964 |
| South Carolina | 968 | 38,058 | 30,203 | 1,543 | 1,634 | 91 | 1,087 | 278 | 54,104 | 9,316 | 2,195 | 3,381 | 1,783 | 2,366 | 19,394 | 30,224 | 10,830 |
| Georgia | 1,441 | 94,941 | 58,056 | 2,888 | 3,055 | 167 | 1,618 | 709 | 86,594 | 20,173 | 4,215 | 6,209 | 3,597 | 5,026 | 27,649 | 60,293 | 32,644 |
| Florida | 2,572 | 215,829 | 54,153 | 5,558 | 5,870 | 312 | 2,805 | 1,439 | 68,398 | 32,025 | 8,593 | 11,999 | 8,522 | 10,684 | 29,286 | 92,864 | 63,578 |
| East South Central | 3,502 | 186,240 | 178,824 | 6,501 | 7,067 | 566 | 4,178 | 1,360 | 269,070 | 44,481 | 10,044 | 15,073 | 8,984 | 12,055 | 71,729 | 130,056 | 58,327 |
| Kentucky | 768 | 49,768 | 39,669 | 1,536 | 1,684 | 148 | 883 | 327 | 62,078 | 7,551 | 2,338 | 3,684 | 1,811 | 2,720 | 17,604 | 30,320 | 12,716 |
| Tennessee | 1,101 | 68,602 | 41,155 | 2,182 | 2,336 | 154 | 1,298 | 502 | 68,559 | 15,132 | 3,157 | 4,784 | 3,195 | 4,027 | 20,483 | 42,126 | 21,643 |
| Alabama | 978 | 42,670 | 50,767 | 1,748 | 1,895 | 147 | 1,185 | 353 | 73,493 | 14,673 | 2,774 | 4,016 | 2,633 | 3,547 | 20,120 | 37,437 | 17,317 |
| Mississippi | 657 | 25,200 | 47,233 | 1,035 | 1,152 | 117 | 812 | 178 | 64,940 | 7,125 | 1,776 | 2,589 | 1,345 | 1,761 | 13,522 | 20,173 | 6,651 |
| West South Central | 4,700 | 354,683 | 427,271 | 11,727 | 12,863 | 1,134 | 5,524 | 2,789 | 429,559 | 110,412 | 17,589 | 26,523 | 13,218 | 19,521 | 97,260 | 231,377 | 134,117 |
| Arkansas | 550 | 20,206 | 52,078 | 1,003 | 1,092 | 88 | 658 | 215 | 69,457 | 7,630 | 1,658 | 2,343 | 936 | 1,445 | 11,829 | 18,306 | 6,477 |
| Louisiana | 730 | 72,962 | 44,521 | 1,715 | 1,949 | 234 | 867 | 322 | 46,061 | 12,211 | 2,614 | 4,345 | 1,953 | 2,891 | 16,724 | 30,279 | 13,555 |
| Oklahoma | 540 | 34,620 | 68,655 | 1,449 | 1,565 | 115 | 669 | 359 | 98,748 | 12,334 | 2,163 | 3,211 | 1,931 | 2,887 | 16,192 | 31,606 | 15,414 |
| Texas | 2,880 | 226,895 | 262,017 | 7,560 | 8,257 | 697 | 3,330 | 1,893 | 215,293 | 78,237 | 11,153 | 16,624 | 8,398 | 12,298 | 52,515 | 151,186 | 98,671 |
| Mountain | 2,881 | 190,465 | 855,194 | 5,955 | 6,417 | 464 | 3,209 | 1,581 | 444,227 | 42,155 | 8,980 | 13,147 | 7,356 | 10,736 | 56,281 | 116,448 | 60,167 |
| Montana | 198 | 8,442 | 145,388 | 373 | 403 | 30 | 223 | 81 | 69,395 | 2,416 | 604 | 805 | 416 | 650 | 5,949 | 8,074 | 2,125 |
| Idaho | 242 | 10,712 | 82,412 | 435 | 473 | 38 | 263 | 102 | 69,253 | 2,386 | 691 | 985 | 579 | 947 | 5,672 | 8,119 | 2,447 |
| Wyoming | 111 | 4,906 | 96,989 | 219 | 240 | 21 | 107 | 47 | 38,211 | 1,864 | 339 | 477 | 282 | 478 | 4,070 | 5,367 | 1,297 |
| Colorado | 516 | 39,870 | 103,595 | 1,564 | 1,694 | 130 | 615 | 424 | 65,653 | 11,077 | 2,310 | 3,261 | 2,221 | 3,033 | 10,497 | 26,968 | 16,471 |
| New Mexico | 493 | 25,780 | 121,335 | 622 | 682 | 61 | 525 | 148 | 49,157 | 4,592 | 1,038 | 1,479 | 803 | 1,285 | 8,234 | 15,116 | 6,882 |
| Arizona | 811 | 63,278 | 113,508 | 1,511 | 1,612 | 101 | 925 | 456 | 66,517 | 11,208 | 2,273 | 3,438 | 1,712 | 2,417 | 13,367 | 31,729 | 18,362 |
| Utah | 271 | 21,492 | 82,073 | 709 | 757 | 48 | 307 | 180 | 44,532 | 5,369 | 1,006 | 1,678 | 754 | 1,114 | 4,819 | 12,679 | 7,860 |
| Nevada | 239 | 15,985 | 109,894 | 522 | 566 | 35 | 244 | 143 | 41,509 | 3,245 | 719 | 1,024 | 589 | 812 | 3,673 | 8,398 | 4,723 |
| Pacific | 6,376 | 483,662 | 896,252 | 17,038 | 18,132 | 1,096 | 7,505 | 5,559 | 252,368 | 96,140 | 24,675 | 36,622 | 20,903 | 27,412 | 80,732 | 299,271 | 218,539 |
| Washington | 691 | 67,665 | 66,511 | 2,085 | 2,255 | 171 | 865 | 606 | 63,399 | 16,110 | 3,157 | 4,533 | 2,702 | 3,828 | 14,799 | 38,520 | 23,721 |
| Oregon | 553 | 38,850 | 96,184 | 1,301 | 1,387 | 86 | 642 | 345 | 85,398 | 8,527 | 2,028 | 2,701 | 1,657 | 2,243 | 13,678 | 23,332 | 9,656 |
| California | 4,935 | 360,699 | 156,299 | 12,938 | 13,729 | 792 | 5,774 | 4,391 | 90,546 | 68,386 | 18,563 | 27,781 | 15,715 | 20,294 | 47,932 | 226,301 | 178,369 |
| Alaska | 70 | 4,983 | 570,833 | 221 | 248 | 27 | 80 | 72 | 10,360 | 1,722 | 300 | 539 | 225 | 357 | 2,123 | 3,900 | 1,777 |
| Hawaii | 127 | 11,465 | 6,425 | 493 | 513 | 20 | 134 | 145 | 2,675 | 1,395 | 628 | 1,068 | 604 | 690 | 2,202 | 7,218 | 5,016 |

**Table 2-15. Dependent Variables for Regression Examples**

| Example | Dependent Variable |
|---|---|
| 1 | Receipts for SIC 7532 - Top/Body Repair & Paint Shops |
| 2 | Employees for SIC 7532 - Top/Body Repair & Paint Shops |
| 3 | Sales for SIC 5198 - Wholesale Trade: Paints, Varnishes, and Supplies |
| 4 | Employees for SIC 5198 - Wholesale Trade: Paints, Varnishes, and Supplies |
| 5 | Non-Fatal Accidents by State |
| 6 | Estimated Number of Refinishing Painters by State and County |

In the regression analysis tables for each example below, the t-ratio is calculated for each variable included in the model. The t-ratio indicates whether the coefficient ($b_i$) of the variable ($X_i$) is statistically different from zero. The statistical level of significance is coded at the bottom of each table. A significance level of 0.05 suggests there is 95 percent certainty that the coefficient of the variable is not equal to zero, while 0.01 suggests 99 percent certainty.

$R^2$ measures the strength of the linear relationship between the dependent variable and the predictor variable(s). The value indicates what percent of the total variation in the dependent variable can be explained by the model. An $R^2$ of zero represents no correlation while an $R^2$ of one represents a perfect fit. There is no predetermined value of $R^2$ that represents a strong relationship. Interpretation of the strength of the relationship has the greatest meaning when comparing similar regression models using the same data.

*Example 1: Auto Refinishing Receipts*

The first example results for correlations with refinishing receipts are given in Table 2-16. Licensed drivers correlates best and the multiple regression $R^2$ is 0.963.

**Table 2-16. Receipts for SIC 7532 Predicted by 5 Independent Variables**

| Dependent variable = REC_7532 | |
|---|---|
| **Variables** | **t-ratio** |
| Licensed Drivers | 9.470** |
| Highways (Rural) | -3.075** |
| Accidents (Non-fatal) | -4.549** |
| Accidents (Fatal) | -3.652** |
| Highways (Urban) | -2.572* |

$R^2$ =0.963001 Adjusted $R^2$ =0.958597 Cp = 39.32060
* Statistically significant at the 0.05 level. ** Statistically significant at the 0.01 level.

*Example 2: Auto Refinishing Employment*

Employment correlates slightly better than receipts with the independent variables. The same explanatory variables serve to predict county refinishing employment levels, as shown in Table 2-17.

**Table 2-17. Employment in 7532 as Predicted by 5 Independent Variables**

| Dependent variable = EMP_7532 | |
|---|---|
| **Variable** | **t-ratio** |
| Licensed Drivers | 9.937* |
| Highways (Rural) | -2.831* |
| Accidents (Non-fatal) | -4.465* |
| Accidents (Fatal) | -3.154* |
| Highways (Urban) | -2.858* |
| $R^2$ =0.972707 Adjusted $R^2$ =0.969457 Cp = 31.74646<br>* Statistically significant at the 0.01 level. | |

The results shown in the first two examples are very similar. The stepwise selection chose the same five variables to predict the quantity of receipts and the number of employees in SIC 7532. More than 95 percent of the variation can be explained by these five variables. The stepwise regression also selected licensed drivers as the first (and most significant) variable for SIC 7532, explaining more than 91 percent of the variation in receipts and more than 93 percent of the variation in employees.

*Example 3: Motor Vehicle Accidents*

For this example, a previous explanatory variable, Non-fatal Accidents (ACC_NF) was selected as the dependent variable to help explain the variation in the business activity from SIC 7532. Conversations with experts from the automobile refinishing industry have revealed that most automobile refinishing is performed as the result of collision damage. Therefore, it is likely that emissions from automobile refinishing is proportional to the number of accidents.

The regression takes three years of data collected for each of the contiguous states. These accidents (as opposed to fatal accidents) are more likely to generate demand for automobile refinishing. The explanatory variables in this regression were chosen because they do not exhibit multicolinearity (redundant variables which can skew the results of statistical analyses).

Table 2-18 shows that there is a strong linear relationship between the number of accident injuries and the explanatory variables, as expressed by the relationship

**Non-fatal Accidents = $b_0$ + $b_1$(Licensed Drivers) + $b_2$(Urban Highways) + $b_3$(Rural Highways)**

**Table 2-18. Results from Motor Vehicle Accident Analysis**

| Variable | t-ratio |
|---|---|
| Constant, $b_0$ | 1.715 |
| Licensed Drivers | 16.278* |
| Highways (Urban) | 1.744 |
| Highways (Rural) | -2.678* |

$R^2$ = 0.949 Adjusted $R^2$ = 0.948
* Statistically significant at the 0.01 level.

The t-ratios and $R^2$ indicate that:

1) As the number of licensed drivers and miles of urban highway in a state increases, the number of accidents is expected to increase.
2) As the number of miles of rural highway increases, the number of accidents is expected to decrease.
3) Nearly 95 percent of the variation in accidents can be explained by these three predictor variables.

*Example 4: Sales in SIC 5198 as Predicted by Labor Force, Total Vehicle Miles, and Population*

The sales for SIC 5198 should provide the best guess at sales of auto refinishing paints using readily available data (see Table 2-19 -- the best data source would be the paint manufacturers -- see Section 3.3).

**Table 2-19. Estimating SIC 5198 Sales**

| Dependent variable = Sales from SIC 5198 | |
|---|---|
| **Independent Variable** | **t-ratio** |
| Civilian Labor Force Employment | 4.114** |
| Total Vehicle Miles Traveled | -2.979** |
| Resident Population | -2.387* |

$R^2$ = 0.923707 Adjusted $R^2$ = 0.918125 Cp = 22.27208
* Statistically significant at the 0.05 level.
** Statistically significant at the 0.01 level.

These results are not as impressive, but that was expected because SIC 5198 is defined as a wholesale trade industry. The sales and employees associated with the industry are not always located in the state where the auto refinishing is

performed, and a significant portion of the paint products are likely to be used for other applications, such as marine painting.

*Example 5: SIC 5198 Employees as Predicted by Labor Force and Rural Highway Miles*

The labor force and rural highways were the best two variables for this correlation. The strong negative t-ratio for rural highway miles would seem to imply that most SIC 5198 employment is in non-rural, metropolitan areas.

Despite these characteristics, 92 percent of the variation in sales and almost 96 percent of the variation in employment could be explained using the variables selection. The number of persons employed in the civilian labor force was the most significant variable with SIC 5198, explaining 89 percent of the variation in sales and 95 percent of the variation in employees (see Table 2-20).

**Table 2-20. Estimating SIC 5198 Employment**

| Dependent variable = EMP_5198 | |
|---|---|
| **Independent Variable** | **t-ratio** |
| Civilian Labor Force Employment | 29.192** |
| Highways (Rural) | -26.27* |
| $R^2$ = 0.957546 Adjusted $R^2$ = 0.955525 Cp = 28.83186<br>* Statistically significant at the 0.05 level.<br>** Statistically significant at the 0.01 level. | |

*Example 6: Auto Refinishing Painter Estimation*

Establishment-level data was acquired from American Business Information (ABI), including all establishments with business in SIC 7532-01 (Automobile Body Repairing and Painting). This list reported 53,890 establishments with primary SIC 7532 (Automobile Top and Body Repair and Paint Shops) and 10,634 with other primary SICs (Total: 64,524). Approximately 90% of the listing includes a measurement of the exact number of employees.

For those establishments without employment figures, the shop was assumed to have 4.5 employees. This is the average number of employees for the other establishments with primary SIC 7532.

To estimate the number of painters (see Table 2-21), it was assumed:

(1) One-third of employees at an establishment are painters (BodyShop, 1992)
(2) No more than four painters per establishment (Meeting, 1993).

To estimate VOC emissions from the painters, it was assumed:

(1) 5.72 lbs. VOC/coating gallon as sprayed (Meeting, 1993).
(2) 72% to coatings (*i.e.*, According to one MRI study (Athey, 1988), 28% of emitted VOCs come from surface preparation and cleanup. Therefore, 5.72 lbs. VOC/coating gallon was divided by 0.72 to account for surface preparation and cleanup emissions, resulting in 7.94 lbs. VOC/gallon.)
(3) 7.94 lbs. VOC for all gallons
(4) 0.125 gallons per painter hour (Mitchell, 1992)
(5) Painters work 8 hours per day, 250 days per year (Meeting, 1993).

From these assumptions, emissions from the automobile refinishing industry are estimated to be 185,763,471 lbs. (or 92,882 tons) of VOC for the United States in 1993.

As a rough estimate, these figures can be compared to:
(1) A recent study (Everette, 1993) indicating emissions of 106,700 tons. This figure does not include surface preparation or cleanup.
(2) The EPA-CTG which estimates emissions at 286,000 tons.

**Table 2-21. Estimating SIC 7532 Total Painters (Single-Variable Regression)**

| Variable = 7532 PNTR_TOT | | |
|---|---|---|
| **Independent Variable** | **t-ratio** | **$R^2$** |
| Licensed Drivers | 121.270 | 0.9878 |
| Civilian Labor Force (Total) | 114.903 | 0.9864 |
| Registered Motor Vehicles | 103.438 | 0.9833 |
| Resident Population | 101.655 | 0.9827 |
| Motor Vehicle Fatalities | 52.627 | 0.9380 |
| All variables are statistically significant at the 0.01 to 0.05 levels. | | |

In addition to the multiple regressions just shown in Example 6, emission estimates were also derived per state using the same assumptions. Single variable linear regressions were executed using the derived emission estimation from estimated painters and 1991 explanatory variable values from the 48 contiguous states. The explanatory variables included in the regressions in order of their correlation rankings (in terms of their $R^2$ value) are shown in Table 2-22.

**Table 2-22. Single Variables for Emissions Estimates from Number of Painters: 48 States**

| | Regression Results | | |
|---|---|---|---|
| Explanatory Variable | Coefficient | Constant | $R^2$ |
| Civilian labor force, total | 0.6918 | 131.45 | 0.97963 |
| Licensed drivers | 0.5213 | 101.58 | 0.97961 |
| Civilian labor force, employed | 0.7465 | 120.14 | 0.97931 |
| Resident population | 0.3376 | 163.96 | 0.97488 |
| Registered motor vehicles | 0.4783 | 59.451 | 0.96990 |
| Registered automobiles | 0.6078 | 126.48 | 0.96951 |
| Vehicle miles traveled, total | 0.0411 | 74.348 | 0.95944 |
| Vehicles miles traveled, urban | 0.0536 | 494.11 | 0.93508 |
| Non-fatal accidents | 0.0237 | 243.44 | 0.91846 |
| Fatal accidents | 2.4101 | 82.473 | 0.91197 |
| Road miles, urban | 0.1119 | 183.02 | 0.90994 |
| Vehicle miles traveled, rural | 0.1287 | -433.33 | 0.75825 |
| Road miles, rural | 0.0221 | 481.70 | 0.20368 |

Therefore, the best explanatory variables for use in estimating the derived state-level emission estimates are total civilian labor force, licensed drivers, employed civilian labor force, and resident population

The same sort of single variable linear regression was also performed for SIC 7532 Sales. The relative correlations, as reflected by $R^2$, Table 2-23, are seen to be less strong, and with a somewhat different priority ordering for the explanatory variables. However, the results support a preliminary conclusion that good estimates can be obtained from annually accessible, local data.

**Table 2-23. Single Variable Linear Regressions for 48 States: Automobile Top and Body Repair and Paint Shops SIC 7532 Sales ($1000) from the 1987 Economic Census**

| Explanatory Variables | $R^2$ |
|---|---|
| Vehicle miles traveled, urban | 0.9328 |
| Licensed drivers | 0.9116 |
| Civilian labor force, employed | 0.9092 |
| Civilian labor force, total | 0.9046 |
| Registered automobiles | 0.9040 |
| Resident population | 0.8943 |
| Registered motor vehicles | 0.8811 |
| Vehicle miles traveled, total | 0.8729 |
| Non-fatal accidents | 0.8411 |
| Fatal accidents | 0.8220 |
| Road miles, urban | 0.7285 |
| Road miles, rural | 0.7081 |
| Vehicle miles traveled, rural | 0.5200 |

In many cases, the observations (data) are likely to exhibit different variances (square of the standard deviation) heteroscedasticity because the observations represent individual states that vary considerably in magnitude of data (California has more than 60 times the population of Wyoming). Histograms for most of the variables show that many states have relatively small measures while a few states have relatively large measures for the different variables. This issue, though relevant, is corrected using statistical methods such as taking the natural log of the explanatory variables before running the regression model. The results of this transformation showed the same direction of correlation between the explanatory variables and the number of accidents, but with even greater statistical confidence ($R^2 = 0.973$, Adjusted $R^2 = 0.972$).

A few state-level variables (*e.g.*, Licensed Drivers, Civilian Labor Force Employment) appear to be highly correlated to the auto refinishing industry. This type of data is collected at regular intervals, available to the public, and is available for small geographic regions, such as counties and cities. If these same variables show a high correlation to auto refinishing solvent usage, national emission figures may be allocated to smaller geographic regions using these predictor variables.

## 2.4 Analytical Tool Set Selection

The previous Section demonstrates that data for emissions estimation exist and that they are readily available within acceptable limits. Therefore, to improve emissions estimation, the next question was how to assess the variable relationships and how to more accurately predict solvent use and emissions. The typical multiplicative calculation for emissions was shown in Section 2.2 to be

$$\textit{Emissions} = \textit{Activity level} \times \textit{Emission factor} \times [1-(CE \times RE \times RP)]$$

However, such an algorithmic approach may not deal well with such information as expert opinion, linguistic descriptions of variables (*e.g.*, "very high solvent use"), very large numbers of variables, or large heterogeneous data sets. Validation of solvent usage in the auto refinishing industry may show that such complications are not actually important. However, until validation results are available (see Section 3), the estimation should provide for using techniques that can manipulate the best data to produce the most accurate results. This means the development of a complete analytical tool set, using some new techniques that are proving themselves to be efficient and capable of extending the range of analysis in many research areas.

This Section describes the basic tools and Sections 2.3.2, 2.5, 3.2, and 4 describe the planned utilization of the tool set once validation data is available to optimize the analysis.

The current toolset includes Computational Intelligence tools, statistical tools, and a geographic information system. *Computational Intelligence* (CI) is a term adopted by the Institute for Electrical and Electronics Engineers (IEEE) for innovative computational techniques like artificial neural networks, fuzzy logic, and genetic algorithms. CI techniques have advantages where:

- Information is imprecise or qualitative. Heuristic rules can analyze and interpret this information.

- The amount of data is very large.

Tool set characteristics are described in more detail in the following. Tools will be used to

- select the best data,
- incorporate the best computational forms for using data,
- incorporate expert opinion and linguistic descriptions, and
- provide optimal information displays and information transmittal.

*Statistics*

Simple statistical techniques are being employed as the preliminary step for analyzing variable relationships and selecting a priority variable set. Multivariate regression analyses (linear correlations) have been applied and correlation indicators derived. Results obtained so far have encouraged development of a comprehensive database of easily attainable variables that can later be used to predict emissions. There appears to be a high correlation between the automobile refinishing industry and several of the explanatory variables have been included in the database, as discussed in the previous Section.

Analysis has been performed within Lotus 1-2-3 by examining 1) the distribution of the variables across different regions of the country, 2) the change in the variables over time, and 3) the ratio of one variable to another. These relationships have been examined in both spreadsheet form and graphical form.

As described in Section 2.3.2, regression analysis has been applied to examine the relationships between the variables. Econometric Software's *LIMDEP* -- a flexible software package for estimating regression models most frequently analyzed with cross section data -- has been used as the tool to examine the county- and state-level, annual data. A first set of regressions predicts the level of business (in terms of receipts, sales, or number of employees) in automobile refinishing-related SICs.

*Expert Systems*

An expert system is a computer-based system that contains human expertise or reasoning capabilities. Traditionally, expert systems have been developed to capture the experience and knowledge of a human expert(s). An expert system may be developed because the expert may be leaving his organization or profession, or cannot meet the many requests for his knowledge. More often than not, an expert system may play an advisory role as a decision support system. This use of an expert system is more readily accepted than replacing the "man in the loop."

This study has examined over 30 expert systems which are related to environmental control, such as GEOTOX (Alberta, 1990), a program with knowledge base and inference engine designed to recommend hazardous waste disposal methods. The programs can be generally classified under 1) diagnosis, 2) planning, or 3) prediction. Almost all deal with highly specific, well-researched problems and extend one or more previous solutions to similar cases. Most of these expert systems are experimental and not used in actual practice.

A true expert system approach for VOC emissions estimation would imply that someone is now performing emissions estimates correctly and their knowledge can be incorporated into rules that will produce consistently accurate estimates. This is not the case. Therefore, a new expert system must evolve if one is to be applied (see Section 3.2).

Expert opinion is considered to be useful in such areas as the following:

1) Explaining discrepancies between receptor models and other emissions estimates.
2) Assessing potential impact of controls and operating practices in the workplace to reduce emissions.
3) Characterizing shops most likely to use controls and responsible shop practice.
4) General factors relating solvent use to population, employee numbers and sales.
5) Rules of thumb for how much paint a shop will use.

Reliance on environmental experts has been deemphasized because of possible bias toward previous estimation methods. Also, effort under this study has been able to gather most of the substantive and creative information from past emissions estimators during discussions in the first part of the case study and from the literature.

Further study (Section 3) should emphasize industry experts, and possibly an expert in the area of source dispersion. The latter should have an overview of the influences on emissions by 1) types of equipment in use, 2) VOC chemical/physical properties as they affect time and space allocations associated with individual area sources, and 3) control and pollution prevention techniques at area sources. This expertise may be strongest in the industry itself. The directive for the research at present does not encompass atmospheric chemistry and specific precursor potential for the VOC constituents from auto refinishing. A fuzzy logic expert system has been chosen to augment estimation of VOC emissions from the automobile refinishing area sources. The fuzzy logic concept is discussed next.

*Fuzzy Logic*

The rules derived from industry and emissions experts thus far have been, at best, very general. Since "crisp-logic", rule-based, expert systems do not handle "approximate reasoning" well, fuzzy logic expert systems are being considered. Fuzzy logic is an approximate reasoning technique used in processing inexact information. While a typical expert system may be thought of as defining "true or false" conditions, fuzzy systems allow for varying degrees of truth, or "shades of gray," more like human reasoning.

Typical artificial intelligence (AI) expert systems chain through rules, inferencing through a decision tree. These trees usually employ only part of the non-interactive rules, the rules are crisply interpreted as true/false (0,1), and the knowledge is structured but stored and processed symbolically, outside of numerical computation. Fuzzy systems use structured knowledge in a numerical framework, use weighted "principles" instead of true/false rules, and fire every interactive rule with every inference (AIM, 1993). The numerical framework and interactive approach allows analysis of the association of "clumps" of output spaces with "clumps" of inputs, so that individual rules can act like partial derivatives, as used to solve engineering problems.

Climate might be a factor in emission levels, and could be classified as *dry*, *moderate*, or *rainy*. Areas where emissions occur might also be loosely classified as: *rural*, *suburban*, or *urban*. A CI rule, based on expert opinion, may be expressed as, "IF the climate is *dry* AND the area is *rural* THEN emissions are *low*." Another rule may state "IF the climate is *wet* AND the area is *urban* then emissions are *high*." These rules describe the increased likelihood of accidents and auto refinishing in a congested area with poor weather and vice versa. This type of reasoning can augment more rigid evaluation computations.

Fuzzy logic will probably supply a set of secondary emission factors (V1, V2, V3,....Vn) based on qualitative or uncertain influences to augment the best quantitative data correlations between emissions and independent variables. These would contribute by such a relationship as

$$\textbf{Total Emission Factor} = \mathbf{EF_{quantitation}} \times \mathbf{V1} \times \mathbf{V2} \times \mathbf{V3}...$$

where a specific example might be

*if{county=suburban} and {winter=average} then {VOC emissions factor V3=moderate}*

Quantitative data are simple to fuzzify. If, for instance, a county has a given population and a given number of farms, it may have a suburban membership of 0.3 (on a 0 to 1 scale) while its rural membership may be 0.7, based on membership functions. A membership function in this case might be based on population per unit area. In another case, a county's snowfall this year might set membership for the winter as severe, average, or mild.

Fuzzy logic can be applied in the computational part of the estimation method programmed rules and a resident database or using information supplied by the interactive user while involved in completing local emission estimations. Of course, an actual rule set will cover a wide range of possible parameters such as accidents, refinishing regulations, equipment and types of coatings used, and economic data. As the number of inputs grows, the number of possible rules may

grow into the hundreds. To verify these rules, it is necessary to have extensive validation data. This data should come from the nationwide survey (see Section 3) which asks questions that are specifically geared to the variables considered essential. Further clarification of fuzzy logic is presented in the next Section.

*Neural Networks*

An artificial neural network (ANN) is an analysis tool that is modeled after the massively parallel structure of the brain. It simulates a highly interconnected, parallel computational structure with many relatively simple, individual processing elements or neurons.

Neural network paradigms are capable of learning or extracting a relationship between two domains, *i.e.*, two sets of information. Neural networks are best applied where there are no known rules (expert systems) or algorithms (statistically-based methods) that accurately relate the independent and dependent variables of interest, but there is an abundance of data resulting from the relationship.

Mathematically speaking, neural networks are non-linear differential equations that parameterize themselves through various learning algorithms. One of the most commonly used learning algorithms is call the backpropagation algorithm. The name originates from the fact that the neural network learns from errors that are propagated backward from the network's output to its input. Neural networks are able to generalize. That is, a trained network will correctly classify an input that it has not seen before. This has proven to be a powerful capability when the training data is incomplete.

<u>Advantages of Neural Nets</u>: 1) The neural network does not have to be programmed. It will learn from example; as in statistics, the more data points, the better. 2) A neural network's ability to generalize will prove beneficial in estimating emissions since disclosure rules may limit the availability of some useful explanatory variable data points. 3) Once a network has been trained, it provides an instantaneous output for each set of inputs. There are no iterations required in generating an output.

<u>Disadvantages of Neural Nets</u>: 1) Since the network learns from example, if it learns from bad data, its answers will be of equivalent quality. 2) The backpropagation learning algorithm does not allow a network to train on additional data points without being retrained on the original data set. This can be a time consuming price to pay if one wishes to regularly update the network. 3) Exactly what relationship the network has learned is not readily apparent. There is no built-in explanation capability. Since the relationship learned by the

network is non-deterministic, it is difficult to quantify the reliability of a network's output without exhaustive testing.

An important distinction between two important techniques in this study is that "neural networks sum throughputs, and fuzzy systems sum outputs" (ModelWare™, 1992). Neural networks can adaptively generate fuzzy rules per the technique of *product-space clustering* (ModelWare™, 1992). This is an attractive technique for handling a large body of unstructured knowledge (*e.g.*, from experts in auto refinishing or computer files from different paint manufacturers). Experts who generate input-output data do not need to articulate the fuzzy rules. They only behave as experts. Rules are made equivalent to the neural net synaptic vector clusters which track how experts associate responses with input stimuli.

*Polynomial Networks*

Another possible technique considered for estimating emissions is polynomial networks (AIM, 1993). The polynomial network tool tested is called *AIM*. AIM is a numerical modeling technique that automatically synthesizes a mathematical model of relationships among data. AIM then implements the resulting model as a standard computer program. AIM excels at modeling numeric parameters such as expert judgements, probabilities, fuzzy values, prices, costs, sensor readings, and control settings. Models are not implemented as rules, but as mathematical models called polynomial networks.

Rules (if/then rules) are very effective at modeling discrete symbolic knowledge. AIM can develop functional models for complex numerical relationships that are generally more compact and faster to execute than if/then rules.

*Universal Process Modeling*

Another technique being considered for use in estimating emissions involves the use of universal process modeling (UPM). The UPM tool being used for this analysis is called *ModelWare*™ (ModelWare™, 1992). The UPM algorithm is an empirical modeling technique. It requires a set of example data, known as the Reference Library, which describes how the system or process behaves under known operating conditions. *ModelWare*™ predicts system behavior from the stored Reference Library, making a prediction for *all system variables* from each set of input system observations. As with all other techniques, ModelWare's role in the prototype system will be determined by its prediction accuracy with respect to the emissions validation data.

*Genetic Algorithms*

Genetic algorithms (GAs) are an optimization technique based on Darwin's "survival of the fittest" theory. GAs use three processes found in natural genetics to attempt to optimize a given problem: reproduction, crossover, and mutation. The parameters of the problem are converted into a binary string. For example a problem with four parameters may have a string which looks like

$$\begin{array}{cccc} |10010| & 11000| & 10010| & 11101| \\ x_1 & x_2 & x_3 & x_4 \end{array}$$

Each variable has a given range over which one is trying to find the optimum value. This range is linearly mapped to give the binary string as shown above.

A population of these strings is then created randomly and becomes the gene pool of initial possible solutions. Each string is then evaluated for its "fitness" to determine how well it solves the problem (*e.g.*, emissions estimation). Based on the fitnesses of all the strings, a new population is generated. Strings with high fitnesses will be given a proportional number of copies in the gene pool, while strings with low fitnesses may die out. The members of the new generation are then randomly matched for crossover, where a point along the string is randomly chosen and the "tails" of the two strings beyond this point are exchanged as shown below.

| | | |
|---|---|---|
| *Parents*: | 100101100010010 | 11101 |
| | 010100101011101 | 00101 |
| *Children*: | 100101100010010 | 00101 |
| | 010100101011101 | 11101 |

After crossover, each bit is flipped (mutated) using a low probability (somewhere around 0.0005). Mutation is used to assist in keeping diversity in the population. This sequence of events is continued over several generations until all the members of the gene pool converge towards the same string. This string should contain the optimum values for the desired parameters.

*Geographic Information System*

Emissions are characterized by their levels and by their distribution in space and time. MapInfo® is a geographic information system (GIS) being used to assign emissions-related explanatory variable values, such as number of employees and annual sales, to the actual location of an individual business. These values can

then be aggregated to combine values within a zip code, county, nonattainment area, metropolitan statistical area (MSA), State, EPA Region, or nation. For State Implementation Plan (SIP) emission inventory purposes, for example, area source emissions would be aggregated to county and to nonattainment area boundaries. The next subsection on system configuration and Section 4 better illustrate the advantages of GIS.

## 2.5 Configuration of the VOC Emission Estimation System (VOCEES)

The best screened data and analytical tools must be combined into an integrated computation system that handles database management, data retrieval, computation and analysis, and output of results. This system should obviously be computerized but simple and affordable. This system has been designed and demonstrated with surrogate data and tools as part of the current effort.

Developing the computational system for emissions estimations consists of selecting the best explanatory variables and survey data and processing this with the assembled tool set. Computational intelligence tools have been specified to help meet the specified method development criteria. The tool set's statistical components have been used to prescreen the best data for use in development.

*System Tools*

A personal computer-based VOC Emission Estimation System (VOCEES) automates the data management, computation, and displays/reports under the new method. The main components of the system are: 1) the essential explanatory variable database; 2) basic algorithms; 3) the supplemental fuzzy logic expert system; and 4) the GIS-based user interface.

Figure 2-6 shows the system paradigm to which the research team has worked. This model is adaptive. The final format for emission estimation will depend on the final, validated data correlations and variable selections.

VOCEES is a fully integrated PC-based software package. Since the system is intended to present data in both map and graph oriented fashions, it was designed to work under Microsoft *Windows*. The heart of the system is an emissions estimation engine derived both in-house and through the use of commercially available software. The core of this engine is written in BASIC, as is the user interface. As additional components become available for the engine (*i.e.*, fuzzy logic or neural networks), they will be written as BASIC code and incorporated directly into the core code or can be written as C or Pascal direct link libraries (DLLs) and connected through *Windows*.

MapInfo® is a geographic-oriented, information display software that provides a natural choice for the VOCEES system. It incorporates the two major components necessary for this type of project: database management and mapping capability. MapInfo provides a full-featured Structured Query Language (SQL) database management system that can directly use either dBASE files or files written in MapInfo's native format. Also, MapInfo can import *Lotus 1-2-3* and Microsoft *Excel* spreadsheets, and, since it is a *Windows* based product, can use cut and

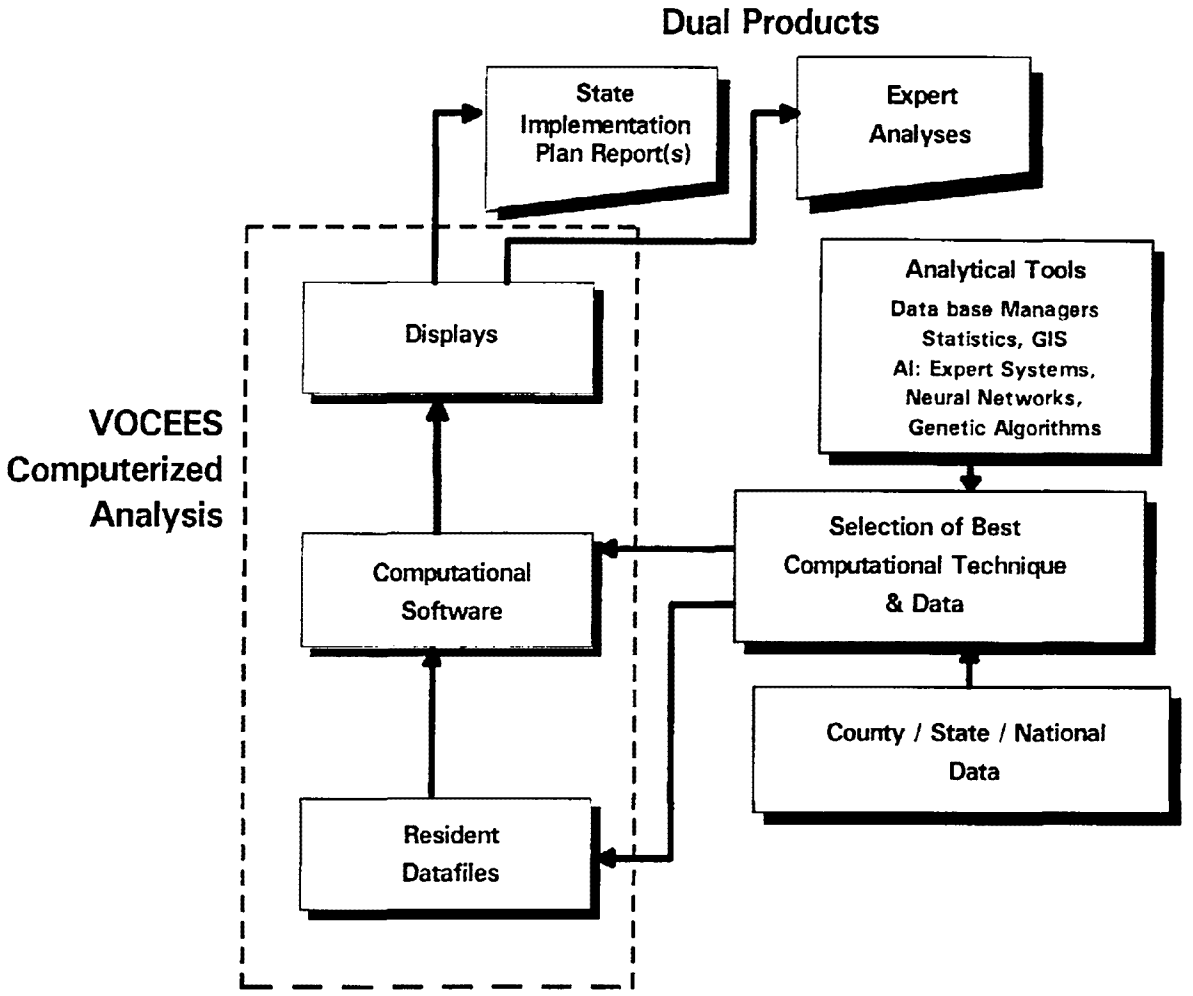



**Figure 2-6. System Configuration in Context of Method Elements**

paste to create MapInfo files from spreadsheets not directly supported. Adding to the list of features which made MapInfo the basis for VOCEES is its companion product, MapBasic®. MapBasic is a BASIC language compiler which provides additional commands specifically designed for MapInfo. MapBasic was used to provide the customized *Windows* interface which transformed MapInfo from a generic mapping software program to an emissions estimation software program.

The geographic coordinates of source locations can be stored in the GIS and analyzed and displayed along with county boundaries and even roads, if desired. Road networks, with attributes indicating the type of road, are available from the Census Bureau's TIGER data (Topologically Integrated Geographic Encoding and Referencing). The TIGER data also has zip code and street address information which allow locations to be geographically located from their street address. The TIGER files and other data bases which can be displayed with the GIS system can represent all 3300 counties as polygons with representative coordinates. The past

emissions estimates by county can be represented using the GIS system to highlight any geographic trends or biases. The same can be done with vehicle registrations, accidents, distribution of auto body shops, and nonattainment areas.

*System Integration and Function*

Using the object libraries available through *MapBasic*, a Windows-based Graphical User Interface (GUI) was created. This interface was designed with ease of use as a primary consideration. The interface follows the standard Windows interface in both look and feel. This is necessary to maintain the concept that all Windows applications should behave and appear the same to increase their usability. The menu bar is the main control center of the interface. From the menu bar, the user can open windows containing information about different geographic regions, edit this information, calculate emissions, and graph or map the results. As with any Windows program, the application can be minimized to allow work on other applications or maximized for full screen use.

VOCEES was designed with a maximum flexibility in the display of information. Data can be presented as maps, graphs, or tables. Users have a choice of examining counties, nonattainment areas, states, or EPA regions. Also, since VOCEES can be used to examine emissions for different years, temporal changes can easily be observed. This capability is especially useful in the examination of the impact of regulations: local, state, and possibly national. One of the advantages of VOCEES is its incorporation of regulatory impact of VOC content limitations and the enforcement of these regulations. Maps, graphs, and tables can display the explanatory variables or the emissions calculated using these explanatory variables. Maps have a wide range of combinations, including counties in a Nonattainment Area (NAA), counties in a state, NAAs in a state, and so on. Since emissions can be calculated using any of these explanatory variables, the user has the opportunity to graphically display variations in emissions distribution using these variables. The ability to display information in many formats can also enhance SIP generation. Many different display modes enhance the presentation of data, and this fact is key to VOCEES functionality. Mapping provides the ability for the user to get an immediate idea of emissions distribution at the county, NAA, or state level, something that cannot be done through the use of tabular data.

VOCEES can examine temporal changes in explanatory variables, regulations, and emissions. The database used to generate these emissions can be modified by the user. From the main menu, the user can choose to update any information at the county level. These changes will be used to update any NAA information (if the county belongs to a NAA), state level information, and EPA region information. Changes cannot be made above the county level since that would mean an aggregation of county level data would not match the corresponding

NAA, state, or EPA region data. Included with the system is default data for each year so if data is accidentally lost a reasonable replacement value can be obtained. Regulatory information is given in the form of VOC content limits for the various auto refinishing products. These limits can be updated and the enforcement of these regulations can be modified (from 0% to 100% enforcement).

File structure is kept as simple as possible. There are 4 input file types containing county, NAA, state, and EPA region level data. Each year of data would contain each of these four types of files. These files are in *MapInfo*'s .TAB format. In addition there are 4 files that contain the information to map the counties, NAAs, states, and EPA regions. Separating the maps from the data can greatly reduce the amount of disk space needed since only one set of maps is needed for many years worth of data. Output can be done in a number of ways. Information changes will be kept in the aforementioned files. Also, any tables created to display information in VOCEES can be saved as either an ASCII text file or a dBASE file. Finally all information displayed on the screen can be sent to any printer through the use of *Windows*.

## 3. EXTENDED METHOD DEVELOPMENT

Five areas of new method development have been begun under this case study, but could not be completed within the confines of time available and the original scope of work. Based upon analysis, preliminary results and EPA recommendation, these five areas should be extended to completion in future. The areas, in suggested order of importance, are

1) Nationwide Survey for Validation of Emissions and Verified Correlations with Explanatory Variables -- this activity is essential to the project's success, providing confirmation of solvent use and variable correlations.

2) Application of Computational Intelligence (Fuzzy Logic, Expert Systems, Neural Nets and Genetic Algorithms) to Emissions Estimation Using Validated Data -- these tools allow new kinds of information to be used, accelerate the data selection process, and provide more accurate estimates.

3) Re-examination and Potential Negotiations of the Use of VOC-Containing Product Manufacturers Data for Validation and Database Updates -- very important to provide an accurate estimate of geographic distribution of product categories and to compare with survey data, and extend survey results to an annual validation update.

4) Sampling and Chemical Analysis of Selected VOC Species at a Limited Number of Area Source Sites -- important to improve credibility of emissions predictions and to improve the VOCEES extrapolation of product use data to actual annual volume of emissions of VOC.

5) Graphical Interpretation of Past Emission Estimation Data -- important for comparison with VOCEES estimates, to illustrate needs for estimating improvement, and to provide a baseline perspective of techniques to date.

A Method for applying the techniques is shown in Figure 3-1. This figure diagrams the recommended New Method for area source emissions estimates. Under the method, a national survey of auto refinishing shops and input from area source experts combine to provide validation data. "Industry experts" would ideally include data from paint manufacturers on distribution of parts and solvents by geography and type. Expert opinion from industry consultants, managers, and sales representatives will also contribute to rules that make up the knowledge base and inference engine for computational intelligence analysis. Validation data consists mainly of area source VOC use by region.

This information is matched against the explanatory variables like those used as surrogate data in the first part of this study. Part of the data will be used to

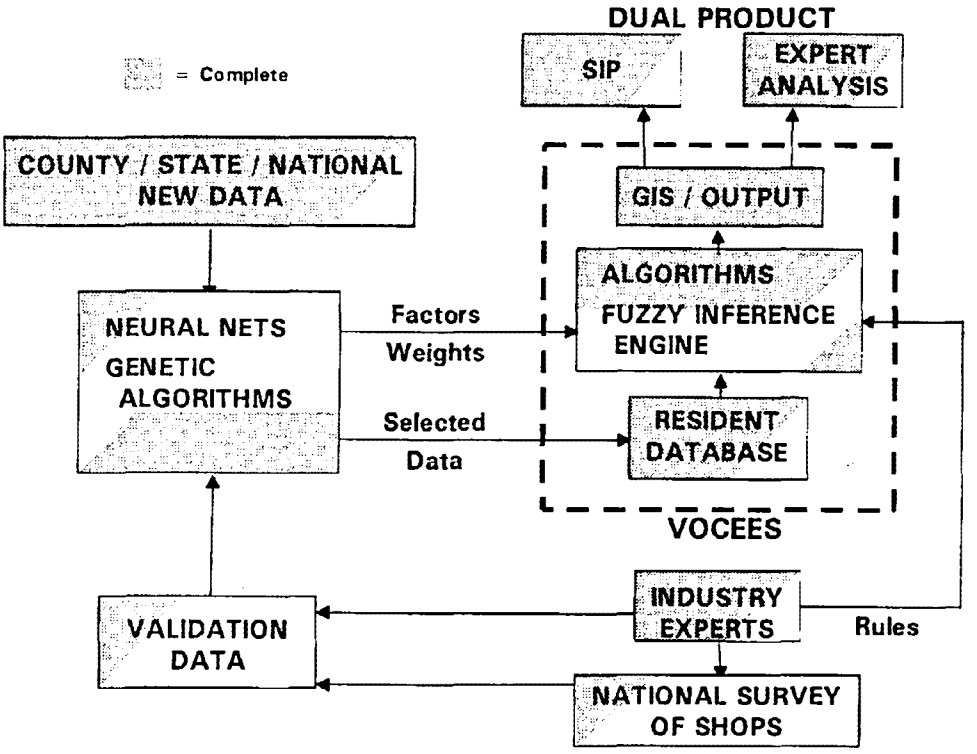



**Figure 3-1. Recommended New Method for Estimating Emissions**

train a neural network to establish optimum weights and function modes to accurately predict VOC use. Trained emission estimation performance will be compared to the remainder of the validation data. Genetic algorithms and statistics will also be used to select the best variables for estimation and optimize estimates. With such validated variables and database selection, surveys need not be performed annually. The main variations in VOC use from year to year should be predictable by expert rules for such factors as new regulations and the distribution of use of various types of paints (as qualitatively assessed by industry consultants and paint manufacturers). A resident database is derived and formatted using the best explanatory variables and the best data for the period(s) under evaluation. Under the planned method, the resident data would be updated by the State's using local data. This information would be filtered, selected, re-correlated, assigned improved rules, and so on by centralized processing by EPA or its agent.

Selected variables, weights, correlation coefficients, relational algorithms, fuzzy logic membership functions and a rule set are then combined to complete the calculation paradigm and inference engine. It is anticipated that expert opinion and fuzzy logic will be applied where linguistic descriptions of behavior pertain, as well as data uncertainty, qualitative assessment, and complex, and nonlinear relationships.

The influence of regulations, estimated enforcement, general economic trends, prevalent shifts in paint mixtures, swings in insurance legislation (*e.g.*, increased no-fault insurance) could possibly all be best evaluated through inference methods. Examples are given in the following discussions of neural nets, genetic algorithms and fuzzy logic.

Once the tools have been applied to the resident database to generate emissions estimates, then the results can be reported and further examined. As described in Section 2.5, this is accomplished through the MapInfo™-based *VOCEES* data handling. A dual product has been devised: first, a State Implementation Plan type of report can be generated showing emission estimates for nonattainment counties and map displays of same. Second, considerable analysis of emission estimates can be done over the U.S. geography and over any period of time for which data exists. Examples of those products are given in Section 4.

The shaded areas in the modules on Figure 3-1 give an estimate of the level of completion of each. Completion of the national survey of auto refinishing shops should allow final resident database selection, inference methods, final design, and training and exercising of the entire method with validated data. Accuracies of the method can be closely assessed and compared with the current approaches discussed in Section 2.2. The generation of expert rules, resident database updates, and low-cost, selective validation should be part of a continuing process. Further attention to items 3) and 4) above could provide EPA a very cost-effective means for insuring validation and high accuracy for its area source emission estimations.

Therefore, the new method covers the basic standard emission estimation elements: activity level, emission factor, control factor, and spatial and time allocation. Speciation can be included, but has not been addressed in this study. For auto refinishing, the emission factor level is straightforward, since all VOCs are either emitted or controlled (*e.g.*, recycled, incinerated, charcoal filtered). Therefore, emission factor = 1. Control has only a small impact on auto refinishing emissions at present.

The five areas of method completion are summarized next.

## 3.1 National and Intensive Local Area Surveys of Auto Refinishing Shops

The only obvious sources for obtaining VOC-use validation data are from the user, from the distributor, and from other agencies. While OSHA requires Material Safety Data Sheets (MSDS), no quantities of the amount of product purchased are included (although it might be possible to correlate MSDS mailings and sales forms at the wholesale or retail levels). No Federal Census microdata (*i.e.*, County Business Patterns (CBP)) provides quantities of materials used by area sources, nor do "Yellow Pages" files. Documentation of Census of Sales by paint and solvent suppliers does not adequately focus on auto refinishing to enable estimation to better than 50% in a region. Even then, more widespread distribution of the product from each source to other regions is not known. Therefore, validation data must be generated through users or manufacturers. Manufacturers are reluctant because of 1) proprietary and marketing considerations, and 2) the level of effort estimated to be required to document.

The latter source should not be neglected (see Section 3.3), but it was decided to move ahead with a user survey approach -- to take a verifiable snapshot of VOC use by the approximately 60,000 shops in the U.S. A preliminary survey plan and questionnaire had been prepared. Focus group meetings have been held with managers of auto refinishing shops and a preliminary endorsement for the survey has been provided by the Automotive Services Association (ASA), the main trade association for the auto refinishing shops. The planned survey has been named ARSUS -- for Automobile Refinishing Solvent Use Survey.

The planned Automobile Refinishing Solvent Use Survey (ARSUS) is the first survey of its kind and almost certainly the most important area source emissions estimation validation undertaken to date. It is also essential for proving the merit of the new estimation methods under development. Survey and statistical experts will conduct ARSUS.

Other important features of ARSUS are

- Results will be statistically defensible, based on random probability sets, with the results represented by statistically correct accuracy estimations and confidence levels.

- Proper survey techniques will be applied to assure a high percentage response, assuring that results are representative and defensible.

- Results are expected to increase available validation data by 3 orders of magnitude and improve accuracy by at least 20 to 200 percent.

- The survey is designed based on a detailed knowledge of the industry built on numerous contacts with shop operators, paint manufacturers and association representatives.

This validation will allow detailed examination of geographic (spatial) influences on solvent use and will provide a more representative data base for area source solvent emissions. Results are being displayed and analyzed utilizing the geographic information system.

ARSUS is a national survey of auto body repair shops, and will also include local-area intensive surveys of 6 high-population areas. The national survey data will be divided into two independent sets with probability proportional to population, each containing 30 areas or Primary Sample Units (PSUs). One of the samples will be assigned for use in estimating model parameters (training the technique).The second national sample will be used to develop a comparison variable (validating the technique or model for emissions estimations) with an unbiased estimate of the difference between the model estimate and the true value. This information should improve current emission estimates accuracy by 20% to 200%.

The survey contains 5900 field samples for the national aggregate survey, about 3400 of which will be allocated to the 6 intensive local-area surveys (a subset of the national sample). Local areas for intensive survey will be selected randomly and all sampling will be probability-based. Examples of such "local areas" are the 1) four county region comprising most of the Boston Primary Metropolitan Statistical Area (PMSA) with a combined population of approximately 2.8 million persons or 2) the Central Piedmont region of North Carolina comprising 12 contiguous counties and three MSAs (Greensboro area; Raleigh-Durham; and Burlington) with a combined population of about 2 million.

The map shown in Figure 3-2 is a hypothetical example of the scope of coverage that would be provided by the 5900 samples and the local-area intensive surveys of 6 high-population areas. The survey data is divided into two independent sets with probability proportional to population, each containing 30 areas or Primary Sample Units (PSUs). One set is assigned for estimating model parameters (developing the method), while the second set is for developing a comparison variable (evaluating and validating the method).

The PSUs are counties or groups of contiguous counties. About 60 to 75 completed interviews can be expected for each PSU or local area. Since this small a subset is insufficient for precise local estimates, much larger samples are to be used for the 6, randomly selected, locally intensive surveys. About 400-550 responding firms are expected in each local intensive area. These figures reflect the fact that the survey experts associated with this study typically obtain a high

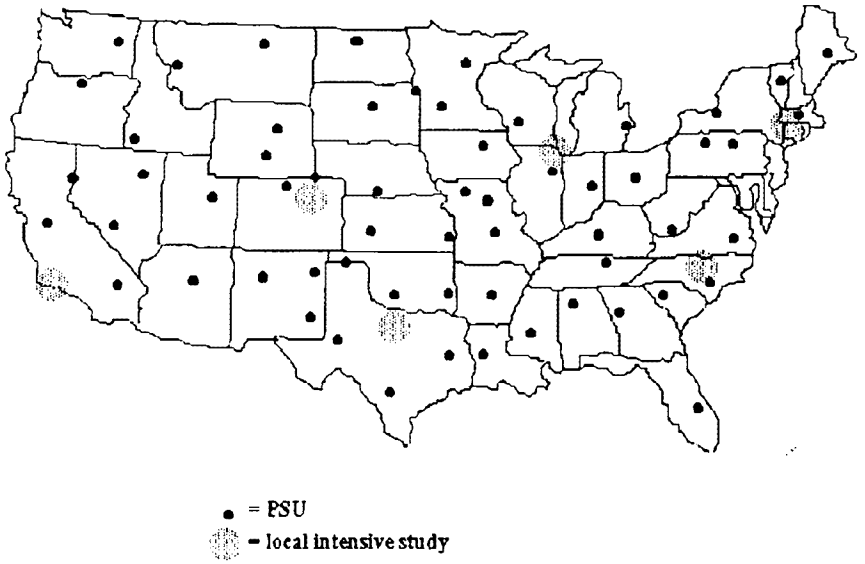



**Figure 3-2. Representation of 5900 Samples and 6 Local Intensive Surveys**

response rate from 70% to 95%. The estimated accuracies of solvent use data from the surveys are shown in Table 3-1 below.

**Table 3-1. Estimated Accuracies of Solvent Use Data**

| SURVEY | SAMPLE SIZE FIELDED | PRECISION ESTIMATE | DIFFERENCE ESTIMATE |
|---|---|---|---|
| NATIONAL | 5900 | 7% | 10% |
| 6 LOCAL INTENSIVES | 3400 | 10% | 14% |

Information services (*e.g.*, American Business Information (ABI) or Dun and Bradstreet) and computerized "Yellow Pages" will be used to retrieve information abstracts on firms with either primary or secondary SIC code 7532 for auto refinishing in the counties selected. Primary and secondary SIC 7532 includes all top/body repair and paint shops and all car dealerships with body and paint shops (covering more than 95% of all listed refinishing establishments). Codes for auto repair such as 7533, 7536, 7538, and 7539 are not representative of refinishing. This file will be stratified by SIC and number of employees and a probability sample of organizations in each of the sample PSUs will be constructed. A detailed file for each sample organization will then be retrieved with the names and addresses for the mail survey and auxiliary data for use in the final statistical analyses. These files constitute a "frame" that assures complete coverage of the

industry and statistically valid estimates (unbiased estimates with known precision).

The questionnaire for the auto refinishing industry has been prepared. This questionnaire is found in Appendix A. The questionnaire is being further updated following review at the ten EPA regional offices and at national trade associations. The survey's design and data collection are summarized as follows:

Survey experts will collect the data from the selected auto refinishing shops using a combined mail and telephone survey approach to maximize response rates, minimize respondent burden, and complete the data collection efficiently. A lead mailing is sent to each selected establishment, including a cover letter, letters of endorsement from State agencies and trade associations, the questionnaire, instructions, a postage-paid return envelope, and a toll-free number to request additional information or arrange an immediate interview. Two weeks after the surveys are received, those establishments which have not returned the data collection instruments or called to provide the data or arrange an appointment will be called. Telephone Survey Unit (TSU) interviewers will prompt for the completed questionnaire and will offer to record the data over the phone. Another call may be made at a time more convenient for the respondent. Results will be entered using bar-coded ID labels and event codes which indicate the pending or final status of the case. Batches of responses are sent to Data Entry (DE) for processing. All documents will be double keyed for quality control, and sent to statisticians for analysis.

A preliminary survey of 9 randomly selected local auto refinishing shops has been performed. This is the maximum number allowed by the OMB without full survey approval. Results for the most part are confidential. So few samples cannot provide any association of solvent use with the explanatory variables. They do offer some limited indications of shops practice, and projected survey success, such as:

- Response in general was thorough and prompt. Only one shop declined any response.
- The correlation between the number of employees and number of jobs or amount of VOC use may not be as strong as anticipated.
- Revenues and number of employees are difficult to correlate with a shop's use of more advanced equipment or paint products. A high ratio of revenues/ employees may indicate "high-end" shops refinishing more expensive vehicles, and utilizing higher grade (and lower emission) products and tools (*e.g.*, HVLP spray guns).

Knowledge and data gained from interaction with regulatory and industry representatives from the six local intensive areas will also be used to expand the

knowledge base of the emission estimation expert system, to more accurately assess influences of climatic, demographic, regulatory, and economic diversity.

The survey data are expected to help weigh the contribution of complementary activity levels and their emission factors. This is analogous to tuning the system with shop-level data. Complementary, regionally-specific survey data will be integrated in a Geographic Information System (GIS) data base format with U.S. Census data and other activity level data and geographic information. Once in the GIS format, these data can be manipulated, analyzed, and visualized to support and better validate the expanded emission estimation method.

Results from a survey by the trade publication, BodyShop Business, are already quoted in this report. Two other surveys of auto refinishing have been reviewed which provide some perspective of the industry, although little environmental analysis. These survey results are discussed below.

*Twin Cities 1990 Autobody Survey*

In 1990, Research Innovations of Minneapolis, MN conducted a survey of autobody shops in the Minneapolis - St. Paul area for the Automotive Service Association (ASA). Although not directed towards VOC estimates, it does assist in characterizing the body shop industry. Research Innovations purchased a list of 480 body shops in the Twin Cities metro area. Initially, 51 responses were received (10.6%). A telephone follow-up yielded another 154 responses for a total of 205 (43%). Survey results indicated that approximately 80% of all body shops in the metro area were independently operated with the other 20% being dealerships.

The survey found that 40% of the body shops had 1-4 employees, 20% had 5-7 employees, 40% had 8 or more employees, and the average number of employees was 7.5. As the number of employees increased, so did the shop's profitability. An increase in personnel was usually characterized by an increase in support personnel and not painters or bodymen. This indicates that using support personnel to do paperwork enables paint and bodymen to be more productive and therefore make the business more profitable. Also, higher profitability for larger shops lends credence to the observation that although the number of body shops are decreasing, those that remain open are becoming larger.

Technology influences are also beginning to show in modern body shops. Of the 205 respondents, 30% indicated that they had a HVLP spray gun. Of shops that had over $1 million in sales (the highest sales volume category), this number was nearly 60%. Computerized management systems have also become popular, especially with larger shops. While only 3% of shops with sales of less than

$250,000 have a computerized management system, that number jumps to 56% for shops with sales of over $1 million.

*Cook/DuPage County 1992 Autobody Market Study*

In the summer of 1992, Research Innovations also did a study of the Cook/DuPage County, Illinois area for ASA. Using a list of 1,139 body shops, Research Innovations used 144 responses (12.6%) in their analysis. Of the respondents, 89.6% were independently owned, 6.4% were franchises, and 4.0% were dealership owned.

The average body shop in the Cook/DuPage area had 9.89 employees, with 2.3 refinishers on average. As was true in the Twin Cities area, larger shops had the highest gross profit. Of the total shops with gross profit margins of 40% or more, nearly 40% were shops with sales volumes of $1 million dollars or more.

Technology changes are also becoming more apparent in the Cook/DuPage area. 54.4% or respondents indicated they presently own a HVLP gun with another 11.2% indicating they plan to purchase one within a year. Computerized management systems are also becoming more popular with 43.1% of shops presently owning a system and 10.1% planning on buying one. Of the computerized management systems in use, 22.6% provide the ability to track VOCs through information on paint consumption.

## 3.2 Use of Computational Intelligence (CI)

As described in the introduction to this Section, Computational Intelligence will be used to

1) Select the best initial data matrix to become the VOCEES resident datafile, by assessing estimates from data and assigning weights to the multiple explanatory variables. CI techniques such as neural networks can prioritize variables represented by complex data that may have little apparent correlation on face value.

2) Continuously update the best data by a training function that reassigns data based on its ability to most accurately predict validated VOC levels.

3) Verify and/or improve statistical correlations between validation data and explanatory values.

4) Quantitatively interpret qualitative responses from the nationwide survey or from other sources (an example is provided for fuzzy logic analysis later in this section).

5) Interpolate to fill in data gaps in the survey or independent, explanatory data sets. For example, a neural net or genetic algorithms can learn the pattern of response to a certain question about shop operation as the response relates to other responses to other questions. The missing response can then be predicted. The same interpolation function can also be performed for data other than that derived from the survey questionnaire.

6) Develop rules. Produce if/then scenarios that allow the integration of expert opinion and the quantitative relationships for uncertain inputs, as mentioned above in 4.

7) Assess geographic and time dependent influences to establish trends that can be incorporated into future estimates.

8) Provide a structured technique for adding and evaluating new factors influencing emissions, as other creative means of relating data evolve.

Neural nets and genetic algorithms will be emphasized for the tasks of selecting, weighting and ordering data. Rules and inferential reasoning are planned to augment and improve on the algorithmic relationships and correlations. These are usually linear or polynomial relationships with coefficients and weights determined by statistics or weighting in a neural net scheme.

For example, statistics and the neural net analysis will produce a relation such as

$$\mathbf{EE = C_1 \times (\#\ licensed\ drivers) + C_2 \times (\$\$\ sales\ for\ refinishing)^2},$$

where EE is emission estimate in tons of VOC/year.

This emission estimate could then be improved where additional expert opinion is available or where interpretation of qualitative information or complex relationships have been ascertained though other computational intelligence methods. For example, an improved emission estimate, IEM, might become

**IEM=EE x(Control factor)x(Regulatory factor)x(Paint type factor)**

Fuzzy logic would be used, for example, to determine that a high average ratio of shop revenues to shop employees in a county should mean a high transfer efficiency and a resulting control factor of 0.87. Similarly, fuzzy rules derived from expert opinion could say that the moderately low incidence of environmental litigation in a state should result in a regulatory factor of 1.05. A very high annual sales of new automobiles over the past three years could imply more refinishing with reduced VOC paints and a paint type factor of 0.93. These are only unsubstantiated examples without validation results but do illustrate how computational intelligence can provide a "value-added" function.

For more inferential knowledge, interaction with the paint manufacturing and auto refinishing industries has allowed the formulation of questions which can be put to experts for further developing a knowledge base. The next steps are therefore to

1) select the 2 or 3 experts from paint manufacturing and auto refinishing and complete preparations for their review of VOCEES requirements and of the current state of the industry, to be followed by interview sessions, both singly and collectively, and

2) complete the list of questions (using on regression analyses results, industry comments, and EPA review).

*Resident Database Selection*

Emission levels can be calculated from material use data collected from a sample of the bodyshops nationwide through a survey or through analysis of state-by-state material distribution. The emissions data are then used, along with other readily available state-level, explanatory variables, to teach a neural network the relationship between the explanatory variables and the emission levels. In the

training process the network learns which variables are most important to determining emission levels.

The preprocessed survey results and explanatory variable data can be presented to a neural network as illustrated in Figure 3-3. Initially, half of the available data will be used to train the neural network while the other half will be used to evaluate that which the network has learned. Genetic algorithms will be used during this phase of development to identify the optimum neural network architecture, learning algorithm, and other critical parameters. Examples of using GA would be in the training of the neural network or development of membership functions. In both cases, a test set would be necessary so GA could properly determine the fitness of each string. This fitness function is the most difficult part of GA to construct and is essential to its performance. To properly optimize a system, GA must know what constitutes good performance. In the emissions case, this would be a knowledge of what emissions are like for a given set of variables.

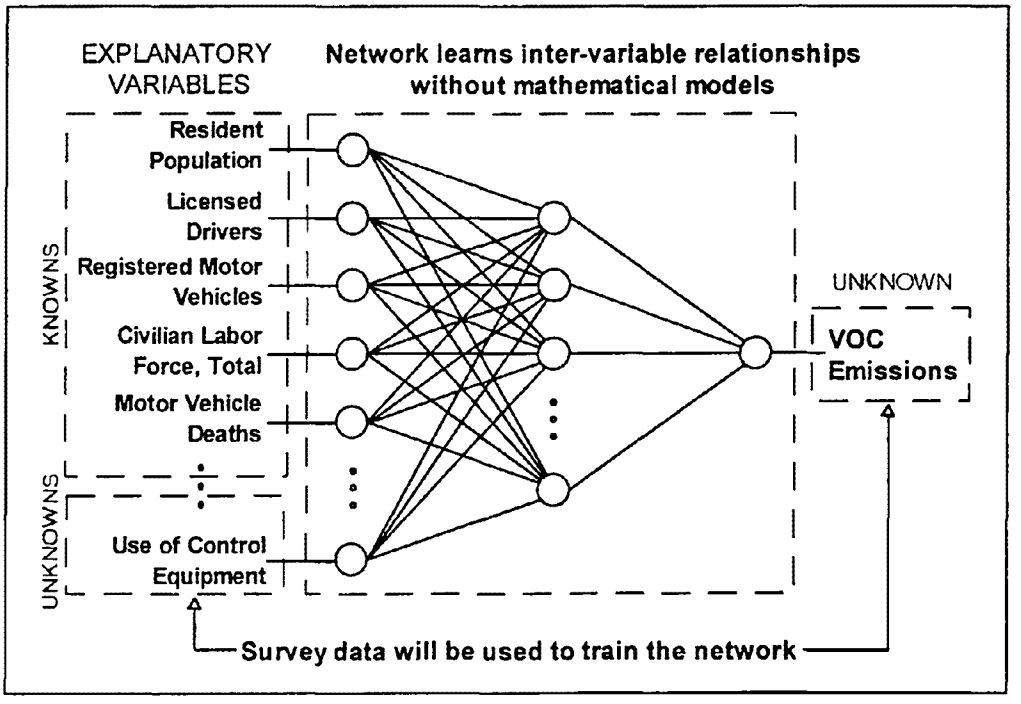



**Figure 3-3. Neural Networks in VOC Emissions Estimation**

Finally, the entire database will be used to train the network, to continue to identify and minimize the input variable set which best estimates emission levels. Analysis of the trained network will identify the input variables which are most important in estimating emission levels, reducing the number of input variables required. A sensitivity analysis will also be performed to determine the error introduced by this minimized artificial neural network.

*Emissions Estimation Computation Module*

As stated earlier, emissions computation will first be tried with coefficients and weights tailored to the resident database and validation data. Polynomials will be used as prescribed by the neural net and statistical correlations.

The inferential system module under development will use fuzzy logic. The neural network can also be structured into the computational module of VOCEES to perform its role in relating dependent and independent variables. Genetic Algorithms will be used to optimize membership functions for fuzzy logic analysis.

To select the fuzzy variables of interest, the statistical correlations are applied along with the analysis of survey data, and the set of questions for experts. Data and expert input will establish the design of the fuzzy sets and rules. A fuzzy system with less than 5 variables and 20 rules is anticipated to be necessary for any area source. A larger model would require fine-tuning beyond the accuracy of available information and would place an excess burden on system users and upgraders.

In a fuzzy logic-based expert system, fuzzy rules reside in the "knowledge base" and the membership functions and defuzzification (fuzzy-set definition, encoding, decoding) are the techniques comprising an "inference engine." This knowledge base will be built and the engine coded in C language.

An adaptive fuzzy system can use sample data and neural or statistical algorithms to choose the coefficients for weighting each output membership function and then to define the fuzzy system over any period of time. This process of weighting and redefinition (new rules) can be a continuous ones with upgrades made in VOCEES on an annual basis. If it is considered more efficient, the hybrid system will be abandoned and all information incorporated in the form of fuzzy logic.

Fuzzy logic system development will consider quantitative versus qualitative inputs. Expert input may be either 1) an uncertain estimate (*e.g.*, <u>about 2 gallons</u> of paint used per employee per day) or 2) a qualitative assessment expressed linguistically (*e.g.*, <u>small</u> shops are <u>much less likely</u> to use closed gun cleaning stations than <u>large</u> shops) where quantitative values are assigned through fuzzy sets, and the outputs defuzzified and summed. The latter, qualitative assessment must be valued on the basis of related, quantitative data (*e.g.*, <u>small</u> means less than 5 employees), <u>much less likely</u> means only 10% on a relative basis. These values must be transferrable from one expert opinion to another, with a reasonable expectation of consistency. Such consistency is established through the statistical and neural data analysis.

As stated, instead of using fuzzy logic to make the actual estimate of auto refinishing VOCs, fuzzy logic is probably best suited to use auxiliary information to refine estimates determined statistically or to fill in gaps of information not available for a specific region. Fuzzy logic would be able to adjust estimates based on local information that may not play a role in determining the initial estimate. To properly create rule bases and membership functions, this auxiliary information must come from experts or survey data must be fuzzified.

As an example of how fuzzy logic may be used, consider the types of coatings used in auto refinishing. As mentioned in Section 2.1, coatings can be roughly divided into three categories: lacquers, enamels, and urethanes. Lacquers are high in VOC content, enamels are more moderate, and urethanes are low. If an estimate of paint use by type (% of all coatings used that are lacquers, enamels, and urethanes) can be made for a given region (county, nonattainment area, etc.), this information can be used to adjust a VOC estimate that was based statistically on a variable such as body shop employment. Not only does this refine the estimate using local information, it also is able to include information about local regulations since the type of paints to be used may be dictated.

Figure 3-4 shows an example set of <u>membership functions</u> for paint use. Since lacquers are quite high in VOC content, the lacquer usage membership function is biased towards lower percentages belonging to linguistically larger fuzzy sets. Enamel usage fuzzy sets are more evenly distributed, while for urethanes there is a bias towards belonging to the linguistically smaller fuzzy sets. The reason for this is given in the fuzzy rules shown in Table 3-2. The rules show that if lacquer usage is large or very large, it will tend to push revising the VOC estimate upwards, while if urethane usage is high, the VOC estimate will be reduced.

The <u>rule base</u> shows why the aforementioned fuzzy set distributions have been defined as they are for the membership functions. Since lacquers are much higher than the other types in VOC content, enlarging the fuzzy sets for the "large" and "very large" variables makes it easier for high usage of lacquer to result in a higher percentage increase in VOC estimate. The reverse is true for urethane usage, where smaller fuzzy sets for "large" and "very large" make it more difficult to obtain a higher percentage reduction in VOC estimate.

Of course, the exact size and shape of these membership functions and the structure of the rules can only be determined by an expert or with the type of data that would come from the nationwide survey.

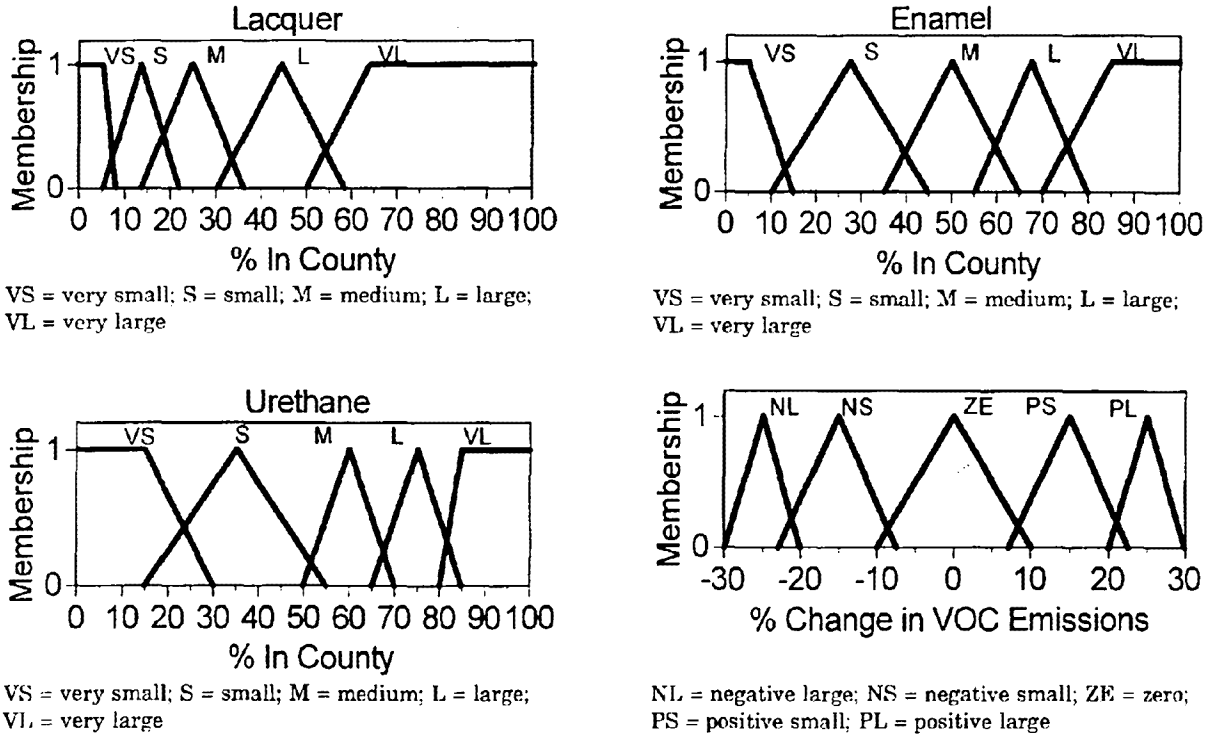



**Figure 3-4. Membership functions for paint use and percent change in VOC estimate**

**Table 3-2. Example rules used to modify VOC estimate using coatings usage**

| Lacquer Use in County | Enamel Use in County | Urethane Use in County | Change in Emissions Estimate |
|---|---|---|---|
| Very Large | Small | Very Small | Positive Large |
| Large | Medium | Small | Positive Large |
| ⋮ | ⋮ | ⋮ | ⋮ |
| Small | Medium | Small | Zero |
| ⋮ | ⋮ | ⋮ | ⋮ |
| Small | Medium | Large | Negative Small |
| Very Small | Very Small | Very Large | Negative Large |

Another possible application of fuzzy logic would be in the fuzzification of geographic locations. This would have a two-fold purpose, 1) to use general rules that apply to specific regions and 2) to assist in estimating data for regions in which the data was unavailable. Geographic locations, for example, can be

partitioned into regions based upon their latitude and longitude. A state such as Virginia would no longer be confined solely to such regions as Mid-Atlantic or Southeast but would have a membership in both. Figure 3-5 illustrates the 10 U.S. EPA Regions. Each region can have overlap into adjacent regions (the gray shading). If information is readily available for a given region or regions, it can be used in the estimation of surrounding regions. Figure 3-6 shows how this may look on a statewide basis. Using fuzzy sets of this type would enable the use of such rules as "If the body shop is in the Northeast and the regional composite consumer index is high, then VOC emissions are larger since more cars are painted following accidents." Since the Northeast region is fuzzified to include parts of other regions, this rule also applies to bordering regions (although less than 100%).

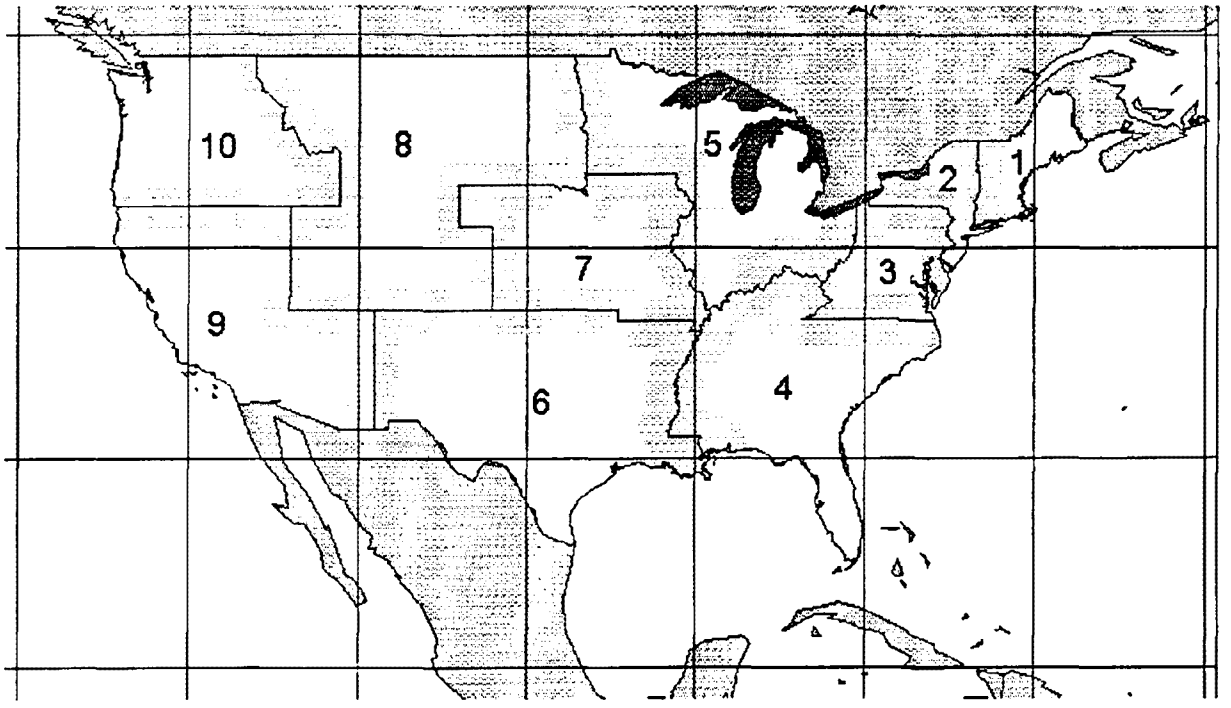



**Figure 3-5. The 10 EPA Regions**

Also, since it is often difficult to obtain complete data for geographic regions, fuzzy partitions provide a means to approximate what data is missing. Fuzzification of boundaries between counties or regions in a state may be the most useful application of this technique. This would provide the ability to "fill in the blanks" when using County Business Patterns, where disclosure laws often prevent the publication of data. Figure 3-7 shows an example using North Carolina counties and nonattainment areas (in dark gray). Disclosure laws resulted in information being incomplete or non-existent for the counties colored in light gray. However, using information that is available for nonattainment areas

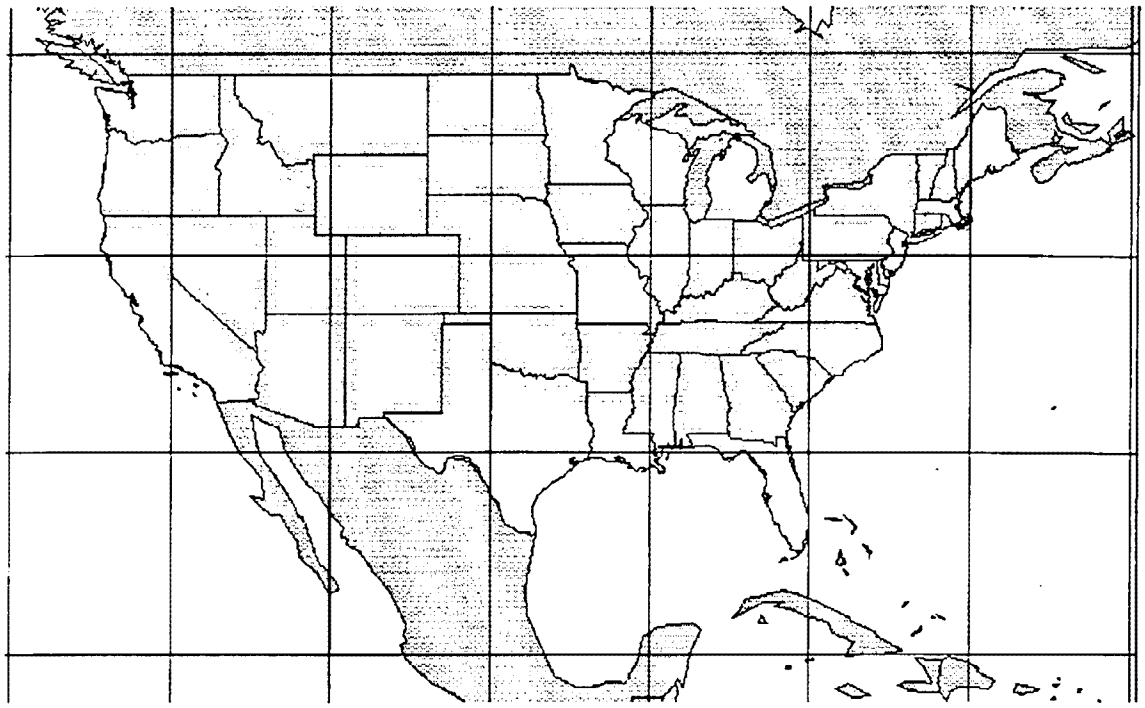


**Figure 3-6. Statewide Representation of 10 EPA Regions**

and surrounding counties, a fuzzy estimator can be used to generate numbers for the other counties. In deference to the importance of the nonattainment area, its information could have a higher weight (*i.e.*, membership) than the other counties. This weight could be based on population, geographic distances, a combination of the two or other means. This would be an ideal method of modelling the influence of large metropolitan areas on surrounding areas. Using the above example, assume the distribution of lacquers, enamels, and urethanes was known for a nonattainment area and three surrounding counties. Table 3-3 shows the calculation of the distribution for a fourth county using the center-of-moment method, the method most commonly used in the defuzzification of an output from a fuzzy system.

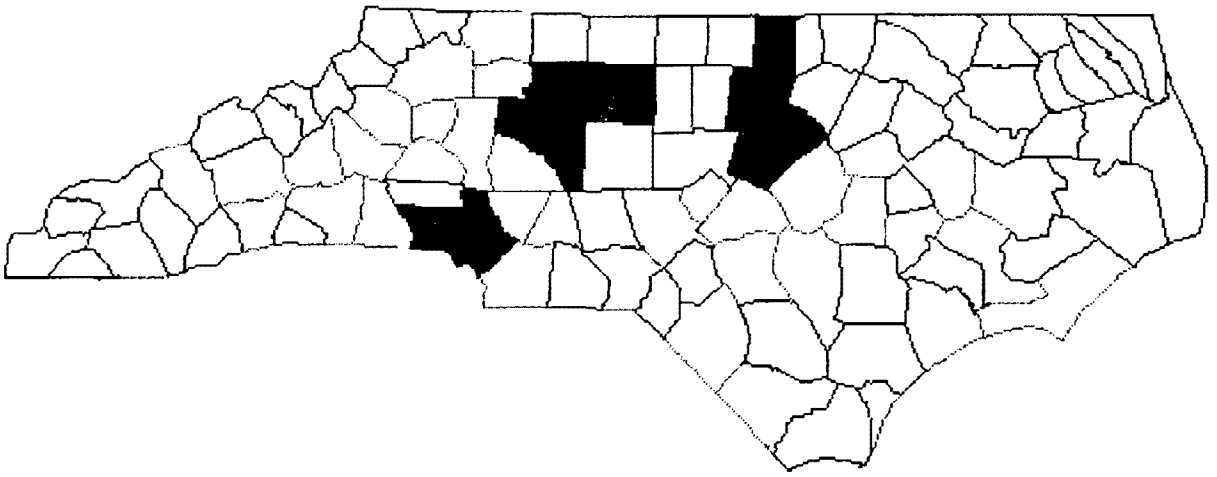


**Figure 3-7. Disclosure laws resulted in information being incomplete or non-existent for the counties colored in light gray.**

**Table 3-3. Estimation of Unknown Data for County Using Fuzzy Weights and Center-of-Moment Method**

| Area | Fuzzy Wt. | Lacquer % | Enamel % | Urethane % |
|---|---|---|---|---|
| Nonattainment Area | 1.0 | 10 | 20 | 70 |
| County 1 | 0.6 | 20 | 30 | 50 |
| County 2 | 0.4 | 40 | 30 | 30 |
| County 3 | 0.3 | 40 | 40 | 20 |
| County 4 Usage | | | | |
| Lacquer = {10(1.0)+20(0.6)+40(0.4)+40(0.3)}/{1.0+0.6+0.4+0.3} = 21.74 % | | | | |
| Enamel = {20(1.0)+30(0.6)+30(0.4)+40(0.3)}/{1.0+0.6+0.4+0.3} = 26.96 % | | | | |
| Urethane = {70(1.0)+50(0.6)+30(0.4)+20(0.3)}/{1.0+0.6+0.4+0.3} = 51.3 % | | | | |

*System of National and State Emissions Experts, and Local Data Experts*

No expert or expert approach exists upon which to base an expert system, *i.e.*, no state agency, EPA office, or EPA support group is consistently providing reliable, accessible, continuously available emission estimates. (California has gone beyond others in regulating, but there is no evidence of an exemplary capability or system for emissions estimation, nor even a better data base on VOC usage.) No obvious surrogate system is known which performs the same function for other types of values. Therefore, an expert system would have to be built through new expertise and knowledge and then captured in software.

The study began with the concept of developing a knowledge-based/rule-based expert system as the main emission estimation technique. It has been found that this concept is a useful element in the method, but is too restrictive as a single format. However, it is suggested that an "expert system" concept could be embodied in the method in the form of EPA area source experts.

If area sources are to be individually regulated, it is obvious that each source's individual characteristics warrant expert attention and analysis. EPA has experts for such point sources as coal-fired power plants, for example. This is especially true where regulatory intentions and control guidelines are ultimately aimed at pollution prevention. Pollution prevention implies intimate knowledge of process operations, materials and internal controls which can eliminate or reduce emissions without added control technology. A system of experts could incorporate this knowledge in EPA planning and regulation and continuously update the knowledge to minimize emissions and costs (in terms of size, region, and economic demographics).

The current VOCEES design, can incorporate an expert system. The process of area source emissions validation can confirm an ever-improving technique, resulting in a highly accurate system of rules.

The expert-system-supported estimation method might be developed in the context of the overall emission inventory method, if possible. The organizational structure for using VOCEES could take several forms. Figure 3-8 shows a possible organization under which VOCEES could be applied.

It is suggested that at least part of the Area Source Emissions Estimation expertise would reside with an "Area Source Officer" within EPA. The information supplied from national data sources (and updated computational techniques) could be transferred by electronic or computer storage media (CD ROM, magnetic disk, electronic mail) and directly incorporated into VOCEES for estimation at state/county levels.

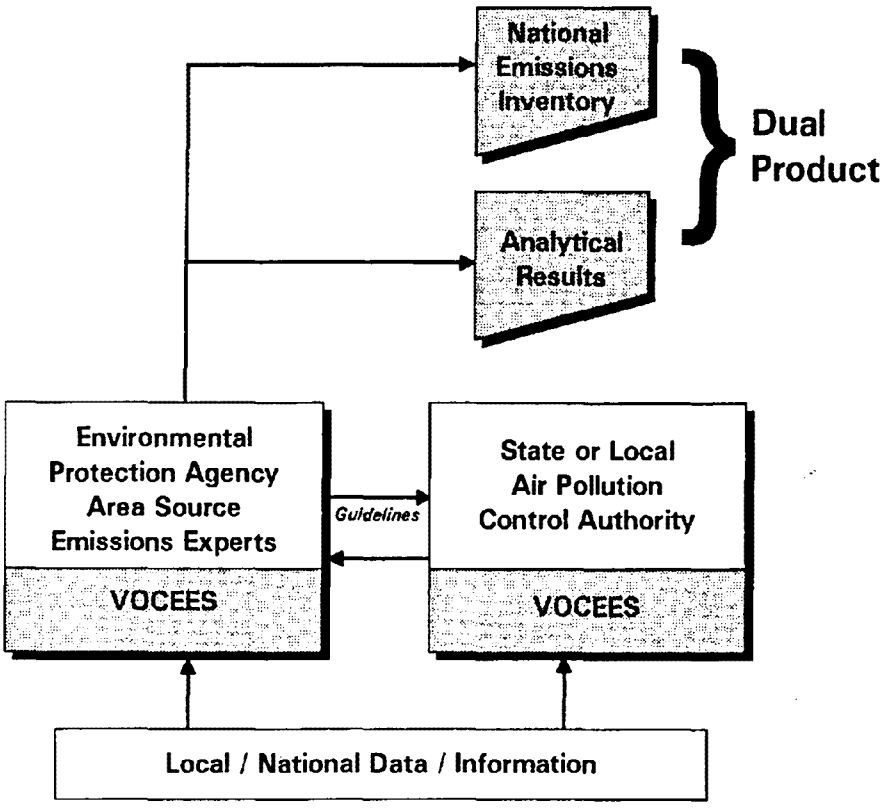



**Figure 3-8. Method Flowchart with Evolving Expert Systems**

The State of local authorities own the emissions estimation data they supply to EPA. However, EPA must approve the method and resulting implementation plan. EPA also supplies activity and emission factors which may be used, or better methods may be substituted by the State or local authority. An EPA expert system could continually improve the default factors and method. Part of this could be an incorporation of the best techniques by State or local experts. An interactive system should provide an optimal knowledge base.

## 3.3 Use of VOC-Containing Product Manufacturers Data

Materials data accumulation has emphasized retrieving auto refinishing product information from the major paint manufacturers in the U.S. These are AKZO Coatings, American Standox, Inc., BASF Corp., DuPont Automotive Products, NASON (DuPont), PPG Industries, and Sherwin-Williams Company. ICI and Glidden are also moving into the market. The National Paint and Coatings Association (NPCA) has become involved in the negotiations, but NPCA does not represent all manufacturers. The pertinent industry group is Special Purpose Coatings, SIC 28513-13, which includes automotive, other transportation, and machinery refinish paints and enamels, including primers.

The Census Bureau publishes information on product sales by Special Purpose Coatings, SIC 28513, under Coatings Manufacturers in the Census of Manufacturers. Information is reported for every 5 years with an annual survey but only at national levels. The main data are the value and quantity in gallons of shipments. County Business Patterns can provide data on distribution to the first level (Wholesale Warehouses and Jobbers for Coating -- SIC 5198) to state levels but only for "Sales" of <u>all</u> paint products.

The results of the annual Survey of Manufacturers for SIC 2851, Paint and Allied Products, mentioned in the preceding paragraph, are published in the Census Bureau's <u>Current Industrial Reports</u> (CIR). National, annual consumption figures for SIC 2851 and its constituent codes (*e.g.*, 28513-13) are also published every 4 years in Stanford Research Institute's (SRI) paint market report (Connolly, 1990). The CIR data are derived from estimates based on a survey of selected producers. SRI's paint and coatings data are based on communication with industry, published information, and SRI estimates (Chemical, 1992). SRI claims that differences between the two sets of estimates are "due to variances in definitions and estimating techniques" (Connolly, 1990). It is readily apparent that the CIR estimates are much more volatile than those from SRI, changing in subsequent years by as much as 14% for SIC 28513 and 37% for SIC 28513-13. The relative accuracy of each source is indeterminate and other mechanisms have been pursued through which actual quantity distribution can be determined.

The most important information is the annual distribution of the entire spectrum of automobile refinishing coatings throughout the U.S. However, other characteristics of the area sources' VOC-containing materials are important besides their distribution in time and space. For example, the chemical constituents of the paint and solvent products are important to determine their VOC content, relative volatility, potential toxicity, and tendency to contribute to ozone formation. The type of product is important in order to know how it is used to auto body shops (*e.g.*, as primer, topcoat, cleaner or surface preparation). The area of application and associated equipment determines evaporation or recycle.

Types of products and marketing or regulatory trends perceived by the manufacturing industry are also important.

The annual sales and geographic distribution of auto refinishing products (paints, solvents, sealers) can provide a very good idea of the amount of VOC emissions from associated body shops. The VOC content of almost all products is well-documented and can be obtained through the MSDS forms that are required for every product. As noted earlier, environmental control regulations are increasingly emphasizing limitations on the VOC content of these products, and therefore documentation of and attention to VOC content is increasing.

Acquiring distribution of products information in space and time is not simple. Preliminary negotiations have been held to obtain a disclosure of such information with the paint manufacturers to finalize a one-time reporting standard. This reporting must not compromise companies' marketing information nor impose a significant burden on their personnel or systems. The best information accessible is sought (*e.g.*, resolution to county-size areas and records over 5 years). This can be a difficult goal for companies. The matrix of auto refinishing products is typically in the hundreds for large companies. When compounded by over 3000 U.S. counties and coverage of 5 years (during which the product line changes), the amount of data can reach millions of records. The product data formatting is not standardized across the industry and is typically not well-categorized by geographic areas. However, in response to short questionnaires provided under this study (see Tables 3-4 and 3-5) the majority of major manufacturers responding said that obtaining data from the first level of distribution would be easy and the second level of distribution provides regular information, also. However the convenience of the filing and data retrieval systems for the distributors was not addressed.

One compromise is to obtain at least one year of information on products under groupings to be agreed upon by the manufacturers. The minimum level of geographic resolution would be to the first level of distribution, *i.e.*, major distribution warehouses or centers. However, because different companies have varying distribution networks, this approach results in uneven coverage for the different products. For example, PPG has about 26 major warehouses serving 3100 to 3200 distributors (jobbers) while DuPont has some 200 major distribution centers (wholesaling warehouses), and AKZO uses only 4 major distribution centers which ship to "wholesalers." This means that an averaging distribution approach must be devised based on areas of coverage around warehouses, and dividing these areas into uniform grids. This can almost certainly be done best by utilizing GIS capabilities.

It is also known that complete records of sales and products are kept down through the jobber level. Almost every paint retailer is on a computer network.

**Table 3-4. Manufacturer Product Category Questionnaire**

## POSSIBLE PRODUCT CATEGORIES FOR YOUR GEOGRAPHIC DISTRIBUTION DATA

RTI recognizes that geographic distribution data covering your auto-refinishing products is voluminous. To reduce the information burden, we are trying to use product groups --like the categories below. We realize that some of these overlap. Which categories would you consider "good" to organize your product data and estimate the distribution of auto-refinishing VOC's in the U.S.? We need to cover all auto refinishing products and estimate average VOC content in each product group. Add other categories you prefer.

| | GOOD CATEGORY FOR CLASSIFYING YOUR PRODUCT DATA? | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface Prep | Primer | Surfacer Filler | Precoat | Sealer | Topcoat | Clear-coat | Cleaning Solvent | Other Solvent Based Product | Water Based Product | Urethane | Lacquer | Enamel |
| **Yes** | | | | | | | | | | | | | |
| **No** | | | | | | | | | | | | | |

**Other Categories** _____

_____

We are also considering another approach using only a few simple categories based on shop operations and major differences in VOC content by group. These categories are:

1) Surface Prep products, 2) Sprayed products, 3) Cleaning products, 4) Water-Based products, and 5) Other

Would these work just as well? **Yes** ☐ **No** ☐

**Comments:** _____

_____

_____

**Table 3-5. Manufacturer Geographic Distribution Questionnaire**

We need an idea about how much geographic distribution information on auto refinishing products is accessible in your central datafiles and how much trouble it is to obtain. Please circle or fill in below the appropriate answers for your company.

| | Estimated Number of Outlets at Level 1&2 | Ease of Access[2] | Typical Rate of Access[3] | Past Years of Accessible Back Data | Info in Computer Datafiles? | For which regions do you have info?[4] |
|---|---|---|---|---|---|---|
| HQ: Headquarters | | | | | | |
| Level 1: Distribution Centers/ Warehouses | Number = -------- -- | EZ12 EZ1 DF1 DF12 O_____ | M A O_____ | 1 2 5 years | Y N | NE NC SA SC M P |
| Level 2: Jobbers | Number = -------- -- | EZ12 EZ1 DF1 DF12 O_____ | M A O_____ | 1 2 5 years | Y N | NE NC SA SC M P |
| Level 3: Individual Customers | Comments | | | | | |

[2] EZ12 = Your HQ receives info regularly from levels 1 and 2; EZ1 = Your HQ receives info regularly from level 1; DF1 = You will have to make a special request to level 1; DF12 = Special request to levels 1 and 2; O = Other (please specify)

[3] M = Monthly; A = Annually; O = Other (please specify)

[4] NE = Northeast; NC = North Central; SA = South Atlantic; SC = South Central; M = Mountain; P = Pacific

Most retailers or jobber level wholesalers deal mainly with one or two paint manufacturers and use similar computer records systems. The main problem is not that records are not kept or are completely unavailable. The problem is one of dealing with non-uniformity across manufacturers.

The other major consideration in this area of data retrieval is that of confidentiality, and avoiding even an appearance of providing one manufacturer advantage over another in terms of disclosure of information. This means that a completely generic form must be devised for reporting data and results obtained from manufacturer's data. It also means there will be no disclosure to EPA or anyone else of any manufacturer or product names associated with data. This confidentiality is not at all a disadvantage in completing the method and emissions estimation system. More important is the generic disclosure format, so that results cannot be "reverse engineered" by any company to obtain information providing them an unwarranted competitive edge. A format that is proposed is

- A computerized format for each paint manufacturer reporting total annual shipments to distribution centers and wholesale outlets. Products would be characterized in 6 to 12 major paint and solvent categories. Companies may alternatively perform internal calculations and provide VOC volumes shipped rather than product volumes. It is recommended that software for data entry be developed in coordination with the manufacturers. The data list would be entirely confidential and handled by a third party other than EPA or any manufacturer. Shipments of new types of paint products (*e.g.*, introduced with in the last 18 months) could be excluded from disclosure if, for example, they make up less than 10% of total sales. This doubly protects the competitive position and proprietary information associated with new products, and also allows for a period in which their actual acceptance and performance can be assessed in the market.

- Data received will be tagged by zip code for the local distribution centers, with all company or center names, addresses, and other specific references removed from the data file. Data will be composited to multi-county regions and averaged over the counties by population, with the minimal size for any region being dictated by the territory served by the counties largest distributing centers for which data is reported. Regions will be <u>within a state or within contiguous states</u> served by the same distribution center.

- The data will be entered into a <u>validation</u> database used in confidence by EPA or its agent for method validation only, and <u>no emissions will be estimated solely on the basis of this data</u>. Manufacturer data will not be provided to states. <u>Other explanatory variables will be used</u> in the VOCEES which best predict emission levels by geographic region. Published results by EPA will not refer to manufacturers' data. EPA will

neither receive nor publish any information on specific companies or products.

Under this system, product distribution by specific companies could not be related to area source emission estimates any more accurately than to many other variables available to companies. This is especially true since the results from emission estimation are normally reports for several area and point source categories combined. Therefore, the only remaining issue should be that of the inconvenience to companies compiling the information. It can be shown by survey experts that this reporting would constitute a smaller burden than that of a nationwide survey, for example. An accurate assessment of the real burden on manufacturers to report such information is needed (it is speculated that normal production inventories and marketing surveys would allow this data to be readily available in computer format).

It is estimated that, using annual reporting by 5 to 7 manufacturers, VOC distribution by county could be consistently validated to -10%, +20% accuracy by this method. Some county validation could be within ± 5% using data for smaller, localized distribution centers. This validation would serve to verify the predicted level of accuracy for the larger regions where data is averaged and then applied to counties.

## 3.4 Sampling and Analysis

This study has examined the possibility of representative sampling of a few auto body establishments to confirm emission concentrations and estimates of pollutant loss rates from individual establishments. The literature shows that typically measured constituents for auto refinishing (outdoors) are methyl-ethyl-ketone (MEK), toluene, ethylacetate, xylene, and methylisobutylketone. The most important constituents are MEK and toluene/xylene (TX). Total hydrocarbons is also a good measure of combined TX and acetate plus ketones/acetones. Samples can be taken using 100 mg charcoal tubes or diffusive samplers. Very good correlations have been obtained between the analyses of samples taken using both these methods at the same sites. Gas chromatographic analysis is sufficient for accurate determination of concentrations.

A few previous ambient air sampling studies have been done, but they vary considerably in their measurements of auto painting and refinishing emissions. Table 3-6 lists some summary results. For measurements at a single shop, outdoor adjacent concentrations of toluene were about 2-20 mg/m$^3$, but less than 1 mg/m$^3$ two blocks away. Measurements at nearby houses were about 1/3 to 1/2 levels at the body shop. At two blocks away, the levels were down to 10% of the samples taken near the shop.

**Table 3-6. Auto Refinishing Air Concentrations of Organics**

| COMPOUND | Auto Refinishing Workplace Ambient Concentrations (mg/m$^3$) | | | |
|---|---|---|---|---|
| | (Verhoeff, 1987) | (Jayjock, 1984) | (de Medinilla, 1988) | (Veulemans, 1987) |
| Toluene/xylene | 2 - 20 | 7 - 105 (40±50%) | 30 - 80 | |
| Isocyanates Diisocyanates | | | .004 - 4 0.15 | |
| Acetates/ketones /ethers | | | 2 - 10 | 2 - 40 |

There are other published indicators of auto refinishing emissions. For example, GM car manufacturing emissions (Sexton, 1983) totalled about 230 gal/hr of hydrocarbons, BTX and aromatics, and about 220 gal/hr of oxygenated hydrocarbons such as methanol, acetone, acetate and esters. These numbers can be compared to production figures for coating losses per car.

OEM painting conditions are, of course, very different from body shops. It has been estimated that, for refinishing surface coating, about 60 to 100 grams of paint are required per square meter of area coated (about 1 to 2 pounds per 100

square feet) (Hughes, 1975). Polyurethane coating requires 80 $g/m^2$ and xylene thinner is 119 $g/m^2$. The lowest OSHA Threshold Limit Value (TLV) for glycol ethers is 16 $mg/m^3$. The TLV for toluene is 375 $mg/m^3$.

It is recommended to first obtain the cooperation of at least 3 shops in a single metropolitan statistical area (MSA). Sampling should be conducted at the boundaries of the shop premises (in the prevailing wind direction) or at a similarly nearby location. At least two 8-hour samples would be taken per day over a period of at least 3 days. Cartridges would require a flow rate to allow measurements down to 1 $mg/m^3$. A flow rate of 25 cc/min of ambient air should allow capture of at least 1 mg levels of species of interest.

TX, MEK and total hydrocarbons are the species to be analyzed. Total hydrocarbon measurements may be adequate depending on background levels. Sampling will begin and end with employee work shifts where possible. Rooftop, main vent, or doorway exit samples will also be measured over two 8-hour periods if indications are that boundary concentrations are significantly different from "shop vent" levels. Standard gas chromatographic columns and analysis techniques are available for these species. It is anticipated that this work can be completed with less than 250 man-hours of effort. This will produce the first reported results correlating a solvent usage inventory and other shop operating variables with emissions measurements for auto refinishing.

Sampling data can be correlated with all relevant shop variables, from size to operating conditions to products types. Figure 3-9 shows typical modules involved in the solvent mass balance for auto refinishing shops. These areas, and their operating variables, are all being considered and incorporated (where appropriate) into the emission estimation method. A brief description is provided in Appendix B of an approximate model derived under this study for relating near-shop ambient samples to total shop VOC emissions.

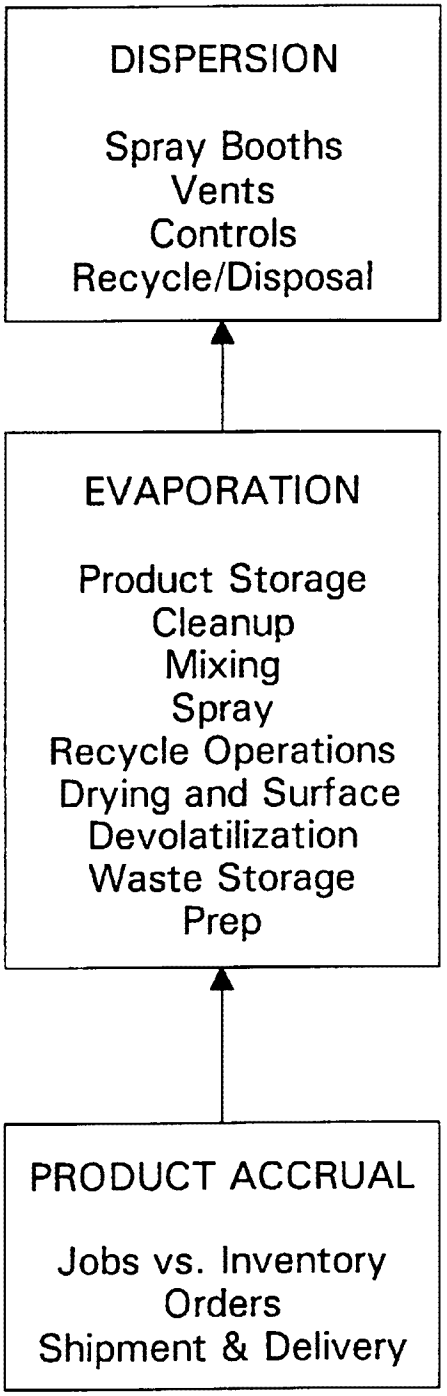



**Figure 3-9. Mass Balance of Emissions Flowchart**

## 3.5 Past Emission Estimation Data and GIS Interpretations

Emissions inventory data for auto refinishing are available for 1982 and 1987 from the EPA Office of Air Quality Planning and Standards (OAQPS). While inherent inaccuracies in the data do not allow strict validation, they can be useful for comparison with preliminary estimates using prescreened explanatory variables. Major discrepancies may highlight bad assumptions. The data medium, format and accessibility have not yet been firmly established. Most of the emission estimates are based on population figures. The data review thus far has included the States' approaches to assessing number of employee hours per year, work days per week and per year, effect of point source emissions on area source estimates, and obvious variations in "per capita" and "per employee" factors used.

Future data analysis will include graphing the trend of emissions estimates by county and nonattainment area for the past 1982, 1987, and some 1990, SIP responses for all 3300 counties. If efforts proceed on the first two to four items covered under this section, then there will be less need for revisiting past SIP-related estimates. Perhaps only 1990 data should be given a thorough review.

# 4. INTERIM RESULTS AND CONCLUSIONS

The results of the case study cannot be complete until validation data becomes available and emissions estimates can be better substantiated. Once the data from the validation survey comes in, the analytical tools will be tested and optimized and the system configuration finalized, as described in the last section. However, a number of steps toward an improved emission estimation method have been taken.

*Results of Current Study*

- A comprehensive information search and development of a database (see Sections 2.3 and 3.3);

- Assessment of current emission estimation methods related to the area source and their limitations (see Section 2.2);

- A PC Windows-, GIS-graphics-based system with computational techniques which provide reasonable examples of system function and output (see Section 2.5);

- Demonstration of the VOCEES system (see following examples) using existing and projected regulations, past and estimated emissions levels, geographic and time (annual) comparisons, extrapolation of emissions estimates to ppm concentrations within nonattainment areas, and other analytical results that might be prescribed by EPA;

- An examination of computational intelligence and recommendations for incorporation into the overall estimation method (see Sections 2.4 and 3.2);

- Preliminary screening of explanatory variables using statistical regressions (see Section 2.3.2);

- Preparation of a survey (questionnaire, sampling population and data storage and analysis system), and completion of a pre-survey (see Section 3.1);

- Development of preliminary source sampling recommendations (see Sections 3.4 and Appendix B);

A few final examples illustrate the present capability of the new method to produce results. The VOCEES part of the new method handles a resident database, makes emissions estimation calculations, and displays results for further analysis. One advantage of VOCEES is its ability to present information in

a new, easy, and quickly understandable way. Figure 4-1 illustrates information about automotive body shops in San Francisco obtained from American Business Information in the form of an ASCII text file. This text file was imported into MapInfo, and each business was assigned a geographic location using a process called geocoding. Geocoding of this file was done using the street addresses of the body shops. Using a file containing all the street locations and block numbers for San Francisco, CA, MapInfo sequentially processed all the body shop addresses and assigned latitude and longitudes to them using the street and block file. This process is completely automated; MapInfo stops only to query the user if a block number or street name cannot be matched.

The ability to display these locations is not the main feature of MapInfo, however. Even more useful, is its ability to show information related to these locations. As shown in the legend, the size of San Francisco's body shops ranges from one-person operations to the S & C Ford Truck Headquarters with 230 employees. To show the size of each body shop, its location is marked with a star that corresponds to its size. These graduated symbols show that, while there may be a few large shops, the majority are small operations usually with five or less employees.

VOCEES can also illustrate temporal changes in emissions estimates. Temporal changes in emissions are affected by regulatory changes. For example, in California local air quality management districts (AQMDs) have implemented different emissions regulations over the past decade and will soon introduce new ones. Figure 4-2 illustrates some of the changes in emissions in California's 58 counties. While estimates for each year were based on population, the estimates do not grow as population grows in some of California's most populous counties. In fact, there is a reduction in emissions in all of California's counties between 1988 and 1995. In 1988, 15 counties were above the average county emissions of 249 tons/yr; while in 1995, only 10 counties are projected to be above this average. The VOCEES maps quickly and easily enable the end user to track the progress of each AQMD and examine the impact of regulations.

The ability to examine different explanatory variables is another capability built into VOCEES. Figure 4-3 illustrates the use of three different explanatory variables to generate emissions estimates: population, American Business Information (ABI) SIC 7532 Employment, and County Business Patterns (CBP) SIC 7532 Employment. Different variables can produce profoundly different estimates. Burlington County, for example, has an estimate of 200 tons/yr using population as an explanatory variable and 285 tons/yr using ABI employment, a 43% increase. Cape May County, on the other hand, has an estimate of 49 tons/yr using population as an explanatory variable and 19 tons/yr using ABI employment, a 61% reduction. VOCEES enables the user to instantly and

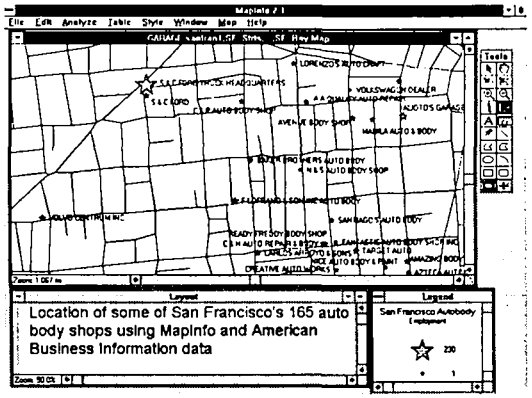



**Figure 4-1. Automotive Body Shops in San Francisco, as Displayed in *MapInfo*.**

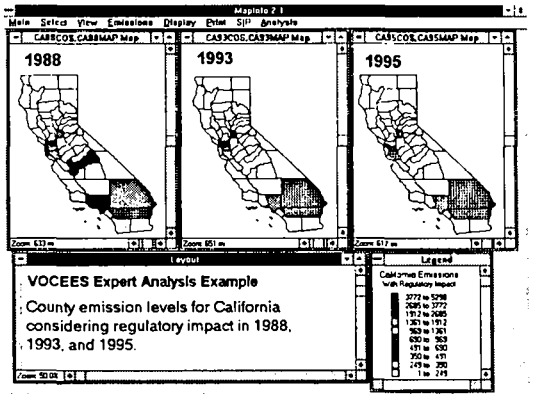



**Figure 4-2. Changes in County Emission Levels for California Due to Regulatory Impact in 1988, 1993, and 1995.**

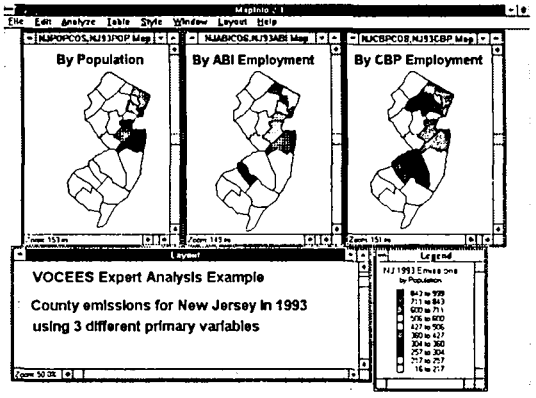



**Figure 4-3. Differences in Three Explanatory Variables Used in Generating Emissions Estimates**

graphically visualize the distribution throughout a state and determine which variable is the best choice.

Finally, one of the major accomplishments of VOCEES is the ability to produce documents which could be incorporated into state implementation plans (SIP). Figure 4-4 illustrates the use of VOCEES to generate all the information necessary for the Raleigh-Durham-Chapel Hill, North Carolina nonattainment area. VOCEES can generate maps, graphs, and tables. This presents the user with a great deal of flexibility for presenting data or adhering to a predetermined standard without reformatting. In addition, this data must be easy to arrange, print, and incorporate into other documents. Since VOCEES is a Windows-based application, much of the input/output difficulty has been removed. Tables can be saved as ASCII or dBASE, and graphics are easily created and printed through the use of layout pages. As illustrated in the figure, the layout window allows the page to be arranged as necessary and permits the inclusion of maps, graphs, and tables.

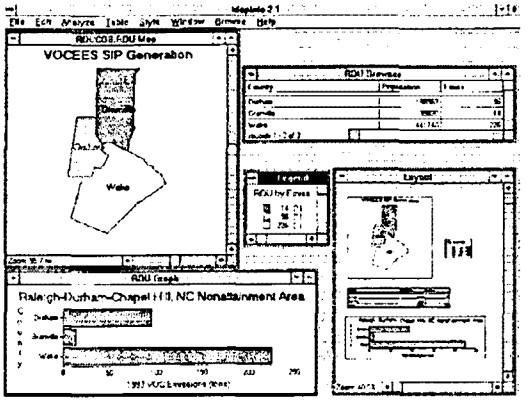



**Figure 4-4. SIP Information Generated by VOCEES for the Raleigh-Durham-Chapel Hill, NC Area**

*Conclusions and Recommendations*

- The automobile refinishing industry is representative of other major area sources associated with VOC use: average number of employees is small; direct customer interaction is important; interest in maintaining environmental compliance is legitimate if only to avoid penalties in some instances; the industry is affected more by major economic cycles than demographics; and materials suppliers (*e.g.*, paint manufacturers) very much determine the mix and VOC content of materials used by the industry. Therefore, demographics data for consumers are not always useful for <u>this particular area source</u>, because advertising and customer preferences are not as closely related to the

materials used as for many retail operations not associated with VOC emissions. Except for very localized areas smaller than counties, industry experts have not defined strong correlations between demographics and types of cars (and related paints), or the likelihood that accident repairs will include refinishing.

- The auto refinishing industry expects to be using lower-VOC materials and to expand the use of high transfer efficiency equipment like HVLP paint guns. Vent emission controls may not become prevalent because of cost, but this is a policy issue not yet definable. Paint product manufacturers say that regulation may possibly put some small shops out of business or cause consolidation into larger shops, but that environmentally non-compliant, backyard shops could flourish until high-VOC paints and older model cars become a small fraction of the market. No final conclusions are possible, but more sophisticated paint mixes, as dictated by the OEM automotive manufacturers, are very difficult to match with low-cost, unsophisticated application and drying techniques.

- Difficulties exist for obtaining product distribution data from automotive paint manufacturers because of "potential competitive advantage to be gained by one manufacturer over another by 'reverse engineering' of distribution data to obtain proprietary market and sales information" (from discussions with industry representatives -- August 1993). The nationwide survey is an excellent alternative approach to validation.

- Some discrepancies in current emission estimation methods exist for auto refinishing (see Section 2.2). These are mainly the result of unsubstantiated activity factors and of fundamental inaccuracies in activity factor data (*e.g.*, numbers of individual shop employees). The implications are that current emission estimates should be liberally interpreted when planning regulations, assigning nonattainment areas, and setting control priorities for area sources.

- PC Windows and MapInfo GIS with computer graphics displays are a good combination for an accurate, easy to use, low-cost emission estimation system. Data are easily input and displayed, and modifications are simple.

- No expert or expert approach exists upon which to base an expert system, *i.e.*, no state agency, EPA office, or EPA support group is consistently providing reliable, accessible, continuously available emission estimates. No obvious surrogate system is known which performs the same function for other types of values. Therefore, an expert system must be built through new expertise and knowledge and then captured in software. One model for this is described at the end of Section 3.2.

- Once validation data are obtained for VOC use associated with a representative population of an area source, genetic algorithms and neural networks (see Sections 2.4 and 3.2) should be efficient for completing selection and weighting

of the best explanatory variables, and for training the system to optimally integrate new information.

- Fuzzy logic is appropriate for manipulating rules to apply inferential estimates in augmenting the correlation of VOC usage variables. Expert opinion can be advantageously used in predicting the influences on auto refinishing emissions of such variables as economic factors, control equipment and emissions abatement operation practices, actual impact of regulations, influence of new products on emissions, and changes in OEM products. Experts can provide insight into the general correlation of emissions with shop size, shop sales per employee, and location in the United States (see Section 3.2).

- State and county databases should be used as activity factor data wherever possible. The best ones are typically updated annually. These databases are usually readily accessible to state agencies that prepare state implementation plans. They do not require the central processing and distribution needed for national data. These data (*e.g.*, licenses, registrations) are used for fee collection, taxation, and personal identification related to other financial transactions, so they are likely to be very reliable. EPA would continuously refine the techniques and tools for applying these databases and should be responsible for centralized validation of the method. However, local retrieval of raw data will make the method most efficient.

- Preliminary indications show that licensed drivers and registered vehicles are better explanatory variables for auto refinishing emissions than the currently applied variables of human population or the number of employees estimated to be working in local auto refinishing SIC businesses (see Section 2.3.2). Population data may correlate as well as most other variables but are not updated as often as other choices. The number of employees is suspect in a fluctuating industry and with inadequate data collection and disclosure by Federal surveys.

- Data related to the area source appear to be best for emissions purposes, including data related to materials volumes and product users' levels of activity (*e.g.*, registered vehicles).

- An estimate of the impact of regulations and standards, and of their level of enforcement requires more accurate emissions estimation and prediction.

- A system for tracking solvent distribution, from point of manufacture to point of retail sale should be developed (see Section 3.3). Manufacturers and OEMs (*e.g.*, auto manufacturers for refinishing, clothing manufacturers for dry cleaning) control the product mix for the most part. A tracking system is the most direct way to determine VOC distribution, and is probably the easiest way to collect the information. This is especially true for auto refinishing, where sales records of about seven large companies (and their distribution centers) could characterize more than 90% of the VOC distribution. The fact that

Material Data Safety Sheets are already distributed to all purchasers indicates that such a system is feasible.

- Validation of data and variable relationships using industry responses is essential to completion of a new estimation method. The two best ways to do this are through a national survey of the users of the pertinent VOC-containing materials or a mass balance distribution of the materials obtained from the manufacturers and/or their distribution centers. The latter is preferred for more continuously updated and state-wide/nation-wide accuracy while the former is preferred because of better cooperation and more local accuracy.

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# APPENDIX A
# SURVEY QUESTIONNAIRE

OP TYPE _____

FOR RTI USE ONLY

RTI ID Number: _____
Firm Name: _____
Mailing Address: _____
City, County, State, Zip: _____
Business Telephone Number: _____
Respondent's Name: _____
Respondent's Title: _____

(ID LABEL BOX)

## Auto Refinishing Questionnaire

A. Identification

1. Is the information printed on the above label complete and correct?

01 . . . YES ☞ Go to Question 2. 02 . . . NO

1b. Please correct or complete information as necessary:

Firm Name: _____

Mailing Address: _____

City _____ State _____ Zip _____

Street Location (If different from above mailing address):

_____

Business Telephone Number: (_____) - _____

Respondent's Name: _____

Respondent's Title: _____

1.c. Please indicate which type of operation is your primary function.

A. New Car Dealership

B. Used Car Dealership

C. Auto Refinishing Shop

D. Other (specify) _____

2. Do you provide autobody refinishing services at this location?

01 . . . YES ☞ CONTINUE to B.1. 02 . . NO

What service do you provide?
Please Specify: _____

STOP. Thank you for your time. Return the questionnaire in the envelope provided.

B. General Information

1a. How many total employees do you currently have working at this shop location?

Number of employees:_____

1b. How many employees use paints, primers, sealers, or other solvents?

Number of Body employees: _____

2. How many years have you been in the auto refinishing business at this location?

Number of years:_____

3a. How many hours per day, and days per week is the paint shop in operation?

Total operating hours per day _____

Total operating days per week _____

3b. Please indicate the time of day when most of the painting is done in your shop. Circle one answer.

01 . . morning (8 - 12)

02 . . afternoon (12 - 6)

03 . . evening (6 - 12)

04 . . other (specify)_____

05 . . no variance by time of day

3c. Please indicate the part of the week when most of the painting is done in your shop. Circle one answer.

01 . . . . . Beginning (Mon. - Wed.)

02 . . . . . Middle (Tues. Thurs.)

03 . . . . . End (Thurs. - Sat.)

04 . . . . . Weekend (Sat. - Sun.)

05 . . . . . Other (specify) _____

4a. Do you regularly service any fleet accounts at this location?

01 ..... YES 02 ..... NO ☞ Please go to Question 5.

4b. Please indicate (✓) what type of fleet accounts you service and what percentage of your total business each represents:

_____Government ..... _____% business

_____Car Rental ..... _____% business

_____Automobile Dealers ..... _____% business

_____Other, Specify_____ _____% business

5. Consider the time period from _____ to _____. How many jobs were completed at this location, in each of the following categories? Please report jobs completed for individual and fleet accounts separately. Enter a zero (0) in any category where no work was done.

| | Individuals | Fleets |
|---|---|---|
| Painting after collision ..... | _____ jobs | _____ jobs |
| Painting after vandalism ..... | _____ jobs | _____ jobs |
| Repainting under warranty ..... | _____ jobs | _____ jobs |
| Cosmetic or discretionary painting ..... | _____ jobs | _____ jobs |
| Custom and restoration ..... | _____ jobs | _____ jobs |
| Other, please specify ..... | _____ jobs | _____ jobs |

_____

6a. What paint/coating system(s) do you use most of the time?

| Manufacturer | Paint/Coating System |
|---|---|
| Example: DuPont | Example: ChromaBase |
| | |
| | |
| | |

6b. Again, consider the time period from _____ to _____. Please provide the *name or specific identifier* (part number) of each product you <u>used</u> with the system mentioned in 6a. For <u>each</u> product you list, indicate the *number of gallons* you used, during this time period. If you have more than one system in your paint shop, indicate the *manufacturer/system* name with each product.

| Category | Name and/or specific identifier | Gallons |
|---|---|---|
| **EXAMPLE** | **BASF LM-LF1508 Candy Apple Red Acrylic Enamel** | 10 gal. |
| Surface Preps | 1. | |
| | 2. | |
| | 3. | |
| Primers | 1. | |
| | 2. | |
| | 3. | |
| Surfacers/Fillers | 1. | |
| | 2. | |
| | 3. | |
| Sealers | 1. | |
| | 2. | |
| | 3. | |
| Topcoats (single and base/clear) | 1. | |
| | 2. | |
| | 3. | |
| Newly Purchased Cleaning Solvent | 1. | |
| | 2. | |
| | 3. | |
| Other Solvent-Based Products | 1. | |
| | 2. | |
| | 3. | |

6c. How did you determine the number of gallons of materials used from _____ to _____?

01 . . . . . Materials inventory records

02 . . . . . Number of jobs completed

03 . . . . . Other, please specify _____

7a. Would you consider the number of jobs you completed from _____ to _____ to be typical for this shop location?

01 . . YES ☞ Please go to Question 8a. 02 . . NO

7b. Was the number of jobs more or less than your typical month?

01 . . More 02 . . Less

7c. Why do you think your business was different during this time period?

_____

_____

_____

8a. Does your business activity vary from month to month?

01 . . YES 02 . . NO ☞ Please go to Question 9.

8b. Which <u>three</u> months are typically your <u>busiest</u>? Please enter a "B" next to those months. Which <u>three</u> months are typically your <u>least busy</u>? Please enter a "LB" next to those months.

| | | |
|---|---|---|
| _____ January | _____ May | _____ September |
| _____ February | _____ June | _____ October |
| _____ March | _____ July | _____ November |
| _____ April | _____ August | _____ December |

8c. Please describe why you think the three months you marked with a "B" are your <u>busiest</u>.

_____

_____

_____

8d. Please describe why you think the three months you marked with a "LB" are your least busy.

_____

_____

_____

9a. Do you use a factory built spray booth?

01 . . YES 02 . . NO ☞ Please go to Question 9c.

9b. Please indicate the manufacturer and model number.

Manufacturer: _____

Model #: _____

9c. Do you use a factory built prep station?

01 . . YES 02 . . NO ☞ Please go to Question 10.

9d. Please indicate the manufacturer and model number.

Manufacturer: _____

Model #: _____

10. Please indicate which types of spray guns are used at this location. Check (✓) all that apply. For each type of gun being used, please indicate the percentage of time it is used applying primer, basecoat, or topcoat.

| | | % time applying: | | | |
|---|---|---|---|---|---|
| Gun Type | Check (✓) if used | Primer | Topcoat (single stage) | Topcoat (two stage) | |
| | | | | Basecoat | Clearcoat |
| Siphon | | | | | |
| Gravity Feed | | | | | |
| Pressure | | | | | |
| HVLP | | | | | |
| Other _____ | | | | | |

11a. Does your shop have factory built gun cleaning equipment in operation?

01 . . YES 02 . . NO ☞ Please go to Question 11c.

11b. Please indicate the manufacturer and model number.

Manufacturer: _____

Model #: _____

11.c Is this gun cleaning system open or enclosed? Please check (✔) your answer.

_____ Open _____ Enclosed

11d. Approximately, how many gallons of waste solvent are generated in gun cleaning per month?

Please specify: _____ gallons

*Solvent-based materials may be used in various locations in the shop. (This may include areas outside of the spray booths and enclosed gun cleaning stations.)*

12a. How often is solvent-based material used in areas other than spray booths or enclosed gun-cleaning stations? Check (✔) one answer.

_____ Daily
_____ 2 or 3 times a week
_____ Once a week

Go to Question 12b.

_____ Less than once a week
_____ Never

Go to Question 13.

12b. During a typical week, how many gallons of solvent-based material are used in areas other than spray booths and enclosed gun-cleaning stations?

_____ gallons

13. *Various equipment is available to improve ventilation and to control emissions and vapors in work areas.* Have you installed any control equipment (e.g., ventilation equipment, recyclers, vapor retaining containers) in your shop?

01 . . YES 02 . . NO ☞ Please go to Question 14.

Please identify or describe this equipment (include make and model):

_____

_____

_____

14. How many gallons of waste which contain solvents are removed from this shop location by a licensed carrier (e.g. Safety-Kleen, Herkules) each month?

_____ gallons

15. Do you expect your auto refinishing business to increase, decrease, or remain the same over the next five years? Circle one answer.

01 . . Increase 02 . . Decrease 03 . . Remain the same

16. What factors (e.g., car safety equipment, DWI laws, traffic patterns, economic growth, changes in weather) did you use to predict your business patterns in question 15?

_____

_____

_____

_____

17a. What percentage of the auto refinishing businesses in your county are unlisted, unlicensed or "backyard" operations?

_____ %

17b. Approximately what percent of the auto refinishing jobs are done by these unlisted, unlicensed or "backyard" operations?

_____ %

18. Do you expect the use of solvent-based painting materials (including surface preps, additives, primers, and sealer) to increase, decrease, or remain the same within the next five years at this location? Circle one answer.

01 . . Increase 02 . . Decrease 03 . . Remain the same

19. How do current local, state, or federal environmental regulations impact your business (e.g. product selection, recycling, productivity, additional costs)?

_____

_____

_____

_____

20. How might changes in mixtures of solvent-based materials (e.g. low VOC paints), or new equipment requirements (e.g. afterburners) impact your business?

_____

_____

_____

_____

21. How are rags used in vehicle prep and clean up?

_____

_____

_____

_____

# APPENDIX B
# SAMPLING AND ANALYSIS DISPERSION MODEL

## Distribution Model

The basic equation typically used to generate air quality models is the diffusion equation. This equation reads as follows:

$$\frac{\partial c}{\partial t} + \bar{u}\frac{\partial c}{\partial x} + \bar{v}\frac{\partial c}{\partial y} + \bar{w}\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}(K_x\frac{\partial c}{\partial x}) + \frac{\partial}{\partial y}(K_y\frac{\partial c}{\partial y}) + \frac{\partial}{\partial z}(K_z\frac{\partial c}{\partial z}) + \textit{source terms} + \textit{transformation terms}$$

| | | |
|---|---|---|
| where, | c | = time-averaged concentration |
| | x, y, z | = Cartesian coordinates |
| | $\bar{u}$, $\bar{v}$, $\bar{w}$ | = components of time-averaged wind vector |
| | $K_x$, $K_y$, $K_z$ | = diffusion coefficients in the corresponding directions |

Several assumptions are made to simplify the solution:

- Steady state diffusion
- The time averaged wind vector is assumed to be oriented in the x-direction only, neglecting any buoyancy or height effects on the wind direction (i.e., $\bar{v} = \bar{w} = 0$)
- No sink or source effects
- No chemical transformations
- Mass transfer due to bulk motion in x-direction is assumed to be far greater than that due to mass diffusion, i.e.,

$$\bar{u}\frac{\partial c}{\partial x} > \frac{\partial}{\partial x}(K_x\frac{\partial c}{\partial x})$$

- Constant mass diffusion coefficients ($K_x$, $K_y$, $K_z$)

The diffusion equation thus reduces to:

$$\bar{u}\frac{\partial c}{\partial x} = K_y\frac{\partial^2 c}{\partial y^2} + K_z\frac{\partial^2 c}{\partial z^2}$$

One appropriate representation of the concentration profile downwind from a point source is given by the following general equation:

$$c(x,y,z) = \frac{K}{x}\exp\left[-\left(\frac{y^2}{K_y} + \frac{z^2}{K_z}\right)\frac{\bar{u}}{4x}\right]$$

K is a constant whose value depends on the boundary conditions of the specific atmosphere problem. One such boundary condition for a point source at ground level is:

$$Q = \int_0^{+\infty} \int_{-\infty}^{+\infty} \bar{u}\, c\, dy\, dz$$

where, Q is the source emission mass flow rate.

By defining:

$$\sigma_y^2 = \frac{2 K_y x}{\bar{u}} \qquad \sigma_z^2 = \frac{2 K_z x}{\bar{u}}$$

the concentration downwind from a ground level point source takes the form of a double Gaussian function:

$$\boxed{c(x,y,z) = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]}$$

The coordinate system used for this equation assumes that the point source is located at position (0,0,0), where the x-axis is pointed towards the direction of wind flow; the z-coordinate indicates the vertical position relative to the ground.

In order to evaluate the emission concentration at a given location (x,y,z), several values are required:

- The emission strength, Q (e.g., kg/s): The mass flow rate is the product of the volume rate, V, which can be measured on location, and the density, ρ, of the air at the point source[1].
- The wind speed, ū (e.g., m/s): Since the wind speed varies with height, a mean value taken through the plume should be used.
- The standard deviations, $\sigma_y$ and $\sigma_z$ (e.g., m): The horizontal and vertical standard deviations are a function of the downwind position x, as well as the atmospheric stability conditions. Although no theoretical expressions are available, several experimental measurements in the atmosphere have led to the evaluation and correlation of these values. It is recommended to select the correlation that best approaches the conditions at the test site (e.g., urban versus rural area).

1 It is assumed that the small concentration of VOC's in the air will have a negligible effect on the air density.

## Auto Refinishing Shop Model

Auto refinishing shops are typically one-story buildings and are generally classified as area sources. Although the formulas presented previously are only valid for point sources at ground level and under certain specific conditions, they could be slightly modified to apply to an auto refinishing shop.

As with point sources, no universal model is available to estimate the concentration downwind of an area source. However, general methods are used and must be modified for every specific problem. For instance, area sources may be subdivided into a series of point sources separated by a constant distance d. The concentrations due to the various sources would then be superimposed to generate an estimate of the concentration downwind of the source.

Unlike other area sources, such as landfills, which emit continuously over the whole area, auto refinishing shops will typically have 3 or 4 localized sources (e.g., exhaust vent, door, and window). Each of these emission "outlets" can be modeled as an individual point source. The total VOC concentration would then be approximated by superposition of the different point sources. Plume rise effects can be neglected in this case due to the low exit velocity of the VOCs. The low height of the buildings also makes it possible to assume that the emissions are generated from sources at ground level.

Another approach, which will be used in this case, is to model the area source as a single point source located at the centroid. The total emission rate would then be the sum of the emission rates from the various outlets.

Several measurements have been taken in the past to determine the values of $\sigma_y$ and $\sigma_z$ at various distances x from a point source. Since these values vary with atmospheric conditions and location, the correlation best approaching the specific topographic and atmospheric conditions of the body shop should be selected. The most frequently used set of data is that of Pasquill-Gifford. These standard deviations were determined for a low level source in open country. Other deviation values have been determined for a low level urban area by McElroy and Pooler[2]. However, since most auto refinishing shops in the Triangle area are located near highways, far from the few tall buildings in the city, the open country approximation would be acceptable. The Pasquill-Gifford data will therefore be used.

[2] McElroy, J.L., and Pooler, Jr., F. St. Louis Dispersion Study. Vol. II: Analysis. Rpt No. AP-53 (NTIS PB190255). National Air Pollution Control Administration, Arlington, VA December 1968.

## Evaluation of the Standard Deviations

The horizontal and vertical standard deviation, $\sigma_y$ and $\sigma_z$ are functions of the downwind position x and the atmospheric stability conditions. The Pasquill-Gifford (or Turner) correlations will be used. These correlations have certain restrictions[3]:

- Sampling time of approximately 10 minutes
- Open country terrain
- Lowest several hundred meters of the atmosphere
- Preferably, distance of receptors from source less than 1 km

The atmospheric conditions were listed under 6 different categories[4]:

A = extremely unstable
B = moderately unstable
C = slightly unstable
D = neutral
E = slightly stable
F = moderately stable

The conditions are listed in Table 1:

**Table 1: Guide to Pasquill-Gifford Stability Categories[3]**

| Surface wind speed @ 10 m (m/s) | Day, incoming solar radiation | | | Night, cloud cover | |
|---|---|---|---|---|---|
| **Class** | **Strong (1)** | **Moderate (2)** | **Slight (3)** | **Mostly overcast (4)** | **Mostly clear (5)** |
| **< 2** | A | A-B | B | E | F |
| **2-3** | A-B | B | C | E | F |
| **3-5** | B | B-C | C | D | E |
| **5-6** | C | C-D | D | D | D |
| **> 6** | C | D | D | D | D |

3 Wark, Kenneth and Cecil F. Warner. "Air Pollution: Its Origin and Control," Harper & Row, Publishers, Inc. New York, 1976.

4 Weber, Erich. "Air Pollution: Assessment Methodology and Modeling," Plenum Press: New York, 1982.

Some examples of these various classes would be:

1. Clear skies, solar altitude greater than 60 degrees above horizontal, typical of a sunny summer afternoon.
2. Summer day with a few broken clouds
3. Sunny fall afternoon, summer day with broken low clouds, or summer day with clear skies and solar altitude from only 15 to 35 degrees above horizontal.
4. Can also be used for a winter day.

The standard deviations can be approximated by the following equations:

$$\sigma_y(x) = (a_1 \ln x + a_2)\, x$$

*and*

$$\sigma_z(x) = 0.465 \exp(b_1 + b_2 \ln x + b_3 \ln^2 x)$$

The coefficients depend on the atmospheric conditions and are listed in Table 2[4].

**Table 2: Deviation Coefficients as a Function of Stability Categories:**

| Diffusion Category | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $a_1$ | -0.023 | -0.015 | -0.012 | -0.006 | -0.006 | -0.003 |
| $a_2$ | 0.350 | 0.248 | 0.175 | 0.108 | 0.088 | 0.054 |
| $b_1$ | 0.880 | -0.985 | -1.186 | -1.350 | -3.880 | -3.800 |
| $b_2$ | -0.152 | 0.820 | 0.850 | 0.793 | 1.255 | 1.419 |
| $b_3$ | 0.147 | 0.017 | 0.005 | 0.002 | -0.042 | -0.055 |

## LOCATION OF CENTROID

If the locations of the various point sources, i, are given by the coordinates $x_i$ and $y_i$ with respect to one of the building corners, then the centroid is located at ($x_g$, $y_g$), where:

$$x_g = \frac{x_1 Q_1 + x_2 Q_2 + x_3 Q_3}{Q_1 + Q_2 + Q_3}$$

$$y_g = \frac{y_1 Q_1 + y_2 Q_2 + y_3 Q_3}{Q_1 + Q_2 + Q_3}$$

In the concentration formulas, $Q_i$ stands for the mass flow rate from source i.

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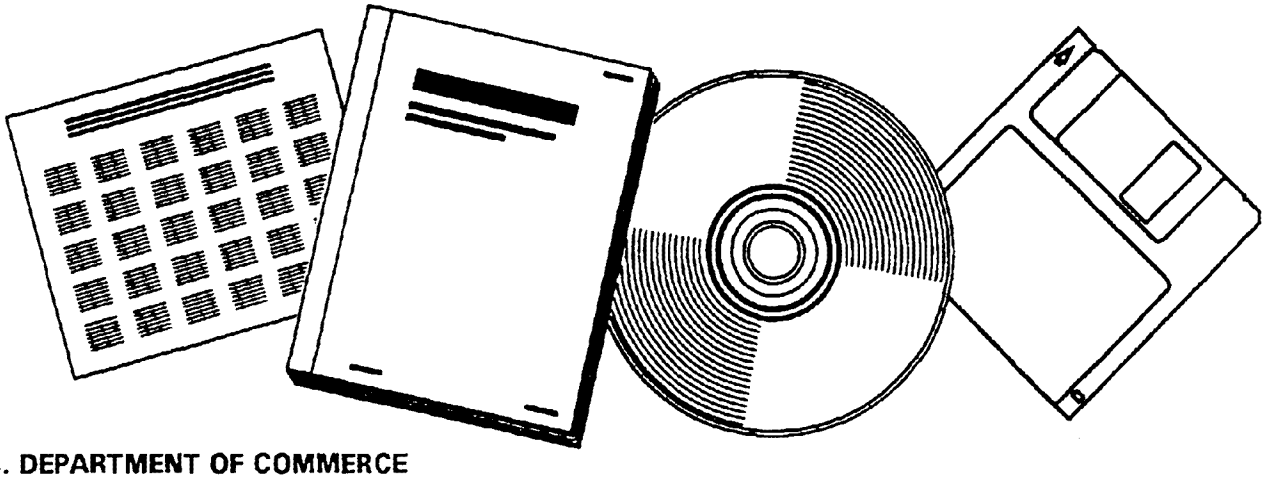

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NOAA TECHNICAL MEMORANDUM NMFS-SEFSC-400

NATIONAL MARINE FISHERIES SERVICE
CHARLESTON LABORATORY

# VOLUNTEER HANDBOOK

Wayne E. McFee

May 1997
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeastern Fisheries Science Center
Charleston Laboratory
219 Fort Johnson Road
Charleston, SC 29412-9110

NOAA TECHNICAL MEMORANDUM
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by

Wayne E. McFee

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# Welcome To NMFS Charleston Laboratory

Dear Volunteer:

Welcome to the National Marine Fisheries Service (NMFS)Charleston Laboratory. Thank you for joining us! We want you to feel that your association with NMFS will be a mutually beneficial experience.

You have joined an organization that is dedicated to the management and protection of marine resources as well as the education of the public about our mission. We hope you will also find satisfaction and take pride in your work to conserve our marine resources.

This Handbook provides answers to most of the questions you may have about the NMFS Charleston Laboratory programs, as well as the policies and procedures we abide by. If anything is unclear, please discuss the matter with your immediate supervisor. You are responsible for reading and understanding this Handbook to ensure safety for you and co-workers and to adhere to NMFS policies and procedures.

Occasionally the information contained in this Handbook may change. Every effort will be made to keep you informed of policy and procedural changes.

Personal satisfaction of doing a job well and career development are two of the many reasons people volunteer. The NMFS Charleston Laboratory is committed to doing its part to provide you with a satisfying volunteer experience.

We extend to you our personal best wishes for your success and happiness at the NMFS Charleston Laboratory.

Sincerely,

Wayne McFee
Volunteer Committee Chairman

Sylvia B. Galloway, Ph.D.
Laboratory Director

# Purpose of this Handbook

This Handbook has been prepared to inform you of the National Marine Fisheries Service's history, philosophy, policies, and expectations of you and the NMFS.

No volunteer handbook can answer every question, so we hope through regular conversations between you and your supervisor we can continue to add to the Handbook as conditions warrant. We hope this Handbook will help you feel comfortable with us. We depend on you in an ever shrinking workforce - your success is our success. Please do not hesitate to ask questions. Your direct supervisor or Volunteer Coordinator will gladly answer them.

We ask that you read this Handbook carefully, and refer to it whenever questions arise. The NMFS policies, benefits and rules, as explained herein, may be changed from time to time as business, volunteer legislation, and economic conditions dictate. If and when changes are made, you will be made aware of the changes.

## About the NMFS Charleston Laboratory

MISSION STATEMENT

The mission of the Charleston Laboratory is to provide scientific information required to resolve management issues associated with NMFS' agency goals. These goals are to:

- Build sustainable marine fisheries
- Maintain currently productive fisheries
- Advance fishery forecasts and ecosystem models
- Integrate conservation of protected species and fisheries management
- Improve seafood safety
- Protect living marine resource habitat
- Improve the effectiveness of international fisheries relationships
- Reduce impediments to U.S. aquaculture

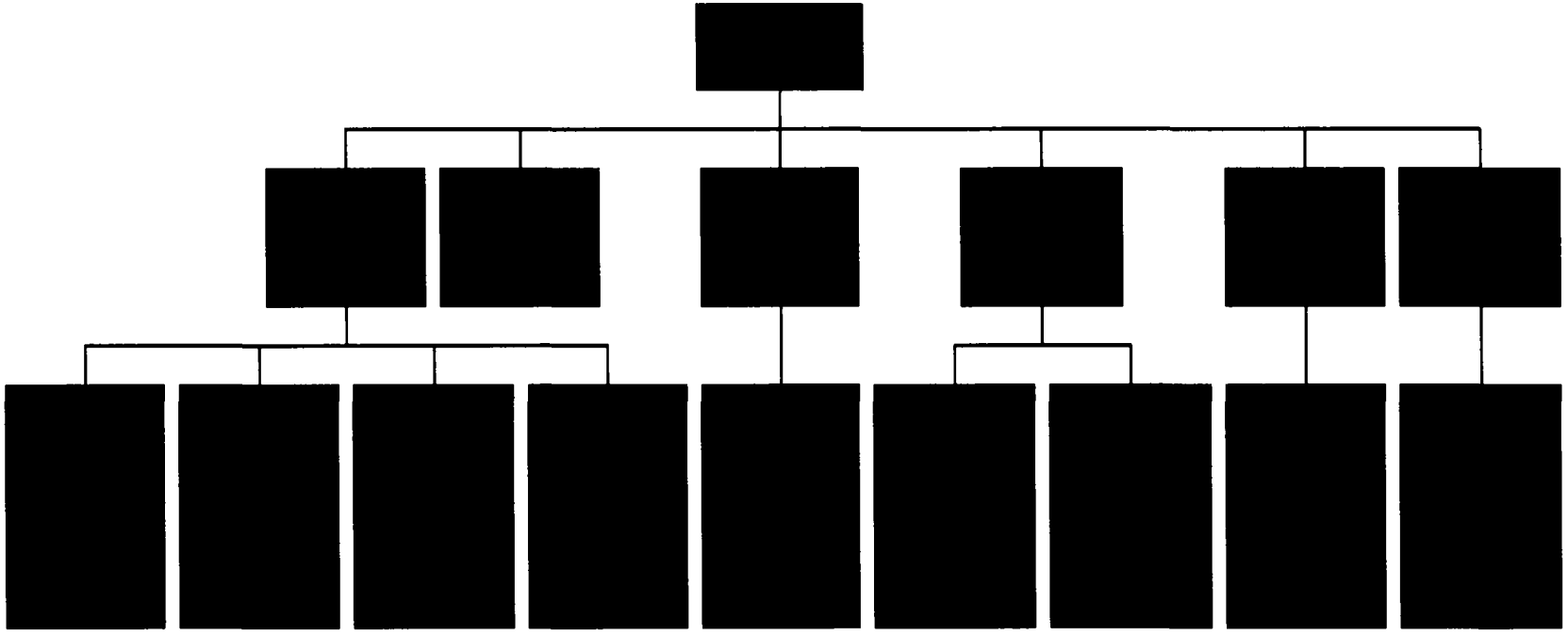
BACKGROUND

The Volunteer Program at the NMFS Charleston Laboratory was initiated as a result of the 1995 Federal Government National Performance Review leading to a reduction in the federal workforce. The loss of Full Time Employee (FTE) positions has resulted in a need to utilize volunteers and to provide opportunities to students and interested professionals interested in marine fisheries careers. The NMFS Charleston Laboratory provides opportunities to volunteer in a number of marine fisheries disciplines (Figure 1):

- Marine Ecotoxicology
- Risk Assessment
- Marine Biotechnology
- Marine Forensics
- Managed and Protected Resources
- Marine Biotoxins
- Seafood Technology and Regulation
- Biomedical Test Materials

Some duties volunteers have undertaken include: routine laboratory duties, water and oyster sampling for water quality analyses, chromatography, assistance in the retrieval and necropsy of stranded marine mammals, preparation of tissue and skin samples for pesticide, heavy metals, and genetic analyses, marine mammal skeletal preparation, and others. Approximately 10-15 volunteers spread among the various programs work throughout the week at the Charleston Laboratory.

# National Marine Fisheries Service
# Charleston Laboratory



Reproduced from best available copy.

## What You Can Expect from the NMFS Charleston Laboratory

The NMFS Charleston Laboratory will provide you with:

- A clear job description
- Assignments that fit your skills, interests, availability, and training
- Orientation, training, and supervision for specific duties, and an explanation for such duties
- A friendly, safe workplace that promotes a pleasant learning experience
- Safety precautions regarding chemicals, field work, and potentially dangerous areas
- Prompt and fair responses to on-the-job problems which may arise
- Recognition and appreciation for a job well done
- Skills and contacts to enhance career objectives and goals
- Confidentiality of individual records
- Personnel records to document experience, skills learned, training, evaluations, and commendations
- Consultation on job performance prior to resigning

## What NMFS Charleston Laboratory Expects from You

The NMFS Charleston Laboratory expects you will:

- Act professionally and maintain a good attitude towards your job and your fellow workers
- Honor the work schedule you have arranged with your supervisor, and notify your supervisor if your schedule changes, or you can not work due to unforeseen circumstances (i.e., illness, car trouble, etc.)
- Perform duties assigned to the best of your abilities
- Ask questions if you are unsure of a job assignment or safety issue
- Follow all safety precautions, policies, and rules outlined by your supervisor and/or provided to you by the NMFS Charleston Laboratory
- Hold in confidentiality anything you may hear at the Laboratory which may jeopardize the security of data produced at the Laboratory
- Obtain permission from your supervisor or Laboratory official to "tour" a friend or family member around the NMFS Charleston Laboratory
- Make this an enjoyable and rewarding experience that will help you in your future endeavors!

# VOLUNTEERING POLICIES

As a new volunteer to the NMFS Charleston Laboratory, you may be overwhelmed with the number of policies and safety issues you are exposed to. As a returning volunteer you may notice changes to policies and procedures. This section is designed to answer any questions you may have regarding policies and procedures.

**Background Checks**

The federal government requires all volunteers fill out a Wage Claim Waiver (Appendix A) and a Security Worksheet for Non-Employees (Appendix B) if work assignment is for less than 60 days. If working over 60 days volunteers are required to fill out a Wage Claim Waiver, a Security Worksheet and submit two sets of fingerprints for a security check. Failure to comply with the above will result in a termination of volunteer service. Acceptance into the Program shall be granted after a Volunteer Program Approval Certificate (Appendix C) has been signed by all listed approving officials and review of all credentials and background have been satisfied.

**Time Commitment**

Volunteers are expected to establish a work schedule with their supervisor by stating the days and number of hours per week to be worked. Requests for changes in time commitment should be communicated to your supervisor at the earliest opportunity.

If you are unable to report to work, or expect to arrive late, please contact your supervisor so that arrangements can be made to cover for your absence. Repeated absence or lateness may require a change in schedule or termination of appointment.

**Attendance**

Volunteers are required to "sign in" in the designated log book at the front desk, or if you do not have a time sheet in the book, you must sign in in the guest register at the front desk. You may also be asked to sign in in your particular area of work.

Sign-in procedures are important for keeping track of number of hours worked, starting and ending dates, for security measures, and for safety requirements in case of fire. It is also a measure to recognize time spent in a program and for evaluating the volunteer program.

**Confidential Information**

As a volunteer in this federal government laboratory, you may view sensitive documents, be present during discussion of sensitive information, such as law enforcement evidence analysis

results, or overhear staff opinions about politically sensitive topics. Because you may not have knowledge of some of these issues, you shall refrain from discussion of any staff conversations or viewed documents outside the room where such conversations or viewings have occurred.

**Public Relations**

Government agencies are constantly in the public's eye and issues related to marine species, especially endangered species, can be delicate subjects. Integrity of samples for receiving and shipping to other researchers need to be handled in a professional manner in order to deliver quality samples for research as well as protect the reputation of the NMFS Charleston Laboratory.

As a volunteer you shall not discuss privileged research information, law enforcement cases, or any other information deemed confidential by the NMFS Charleston Laboratory to the general public. Your supervisor will explain these items to you. As a volunteer you shall not answer **any** questions from the media without the permission of your supervisor. Please refer questions from the media to your supervisor regardless of whether you can answer the question or not.

From time to time you may be asked to assist in educational projects or participate in field research which places you face-to-face with the public. Please communicate pleasantly and respectfully to the public and refer questions to your supervisor.

Acting professionally and using common sense can save you and the Laboratory from embarrassing situations.

**Equal Opportunity**

The NMFS provides equal volunteering opportunity for everyone regardless of age, sex, color, race, creed, national origin, religious persuasion, marital status, or disability that does not prohibit performance of essential job functions, with or without accommodations, as stated in the job description.

**Harassment**

The NMFS Charleston Laboratory intends to provide each volunteer with a pleasant, healthful, and comfortable working environment, free from intimidation, hostility or other offenses which might interfere with your performance as a volunteer. Harassment of any sort - verbal, physical, visual, sexual - will not be tolerated. Any volunteer who becomes aware of harassment in any form, or is harassed him- or herself, has an obligation to report the incident(s) to their supervisor or a trusted employee immediately. The NMFS is obligated by law to investigate allegations of any form of reported harassment.

### Job Descriptions

We maintain a job description for each volunteer position in the NMFS Charleston Laboratory. Job descriptions may be very general or very specific depending on the needs of the particular Project. If your duties are changed, your job description will be updated. You may ask to see a copy of your job description at any time.

## OTHER POLICIES

### Computer Software

Unauthorized duplication of software is a federal crime! U.S. Code, Title 17, Section 106 states that "it is illegal to make or distribute copies of copyrighted material without authorization" from the copyright holder.

At the NMFS Charleston Laboratory you may receive authorization from your supervisor and/or computer analyst to use the Government computers and will receive a password to log-in to the network system.

The NMFS Charleston Laboratory computers shall be used only by volunteers for carrying out routine laboratory activities that are described in your job description and approved by your supervisor (e.g., data entry). **Personal computer software shall not be added to Laboratory computers. The NMFS Charleston Laboratory computers are not for personal use (i.e, typing letters, school work, resumes, etc.).**

### Personal Use of Government Property

At no time shall a volunteer use Government property for personal purposes.

### Copy Machines

Copy machines are not for your personal use. You may be asked to make copies as part of your job duties. These machines are located in the mail room near the front reception desk and in the back hallway near the Biotoxins section.

### Personal Phone Calls

Personal use of Laboratory phones is not permitted unless absolutely necessary. Long-distance phone calls are not allowed except in the case of an emergency. Otherwise you must use your own calling card and long-distance carrier. Local calls must be kept to a minimum.

**Parking**

Please park in the front of the NMFS Charleston Laboratory along with other staff members. Do not park in the designated "Visitor" spaces or "Handicapped" spaces (unless you are authorized to do so). Please do not park on the grass in front of the flag pole or in the back of the Laboratory by the loading dock. These areas are needed for emergency vehicles and delivery trucks.

**Smoking**

Smoking is not allowed anywhere in the Laboratory buildings. If you must smoke, please do so outside and use the cigarette receptacles.

**Dress Code**

Please see your supervisor for the appropriate dress required for your duty station. Safety concerns may require specific dress conditions.

While the majority of Laboratory personnel enjoy the freedom of dressing casually, there are instances when more formal dress is appropriate (i.e, meetings, public appearances, etc.). There are also instances when you may be in the field where "throw-away" clothes and footwear may be appropriate. Your supervisor should keep you informed as to the above situations.

**Substance Abuse**

Mind altering substances, such as alcohol or cocaine, will not be tolerated at the NMFS Charleston Laboratory. The use of drugs has an impact on the image of the Laboratory and personnel, as well as in our ability to achieve our objectives of safety and security.

The possession, sale or use of mind altering substances while volunteering shall result in immediate termination of volunteer service. If you have knowledge of anyone participating in the above while at the Laboratory please see your supervisor, personnel director, or Laboratory Director. Your name will be held in confidentiality.

**Problems**

Your problems are important to the NMFS Charleston Laboratory. In order to run an efficient laboratory we need to know when problems arise.

Be assured we will be receptive to your concerns regarding any situation which you believe violates your civil rights, is discriminatory, or presents a feeling of discomfort in your duties. This includes statements, attitudes, or opinions held by your supervisor or a fellow worker.

If you sense a problem, please see your immediate supervisor first. If the problem is against your supervisor please see the Volunteer Coordinator of the Laboratory. After a confidential discussion regarding the issue, if you are still not satisfied with the outcome, you may bring your problem directly to the Volunteer Committee. The problem will be discussed with the Committee and a decision rendered as final. The purpose of this procedure is to give each volunteer the chance to voice opinions regarding any problem situation.

**Expense Reimbursement**

You must have your supervisor's authorization to incur an expense on behalf of the NMFS. Situations may arise in the field where you may have to purchase small items (such as ice) to complete a job. To be reimbursed for all authorized expenses, you must produce receipts and signed approval from your supervisor.

**Resignation and Exit Interview**

If you are planning to resign as a volunteer, the NMFS Charleston Laboratory would appreciate notice as far in advance as possible to make arrangements for an exit interview with your supervisor and to allow for time to staff your volunteer position. An informal exit interview with your supervisor is recommended in order to obtain your ideas of ways to improve our program, answer any questions you may have, and to see how you enjoyed your time with us.

## STANDARDS OF CONDUCT

Because of the professional nature of business conducted at this Laboratory, stringent safety precautions, and law enforcement issues, certain standards of conduct are expected of each volunteer, as well as NMFS employees, to assure high quality products in a safe environment. The purpose of these standards is not to restrict your rights, but rather to be certain that you understand what is needed for you to meet these important responsibilities.

**Unacceptable Activities**

If you have any questions concerning any safety rule or any of the unacceptable activities listed below, please see your supervisor for an explanation. Occurrences of any of the following violations may result in immediate dismissal without warning:

- Willful violation of any NMFS policy or rule, including actions that are obviously detrimental to the NMFS.
- Willful violation of security or confidentiality policies.

- Willful or repeated violation of safety policies or rules; failure to wear required safety equipment; tampering with NMFS equipment.

- Negligence or any careless action which endangers the life or safety of another person.

- Being intoxicated or under the influence of controlled substance drugs while volunteering or on Government property; use or possession or sale of controlled substance drugs in any quantity while on NMFS premises.

- Unauthorized possession of dangerous or illegal firearms, weapons, or explosives on NMFS premises or while working in the field.

- Engaging in criminal acts of violence, threats of violence, fighting, provocation of fighting, or negligent damage to property while on NMFS premises.

- Insubordination or refusing to obey instructions deemed proper by your supervisor.

- Theft of NMFS or Government property or the property of co-workers; unauthorized possession or removal of NMFS or Government property, including documents, manuscripts, journals, books from the premises; unauthorized use of NMFS or Government equipment or property for personal use; using NMFS or Government equipment or property for profit.

- Dishonesty; willful falsification of personnel records; altering of personnel records or other NMFS or Government documents.

- Engaging in behavior designed to create discord and lack of harmony; interfering with the work of others within the Laboratory.

- Immoral conduct or indecency on NMFS premises.

- Unauthorized presence on NMFS premises after hours.

**Disciplinary Actions**

Unacceptable behavior which does not lead to immediate dismissal may be handled with a verbal warning, written warning, or suspension. Written warnings will include the reasons for the warning and any supporting evidence. You will have the opportunity to contest the warning by presenting your case to the Volunteer Coordinator and/or Volunteer Committee.

**Dismissal**

Volunteers who do not adhere to the rules of the agency or who fail to satisfactorily perform their

assignment are subject to dismissal. Repeated absence or failure to honor a pre-arranged schedule may also be cause for dismissal.

Volunteers may be dismissed without warning for just cause. The NMFS has the right to request a volunteer leave immediately. Grounds for immediate dismissal may include, but are not limited to:

- Gross misconduct or insubordination
- Being under the influence of mind altering drugs, including alcohol
- Theft of property or misuse of NMFS equipment or materials
- Lies or falsification of records
- Illegal, violent or unsafe acts
- Conflict of interest
- Breach of security policies
- Breach of confidentiality policies
- Abuse or mistreatment of co-workers or animals

## WORKERS' COMPENSATION

You are covered under Workers' Compensation title 5 U.S.C. chapter 81, relative to compensation for injuries sustained during the performance of work assignments. Claims related to injuries should be referred to the Office of Workers' Compensation Programs, U.S. Department of Labor.

Should you become injured or ill while performing your volunteer duties at the NMFS Charleston Laboratory please notify your supervisor immediately. Your supervisor will put you in touch with the proper authorizing official to fill out a claim form.

# SAFETY AND SECURITY

The NMFS Charleston Laboratory has a Laboratory Safety Program, which includes a Chemical Hygiene Plan (Appendix D) and an Emergency Preparedness Plan (Appendix E), that all employees and volunteers must read and follow. Each Program at the NMFS Charleston Laboratory has its own specific guidelines and policies for safety and security. These guidelines and policies will be explained to you by your immediate supervisor after assignment.

While each Program may have slightly different safety policies and procedures, the Laboratory as a whole believes that safety comes first and is everybody's business. If you are placed in a situation that you are not comfortable in, and you feel the activity is a hazard to you or someone else, please stop and notify your supervisor of your concern before proceeding. Please pay attention to all warning signs. All NMFS volunteers are required to view safety videos before beginning work.

Maintaining security in each Program may also be slightly different, but the Laboratory does have common practices. Maintaining security is also everybody's business.

Everyone is to be aware of new faces in the building. If you see someone in the building or on the property who is suspicious or who you do not recognize, kindly ask them if you can help them, or find a co-worker who may be able to identify that person. Everyone should sign into the guest register when they come in the building. If you see someone who does not sign in when they come in the building, kindly ask them to do so, or alert an Office Support Specialist at the front desk.

All outside doors to the buildings are to remain locked at all times. After you leave an area please lock the outside door if it requires a key. If you do not have keys or a magnetic card and notice an outside door unlocked, alert your supervisor so that he/she can lock the door. Again, each Program or Project may have other security measures for door access, computer access or file cabinet access. You will be issued a magnetic access card which will be coded for the appropriate areas you need access to in order to perform your duties.

## ACKNOWLEDGMENTS

I would like to thank the following people for their review and comments: NMFS Charleston Laboratory Volunteer Committee (Ms. Nancy Davey, Ms. Pat Smallwood, Ms. Carol Preston, Dr. Dan Bearden, Dr. Mike Fulton, Mr. Ron Lundstrom, Dr. Peter Moeller), Dr. Sylvia Galloway, Dr. Malcolm Meaburn, Dr. Paul Comar, Dr. Pat Fair, and Ms. Marlene Wiggins. I would also like to thank all of the volunteers both present and past who have contributed their time and efforts to make all of our work more manageable, productive, and enjoyable.

# APPENDIX A

## SECURITY WORKSHEET FOR NON-EMPLOYEES

1. Full names of non-employee: _____

2. Other names and dates used: _____
   _____
   _____

3. Position: _____

4. Project Title: _____

5. Place of Birth: _____
   _____
   (Be sure to include the city, county, state, and country, if other than the U.S.)

6. Date of Birth: _____

7. Social Security Number: _____

8. Sex: Male _____ Female _____

9. Has guest worked for DOC in the past: Y _____ N _____
   Location: _____ Date: _____

10. Period of Visit: Beginning Date: _____ Ending Date: _____

ARREST RECORD:

11. During the last 10 years have you ever forfeited collateral, been convicted, been imprisoned/been on probation or parole? Y ___ N ____

12. Are you now under changes for any violation? Y ____ N _____

13. Have you ever been convicted by a military court-martial or received Non Judicial punishment under the Uniformed Code of Military Justice? Y____ N _____

14. In the last five years have you ever possessed, used or manufactured illegal drugs? Y _____ N _____

HEALTH CARE:

15. Have you ever seen a health care professional for the treatment of an alcohol, drug, mental or emotional disorder? Y _____ N _____

If you answered yes to any of items 11-15, please explain your answer on a separate sheet of paper.

_____ _____

Signature Date

This section to be completed by the requesting official:

1. Name: _____

2. Mailing Address: _____

3. Position or Title: _____

4. Will access to departmental facilities be restricted to normal office hours or under escort? Y _____ N _____

5. Furnish accounting data if visit is for more than 60 days.
   Accounting data: _____

6. If the visit is for less than 60 days, this form may be sent to security for Regional Security Officer review.

7. Failure to forward this form, assumes Facility Manager permitting visit accepts full responsibility and risk for the actions of the non-employee.

_____ _____ _____

Date of Request Signature of Requesting Official Date

_____ _____ Approved Y __ N __

Date Received Date Processed

_____ Date: _____

Robert E. Dickson
Regional Security Officer

# APPENDIX B

NOAA/NMFS
CHARLESTON LABORATORY

Volunteer Program Approval Certificate

After review of credentials, including past and present coursework, employment history, internships (if any), volunteer experiences (if any), and present availability, the undersigned approve/reject the request of _____, for a volunteer position at the NMFS Charleston Laboratory.

Signed _____ Approve _____ Reject _____ Date _____
Supervisor

Signed _____ Approve _____ Reject _____ Date _____
Division Chief

Signed _____ Approve _____ Reject _____ Date _____
Prom. Mgmt. Spec.

Signed _____ Approve _____ Reject _____ Date _____
Volunteer Comm. Chair

# APPENDIX C

WAGE CLAIM WAIVER
Against
Federal Agencies

Under the
Student Volunteer Service Program

I hereby acknowledge that no Agency of the United States Government is responsible for the payment of any wages to me because of any work performed as an Enrollee for the National Marine Fisheries Service, U.S. Department of Commerce as part of the Student Volunteer Service Program. I agree that I will not make a claim against the United States Government or the National Marine Fisheries Service for wages for my services.

_____ _____
Signature of Enrollee Date

_____
Street Address

_____ _____ _____
City State Zip Code

_____ _____
Witness Date

_____ _____
Witness Date

# APPENDIX D

CHEMICAL HYGIENE PLAN

FOR

CHARLESTON LABORATORY
SOUTHEAST FISHERIES SCIENCE CENTER
NATIONAL MARINE FISHERIES SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
DEPARTMENT OF COMMERCE

## REGULATORY REQUIREMENT/INTRODUCTION

The Department of Labor, Occupational Safety and Health Administration (OSHA) Standard 29 CFR 1910.1450, Occupational Exposures to Hazardous Chemicals in Laboratories, became effective on May 1, 1990. The Federal Register announcement states that "employers shall have completed an appropriate Chemical Hygiene Plan and commenced carrying out its provisions by January 31, 1991". The new standard recognizes that laboratories typically differ from industrial operations in their use and handling of hazardous chemicals and that a different approach than that found in OSHA's substance specific health standards is warranted to protect workers.

The standard applies to laboratories that use hazardous chemicals in accordance with the definition of laboratory use and laboratory scale as provided in the standard. Laboratories are obligated to maintain employee exposures to hazardous chemicals at or below the permissible exposure limits (PELs) specified in 29 CFR 1910, subpart Z. The manner in which this obligation is achieved will be determined by each employer through the formulation and implementation of a Chemical Hygiene Plan (CHP). The CHP must include the necessary work practices, procedures and policies to ensure that employees are protected from all potentially hazardous chemicals in use in their work area.

The OSHA Standard defines a Chemical Hygiene Plan as a written program developed and implemented by the employer which sets forth procedures, equipment, personal protective equipment and work practices that (I) are capable of protecting employees from the health hazards presented by hazardous chemicals used in that particular work place and (ii) meets the requirements of paragraph (e) of this section (of the standard). Paragraph (e) states that the CHP shall be available to all employees and shall include the following elements: (I) Standard operating procedures for the use of hazardous chemicals, (ii) Control measures to be implemented to reduce employee exposure to hazardous chemicals, (iii) Specific measures to be taken to assure that fume hoods and other protective equipment are functioning properly, (iv) Provisions for employee information and training, (v) The circumstances under which a laboratory activity shall require prior approval, (vi) Provisions for medical consultation and

medical examinations, (vii) Designation of personnel responsible for implementation of the Chemical Hygiene Plan, (viii) Provisions for additional employee protection for work with particularly hazardous chemicals. Eleven components of a CHP as recommended by the National Research Council are included in this plan and are listed in the Table of Contents (page I).

This Chemical Hygiene Plan as well as more specific references relating to chemical safety, and safety in general at this facility, are available on the shelves adjacent to the lobby of the Charleston Laboratory. Included are:

(1) Charleston Laboratory Emergency Preparedness Plan - Instructions for evacuation of the building for fire alarms or other emergencies and preparation/response for hurricanes and other natural disasters.

(2) A copy of the Hazard Communication Program for the Charleston Laboratory. It includes an inventory list of hazardous chemicals used in this laboratory.

(3) Radiation Safety Manual - Rules and guidelines for those who work with radioactive materials.

(4) Working procedures for the control and containment of biotoxins.

(5) Biomedical Test Materials Program: Production Methods and Safety Manual - Detailed instructions for BTM/fish oil processing operations.

(6) Additional, selected publications on chemical safety and first aid.

## BASIC RULES AND PROCEDURES

1. Minimize all chemical exposures. Do not taste laboratory chemicals and avoid any contact with your skin. Smell chemicals only briefly and sparingly if necessary to identify them.

2. Don't underestimate risks. Use general precautions for handling all lab chemicals and use special precautions for chemicals that present special hazards.

3. Provide adequate ventilation. The best way to prevent exposure to airborne chemicals is to use hoods and other ventilation devices.

4. Use the hood for operations which might result in the release of toxic chemical vapors or dust.

5. Use only those chemicals for which the quality of the available ventilation system is appropriate. If hood operation is questionable, arrange for use of a more efficient hood for more hazardous chemicals.

6. Vent apparatus which may discharge toxic chemicals (vacuum pumps, distillation columns, etc.) into local exhaust devices (hoods or direct discharge from building).

7. Do not allow release of toxic substances in cold rooms, clean rooms, incubators, or any rooms which have closed, recirculated atmospheres.

8. Smoking is not allowed in the laboratory building. Do no eat, drink, or apply cosmetics in rooms where lab chemicals are present. Wash hands before conducting these activities.

9. Do not store food or beverages in refrigerators or other areas where chemicals are stored. Glassware or utensils which are used for laboratory operations should not be used to store or consume food.

10. Do not use mouth suction for pipeting or for starting a suction.

11. Do not engage in horseplay or other behavior which might startle or distract another worker or cause an accident.

12. Keep long hair and loose clothing confined. Wear shoes at all times, but sandals or perforated shoes should not be worn where chemicals are being used or mechanisms work is being done.

13. Wear safety glasses or goggles when hazardous chemicals are being handled in the laboratory.

14. Wear appropriate gloves when the potential for contact with toxic materials exists.

15. Avoid the use of contact lenses in the laboratory. If they are necessary inform the supervisor and takes precautions.

16. Wear lab coat when working with chemicals. Remove lab coat if it becomes significantly contaminated and decontaminate it if it would be hazardous to laundry personnel.

17. Wash areas of exposed skin before leaving the laboratory.

18. Avoid working alone in the building. Do not work alone in the laboratory if procedures could be hazardous.

19. Seek information about hazards, and plan appropriate equipment layout and protective procedures prior to performing work.

20. Be alert to unsafe conditions and see that they are corrected. Warn others of unsafe practices when they are detected. Those working regularly in an area are most aware of possibly unsafe conditions. Formal reports of unsafe conditions may be made on Form CD-351, "Report of Possible Safety/Health Hazard".

21. Pets and unsupervised children are not allowed in the Laboratory.

## CHEMICAL PROCUREMENT, DISTRIBUTION AND STORAGE

1. Before a chemical is ordered, investigate the potential for special hazards. Request Material Safety Data Sheet (MSDS) from the supply source. If special hazards exist, less hazardous substitutes should be considered.

2. New solvents will not be ordered when an excess amount that is suitable for use is already in storage.

3. Before a substance is received, information on proper handling, storage and disposal should be determined by those involved.

4. No container may be accepted without an adequate label. Labels must identify the contents and hazard class, and should contain first aid information.

5. All incoming orders will be received and noted by the purchasing agent, Sandra West (Karen Bauersfeld, backup), prior to distribution.

6. Material Safety Data Sheets (MSDS) are normally mailed by the supplier to the Area Safety Representative (ASR, Malcolm Hale) for each new shipment of chemicals received. The ASR will check to see if the sheets are needed for our central MSDS file or if special precautions are needed. Copies of the MSDS will then be passed on by Sandra to the person who ordered the chemical. If you are missing a MSDS, first check our MSDS file in the library, then the LabLink computer data base or request one from the supplier of the chemical.

7. Chemicals which generate acute hazardous waste (e.g. carbon disulfide) or unstable chemicals (e.g. diethyl ether) will be identified and monitored from purchase to disposal. The ASR will keep a log on future purchases of such chemicals. Wastes will be stored in appropriate, labeled containers and not mixed with incompatible wastes. Smaller containers shall be purchased, unless there is a short-term need for larger volumes.

8. Chemicals such as diethyl ether or dioxane, which may form dangerous peroxides, will be protected from light and heat and kept for no more than 2 years. Small quantities of ether that are being used in the lab will be stored in an explosion-proof refrigerator.

9. Diethyl ether bottles will be dated when opened and disposed of within 6 months of opening. The waste or outdated ether will be added to solvent wastes in a steel drum for approved commercial disposal.

10. All samples of marine biological toxins shall be stored in the padlocked, explosion-proof refrigerator in Room 216.

11. Environmental samples which appear edible will be marked as unsafe for human consumption during refrigerated storage.

## ENVIRONMENTAL MONITORING

Regular instrumental monitoring of airborne concentrations is not usually justified or practical in laboratories but may be appropriate when testing or redesigning hoods or other ventilation devices, or when a highly toxic volatile substance is stored or used regularly (e.g. 3 times/week).

Monitoring procedures and requirements for employees working with radioactive materials are described in the Laboratory Radiation Safety Manual, available on the library safety shelf, or see John Bemiss, the Radiation Safety Officer.

## HOUSEKEEPING, MAINTENANCE AND INSPECTIONS

1. Laboratory inspections for safety, housekeeping and chemical controls will be performed at least once each six months. Informal inspections of specific areas may be carried out at any time.

2. Areas should be kept orderly and floors cleaned regularly.

3. Eyewash fountains will be inspected every three months. They should be operated at least weekly to prevent rust buildup in the water.

4. Safety showers will be inspected and tested every six months.

5. Access to exits, emergency equipment and utility controls shall not be blocked.

6. Hoods will be monitored, and modified if inadequate. If you suspect that a hood is malfunctioning, notify your supervisor or the ASR.

7. The Area Safety Representative is primarily responsible for scheduled inspections. Informal inspections and safety surveillance are primarily the responsibility of supervisors.

8. The results of scheduled inspections will be given to the appropriate supervisors along with suggestions for correcting any and all violations.

## MEDICAL PROGRAM

1. For medical emergencies dial 911 and take appropriate first aid measures.

2. For less critical injuries that require medical attention the employee will be transported to James Island Medical Care (Dr. Costa) at 430 Folly Road. Form CA-16, authorization for medical treatment, should be obtained from the Administrative Officer (Karen Bauersfeld) and signed by the supervisor prior to leaving if possible.

3. When an employee develops symptoms associated with a hazardous chemical exposure, the employee shall have the right to an appropriate medical examination free of charge.

4. In the event of an accident in the laboratory resulting in the likelihood of hazardous exposure, an affected employee has the right to a medical consultation to determine the need for a medical examination. The employee must first notify his/her supervisor and complete a Form CA-16.

5. All medical examinations and consultations shall be performed by a licensed physician without cost to the employee, without loss of pay and at a reasonable time and place. The

employee may choose his/her personal physician, but the form (CA-16) authorizing medical procedures must be completed first.

6. Any medical conditions resulting from hazardous chemical exposure which requires treatment will be documented with details of the exposure and detailed statements from the attending physician.

## PERSONAL PROTECTIVE APPAREL AND EQUIPMENT

1. Protective apparel (gloves, safety goggles, aprons, etc.) shall be provided from operating funds for the degree of protection required for substances being handled.

2. An easily accessible drench-type safety shower shall be available in areas of higher risk.

3. An eyewash fountain shall be provided in high risk areas.

4. Fire extinguishers shall be readily accessible to all work areas.

5. Respiratory protection, a fire alarm and a telephone for emergency use shall be available nearby to all work areas.

## RECORDS

1. Accident records, including recommendations to prevent a recurrence, will be retained in the Administrative Office (KB) and by the Area Safety Representative (MH). Employees incurring an accident or illness believed to be work related will complete and file a Form CD-137 (Report of Accident/Illness) within 24 hours.

2. Chemical Hygiene Plan records will document that facilities and precautions are compatible with current knowledge and regulations.

3. An inventory of Room 266, volatile solvents storage, will be recorded each year and purchase restrictions applied to specific items if needed.

4. Records of hazardous chemicals stored in individual work areas will be posted inside the entrance of each room and periodically updated. Once a year workers will be instructed by Division Chiefs to update their lab inventories. Any chemical with one or more NFPA (diamond) Codes rated at 2 or above may be considered hazardous.

5. Records of high-risk substances (e.g., toxins or HCN) will be maintained in the laboratories by Project Leaders, and will include amounts on hand, amounts used and names of workers

involved.

6. Medical records will be retained by the Laboratory in accordance with the requirements of state and federal regulations.

## SIGNS AND LABELS

1. All containers shall be labeled as to contents and date made or purchased. This includes reagent bottles, chemical waste containers and receptacles. The labels on purchased chemical containers, including hazard and first-aid information, shall not be removed.

2. Emergency telephone numbers will be posted for supervisors, emergency personnel and workers responsible for equipment and facilities.

3. There will be prominent signs for locating fire extinguishers, exits, safety showers, eyewash fountains and other safety and first aid equipment.

4. There will be warnings at areas or equipment where special or unusual hazards exist.

## SPILLS AND ACCIDENTS

1. Procedures in case of fire, disaster or incidents that require evacuation are described in the Charleston Laboratory Emergency Preparedness Plan, of which each employee should have a copy. A reference copy is on the Safety/MSDS shelf in the Charleston Laboratory Library.

2. General rules for accidents and spills involving hazardous chemicals:

Eye Contact: Promptly flush eyes with water (15 minutes are recommended) and get medical attention.

Ingestion: Check container label and MSDS for first aid recommendations. Get medical attention as soon as possible.

Inhalation: Remove to fresh air and get medical attention.

Skin Contact: Flush thoroughly with water and immediately remove contaminated clothing.

3. In the event of a spill of hazardous material, take steps to contain and absorb it, if personal safety permits. Inform others in the area who might be affected and/or could assist.

4. In the event of a large spill of a hazardous material such that cleanup requirements exceed

the in-house capability, sound the fire alarm and have the building evacuated. Fire department personnel having self contained breathing apparatus (SCBA) and protective equipment should be informed of spill conditions upon their arrival.

5. In the event of a serious accident, do not move a worker with a possible serious injury unless the immediate area is not safe. Call 911 for medical assistance, alert others in the laboratory and provide first aid.

6. Use or transfer of hazardous chemical should take place in a properly operating hood if possible. Have absorbent or neutralizing materials available in case of spills.

7. Contaminated absorbent materials will be placed in a plastic bag or other suitable container and disposed of according to waste regulations.

8. All accidents or near accidents will be investigated and analyzed and the results distributed to all who might benefit. The Administrative Officer (KB) and the Area Safety Representative (MH) are required to maintain records of any accidents that involve injury or property damage.

## TRAINING AND INFORMATION

1. Aim: To assure that all individuals at risk are adequately informed about the work in the laboratory, its risks, and what to do if an accident occurs.

2. Supervisors will provide employees with information and training on hazardous chemicals in their work area at the time of their initial assignment, and whenever a new hazard is introduced.

3. Employees will be informed of the location and availability of the written hazard communication program for the laboratory.

4. The Hazard Communication Program, including the required inventory list of hazardous chemicals, will be available in the Library in the section with the Material Safety Data Sheets.

5. Employees shall receive initial Hazard Communication training and annual refresher training in accordance with the requirements of the Hazard Communication Program (HCP). Initial training shall include at least:

(i) Method and observations that may be used to detect the presence or release of a hazardous chemical in the work area.

(ii) The physical and health hazards of the chemicals used in the work area.

(iii) The measures employees can take to protect themselves from these hazards, including work practices, emergency procedures and personal protective equipment.

(iv) Details of the Hazard Communication Program, including an explanation of labeling systems and material safety data sheets.

6. The objectives of the HCP training are to enable employees to recognize and respond to chemical hazards, become familiar with material safety data sheets and personal protective equipment, and safely handle, use and store chemicals.

## WASTE DISPOSAL

1. Aim: To assure that minimal harm to people, other organisms, and the environment will result from the disposal of laboratory chemicals.

2. Room 266 is designated for organic solvent storage, and not for acids, alkalies or waste chemicals. Moderate amounts (1 to 4 gallons) of waste organic solvents may be stored temporarily (on floor to the right inside door) if they are properly labeled as to contents and if the ASR is notified.

3. Waste solvents will be transferred from temporary storage or directly from labs to storage drums in Container C behind the Laboratory building until pickup by a commercial waste disposal company can be arranged. Transfers will be made by the ASR or by Laboratory personnel in consultation with the ASR.

4. The ASR, with assistance from project personnel if needed, will assure that waste will only be added to drums containing other wastes that are chemically compatible. The volumes and compositions of wastes added will be recorded as the drums are filled. Each staff member is responsible for keeping records of contents of temporary waste containers used in each laboratory.

5. Wastes will be removed from the premises only by EPA certified waste disposal companies.

6. Most waste acids or bases can be disposed of by neutralization in a sink and flushing down the drain with excess water. Special care and sink within a fume hood should be used.

7. Radioactive waste materials will be handled in accordance with the Laboratory Radiation Safety Manual and will be stored in the restricted area in Room 410 until they can be disposed of.

8. All supplies used in toxin bioassays and extracted cell debris are collected of in approved

biohazard disposal bags. All animal cages are to be treated with a strong sodium hypochlorite solution and steam cleaned following toxin bioassays. When toxic wastes are neutralized by autoclaving or bleach treatment, they will be placed inside a plain plastic bag without the biohazard warning before they are placed in the dumpster for disposal.

9. Environmental samples that appear edible will be made unpalatable and marked "unsafe for human consumption" prior to disposal.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southeast Fisheries Science Center
Charleston Laboratory
PO Box 12607
Charleston, SC 29422-2607

June 9, 1995

MEMORANDUM FOR: Staff

FROM: MBH
Malcolm Hale

SUBJECT: (1) HVAC recirculation
(2) Sharps Disposal

Two subjects are included in the interest of conserving paper:

(1) HVAC - Our new HVAC system is more energy efficient than the old one due to the fact that most of the laboratory air is recirculated and mixed with a smaller volume of fresh make-up air. Because of this and as a normal safety precaution, please use a fume hood for any volatile chemicals. Do not transfer or work with volatile chemicals on open lab benches, because fumes will be distributed to all other work areas that are on the same air handler system.

(2) Sharps Disposal - Disposable hypodermic needles, used blades and other "sharps" should be accumulated in plastic "sharps" containers. These secure plastic containers can be added to the biohazardous waste boxes in freezer C for later transportation and incineration. Even if your sharps are not true biohazards, they should be disposed of in this way to avoid any misunderstandings if they are found in normal trash containers.

# APPENDIX E

## CHARLESTON LABORATORY

## EMERGENCY PREPAREDNESS PLAN

## OCCUPANT EMERGENCY

## PROCEDURES AND RESPONSIBILITIES

April 1992

## EVACUATION INFORMATION

Persons authorized to order evacuation:

Laboratory Director - Sylvia Galloway

Administrative Office - Karen Bauersfeld

Bldg.. Maint. Supervisor - Robbie Meyer

Notification for Evacuation

Fire - Fire Alarm Bells

Explosion or Gas Leak - Public Address announcement

Suspicious Object - Public Address announcement

Reporting Site

All employees should report to the parking lot in front of the building near the flagpole.

Building Re-entry

Re-entry to the building will be announced by the Laboratory Director or designated official.

Drill Schedule

Before a quarterly fire drill, the Laboratory Director and the Fire Department must be notified - other staff will not be notified.

# EMERGENCY PERSONNEL

**Designated Official/** Laboratory Director - Sylvia Galloway

**Occupant Emergency Coordinator/** Chief, Office of Administration

Karen Bauersfeld

**Team Coordinator/** Area Safety Representative

Malcolm Hale

**Area Monitors**

| Primary/Alternate | Area |
|---|---|
| Debbie Braddock/Karen Bauersfeld | Administration (Rm 100-118) |
| Malcolm Hale/Jon Ahlquist | Open Office Area (Rm 200-214) |
| Tod Leighfield/Bernie Lanoue | Biotoxin/Toxicol. (Rm 215-224) |
| Al Fortner/Scott Sivertsen | Back Hall, West (Rm 225-230) |
| Greg Mitchum/ | Back Hall, East (Rm 231-247) |
| Laura Webster/John Bemiss | Microbiology (Rm 248-257) |
| Carl Kinerd/Tom Edwards | ADP/Office Area (Rm 258-260) |
| Robert Roberts/Aaron Dias | Processing et al. (Rm 400-426) |

**Handicapped Monitor**

Karen Bauersfeld

**Damage Control Team**

Robbie Meyer

**After Hours/Weekend/Holiday Team**

| | |
|---|---|
| Paul Bauersfeld (Coordinator) | Home 795-0586 |
| John Babinchak | 795-8738 |
| Alan Fortner | 795-7716 |
| Robert Roberts | 795-8553 |
| Malcolm Hale | 795-0267 |

# FIRE EVACUATION PROCEDURES

1. **Upon detection of a fire**, regardless of the size, do the following immediately and in sequence, unless there are others available to permit simultaneous execution.

- **Activate fire alarm** - located in rooms or hallways as identified by signs

- On hearing the fire alarm the receptionist will not attempt to silence the alarm. She/he will ascertain from the annunciator panel in which one of the five zones the alarm is coming from and transmit this information over the paging system.

- **Attempt to extinguish fire immediately**, if possible - Using fire extinguishers located throughout the building, immediately attempt to extinguish the fire if it is safe to do so. If this attempt fails, or is not possible due to the size or nature of the fire, leave the building.

2. **Upon hearing the fire alarm**, the personnel will:

- **Stop work immediately**. Terminate all telephone calls, conferences, meetings, and if time permits, close all doors, turn off lights, and other equipment except those marked "Do Not Turn Off". Do not attempt to remove personal belongings or records.

- **Evacuate the building.** When area/zone in which the fire is located is known, the receptionist will make the following announcement over PA system:

**"ATTENTION: - There is an alarm in zone (give #). Please leave the building via the nearest exit, avoiding zone (give #). Repeat. There is an alarm in zone (give #). Please leave the building via the nearest exit, avoiding zone (give #)."**

Area monitors should take their stations and assist in evacuating personnel. Check to see that lights are off and doors are closed. If alarm sounds when you are far from your area, leave the building by the nearest exit.

- During evacuation, do not run, push, shout or congregate, and limit talking to a minimum. Move in a swift, orderly manner to the nearest exits (marked by red lighted exit signs) avoiding if possible the zone where the fire is located. Room 236 has a fire exit door and Rooms 243 and 246 have fire escape windows. Large or heavy objects (e.g., chair) may be used to break through any window, in the event the hallways are impassable, however, the main hallway is to be used as the first choice for evacuation.

- Upon exiting the building, move to the parking lot in front of the building near the flag pole, report to your supervisor and remain there until advised that it is safe to return to the building.

- All driveways and roadways must be kept clear for the use of emergency apparatus and fire equipment. Under NO circumstances will personnel be permitted to move any vehicles, unless otherwise directed.

3. **Return to the building** only after an official 'all clear' is given.

## VISITORS AND HANDICAPPED EVACUATION INSTRUCTIONS

Visitors

Visitors pose a different problem which must be dealt with on the spot, according to the emergency conditions. In this respect, all employees are expected to serve. In the event the evacuation alarm is sounded, the employee with whom the visitor is visiting, or the employee closest to the visitor will immediately inform the visitor that the alarm requires the evacuation of the building and that they will be assisted in this evacuation. If the visitor cannot leave the building on his/her own power, the employee will instruct the visitor to remain in place while they (the employee) go for assistance. The employee will go immediately to the Area Monitor, who will be located in the vicinity of the exit of that area, and report the exact nature of the problem. The Area Monitor will obtain the necessary assistance needed while the reporting employee returns to the handicapped person.

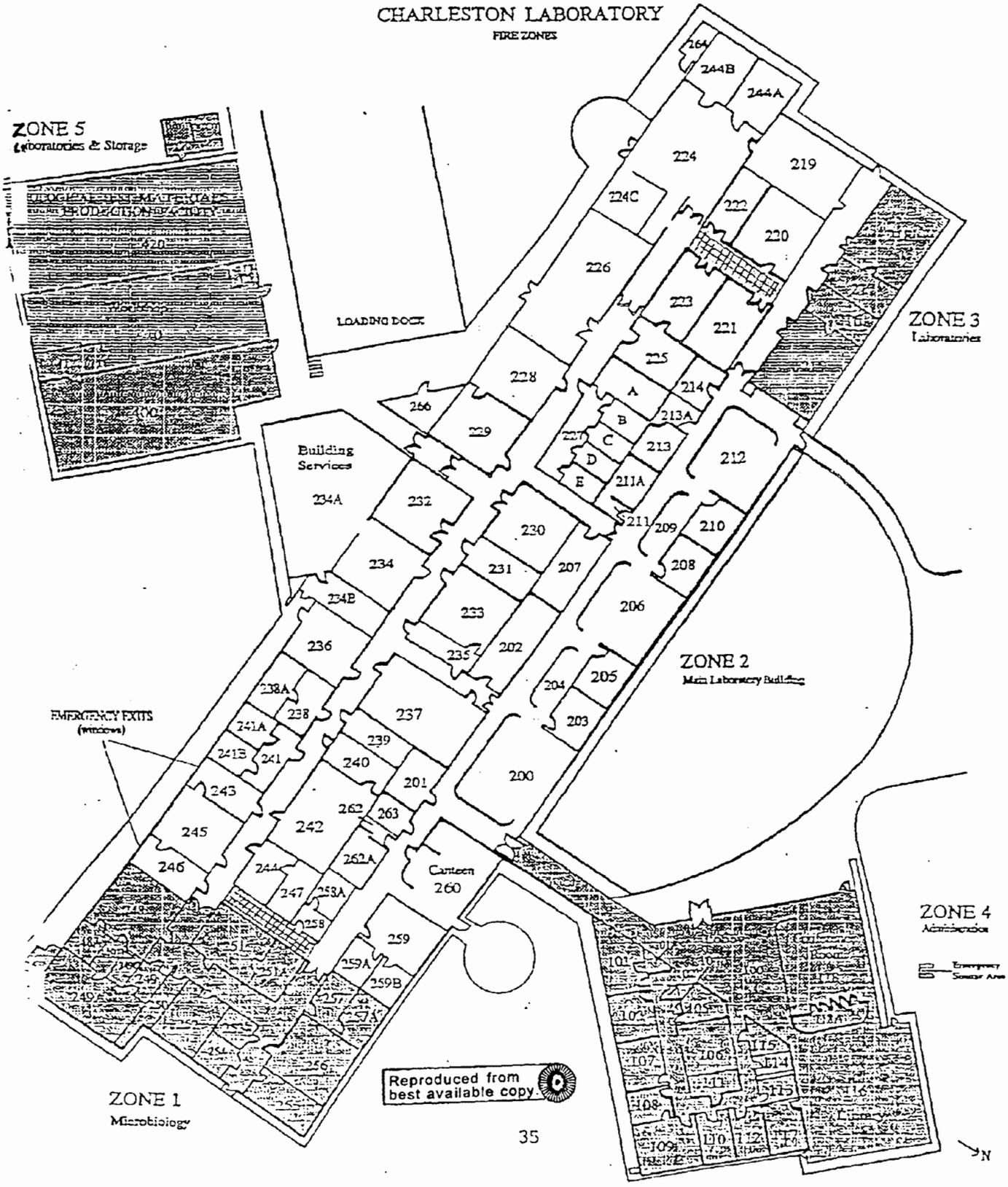
Handicapped Employees

Area Monitors will be made aware of handicapped employees in their respective areas and the nature of their handicap. A method of evacuation will be planned, by the Area Monitor, consistent with the handicap, prior to any emergency. Handicapped Monitors will be specifically assigned to each handicapped employee. Each handicapped employee will be fully advised of their individual evacuation plan by the Handicapped Monitor.

SOUTHEAST FISHERIES SCIENCE CENTER

CHARLESTON LABORATORY

FIRE ZONES

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# BOMB THREAT OR OTHER SUBVERSIVE ACT

If a bomb threat against SEFSC Charleston Laboratory is received by an employee, it shall be reported immediately to the Laboratory Director or his designee for appropriate action. The Laboratory Director will direct the evacuation of the building. The following personnel have been designated to act for NOAA/NMFS in determining course of action to be taken for employees located in SEFSC; this listing is in descending order of priority:

- Laboratory Director - 8525
- Administrative Officer - 8561 (will contact the Acting Director, if LD is unavailable)

When the decision is made to evacuate the building, the Laboratory Director or his representative will:

- Order immediate evacuation of the building by notifying the Administrative Officer. (NOTE: The Fire Alarm system will not be used for evacuation during a bomb threat.)
- Make the following announcement over the P.A. system:

  "Attention Staff. The Laboratory has received a bomb threat. Please turn off all unnecessary equipment including gas, water, and electricity, close doors and leave the building by the nearest exit. Go to and remain in the front of the guard shack, just inside the main gate, until notified otherwise. This is not a test. Do not stay in the building." Repeat.
- The Laboratory Director or his designee will call the Charleston County Police and Fire Department (dial 911).
- No evacuation order shall be given without approval of the Laboratory Director. However, when there is an immediate danger to persons such as an actual fire or explosion, the premises shall be evacuated at once, without consultation, by sounding the fire alarm system in the building and notifying Charleston County Fire Department (dial 911), the following normal evacuation procedures.

Special Instructions to all Employees

If you receive a call from a person stating there is a bomb in the building:

- Keep the caller on the line as long as possible. Ask the caller to repeat the message. Record (write) every word spoken by the person making the call.
- If the caller does not indicate the location of the bomb or the time of possible detonation, the person receiving the call should ask the caller to provide the information.

- Pay particular attention to any strange or peculiar telephone noises such as motors running, background music, and any other noises which might give even a remote clue as to the place from which the call is being made. Listen closely to the voice (male - female), voice quality, accents or speech impediments. It may be advisable (if time permits) to inform the caller that the building is occupied and the detonation of a bomb could result in death or serious injury to many people.

- Immediately after the caller hangs up, the person receiving the call should report this information to the Laboratory Director.

- In the event you see a suspicious-looking object during or before an evacuation, observe the following:

  - Do not disturb the object
  - Notify the Laboratory Director (8525) or the Administrative Officer (8561) and inform him/her of its location.

## INTRUDER ON PREMISES

In the event an intruder(s) is/are observed on the premises during the working hours, call the reception desk (8511) stating nature of intrusion, i.e., demonstration, vandalism, theft, bomb, arson, etc. State whether the intruder has a weapon. The receptionist will relay your call to the County Police and/or MRRI Security. During off hours notify the MRRI Security Office (762-5044) or MRRI Law Enforcement (762-5018 from 7:00a - 9:00p and 1-800-922-5431 after hours and holidays).

In no case attempt to apprehend an intruder. If possible record appearance of individual(s), sex, race, clothes, hair, behavior, etc., and means of escape, on foot, car, truck, bike, etc. Record license plate number if possible.

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 487-4650