Benefit-Cost Analysis of a Vehicle Scrappage Program

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I. INTRODUCTION

With the latest series of Clean Air Act amendments, metropolitan planning organizations and air quality management districts are faced with the difficult task of ensuring conformity between transportation projects and air quality management plans. Under the new legislation, industry and manufacturers in California are required to reduce emissions incrementally, and over the long term[1]. In meeting these requirements, polluters can choose technology options, or may choose to reduce emissions elsewhere in the basin, so long as they meet their net loss emission requirements. One way to minimize technology costs, or in some cases, to delay costs of technological measures, industry can propose emission offsets in other sectors[2]. One of these sources of emissions is mobile sources.

An example of an offset proposed for reducing mobile source emissions is vehicle scrappage programs, an example being the Southern California Retired Automobile Program (SCRAP), executed by UNOCAL on June 1, 1990[3]. In these programs, 'dirty' vehicles are purchased from individuals in the air basin, and removed from the vehicle fleet. The theory is that emissions produced by scrapped vehicles is higher than those produced by their replacement vehicles. The difference in emissions between retired and replacement vehicles is claimed as emission reductions.

Many questions arise as to the 'real' emission reductions realized by a vehicle scrappage program, especially since vehicle manufacturers are already mandated to systematically reduce vehicle fleet emission averages over the next decade or so[4]. Given average fleet turnover rates, how beneficial is a vehicle scrappage program? What are the costs and benefits to society from a vehicle scrappage program? Can we quantify the real emissions reductions from a vehicle scrappage program?

This paper presents a benefit-cost analysis for a vehicle scrappage program proposed for the greater Sacramento, California metropolitan area. In performing the benefit-cost analysis, uncertainties are made visible and controversies surrounding scrappage programs are addressed. Conclusions are drawn as to the feasibility, appropriateness, and benefits of such programs.

II. RESEARCH METHODOLOGY

A traditional benefit-cost analysis is used to assess the feasibility of a proposed Sacramento Area Scrapage Program (SASP). Costs and benefits are approximated by single point estimates. However, there are usually data limitations and assumptions that make point estimates misleading. In these cases, a range of values is given to provide a sense of the uncertainty involved in forecasts and assumptions. These ranges of values are used to facilitate sensitivity analysis, and to demonstrate the likely range of outcomes.

The social rate of discount used is 7%. This discount rate was chosen as it clearly fits in the realm of 'middle ground' in terms of prescribed use of social rate of discount. Many methodologies have been proposed to determine the social rate of discount including a method of weighted opportunity costs[5] and social time preference[6]. As social rates of return from 3% to 5% have been used, they have been criticized for being too low, thereby unjustifiably encouraging selection of government or social projects. Conversely, discount rates near the 10% to 14% value have been criticized for being too high, therefore discouraging the selection of long term projects.

A thorough benefit-cost analysis includes a clear definition of accounting stance. In this paper, the accounting stance shall be one of a local government agency. This is unique, since most vehicle scrappage programs have been proposed by industry. So, in the case of SASP, the agency proposing the program shall be Sacramento Area Council of Governments (SACOG). Of course, proposed emission reduction programs need more than just the endorsement of the local air district. This analysis assumes there are no significant barriers to implementation of a vehicle scrappage program.

III. DESCRIPTION OF PROPOSED SACRAMENTO AREA SCRAPPAGE PROGRAM

For conveniences, the proposed scrappage program is dubbed the Sacramento Area Scrapage Program (SASP). This program, though hypothetical, is constructed to resemble a program that might be proposed to reduce regional mobile source emissions in the Sacramento metropolitan region. The motivation for such a program is to comply with California Clean Air Act air quality standards.

The section is divided as follows. First, regional demographics are summarized, including population and population density, vehicle characteristics, and driving behavior. Then, a description of the SASP is provided, including required emission offsets and vehicle target group identification.

A. Sacramento Region Demographics

Population and Population Density
Sacramento has a large downtown area (Sacramento), comprised of many state offices and large employers. The downtown core area is surrounded in any direction by typical tract subdivisions, with population density generally decreasing with increasing distance from the downtown. The metropolitan area encompasses approximately 150 square miles.

Within this region there are many smaller cities, comprised mostly of large shopping centers, warehouse type attracters (Home Depot, etc.), and a diminishing number of neighborhood size stores. There is a small amount of mixed use development, primarily located in downtown Sacramento.

The greater Sacramento metropolitan region comprises about 750,000 people. This group represents the target population for the SASP. It is assumed that a limited number of people from both Placer and Yolo counties, the two most densely populated adjacent counties, also take advantage of this program.

Auto Ownership and Travel Behavior Characteristics
Auto ownership projections are based upon national averages. According to 1990 national average statistics, and given a population of 750,000, the Sacramento region is projected to contain approximately 510,000 licensed drivers (68% of population), 292,500 households (39% of population), and 517,500 vehicles (69% of population)[7]. On average, there is more than one car per licensed driver.

In 1990 on average, 18% of households in the U.S. had 3 or more autos, 38% had 2 autos, 33% had one vehicle, and 11% had zero vehicles[8]. About 89% of households have access to at least one automobile. The number of households corresponding to the percentages shown in Figure 1 for the Sacramento Region are 32,175, 96,525, 111,150, and 52,650 for zero, one, two, and three or more available vehicles respectively.

An important characteristic of vehicle ownership with regard to scrappage programs is the distribution and ownership of vehicles by model year. Since we are typically concerned with the replacement of vehicles dating before a particular model year, it is important to estimate the number of these vehicles available for retirement. It is assumed that approximately 15.6% of the vehicle fleet are 0 to 2 years old, 27.7% are 3 to 5 years old, 26.8% are 6 to 9 years old, and 29.9% are 10 years or older[9]. Using these national averages, the projected number of automobiles that are 6 - 9 and 10 or more years old for the Sacramento region is 138,690 and 154,732 respectively.

When considering average annual mileage and vehicle age, we find that 0 to 2 year old vehicles are driven about 16,811 miles, 3 to 5 year old vehicles about 13,706 miles, 6 to 9 year old vehicles about 12,554 miles, and 10 years or older vehicles about 9,176 miles[10]. Older vehicles are not typically driven as many miles annually as newer vehicles. This suggests that owning a single older vehicle may discourage some trips, and replacing an older vehicle might encourage new travel (i.e. discretionary trips such as vacation and recreation).

To estimate the distribution of vehicle age by number of vehicles owned, a representative distribution is assumed. That is a distribution where households with one vehicle are one-third as likely to own an old vehicle as are households with 3 vehicles, and one-half as likely to own an old vehicle as a 2 vehicle household.

This assumed distribution of vehicle ownership with age of vehicles may not be accurate. First of all, low income households, who are more likely to own only one vehicle, may also be more likely to own an older vehicle. These households are unlikely to own a second vehicle, and if they do it is likely to be an older vehicle. On the other hand, households with 3 or more cars may include a vehicle for a teenager living at home, who also can not afford a newer vehicle.

The estimated number of automobiles by age and number of available vehicles for the greater Sacramento region is shown in Table 1. The total number of vehicles in the region (517,500) has been divided among households according to number of vehicles available. This data is valuable for determining the target population of vehicles for the SASP, and for determining the benefits and impacts of the program. This table is based upon the representative distribution discussed previously.

B. The Sacramento Area Scrapage Program (SASP)

The proposed SASP aims to reduce carbon monoxide (CO), hydrocarbon (HC), and oxides of nitrogen (NOx) emissions in Sacramento's air basin. This section first discusses the theoretical basis of such a program. Then, the target vehicle group for the Sacramento region is estimated. Finally, a discussion of the emission offset determination is provided.

Theoretical Basis of Program
The proposed SASP intends to accelerate retirement of older 'high polluting' vehicles in the vehicle fleet. The theoretical basis for the program is that emissions reductions are achieved when high emitting vehicles are retired from the vehicle fleet sooner than they would have been without the program. The emissions reduction equals emissions from retired vehicles minus emissions from replacement vehicles, calculated over the remaining useful life of the retired vehicles. The motivation to replace older vehicles is due to estimates that pre-1971 vehicles drive about 1.7% of national VMT, but produce about 5%, 7%, and 7.5% of NOx, HC, and CO emissions respectively[11].

Determining Vehicle Target Group
The number of vehicles to be scrapped in the program is subject to some judgment, and is guided by a series of assumptions. For this study, light duty automobiles are targeted for replacement (See table 1). However, it is reasonable to also include light duty trucks in a proposed scrappage program.

Table 1 shows that there are approximately 155,000 vehicles in the Sacramento area that are older than 10 years of age. Clearly, this is too many vehicles to consider for a feasible program, since we can only expect partial participation from targeted participants. To get an idea of a feasible target number of vehicles, UNOCAL's SCRAP program scrapped 8,400 vehicles in the summer of 1990. So, using SCRAP's number as a low estimate, it is assumed that between 8,000 and 12,000 vehicles are scrapped.

Determining Required Emission Offsets
Estimating the amount of emissions in the Sacramento region to be reduced by the SASP depends on the severity of air quality violations, basin-wide aggregate emission inventories, time of year, and travel patterns and behavior among others. Instead of estimating the emission reductions required in the basin, it is assumed that the program will aim to scrap all attainable dirty vehicles, thereby maximizing emission reductions.

Estimating the maximum emission offset requires estimation of several key variables. First, vehicle emissions by model year and average annual mileage by model year are needed. Then, the number of vehicles on the road by model year are estimated. Finally, the mix of vehicles leading to largest reduction in emissions for a given number of vehicles are determined. It should be noted that the ideal mix of vehicles identified for the program will not necessarily participate.

The ideal mix of vehicles could not be obtained for several reasons. First, the vehicles identified for scrappage can not be solicited with any degree of certainty into the program.

In other words, the people who actually decide to take advantage of the SASP may not be the people who are identified as optimal participants. Secondly, there is a response level that is significantly less than the solicited

TABLE 1
Estimated Number of Automobiles by Vehicle Age and Number of Available Household Vehicles in Sacramento

	Number of Autos in:		
Age of Oldest Vehicle in Years	1 Car Households	2 Car Households	3 Or More Car Households
0 - 2 years	29,938	34,468	16,326
3 - 5 years	53,151	61,204	28,992
6 - 9 years	51,424	59,216	28,050
10 years +	57,373	66,066	31,293

number of candidate 'scrappers'. Finally, to be equitable, a model year cut-off date must be established which allows anyone who qualifies to participate, effectively barring any sort of selective candidate solicitation.

To estimate the number of vehicles by model year available for scrappage in the Sacramento Region, a regression equation was developed (see Washington, 1993) based upon nationwide data [12]. The regression equation is used in combination with figures in Table 1 to derive the target vehicles for the Sacramento region, shown in Table 2. The table shows the number of estimated vehicles by model year and household group for model years 1961 through 1979 for the Sacramento region. The totals shown at the end of the table match closely the totals shown in Table 1, the slight difference due to prediction errors made by the regression equation.

Having an estimate of candidate total vehicles for the SASP, we now must estimate how many of these vehicles can be expected to participate. Vehicle owners may not offer their 'old' car for many reasons: the car is a collector's item; the car is the owner's only mode of transportation and the owner can not afford an improved vehicle with the scrappage program compensation; the vehicle owner feels the car is worth more than the scrappage rebate; or the vehicle owner has a non-monetary attachment to the vehicle. Because of these reasons and others, vehicle owners may not participate in the program.

There are also vehicles that should not be allowed to qualify for the SASP. Since the intent is to remove active polluting vehicles from the fleet, the program is designed to ensure that vehicles are being driven. To ensure this, participants' vehicles must be in operating condition, have current registration, and have proof of continual previous registration. This selection process further reduces the candidate number of potential vehicles for participation in the SASP.

Considering the above factors, the expected participation rate for a proposed Illinois scrappage program was estimated to be about 10% [13]. The same 10% participation rate is assumed for the SASP. Using this figure, and considering a target population between 8,000 and 12,000 vehicles, we must target between 80,000 and 120,000 vehicles. Table 2 shows that if we consider pre-1978 vehicles, 99,000 vehicles are targeted, and about 147,000 vehicles are targeted if pre-1979 vehicles are considered. Based upon this criteria, pre-1979 vehicles are targeted, which, by erring on the conservative, provides a sufficient

TABLE 2
Target Vehicles by Model Year and Number of Vehicles in Household for Sacramento

Model Year of Vehicle	1 Car Households	Number of Vehicles in: 2 Car Households	3 + Car Households	Cumulative Total
1961	21	26	12	59
1962	55	64	30	208
1963	112	130	60	510
1964	200	232	108	1050
1965	325	374	177	1926
1966	494	568	270	3258
1967	712	820	387	5177
1968	987	1136	540	7840
1969	1324	1525	723	11412
1970	1731	1994	945	16081
1971	2214	2550	1209	22054
1972	2779	3200	1515	29548
1973	3433	3954	1872	38807
1974	4182	4816	2280	50085
1975	5033	5796	2745	63659
1976	5992	6900	3267	79818
1977	7066	8136	3855	98875
1978	8261	9512	4506	121154
1979	9583	11036	5226	146999
Totals	54,503	62,769	29,727	

number of program participants (it is presumably easier to terminate the program with un-served customers than to re-solicit program participants). This cut-off model year is also reasonable from the standpoint of emissions, since significant reductions occurred with 1980 model year vehicles.

IV. IDENTIFICATION AND ESTIMATION OF THE SASP COSTS

The SASP costs can be broken down into the following categories: advertising; administration and vehicle collection labor; vehicle purchase; emissions testing; data analysis and report; and vehicle scrappage. Costs are provided for two implementation scenarios: Scenario 1 - 8000 vehicles scrapped in the SASP; and Scenario 2 - 12,000 vehicles scrapped in the SASP. Also provided, when appropriate, are low and high estimates of costs.

A. Advertising

The advertising costs for the SASP are incurred during the initial stages only, as UNOCAL's program showed, once the program is up and running no additional advertisement is necessary. The budget for advertising is estimated between $1000 and $2000, and is usable for billboard, newspaper, or local television advertisements during the pre-implementation and earliest (perhaps one month) stages of the program. This cost is the same under both scenarios.

B. Administration and Vehicle Collection Labor

The administrative costs for the SASP are associated with telephone answering services for program participant inquiries, document processing for program participants (for program effectiveness analyses), and overall program accounting purposes for the one month program duration. The assumption is that 2 people are hired to work fifteen 8-hour shifts each at an average burdened labor rate of $40 per hour for a total cost of $9600. This cost is the same under scenarios 1 and 2.

The vehicle collection laborers perform vehicle inspections and scrappage preparation. It is assumed that 10 laborers are hired to work twenty 8-hour shifts at an average burdened labor rate of $40 per hour for a total cost of $64,000 under scenario 2, and 7 laborers hired to work twenty 8-hour shifts at an average burdened labor rate of $40 per hour for a total cost of $44,800 under scenario 1.

The total cost of labor for the SASP is an estimated $54,400 and $73,600 for scenarios 1 and 2 respectively. The costs are payable over the duration of the SASP, a period of about six weeks (2 weeks pre-program and one month vehicle collection at 75 vehicles collected per day).

C. Vehicle Purchase

The purchase price for the SASP vehicles must be high enough to encourage people to sell their vehicles. This requirement suggests that the purchase price must be at least as high as the market value for their vehicle. The experience of UNOCAL's SCRAP program, however, was that vehicle owners were willing to sell their car even though they valued their car higher than the SCRAP's offering of $700[14]. This suggests that fair market value for vehicles is an acceptable offering price for the SASP vehicles. In addition to fair market value compensation, potential SASP participants do not have to be burdened with advertising costs, salesman time, and any miscellaneous fix-up costs associated with selling their vehicles. These additional benefits might motivate individuals to take advantage of the SASP as opposed to offering their vehicles for sale on the open market.

The actual price paid for individual vehicles in the SASP program is a stepped pricing function. It is assumed to range from a low of $650 to a high of $900, depending on vehicle make, model, and model year. The actual price determinations could be made over the phone or in the field by one of the field technicians. The average price offered is assumed to range from a low of $700, to a high of $850. The average price paid for vehicles in UNOCAL's SCRAP and the proposed Illinois Vehicle Scrapage Program were $750 and $850 respectively[15 16].

So, for scenario 1, the cost of purchasing vehicles is estimated to be between a low of $5.6 million and a high of $6.8 million. And, under scenario 2, the cost of purchasing vehicles is estimated to be between a low of $8.4 million and a high of $10.2 million.

D. Emission Testing

Emissions testing is a vital component needed to be able to measure the effectiveness of the program. Currently, the IM240 test with purge and pressure tests is $250 per vehicle. The number of vehicles needed for testing depends upon the desired level of confidence associated with the results. For obvious reasons, the more vehicles tested, the higher the accuracy of the results.

To determine the minimum sample size needed for each model year group, the following equation was used:

$n = \left(\frac{z \cdot \sigma}{E}\right)^2$ where: n = minimum sample size needed, z = number of standard error units associated with level of confidence, sigma = standard deviation of the universe, and E = maximum allowable sampling error (difference between universe and sample mean).

Thus, sample size is ideally determined upon collection and testing of an initial set of vehicles. Say, for example, that after ten 1969 model year vehicles were tested on the IM240 for HC emissions, the average gram per mile emissions were 15.5 grams per mile, with a standard deviation of 5.0 grams per mile. Assuming a desired confidence level of 95%, a maximum allowable sampling error of 2 grams per mile, and that the sample standard deviation is approximately equal to the universe standard deviation, the formula yields: $n=\left(\frac{1.96 \cdot 5.0}{2.0}\right)^2=24$. If we relax the confidence level to 90% and increase the allowable maximum sampling error to 3.0 grams per mile, we get a sample size of 7.5.

So, as an approximation we need between 8 and 24 samples for each model year grouping. And, assuming model years between 1961 and 1978 are represented, we need between 144 and 432 emissions tests, resulting in emission testing costs between $36,000 and $108,000.

E. Data Analysis and Report

To estimate the effectiveness of the SASP, the emissions testing results, participant surveys, and program costs and benefits need to be analyzed. It is assumed that this task is sub-contracted to a university or consulting firm, and costs about $10,000 to $25,000 dollars, depending on the depth and breadth of analysis desired.

F. Vehicle Scrapage

The salvage value for scrapped vehicles ranges from approximately $35 to $100 per vehicle. Assuming an average scrap value of between $60 and $75 for all vehicles sold, a benefit of between $480,000 and $600,000 for scenario 1, and a benefit between $720,000 and $900,000 for scenario 2 is expected.

G. Miscellaneous Costs

Two additional costs are return transport and free bus passes (one month pass) for participants. In UNOCAL's experience, only about 24% took advantage of the bus pass offering, and most participants (more than 50%) arranged for their own transportation away from the facility[17].

An offering rate of between 25% and 40% is assumed for the $30 bus pass, which results in a cost estimates from $60,000 to $96,000 for scenario 1, and from $90,000 to $144,000 for scenario 2.

Transport from the facility via taxi service (based on $7.50 per trip), and assuming a participation rate between 30% and 70% for this service, the cost is between $18,000 and $42,000 for scenario 1, and between $27,000 and $63,000 for scenario 2.

H. Summary of Cost Estimates

The cost estimates for the SASP are shown in Table 3. Shown are average, low, and high costs estimates for all of the SASP costs under scenarios 1 and 2.

TABLE 3

Summary of Cost Estimates for the Sacramento Area Scrapage Program

	Scenario 1			Scenario 2		
Cost Category	**Average Cost Estimate**	**Low Cost Estimate**	**High Cost Estimate**	**Average Cost Estimate**	**Low Cost Estimate**	**High Cost Estimate**
Program Advertising	$ 1500	$ 1000	$ 2000	$ 1500	$ 1000	$ 2000
Program Administration	9600	9600	9600	9600	9600	9600
Program Labor	54,400	54,400	54,400	64,000	64,000	64,000
Vehicle Purchases	6,200,000	5,600,000	6,800,000	9,300,000	8,400,000	10,200,000
IM240 Emission Testing	72,000	36,000	108,000	72,000	36,000	108,000
Data Analysis and Report	17,500	10,000	25,000	17,500	10,000	25,000
Vehicle Scrapage Value	- 540,000	- 600,000	- 480,000	- 810,000	- 900,000	- 720,000
Bus Pass Provisions	78,000	60,000	96,000	117,000	90,000	144,000
Transport Service	30,000	18,000	42,000	45,000	27,000	63,000
Totals	5,923,000	5,189,000	6,657,000	8,816,600	7,737,600	9,895,600

V. IDENTIFICATION AND ESTIMATION OF THE SASP BENEFITS

Determining the 'real' emissions reductions of the SASP requires estimating the remaining useful life of vehicles, average emissions rates, and mileage of retired and replacement vehicles. Not surprisingly, the estimation of benefits of vehicle scrappage programs, depending on the assumptions made, can result in a wide range of benefit estimates. Effort is made to realistically quantify the range of uncertainties. To this end, results from UNOCAL's SCRAP, as well as national statistics are used to aid in the analyses.

A. Emissions Reductions

To estimate emissions reductions associated with the SASP, several assumptions are made throughout the analyses. These include assumptions about the distribution by model year of vehicles willing to participate in the SASP, the remaining useful life of scrapped vehicles, and the distribution of vehicle replacements and purchases made by SASP participants. These issues are addressed in the following sections.

Remaining Useful Life of Participating SASP Vehicles
Estimating the remaining useful life of vehicles participating in the SASP is critical. Table 4 shows the estimated remaining useful life for model year vehicles 1961 through 1979, based upon vehicles in California[18]. Remaining useful life estimates are generally higher for west coast vehicles, typically about 2 to 3 years higher than the rest of the country for similar vehicles[19 20].

Values shown in Table 4 represent an average of the entire vehicle fleet. We expect that vehicles submitted to a vehicle scrappage program are in poorer than average condition for the given model year. The uncertainty in estimated vehicle useful life is reflected in the estimates of emission reductions discussed shortly.

Distribution of Vehicles Participating in the SASP
The number of scrapped vehicles in the SASP is considered in two scenarios: scenario 1, where 8,000 vehicles are scrapped; and scenario 2, where 12,000 vehicles are scrapped. Recall that pre-1979 vehicles are targeted for the SASP. The distribution of the vehicles (by model year) is now needed.

As discussed earlier, 10 times as many vehicles were included in the target group in order to solicit the desired SASP participants. We expect, based upon the regional distribution of vehicles, that the number vehicles in each model year represents to some extent the proportion of those model years from the Sacramento sample. Based on this assumption, a distribution of program participants was derived for scenarios 1 and 2[21].

Distribution of Vehicle Replacements and Vehicle Purchases of the SASP Participants
It is difficult to estimate the distribution of replacement vehicles by model year for SASP participants. Replacement vehicle selection is determined by many factors including income, number of available vehicles, personal taste, and trip making behavior. For these reasons, two estimates of vehicle distributions are provided. The first is based on UNOCAL's results, the second is based on a representative sampling scheme.

TABLE 4
Estimated Useful Remaining Life by Model Year for California Vehicles

Model Year of Vehicle	Expected Remaining Useful Life in Years	Model Year of Vehicle	Expected Remaining Useful Life in Years	Model Year of Vehicle	Expected Remaining Useful Life in Years
1961	4.41	1971	4.59	1981	5.55
1962	4.43	1972	4.60	1982	5.93
1963	4.45	1973	4.62	1983	6.41
1964	4.47	1974	4.64	1984	6.99
1965	4.48	1975	4.67	1985	7.65
1966	4.51	1976	4.72	1986	8.39
1967	4.52	1977	4.80	1987	9.20
1968	4.54	1978	4.90	1988	10.06
1969	4.56	1979	5.05	1989	10.96
1970	4.57	1980	5.26	1990	11.88

In UNOCAL's experience, replacement vehicles were purchased by approximately 52% of program participants. Of the vehicles purchased post - SCRAP, approximately 16% were pre-1974, 29% were between 1975 and 1980 model years, and 55% were model years 1981 or later.

Since the post-survey results only represent a sub-sample of program participants (25 out of 8376 or 0.3%), and the total sample of program participants represents a sub-sample of the total basins estimated number of vehicles (8376 out of 410,000 or 2.0%), we really have a sample less than 7/1000 of 1 percent. However, the results of UNOCAL's SCRAP is used to provide a measure of variation in the subsequent analyses.

It is assumed that 50% of program participants purchase a vehicle after the SASP. To estimate the model years of vehicles purchased, it is assumed that model years are purchased with numbers representative of the existing vehicle fleet. For example, if 5% of the vehicle fleet are 1977 model year vehicles, then 5% of vehicle purchases are 1977 model year vehicles. A comparison of both SCRAP's method and the representative distribution are compared in Table 5.

Of the 46% of the SCRAP participants who did not purchase a new vehicle (2% of sample unaccounted for), 78% of them drove another vehicle, 8% got rides from others, 7% took public transportation, and 4% no longer drove[22]. It was also found that 70% of the sample had 2 or more vehicles, so liquidation of one did not necessarily leave them immobile[23]. It is assumed that the replacement vehicle (already owned) is representative of the participants 'second' vehicles, and that 10% of the total sample switch to public transportation or get rides with others (UNOCAL's SCRAP post survey revealed 15% used public transportation or get rides, while an additional 4% did not drive any longer[24]).

The assumptions for the representative distribution determines the number of replacement vehicles by model year based on 90% of participants replacing vehicles. This includes a 50% rate of 'new' vehicle purchases and a 40% of substitute vehicle usage. The distribution of vehicles based on UNOCAL's SCRAP are the sum of two distributions. The first is based upon a 50% rate of 'new' vehicles purchases based upon SCRAP findings. The second is based upon a 40% substitution rate based upon the representative distribution of vehicles.

Estimating Expected Emissions Reductions

To estimate emissions reductions from the SASP, the emissions 'saved' by scrapping vehicles must be subtracted from the emissions inventory, and then emissions from replacement vehicles must be added to the inventory. In essence, the net difference between the emissions from vehicles scrapped and replacement vehicles is the expected emission reductions from the SASP. The reductions are spread over the remaining useful life of the scrapped vehicles.

Emissions reduction estimates are calculated for scenarios 1 and 2[25]. And since remaining useful life estimates are based on vehicle fleet averages, they do not reflect the over-representation of below average conditioned vehicles participating in the SASP. To account for this, one scenario was run with the remaining useful life reduced by 1 year.

The emissions produced by replacement vehicles are calculated in same manner as done for emissions 'saved' by vehicles scrapped. In the replacement vehicle emissions analyses, the uncertainties involve the number and distribution of vehicles estimated to replace scrapped vehicles. It is assumed throughout that the useful remaining life of replacement vehicles is the average useful remaining life of all replaced vehicles, 4.582 years.

The emission reductions are calculated by subtracting the replacement vehicle emissions from the scrapped vehicle emissions. The difference is the emissions reduction realized by the SASP. Table 6 shows the results of the SASP emissions reduction analyses. The best and worst case results are shown for scenarios 1 and 2. Given are ranges of expected emission reductions based on the uncertainties discussed in previous sections.

TABLE 5

Comparison of Vehicle Purchases by Representative Distribution and Vehicle Purchases found in UNOCAL's SCRAP

Period of Comparison	UNOCAL's SCRAP Results	Results Based upon Representative Sample
Pre 1974 Model Year Vehicles	16 %	6.5 %
1975 to 1980 Model Year Vehicles	29 %	24.5 %
Post 1980 Model Year Vehicles	55 %	69 %

TABLE 6
Summary of Emission Reductions from the SASP
Emission Reductions Under Likely Worst and Best Case Scenarios (tons)

Scenario and Distribution Type	Estimated Hydrocarbon Emissions	Estimated Oxides of Nitrogen Emissions	Estimated Carbon Monoxide Emissions
—— Scenario 1 ——			
Best Case Results - Regular Useful Life and Representative Distribution of Vehicles	1278	306	9221
Worst Case Results - Reduced Useful Life and UNOCAL's SCRAP Distribution of Vehicles	721	129	5466
—— Scenario 2 ——			
Best Case Results - Regular Useful Life and Representative Distribution of Vehicles	1917	459	13,830
Worst Case Results - Regular Useful Life and Representative Distribution of Vehicles	1069	187	8157

B. Best Available Control Technology

To quantify emissions reductions, best available alternative control technology emission reduction costs are used. By using these costs, it is assumed that in order to achieve equivalent emissions reductions elsewhere in the basin, the cost of the best alternative emission control technology is foregone. We are avoiding these costs by implementing the SASP, and therefore are receiving a benefit equal to the cost of alternatively controlled emissions reductions. This is a reasonable assumption in non-attainment regions, where emission reductions are mandatory. The alternative minimum cost controls for HC, NOx, and HC are discussed in turn.

Hydrocarbon reduction strategy costs for 1994 are estimated to be between about $900 per ton (controls on hazardous waste treatment, storage, and disposal), to about $51,000 per ton (methanol substituted for gasoline as motor fuel)[26]. For a cost of about $1000 per ton, onboard and gas pump controls can be purchased which effectively reduce running and refueling evaporative losses[27].

Oxides of nitrogen can be controlled at a cost of about $1200 to $3300 per ton. The alternative investment involves enhanced inspection and maintenance programs for cars and light duty trucks. Recent estimates of CO reduction strategies estimate actual cost savings associated with future controls to be about $200 per ton, but actually save enough fuel to more than compensate for the cost. Present oxygenated fuel strategies used to control CO are estimated to be between about $300 and $600 per vehicle[28].

Based upon the above estimates of alternative emission control strategies, an estimate for the benefit of reduced emissions from the SASP is derived. With information as to the amount of emissions reduced by the SASP, and using the minimum alternative control cost, estimates for benefits are derived. The results are shown in Table 7.

C. Other Benefits

There are benefits other than emissions reductions provided by the SASP, however, the quantification of these 'other' benefits are difficult to estimate. Nevertheless, these other potential benefits are identified below.

Reduced Non-Recurrent Congestion Benefits
Since older vehicles are in general being replaced with newer, more reliable vehicles, we expect fewer breakdowns. During non-congested times this may not result in significant benefits for society, but during

TABLE 7
Summary of Emission Reductions Benefits from the SASP
Benefit = Emission Reduction Costs of Best Available Option x SASP Reductions

Scenario	Estimated 'Best' Available Emission Control Cost ($ / ton)	Emissions Reductions Estimated from the SASP (tons)	Estimated Benefit ($)
—— Scenario 1* ——			
Best Case Results: Regular Useful Life and Representative Dist. of Vehicles	HC - $1000 / ton	1278 tons	1,278,000
	NOx - $1200 / ton	306 tons	367,200
	CO - $300 / ton	9221 tons	2,766,300
			Total = 4,411,500
Worst Case Results: Reduced Useful Life and UNOCAL's SCRAP Dist. of Vehicles	HC - $1000 / ton	721 tons	721,000
	NOx - $1200 / ton	129 tons	154,800
	CO - $300 / ton	5466 tons	1,639,800
			Total = 2,515,600
—— Scenario 2** ——			
Best Case Results: Regular Useful Life and Representative Dist. of Vehicles	HC - $1000 / ton	1979 tons	1,979,000
	NOx - $1200 / ton	459 tons	550,800
	CO - $300 / ton	13,830 tons	4,149,000
			Total = 6,678,800
Worst Case Results: Reduced Useful Life and UNOCAL's SCRAP Dist. of Vehicles	HC - $1000 / ton	1069 tons	1,069,000
	NOx - $1200 / ton	187 tons	224,400
	CO - $300 / ton	8157 tons	2,447,100
			Total = 3,740,500

congested periods this could significantly reduce traffic delays and emissions.

Increased Traveling Safety Benefits
Also associated with older vehicle mechanical failures are the reduced numbers of accidents. Again, these are extremely difficult to quantify, but the reduction, of say, one accident with two fatalities and two injuries could add a significant dollar benefit to a scrappage program. Valuing human lives has long been a topic of debate in benefit-cost analyses, and perhaps the number of lives saved might be the better way to quantify the benefits[29].

Benefits of Reduced Petroleum Consumption
Again, the quantification of the benefits of reduced petroleum consumption are difficult. Associated impacts include import taxes and costs, military protection of foreign oil supplies, and national security issues.

VI. COST BENEFIT ANALYSIS OF THE SASP

The net present value under scenarios 1 and 2 can be computed easily by looking at flows of previously estimated costs and benefits over the life of the project (see Washington, 1993).

In the following analyses, the discounted value of money (7% in all analyses) is incorporated in the following manner. The costs associated with implementing the SASP occur in the period of about six weeks, which does not allow a realistic distribution of payments over time. For this reason, program costs are not discounted, and are assumed to occur at year zero.

The benefits of foregone alternative control costs are costs that are not paid, and therefore do not occur over time either. However, the benefits of reduced emissions (and foregone costs) are assumed to occur over a period of the average useful life of retired vehicles, or about five years. Taking this into account, interest, or foregone discounted annual control costs, accrue over a period of the five years.

A. Scenario 1 Results

The flows of costs and benefits for the average, best-case, and worst-case scenarios is shown in the detailed report[30]. The results show that even under the best-case scenario, the SASP is not justified on purely economic grounds. Specifically, the net present worth under scenario 1 for the average, best-case, and worst-case scenarios is - 3.084 million, -1.571 million, and - 4.594 million dollars respectively.

B. Scenario 2 Results

Similar to scenario 1, the SASP under scenario 2 is not justified on purely economic grounds. The net present worth for the average, best-case, and worst-case scenarios is - 4.544 million, -2.261 million, and - 6.828 million dollars respectively. The implications of these findings are now discussed.

VII. SUMMARY AND CONCLUSIONS

The successful (in terms of public opinion) vehicle scrappage program implemented by UNOCAL in 1991 spurred interest nationwide in vehicle scrappage programs. As air quality planners are trying to find cost effective ways to reduce emissions, the cost of vehicle scrappage programs, on a dollar per ton basis, is important. Old and 'dirty' vehicles are ideal targets for retirement.

This paper provides a benefit-cost analyses of a proposed vehicle scrappage program for the Sacramento region. The framework for the analyses are designed around Sacramento regional demographics and car ownership patterns, while inputs such as annual miles traveled by model year are derived from national averages.

An effort is made to capture uncertainties in the analyses. These elements include capturing variation in vehicle distributions of post-SASP vehicle purchases, variation in the estimated useful remaining life of scrapped vehicles, and many uncertainties in cost valuations. The uncertainty estimations are carried through the analyses, with the goal of providing a realistic range of possible outcomes.

The benefit-cost analyses showed that the SASP is not justifiable on purely economic grounds for either scrappage of 8000 or the 12,000 vehicle scenarios (scenarios 1 and 2 respectively). In fact, even under best-case scenarios, there is a net cost of about 1.5 million dollars for scenario 1, and about 2.3 million dollars under scenario 2.

The analyses, however, do not include possible benefits from improved health and safety, reduced productivity losses due to congestion, and reduced emissions from reduced non-recurrent congestion. These benefits would have to total at least $200 per vehicle scrapped to make scrappage attractive economically.

The SASP is not economically viable when compared to minimum alternative control costs. In this light, if estimates of costs for alternative programs are significantly under-estimated, then the SASP may become more attractive. Table 8 shows the costs of alternative programs in dollars per ton of emissions reduced. The table shows that the SASP is fairly competitive for reductions in HC and CO. However, the cost for reducing NOx emissions is 5 to 20 times higher than its competitors.

Several issues are identified for further research. First, the data available to estimate expected useful lives of vehicles are poor. This deficiency could be rectified with the use of DMV records, although they are poorly managed, or through the use of survey information. The estimation of expected useful life is important in the calculation of emission reductions from scrapped vehicles.

In addition, the 'other' benefits discussed previously should be quantified. For example, the impact of vehicle scrappage programs on roadway safety could be significant - perhaps saving lives.

Finally, we need to improve the estimation of emissions from vehicles. Current models poorly predict emissions[31], so the emissions impacts of proposed programs like the SASP can not analyzed with a high degree of precision. Furthermore, the driving behavior associated with 'old' vehicle owners is unclear, so the real emissions impacts of a vehicle scrappage program are contingent upon many assumptions about driving behavior.

TABLE 8
Comparison of Emission Reduction Alternative Costs Reduction of Emissions in Dollars per Ton

Emission Reduction Strategy	Hydrocarbon Emissions Reduction Cost (dollars/ ton)	Oxides of Nitrogen Emissions Reduction Cost (dollars/ ton)	Carbon Monoxide Emissions Reduction Cost (dollars/ ton)
SASP - 8000 vehicles scrapped*	1353	5652	187
SASP - 12,000 vehicles scrapped*	1303	5619	187
On board Evaporative Emission Controls**	1000		
Methanol Fuels replacing gasoline**	8700 - 51000		
Electric utility boiler emission controls**		240 - 5500	
Enhanced Vehicle Insp. & Maint.**		1200 - 3300	
Oxygenated veh. fuel additives**			208 - 576

** Based on best case scenario - i.e. least costs and greatest reduction in emissions. Total cost of SASP divided by 3 to arrive at cost per pollutant reduced. *Adapted from OTA, 1993.

REFERENCES

[1]Quarles, John and William H. Lewis, Jr. (1990). "The New Clean Air Act: A Guide to the Clean Air Program As Amended in 1990". Morgan, Lewis & Bockius.

[2]California Environmental Protection Agency: Air Resources Board (1993). "Mobile Source Emission Reduction Credits: Guidelines for the Generation and Use of Mobile Source Emission Reduction Credits". Prepared by Stationary Source Division, Mobile Source Division.

[3]Fairbank, Bregman, and Maullin (1991). "Final Summary Report on the Results of the Unocal Scrap Program Post-Participation Survey". Fairbank, Bregman and Maullin Marketing Research and Public Opinion Analysis, March 22, 1991.

[4]Guensler, Randall (1992). "Reconciling Mobile Source Offset Programs with Air Quality Management Plans". Unpublished.

[5]Baumol, William J. (1970). "On the Discount Rate for Public Projects". R.H. Haveman & J. Margolis. Public Expenditures and Policy Analysis, First Edition.

[6]Bradford, David F. (1983). "The Choice of Discount Rate for Government Investments" R.H. Haveman & J. Margolis. Public Expenditures and Policy Analysis, Third Edition.

[7]Hu, Patricia and Jennifer Young; Oak Ridge National Laboratories (1992).

[8]Hu, Patricia and Jennifer Young; Oak Ridge National Laboratories (1992). "1990 National Personal Transportation Survey: Summary of Travel Trends". US Department of Transportation, Federal Highway Administration.

[9]Hu, et. al. (1992).

[10]Hu, et. al. (1992).

[11]Environmental Protection Agency (1991). "Accelerated Retirement". Draft EPA Information Document. Unpublished.

[12]Motor Vehicle Manufacturing Association (1989). "MVMA Motor Vehicle Facts and Figures 89".

[13]Engineering-Science, Inc. (1992). "Project Design for High-Emission Vehicle Scrapage". Engineering-Science Inc., 1000 Jorie Boulevard, Suite 250, Oak Brook, Illinois 60521.

[14]Fairbank et. al. (1991).

[15]Fairbank et. al. (1991).

[16]Engineering-Science, Inc. (1992).

[17]Fairbank et. al. (1991).

[18]Davis, Stacey C. and Melissa D. Morris (1992). "Transportation Energy Data Book: Edition 12". Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831.

[19]Engineering-Science, Inc. (1992).

[20]Office of Technology Assessment, Congress of the United States (1992). "Retiring Old Cars: Programs to Save Gasoline and Reduce Emissions". OTA-E-536. Washington, DC: U.S. Government Printing Office, July.

[21]Washington, Simon (1993). "Cost-Benefit Analysis of a Vehicle Scrappage Program". Research Report, Institute of Transportation Studies, University of California at Davis, Davis CA 95616.

[22]Fairbank et. al. (1991).

[23]Fairbank et. al. (1991).

[24]Fairbank et. al. (1991).

[25]Washington (1991).

[26]Office of Technology Assessment, Congress of the United States (1992).

[27]Office of Technology Assessment, Congress of the United States (1992).

[28]Office of Technology Assessment, Congress of the United States (1992).

[29]Cropper, Maureen, and Portney, Paul (1992). Resources for the Future. Number 108, Summer 1992.

[30]Washington (1991).

[31]Guensler, Randall, Simon Washington, and Daniel Sperling (1992). "A Weighted Dis-Aggregate Approach to Modeling Speed Correction Factors". Transportation Research Record, forthcoming.