CHARACTERIZATION OF THE OFF-ROAD EQUIPMENT POPULATION – PHASE I

ARB Contract No. 04-315

Final Report

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Disclaimer

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Abstract

Off-road equipment is a major contributor to pollution levels in California and across the country, generating emissions of ozone precursors, particulate matter, toxics, and carbon dioxide. These equipment are found in a wide variety of applications, including lawnmowers, bulldozers, aircraft support equipment, and portable generators, among other categories. Off-road equipment is used in essentially all types of businesses, as well as in residential applications. Given the large number of engines involved, and the highly diverse set of operators, off-road engines have proven more difficult to characterize and control than many other emission categories such as on-road mobile and major stationary sources.

Although significant progress has been made by ARB and others in characterizing off-road engines and their emissions, the profiles developed to date are based on different methodologies and data sources. In order to develop a more comprehensive and consistent data set of engine characteristics and activity, ARB contracted with Eastern Research Group (ERG) to conduct a study of off-road engines less than 175 horsepower operating in the state. Under Phase I of this study surveys of off-road equipment operators were developed and tested to collect detailed information on equipment characteristics and activity, including application, horsepower, and hours per year of use. Instrumentation of data loggers was also performed to test the feasibility of collecting engine-on time and in-use RPM data for different engine types. The results of the Phase I study indicate that the data collection methods developed are likely to produce a representative profile of off-road engine characteristics and activity. Recommendations regarding potential improvements to collection methods are presented, along with options for addressing possible resource constraints during a full-scale Phase II study.

Executive Summary

Background

Off-road sources include motorized equipment that is mobile and not registered for highway use. Examples include lawn and garden equipment, construction equipment, and aircraft ground support units, among others. The equipment types included in this source category are numerous, with the applications and end-users highly diverse. As such, these sources are difficult to characterize and regulate. Since ARB is responsible for developing comprehensive and accurate emissions estimates for the state, a study was proposed to design and execute detailed, bottom-up data collection for these sources. Data collected on activity and end-use applications can also be used to better understand equipment categories and their users, including federally preempted equipment types.

Methods

The study is being conducted in two phases. Phase I involves the planning and designing of the study, as well as conducting a pilot test of data collection and field instrumentation methods to assess their effectiveness. The Phase II study will include the full-scale data collection effort, to begin after review of the Phase I report and written authorization by ARB. This report presents the study design for Phase I, along with the results of the pilot data collection effort, conclusions, and recommendations for improvements under Phase II of the study.

The Phase I study featured two primary tasks. First, an equipment characterization survey was designed and tested to collect key equipment information. A sample frame was developed for the survey (e.g., the commercial businesses and residents to be included in the study). Next, equipment types and the data elements to be collected were established. A survey instrument and other materials were then developed and pre-tested for understandability and validity. The questionnaire was designed for paper, Internet, and telephone surveying approaches. Once complete, survey responses were quality assured and evaluated for reasonableness. Survey response rates and other factors were evaluated to assess the potential success of the Phase II study.

The second study task involved collecting engine-on time and engine RPM via data logger instrumentation in the field. Cost and ease of installation were considerations in selection of a logger unit. For Phase I, two engines (one mechanically-controlled and one electronically-controlled diesel) were identified and instrumented with the logger to test the feasibility of the process, as well as to evaluate the quality and utility of the resulting data.

Results

Although the number of survey responses and equipment instrumentation was necessarily small for the pilot study, general observations can be made regarding the reasonableness and representativeness of the data. Most important for the execution of the full-scale survey, most respondents were able to provide reasonable answers to key questions, such as engine type, fuel type, hours of use, and horsepower/horsepower range. (In other words, item non-response was relatively low compared to similar surveys.) In addition, the distribution of reported equipment types appeared reasonable for the different survey sectors (agricultural, construction/mining, residential, and other). Other results, such as fuel type and horsepower distributions, were also reasonable based on the project team's experience with similar surveys, although the data set for the construction sector was too small for meaningful conclusions to be drawn. Reported values for hours per year of activity appeared somewhat low, and may require additional validation and verification in the full-scale study, however.

The results from the instrumentation task clearly indicate that the selected data logger provided clean, reliable time-stamp and engine RPM readings for diesel engines. However, the instrumentation process revealed potential difficulties in identifying engines capable of installation. Once viable candidates are identified though, loggers can be installed and retrieved in a relatively short period of time, thereby minimizing costs for the Phase II study.

Conclusions

The Phase I findings appear promising for conducting Phase II of the study. The survey and instrumentation methods proved feasible and effective in collecting reasonably representative profiles of off-road equipment characteristics and operation. Nevertheless, the performance of the pilot study clearly indicated that survey response rates are substantially lower than anticipated during initial study design. As such, modifications will need to be made to the survey methodology in order to conduct full-scale data collection within available resource constraints. Recommendations are provided for cost-effective modifications to the study design, with minimal impacts on study outputs. In addition, recommendations are also presented to potentially improve the efficiency of the instrumentation protocol, and the validity and utility of any instrumentation data collected under Phase II.

1.0 Introduction

Project Background

Off-road internal combustion engines are significant contributors to the fine particulate matter, air toxics, and ozone precursor emission inventories in California. These sources operate in a broad range of applications for an extremely diverse set of industrial and residential end users, from manufacturing and warehousing companies to recreational boaters. As such, off-road engines have proven more difficult to characterize and regulate than many other emission categories such as on-road mobile and major stationary sources. Nevertheless, their widespread use across so many applications requires they receive detailed assessment for both emissions inventory improvement and potential regulatory development in California.

The California Air Resources Board (ARB) has been at the forefront of emissions inventory and regulatory development in the off-road sector with initiatives such as the Small Off-Road Engine (SORE) rulemaking, and the recently completed residential lawn and garden equipment survey.[1] In addition, in many ways the California OFFROAD emissions model provides more detailed data on a broad range off-road engine categories than does the U.S. Environmental Protection Agency's (EPA's) NONROAD model.

However, much of the equipment population and activity data used in the latest version of OFFROAD are obtained from a host of different data sources, each with its own advantages and disadvantages. For example, the MacKay and Company and Power Systems Research (PSR) data sets used to compile much of the construction, light commercial, and industrial equipment category information are based on nationwide surveys, allocated to California using varying adjustment factors. On the other hand, while the U.S. Department of Agriculture's (USDA) Agricultural Census data are specific to agricultural equipment in California, the Census does not cover all equipment types in this category. Also, the Portable Equipment Database, which is the basis for certain portable engine information, relies on voluntary registration and therefore underestimates equipment counts to some degree. Finally, for many of these data sources the level of information regarding specific equipment applications and end-users is inadequate for ARB's needs.

Ideally all the source category information used in OFFROAD and ARB's regulatory development efforts would be based on comprehensive, bottom-up survey data from across California. In recent years, ARB has taken steps to initiate this process, including development of an inventory for public sector fleets, [2] the residential (completed) and commercial/institutional lawn and garden survey and instrumentation studies, and the survey of Transportation Refrigeration Unit (TRU) vendors[3]. (In addition, locality-specific inventory information for other source categories such as aircraft ground support equipment (GSE) is sometimes provided

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[1] Eastern Research Group, "Acquisition and Analysis of Commercial and Institutional Lawn and Garden Population and Activity Data", Final Report, prepared for the California Air Resources Board, August 8, 2006.

[2] TIAX LLC, "California Public Fleet Heavy-Duty Vehicle and Equipment Inventory", prepared for the California Air Resources Board, March 17, 2003.

[3] Kidd, Sandee. "OFFROAD Modeling Change Technical Memo: Revisions to the Diesel Transport Refrigeration Units (TRU) Inventory", Preliminary Draft, California Air Resources Board, July 18, 2003.

at the air district level, in this case often utilizing the Federal Aviation Administration's (FAA's) Emission Dispersion and Modeling System (EDMS).

In August 2005, Eastern Research Group (ERG) was selected to conduct continuing research into the characteristics of California's off-road equipment fleet. The study is being conducted in two phases. Phase I covers the tasks associated with planning and designing the study: defining the equipment types for inclusion, defining the data to be collected on the equipment types, developing a survey plan, and creating a survey instrument and sample. Phase I also includes a small-scale pilot test of data collection and field instrumentation methods to assess their effectiveness and efficiency. Phase I concludes with documentation of all activities through the pilot test, with recommendations on methodology refinements for the full-scale study. The full-scale, Phase II study will begin after submittal of the Phase I report and written authorization by ARB. This report summarizes the efforts in conducting Phase I of the study.

Project Objectives

Through this study, ARB desires to develop a comprehensive and consistent profile of off-road equipment applications, end-users, populations, and activity patterns for the range of different industrial, public, and residential equipment operators across California. The focus is on off-road equipment less than 175 horsepower (hp). Data collection will rely on self-reported information from a stratified random sampling of off-road equipment operators across the state, using questionnaires administered primarily by phone. Additional in-use activity data will be collected through the deployment and retrieval of data loggers in the field. This approach, utilizing California-specific, "bottom-up" data collection, is assumed to provide a more reliable characterization of equipment types and use patterns than prior "top-down" efforts, which commonly rely on national data combined with regional allocation routines.

The proposed inventory should also:

- Create and/or use an existing categorization scheme that will facilitate improvement of the emission inventory and regulatory development,
- Characterize the populations in the various categories and types by the sizes of engines, the business categories of the owners or users, the seasons of use, and the applications of the equipment,
- Obtain in-use data on equipment activity which will be used by ARB to identify types of equipment that are amenable to various possible control strategies; and
- Provide equipment counts that can be used to estimate relative numbers of the equipment in the various categories, sizes and uses.

Report Organization

The following sections of this report document the study methodology followed for conducting the pilot test, and presents the pilot survey results. Recommended revisions to the study including the survey plan, questionnaire, and data collection approach are then presented.

2.0 Materials and Methods

Overview

The purpose of the Phase I pilot study was to test the survey methodology including the sample design, questionnaire, and data collection approach on a reduced scale so that refinements could be made to improve a full-scale data collection effort under Phase II (e.g., maximize resources, achieve higher survey participation and response rates, assure proper instrumentation of equipment, etc.).

Working closely with ARB and key stakeholders, the study design was developed by defining the sample frame (e.g., the commercial businesses and residents included in the study), equipment types, and the data elements to be collected, designing a survey instrument and other survey materials (e.g., survey instructions and advance letter), and programming the survey questionnaire for data collection via paper, Internet, and telephone surveying approaches. The pilot study data collection effort was conducted from April 24, 2006 through June 14, 2006. It followed a two-stage data collection approach:

- Stage 1: Advance letter sent to prospective respondents to inform them about the upcoming survey, and enlist their participation by completing the survey in one of three ways: (1) self-completion of an enclosed survey form and returning it in a postage-paid envelope, (2) self-completion of the survey on the Internet, or (3) waiting to receive a telephone survey within one week.
- Stage 2: Follow-up telephone survey with those who did not complete the survey using the paper or Internet options.

Once complete, survey responses were quality assured and otherwise evaluated for reasonableness. The effectiveness of the survey was also evaluated in terms of overall response rates, response rates by mode (e.g., phone vs. Internet), non-response for individual questions, and other factors that could influence the success of a full-scale survey.

In addition to the survey effort, a parallel task was undertaken to identify candidates for data logger instrumentation, in order to collect engine-on time, temporal operation profiles, and engine RPM. Cost and ease of installation were considerations in selection of a logger unit. For Phase I, two engines (one mechanically-controlled and one electronically-controlled diesel) were identified and instrumented with the logger to test the feasibility of the process, as well as to evaluate the quality and utility of the resulting data.

The following sections of this report document the data collection methods for the survey as well as the instrumentation tasks.

2.1 Equipment Characterization Survey

Sample Definition and Stratification

At the onset of the survey planning process, three broad categories, or sample frames, were identified to characterize the range of possible off-road equipment operators. A sample would then be derived from these three distinct sampling frames:

- One frame (agriculture) to characterize the agricultural industry, consisting of all farmers in the State of California that report income from the sale of their crops and/or operations;
- One frame (commercial) consisting of California businesses and public entities. This was further disaggregated, using SIC codes, into the following strata for purposes of manageability and subsequent application of surrogates: Construction and Mining; other commercial and government entities, referred to as the "Residual" sample;
- One frame (residential) consisting of listed and unlisted non-business telephone exchanges in the state of California.

During several subsequent planning sessions and project meetings, and through consultation with ARB, stakeholder groups and commercial sample providers, it was determined that three levels of sample stratification (and response targets within each sub-strata) would be necessary to collect sufficient data for evaluation purposes. Table 1 provides a summary of the study sample types and strata.

Table 1: Off-Road Sample Types

Sample Type 1	Sample Type 2 (Sub Type)	Sample Type 3 (Sub-strata)
Agriculture	Agriculture	Nut
		Row Crop
		Tree Fruit
		Other
		Farm Management
Commercial	Construction and Mining	Construction
		Mining
	Residual-Air-Logging-Government	Logging
		Residual-Air-Government
Residential	Residential	Recreational
		Other

Sample Type 1 provides the broadest level of detail, stratifying the universe into the three broad categories: agriculture, commercial and residential. Sample Type 2 is the same as Sample Type 1 for all strata with the exception of the commercial sample type. For the commercial sample type, the sample universe is further stratified into those entities that are primarily engaged in construction and mining activities vs. those agencies that are not primarily engaged in construction and mining activities. These later entities, referred to as “Residual”, include Airports, Logging, and Government activities, among others. Sample Type 3 provides the most detailed level of stratification for each sample type:

- The agricultural entities are identified by crop types as reported to the Federal Census Bureau, with further differentiation defined by ARB and stakeholders (Nut, Row Crop, Tree Fruit, Other,)[4] and Farm Management companies.[5] Each crop type was further stratified into a “large” or “small” acreage classification based on a review of available crop acreage data reported to the Federal Government. The cutoff for each farm size was 50 acres, below which a farm was classified as small. Farms equal to and/or greater than 50 acres were classified as large.[6]
- Within commercial entities, there is a further delineation based on primary activity: construction or mining, logging, and the residual-air-government category. The residual-air-government category contains all businesses that are not included in any of the other commercial categories. As such, this last category is extremely broad with respect to the types of businesses that would be contacted.
- The residential sample type is stratified into two distinct categories for Sample Type 3: Recreational and Other. Recreational households are those that are located in a close proximity to lakes. This sub stratum was defined in hopes of encountering households who owned, rented or leased recreational off-road equipment such as ATVs or personal watercraft, to further diversify the types of equipment about which data was collected. Other households were households randomly selected across the state.

During study design planning, Agricultural stakeholders raised concerns regarding how the survey would capture equipment data from farms with “absentee” owners (owners of farms that do not reside on the farm and use a farm management company for all farm operations), and from farms which contract out some, but not all, of their operations to another local farmer (who is not considered a farm management company). This issue was explored further during pretest interviews with farmers that provide services to, or receive services from, other farmers in their community. To ensure this equipment was properly captured, farm management firms were included in the sample frame (subtype 3). Further, the questionnaire was designed to capture equipment owned or leased by individuals (i.e., not farm management companies) who provided agricultural services on land owned by other farmers in addition to their own. To collect this information, the questionnaire asked farmers/operators about the equipment they own and

[4] For generation of this sample type, the project team used a sample frame consisting of an agricultural database maintained by the US Department of Agriculture (USDA). The sample was purchased through a third party that pays a subscription service for access to the database. The project team received a summary report of crop types grown in California and aggregated them into the four broad categories presented here. For a detailed list of all crop types included in each crop type category, please see Appendix A of this report.

[5] Farm management entities are defined as businesses that perform agricultural activities (such as harvesting, plowing, etc.) for other farmers for a fee, as their primary activity.

[6] This cut point was based on summary reports provided to the project team from the commercial sample provider using the agricultural database maintained by USDA.

operate in California, as opposed to the equipment used specifically on their farm. "Now, this next series of questions will focus only on the equipment contained in your current inventory of owned or leased equipment that operates in California" [from telephone interview script].[7]

Sample Sizes

Based on the resources available for this study, a total of 1,200 completed surveys were planned for the full-scale study (see Table 2). The Phase I pilot study design initially planned for ten completed pilot surveys each for the agriculture and commercial/residential sample types, for a total of twenty completed surveys. The Phase I design was subsequently expanded to conduct a total of ten surveys within each primary Sample Type, for a total of 40 surveys. The rationale for conducting an additional twenty surveys was to produce adequate data to assess/calibrate the sample performance (e.g., incidence rates, response rates) in preparation for the full study.[8]

Table 2: Pilot and Full Study Completes By Sample Type and Sub-Strata

Sample Type	Sub-strata	Pilot Target # of Completes	Full Study Completes	Total Completes
Agriculture	Nut	2*	290	300
Agriculture	Row Crop	2*		
Agriculture	Tree Fruit	2*		
Agriculture	Other	2*		
Agriculture	Farm Management	2*		
Construction and Mining	Construction	5	240	250
Construction and Mining	Mining	5		
Residual-Air-Logging-Government	Logging	3	290	300
Residual-Air-Logging-Government	Residual-Air-Government	7		
Residential	Recreational**	7	340	350
Residential	Other	3		
Total		**40**	**1,160**	**1,200**

*One complete to come from a "large" acreage farm, and one from a "small" acreage, with farm size determined upon review of sample provider database.
**Defined as households that live in close proximity to recreational areas (e.g., lakes, oceans or recreational areas).

[7] One option for capturing equipment used on property that is not owned or leased by the owner/farmer is to obtain a referral of the name of the operator/service provider, and then collect data on equipment used on the property. ARB decided against this option for several reasons, including the potential response error due to service providers inaccurately reporting annual/seasonal activity data regarding equipment used on a particular farm, and the overall increase in data collection costs to pursue multiple referrals for a single farm.

[8] The purpose of breaking down sample types into subtypes is to ensure representation of the sample (e.g., so that even with random sampling, one does not get all row crops for the agriculture sample type).

Estimated Number of Samples Needed For Pilot Study

At the onset of a survey study it is generally unknown how many sample records it will require to complete a survey within each strata and sub-strata. “Ineligible” sample can arise for a number of reasons – establishments are no longer in business; they have moved operations out of state; the business was bought out and now is listed under a new owner or name; etc. Moreover, not all establishments will operate off-road equipment. Finally, not all establishments will ultimately cooperate with the study. For these reasons it is important to select substantially more sample than the targeted number of completes. Results from the pilot portion of this study will help answer these questions, providing integral planning information for the full survey.

Preliminary estimates of the minimum number of sample needed to obtain the pilot study number of completes (40) are contained in Table 3.

Table 3: Preliminary Estimate Of Sample Needs

A	B	C	D	E
Sample Type Domain:	**FULL Study N**	**Estimated FULL Sample Needs**	**Pilot Study N**	**Estimated Pilot Sample Needs**
Agriculture	300	4,000	10	150
Construction and Mining	250	3,500	10	150
Residual	300	20,000	10	750
Residential	350	23,000	10	750
Total	**1,200**	**50,500**	**40**	**1,800**

These estimates are largely based on Standard Industrial Classification code (SIC) lists obtained from Dunn and Bradstreet for the state of California, US Census data, along with past survey experience regarding contact rates, non-contact rates, screening response rates, eligibility rates, and interview response rates.

Sample Frame Development

Sample frames were developed using existing databases maintained by the following commercial sources.

- Two agriculture sample frames were necessary: (1) For non-farm management agricultural entities the sample frame consisted of an agriculture database maintained by the US Department of Agriculture (USDA) and subscribed to by Survey Sampling International (SSI), a commercial survey sample vendor. This database contains nationwide coverage for growers of agricultural crops. In addition to administrative data such as name, address and phone number, the database lists the following for each grower: crop type, acreage, and reported income from sale of crop. (2) For farm management entities the sample frame was based on the SIC database maintained by Dunn and Bradstreet. Standard Industrial Classification is a four-digit code that identifies the primary industry sector of which the company is a member. For further detail on the specific codes selected for farm management entities, see Appendix B.

- The commercial sample frame was also developed from the SIC database maintained by Dunn and Bradstreet. For further detail on which specific codes were selected for commercial entities (by sub-strata), see Appendix B.
- The residential sample frame consisted of both listed and unlisted phone numbers from Marketing Systems Group (MSG). MSG uses InfoUSA (a commercially available telephone database) to identify known working listed exchanges, which are then used to generate both listed and unlisted records. The database contains nationwide coverage.

The generation of SIC-based samples (excluding non-farm management and residential samples) involved providing a list of appropriate SIC codes to SSI for each sample type, at the most detailed level available (Sample Type 3), as well as the number of requested sample pieces. Samples were then randomly selected from the SIC database by SSI and delivered electronically for further processing.

SSI generated the non-farm management agriculture sample in a similar manner by randomly querying the USDA database until the specified number of records by crop type and farm size had been generated. The files were then delivered electronically.

MSG generated listed residential sample in the following manner. Based on the areas provided, geo-demographers mapped these areas to known residential telephone exchanges. In the case where exchanges overlapped between specified areas, exchanges were attached to those areas that contained a higher proportion of households. Once all exchanges serving the area of interest had been identified, actual telephone numbers were randomly selected from the InfoUSA database, which contains over 97-million known working residential telephone numbers. Geographic accuracy for these records is extremely high, as MSG can target down to the zip+4 level.

Upon receipt, the electronic sample was processed for both dialing and mailing by partitioning the sample into “replicates”, or subsamples, of the main sample. Each replicate ranged in size from 67 to 250 sample pieces, with each replicate containing sample of the same sample type (i.e., sample type 3). The mail database contained name and address information for each record, as well as sample type. The dialing database contained non-address related information (except first and last name), phone number and geographic identifier (census tract). Both the mail and phone database contained a unique sample number to link each record between databases and track each record throughout the survey process.

Survey Instrument Design

The survey instrument (or questionnaire) contained approximately 20 questions. The first series of questions establishes eligibility (owning and/or leasing at least one piece of off-road equipment with a maximum horsepower rating of less than 175), then proceeds with the substantive part of the data collection effort. In addition to collecting details on the numbers and types of equipment contained in a respondent’s inventory, the survey also queries respondents for the seasonal and annual use of each piece of equipment, as well as details on fuel type, horsepower and displacement, etc. The questionnaire also contains, at the very end, an instrumentation recruitment question for construction businesses only.

Cognitive testing[9] of a draft version of the questionnaire was conducted on December 15, 2005. Minor adjustments to question wording and flow were made based on the cognitive test results. A final, ARB-approved version of the questionnaire was then designed for three modes of administration: Telephone, and self-completion by Internet or Hardcopy. In addition, to facilitate respondent completion, the survey instrument was tailored to each specific Sample Type. For instance, example equipment categories were made appropriate for construction, residential, and agricultural respondents. Another approach was adopted to reduce respondent burden in the telephone interview, demonstrating sensitivity to a respondent's time and availability. Specifically, inventories were classified as small (less than 10 pieces of equipment) or large (ten or more pieces of equipment) based on the participant's response. During the telephone interview, respondents with ten or more pieces of equipment in their inventory (i.e., large inventories) were offered several options for providing detailed equipment information, including receiving forms in the mail, completing forms over the Internet, faxing inventory information back, conducting the interview at another time, or conducting the interview at that time.

A copy of the print version of the survey instrument is provided in Appendix C.

Advance Notification Packet

Administration of the survey began with an advance letter to inform business owners and residents of the purpose of the survey, and to enlist their participation in the study. The advance letter also provided prospective respondents with a paper version of the survey, and with instructions for completing it in one of three modes: telephone, Internet, and hardcopy/mail back. A copy of the draft advance letter for both the commercial and residential sample types is contained in Appendix C.

Prior to conducting the survey, each sample record was sent an advance mail packet containing the advance letter (specifically designed for each sample type), a log sheet, an instructional form detailing how to complete the survey via web, log or phone, and a postage-paid envelope to be used to return the completed form. A limited number of pre-screening interviews were also conducted with a subset of potential respondents in the following sample types: construction (100 records), mining (100 records), logging (100 records), and residual (100 records). This interview was conducted prior to the advance mailing and sought to identify a contact person to whom the advance letter could be sent that was the most knowledgeable regarding that entity's equipment. The impact of the pre-screening interview on survey rates (shown in Table 13) are discussed in the Results and Discussion section of this report.

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[9] A cognitive interview is a preliminary test of a draft survey questionnaire with persons that possess similar characteristics to the survey's intended audience, involving in-person interviewing. The testing objectives are related to the question-answering process of potentially complex questions, assessing the respondents' ability to provide a response by examining their comprehension of questions, and their ability to retrieve relevant information from memory. Cognitive interviews are also used to assess the adequacy of the questionnaire flow (structure and design).

2.2 Equipment Instrumentation

As part of the effort to characterize off-road engine operation, data loggers were to be installed to record engine RPM on selected pieces of equipment operated in the construction and mining sector in California. This effort was designed to test the feasibility and value of monitoring the in-use activity (time-on/off and engine RPM). Phase II of the project may require that data loggers be installed on a much larger number of construction and mining equipment across the state by field technicians.

At the start of the study, ARB determined to limit instrumentations to equipment in the construction and mining sector. This limitation was made in part due to the extremely diverse equipment and application types within many of the other survey sectors, including the agricultural and residual sectors. In addition, the construction and mining sector is heavily dominated by large diesel equipment, and therefore, a predominant contributor to total NOx emissions from off-road engines.

In Phase I of this assessment, data loggers were installed on two pieces of construction equipment, one with a mechanically controlled diesel engine, and one with a computer controlled diesel engine, for a period of one week. Additional configurations and engine types (e.g., gasoline and/or portable units) were to be investigated and instrumented as well, if feasible. Under Phase II logger data will allow for the estimation of daily hours of use, as well as inferred mode (idle versus load) for a range of different equipment types and applications. Such data can be used to validate survey responses regarding equipment activity, or to help establish detailed operational profiles for emissions estimation and/or control assessments.

Data Logger Selection

Two types of loggers were considered for this assessment. First ERG considered a logger of their own design, normally used on gasoline-powered vehicles. Other logger options were also researched, with industry contacts ultimately recommending the Clēaire logger.

After evaluating both options, the Clēaire logger was selected because of the unit's relative compatibility with many types of diesel powered equipment. The installation process for the ERG logger would have to have been modified significantly to be compatible with diesel engines. Specifically, these loggers were designed to measure gasoline engine RPM by acquiring a signal directly from the ignition coil. Since diesel engines have no ignition coil, RPM would have to be obtained using the logger speed input channel, attaching a magnet to a rotating pulley on the engine. A bracket would also need to be fabricated to hold the magnetic induction pick-up coil near the path of the magnet. The pulses produced by the magnet and inductive coil would then have to be calibrated on the speed channel of the logger using a hand-held photo-tachometer and a timer. This process was anticipated to be time consuming, and subject to significant validation and operational errors.

On the other hand the Clēaire data logger is normally used to monitor diesel engine parameters, and to operate an emissions control system that can be retrofit onto diesel vehicles. Therefore it has many more capabilities than simply recording RPM data. A picture of the main parts of the Clēaire logger system is shown in Figure 1. The gray box contains the logic and memory of the data logger. The various black and blue umbilicals connected to the gray box are used to transmit engine data, emission control system data, and to power the logger. In Phase I only two umbilicals were used, one to transmit the RPM signal to the logger and the other to power the logger. The unused umbilicals were secured safely out of the way during data logging operations.

Figure 1. Clēaire Data Logger System
(Source: Clēaire)

Identifying Off-road Engines for Instrumentation

The survey being performed by NuStats, as part of this project, identified a few candidate fleets whose owners were willing to participate in the Phase I instrumentation study. However, none of these were in the Sacramento area. Therefore ERG recruited two Sacramento area fleet owners for participation in order to minimize costs.

ERG inspected equipment operated by Western Engineering Contractors and CSI Construction at two construction sites. Western Engineering owns and operates many pieces of off-road equipment. They are generally used as a general or a specialty contractor in commercial construction jobs. CSI Construction is a general contractor who owns a few pieces of off-road equipment and subcontracts owners/operators such as Western Engineering at commercial construction projects. All but one piece of the off-road equipment used in the Sacramento area by these two fleet owners was diesel powered. The locations of the equipment are indicated in the map in Figure 2, with one construction site being at the “Start” location and the other being at the “End” location of the highlighted route. (The center of Sacramento is about 20 miles southwest of the center of this map.) Both of the construction sites were for retail or wholesale commercial buildings and parking areas.

Figure 2. Locations of Equipment Instrumented by ERG (Source: MapQuest)

The following list of equipment was inspected by ERG at these locations. The list includes summary notes pertaining to the ability of the equipment to be logged with the chosen system.

Caterpillar Motograder: 2005 model 14H

- Western Engineering ID = MG07
- 240 HP diesel powered.
- Accessible portion of bell housing (top) was situated under a firewall. Threaded port identified immediately below the firewall. Accessing the port and installing an RPM transducer would require cutting the firewall.

Ingersoll-Rand 82-inch Roller: 1993 model ProPac Series 100

- Western Engineering ID = RL05
- 125 HP diesel powered.
- Threaded port in bell housing was easily accessible. Ready to receive 3/4-inch RPM transducer provided with Clēaire logger.

Hitachi Excavator: 2006 model ZAXIS 350 LC

- Western Engineering ID = N/A
- Diesel powered.
- Bell housing was not readily accessible and no threaded port could be located.
- Visually identified a possible RPM sensor in the bell housing at the rear side of the vehicle.
- Visually identified a possible plugged port in the bell housing above the starter.
- The alternator was easily accessible but no stator terminal could be identified.

Caterpillar Backhoe: 2005 model 430D

- Western Engineering ID = N/A
- Diesel powered.
- Found a threaded port in the bell housing accessible under the vehicle on the driver's left hand side. Required a 5/8-inch transducer.
- Alternator could not be accessed without raising the hood. Mechanic or operator with lock key not available at time of inspection.

Volvo Loader: 2005 model L120E

- Western Engineering ID = N/A
- Diesel powered.
- Bell housing was accessible, but no threaded ports were identified.
- Alternator accessible, but no stator terminal could be identified.

Kymco ATV: 2005 model MXU 150

- Owned by CSI Construction
- 11 HP gasoline powered.
- Air-cooled motorcycle type engine.
- Bell housing and flywheel not accessible without dismantling.
- Alternator not accessible without dismantling.

Caterpillar Scraper: 2004 model 615C

- Western Engineering ID = N/A
- Diesel powered.
- Bell housing was partially accessible. 5/8-inch RPM sensor already installed and accessible.
- Alternator easily accessible. Possible stator terminal visually identified.

Based on the findings of the initial equipment inspection, ERG decided to install data loggers on the 1993 Ingersoll-Rand 82-inch Roller, and the 2004 Caterpillar Scraper. They appeared to be fairly good candidates for installation, representing one mechanically controlled and one computer controlled piece of diesel-powered equipment. In addition, these equipment were used in significantly different, but representative ways at the construction sites. Most of the other pieces of equipment would have required too much down-time, modification, or disassembly to monitor RPM. Note that only one piece of equipment was gasoline powered, and none were portable. [10]

The fact that only about one-half of the equipment ERG inspected was compatible "as is" with the Clēaire logger led ERG to recommend alternative methods for monitoring engine activity on a wide array of equipment. Those recommendations are listed later in this report.

Collecting RPM on the Ingersoll-Rand 82-Inch Roller

The roller was used to compact fill material after it was deposited and leveled by other equipment in a parking lot under construction. The parking lot was level with uniform soil quality. It would roll back and forth over the fill, usually with its roller in a "vibratory" mode to help further compact the fill. A picture of the roller is shown in Figure 3.

Figure 3. The Ingersoll-Rand 82-inch Roller

Installation of the Roller's Data Logger

The roller had ample room for installing the data logger box in sight of the operator and out of harm's way. ERG decided to install the box on a pillar of the roll cage, near the driver's seat but out of the operator's access path. From that position, the power and RPM umbilicals could easily reach the engine compartment and the area of the engine's bell housing, where the RPM sensor would be installed. The picture in Figure 4 shows the logger box installed on the roll cage pillar, with unused umbilicals attached beneath.

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[10] ERG's original project proposal recommended instrumenting gasoline and/or portable engines, in addition to diesel units, during Phase I to demonstrate the viability of the logger installation and data collection procedure across numerous equipment configurations. However, subsequent limitation of the study to the construction and mining sector severely limits the availability (and value) of non-diesel instrumentation options.

Figure 4. Clēaire Logger Box on the Roller

The roller had a 12-volt electrical system, so it was possible to attach the logger's power leads to the starter solenoid and an existing ground lead in the engine compartment. The power lead attachments are shown in Figure 5.

Figure 5. Power Umbilical Attached to Starter Solenoid and Ground

The roller had a threaded RPM port readily accessible in the bell housing of the engine. The port was the proper size for an RPM sensor provided by Clēaire. ERG installed the RPM sensor into the bell housing and used "zip ties" to relieve tension on the leads and to ensure they would remain in place under severe use. A picture of the installed RPM sensor (gold colored with two black leads) is shown in Figure 6.

Figure 6. RPM Sensor Installed into Bell Housing of Roller

To commission the logger ERG input and saved identifying information into the logger using a “dumb terminal” software that typically comes with all Windows© operating systems, named Hyperterminal. Based upon interviews with construction supervisors, and the memory capacity of the logger, ERG set the logging interval for the roller to every 5 seconds.

Collecting RPM on the Caterpillar Scraper

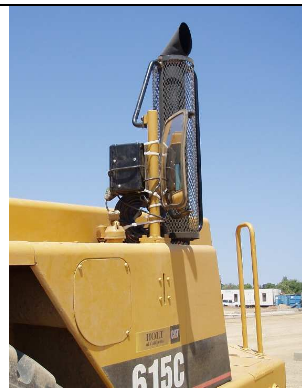
The Caterpillar scraper was used on a parking lot under construction. Its principal use was to move fill material short distances, picking up and leveling fill at the same time by scraping it from the ground into a hopper. It typically carted the fill to a nearby location to dump it in a linear pile. A picture of the scraper is shown in Figure 7.

Figure 7. The Caterpillar 615C Scraper

Installation of the Scraper’s Data Logger

The scraper had ample room for installing the data logger box in sight of the operator and out of harm’s way. ERG installed the box on a rear-view mirror post, near the exhaust stack. From that position, the power and RPM umbilicals could easily reach the battery box and the area of the engine’s bell housing, where an RPM sensor was already located. The pictures in Figure 8 show the cab-end of the scraper, the location of the logger box on the scraper, and a detail of the logger box installed and locked in its position.

Figure 8. Clēaire Logger Box on the Scraper

Cab-end of scraper	Box mount location	Detail of box
		

The scraper had a 24-volt electrical system, so it was necessary to tap power for the logger across only one of the two 12-volt batteries that comprised the scraper’s electrical storage system. The battery box of the scraper, with the power umbilical attached, is shown in Figure 9. The power umbilicals are attached to the battery on the left.

Figure 9. Power Umbilical Attached in the Battery Box of the Scraper

As previously noted, the scraper had an RPM sensor already installed, and no other threaded port was readily available for another RPM sensor. Normally a "dual pick-up" RPM sensor can be obtained as an off-the-shelf part from Caterpillar to allow the logger to access the existing RPM signal without permanently altering the existing RPM signal leads. This off the shelf part typically costs between $100 and $200. [11] In this case, however, there was not enough time to order and receive the desired part. Therefore, it was necessary to fashion a "Y" junction using a special type of splice connector that is self-stripping. ERG carefully spliced a Clēaire RPM connector to the existing RPM signal leads in this way, making sure not to damage the signal lead conductors. ERG used "zip ties" to relieve tension on the splices and to ensure they would remain in place under severe use. A picture of the "Y" splices is shown in Figure 10.

Figure 10. Splice into Existing RPM Signal Leads

[11] Personal conversation between Andrew Burnette of ERG and Al Reicerd of Cleaire, August 15, 2006.

3.0 Results and Discussion

The findings for the equipment survey and instrumentation tasks under Phase I of the study are presented below. By its nature, the results from the pilot testing are not extensive or robust – the data gathered in this Phase I was intended to demonstrate the feasibility and efficacy of the data collection methods, rather than to develop data for analytical purposes. For this reason the data cannot be subjected to rigorous statistical analyses, given the limited sample size. However, general observations can be made regarding the reasonableness and representativeness of the data, based on the simple descriptive statistics presented in the following section. For the most, part these observations tend to support the conclusion that the data collection methodology, if adopted for the full study, will provide adequate response rates and a reasonably representative profile of off-road equipment characteristics and operation in the state.

3.1 Equipment Survey Results

Survey Rates

As shown in Table 4, the pilot study resulted in a total of 63 completed surveys, exceeding the study goal of 40.

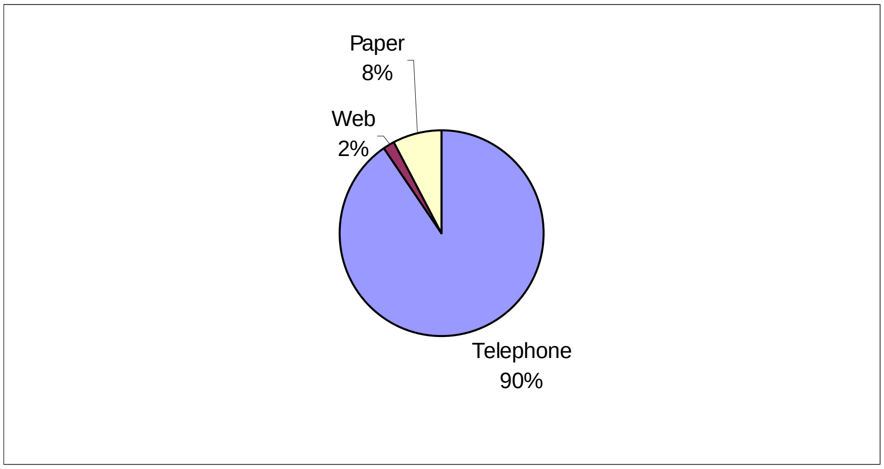
Table 4: Completed Questionnaires By Sample Type

Sample Type	Target # of Completes	Actual # of Completes	Percent Actual
Agriculture	10	29	46%
Construction and Mining	10	10	15.9%
Residuals	10	12	19.0%
Residential	10	12	19.0%
Total	**40**	**63**	**100%**

Surveys that were completed over and above the expected number were the result of the mixed-mode administration of the survey (i.e., additional mail-in questionnaires were received after telephone interviews were conducted).

As shown in Figure 11, most of the surveys were completed by telephone (90%), followed by mail back (8%). All of the mail backs were received from the agriculture sample (N=5).

Figure 11. Survey Completion By Mode



In order to determine how the survey "performed" for each sample type, disposition tables were developed to provide results for all sample pieces identified during the pilot survey, as well as assorted survey response parameters. Table 5 provides a description of the final dispositions of the 1,916 equipment pieces that were reported during the Phase I survey, by response sector.

Table 5: Final Dispositions For All Off-road Sample

Survey Parameter	Agriculture		Const/Mining		Residual		Residential		Pilot Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
Sample Pieces Used	788	100%	399	100%	284	100%	445	100%	1,916	100%
Completed Surveys	29	4%	10	3%	12	4%	12	3%	63	3%
Eligible to Participate	58	7%	27	7%	22	8%	27	6%	134	7%
Ineligible to Participate	209	27%	117	29%	121	43%	112	25%	559	29%
Response Rate		16.9%		13.4%		27.5%		13.9%		17.0%
Refusal Rate		46.6%		55.6%		45.5%		51.9%		49.3%
Average Interview Length	18.6	Minutes	13.6	Minutes	24.1	Minutes	11.6	Minutes	19.7	Minutes
Completes per Hour (cph)	0.19	CPH	0.24	CPH	0.27	CPH	0.34	CPH	0.26	CPH

Overall, there were a total of 63 surveys completed, representing 3% of all dialed records. Seven percent of all dialed records were eligible for participation, with 29% deemed ineligible. Almost two-thirds of the sample (64%) was of unknown eligibility, meaning that either that contact was never made with that record or the call resulted in a callback or a soft refusal prior to eligibility being determined.[12] The response rate for the pilot study was 17% and the completed surveys per interviewer per hour (cph) was 0.26 (less than 1 survey was completed per hour by a single interviewer).

[12] A soft refusal is someone who initially says they won't participate in the survey. They are called back until they make it clear they have no intention to participate.

The proposed study design was based on estimates for these key parameters (based upon past experience), particularly eligibility and response rates and completed surveys per interviewer per hour, referred to as completes per hour (cph). Overall, the study response rate is slightly lower than the study team's past experience in conducting similar survey research (typically about 23%), and the cph is much lower than anticipated (the expected cph was 0.5). A significant factor contributing to these lower performance parameters was finding an eligible participant.[13] The implications of the pilot performing at rates lower than expected are discussed in the conclusions and recommendations section of the report.

Because of the extreme variation within the agricultural industry (e.g., types of crop, acreage range), the agriculture sample was further broken down into five segments to ensure representation within the industry's multiple crops: Citrus (lemons, orange, tangerines), Fruit Trees (apricots, peaches), Row Crops, Nut Crops, and Other. Table 6 summarizes the number of completes by crop type within the Agriculture sector.

Table 6: Agriculture Completed Interviews by Crop

Crop Type	Total Completes*	Percentage*
Fruit Tree	3	10.3%
Row Crop	3	10.3%
Citrus Tree	5	17.2%
Nut Crop	7	24.1%
Other	11	37.9%
Total	**29**	**100%**

*Does not add up to 100% due to rounding.

Agriculture respondents were also asked to provide information on the total acreage their offroad equipment was used on. The following table provides details on the acreage data provided by each agriculture respondent, categorized by crop type. The average acreage for each crop type is also provided in Table 7, with row crops having the largest average size and nut crops the smallest, as expected.

Table 7: Agriculture Completed Interviews by Crop

Crop Type	Total Acreage Reported	Mean
Fruit Tree	26	215
	125	
	200	
Row Crop	30	977
	900	
	2000	
Citrus	60	114

[13] Eligible respondents responded "yes" to the questions: (1) do you own or lease at least one piece of off-road equipment, and (2) does that equipment have a maximum horsepower rating of less than 175?

Crop Type	Total Acreage Reported	Mean
	71	
	151	
	175	
Nut	0	53
	5	
	20	
	27	
	60	
	110	
	150	
Other	0	215
	2	
	5	
	5	
	15	
	20	
	20	
	20	
	33	
	45	
	100	
	2100	
Total	**29**	**NA**

The following figures provide a breakdown of the reported equipment types and frequency (number of pieces reported).

Equipment Inventory Findings

One of the primary purposes of the survey is to help create an inventory of off-road equipment. As summarized in Table 8, the pilot survey collected data on 367 pieces of equipment across 32 distinct equipment types (with one designated a miscellaneous "Other" category). Because one respondent in the Residual sample type reported 130 Transportation Refrigeration Units, the total types of equipment is also presented as an adjusted figure of 237 to account for this anomaly.

Table 8: Number Of Equipment Types And Pieces Reported By Sample Type

Sample Type	Total Reported Equipment Types*	Total Reported Equipment Pieces	
		Unadjusted	Adjusted
Agriculture	18	114	114
Construction and Mining	12	19	19
Residual	11	207	77
Residential	6	27	27
Total	**32**	**367**	**237**

* Certain equipment types are reported in multiple sample types – 32 unique equipment types reported across all respondents

Figure 12. Number Of Pieces By Equipment Type – Agricultural Sector

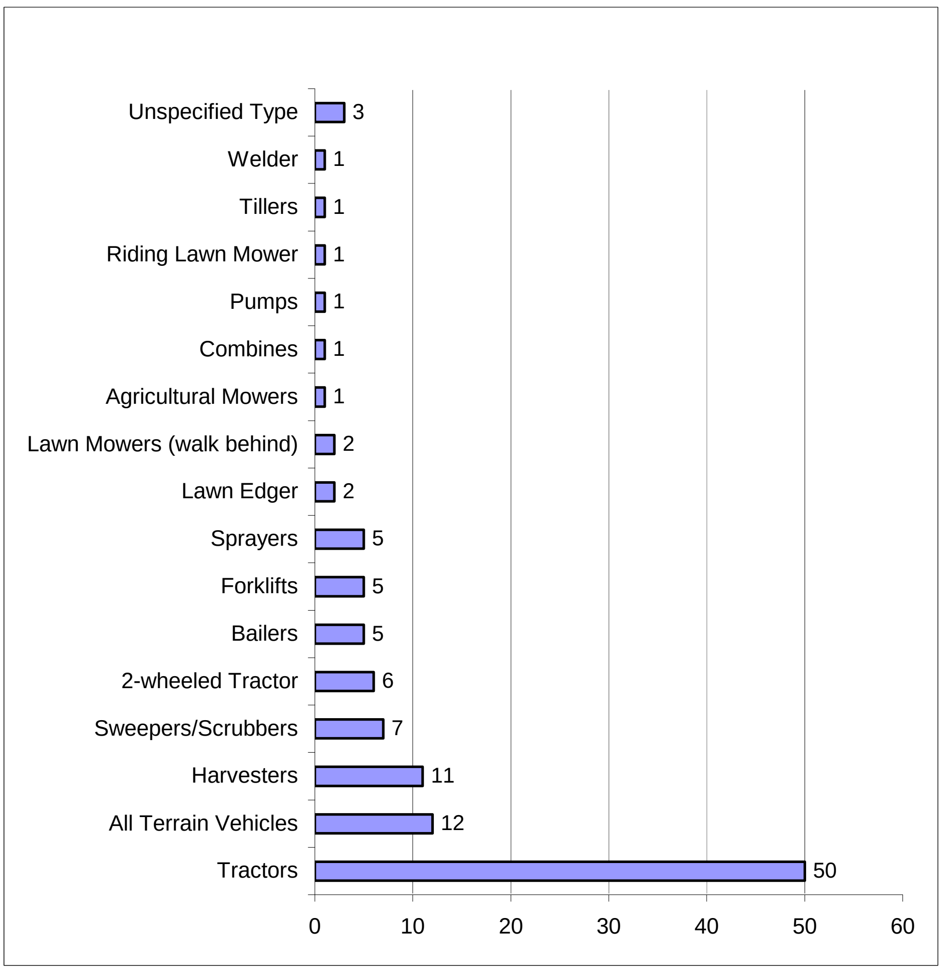


Figure 13. Number Of Pieces By Equipment Type - Construction & Mining Sector

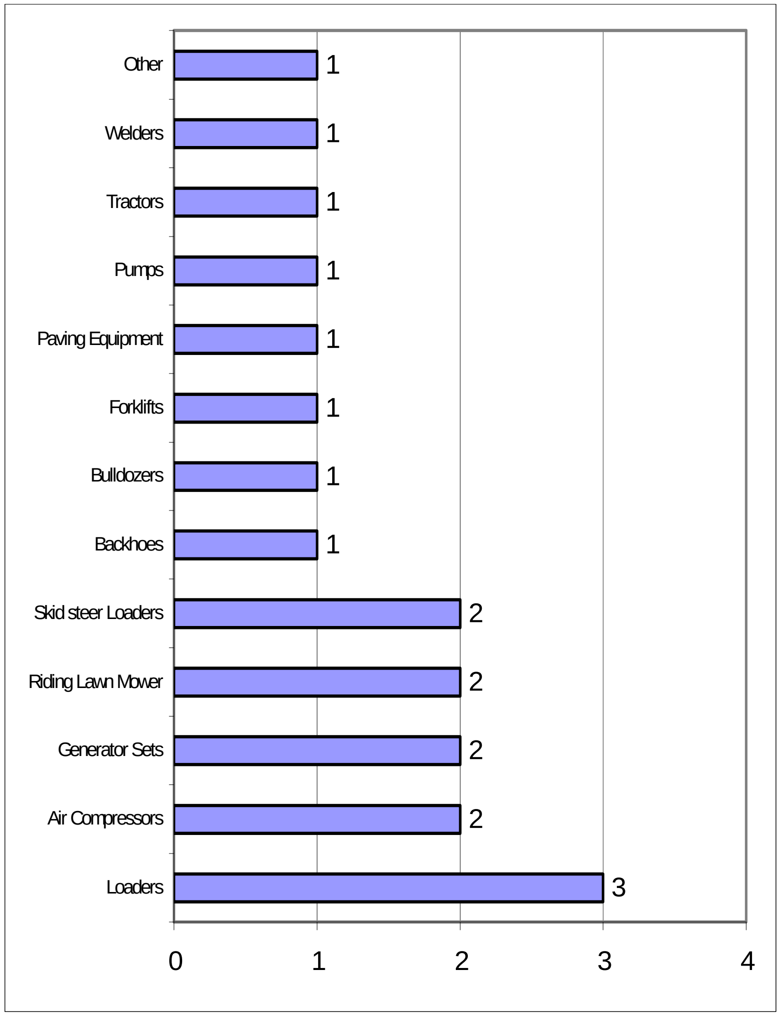


Figure 14. Number Of Pieces By Equipment Type – Residual Category

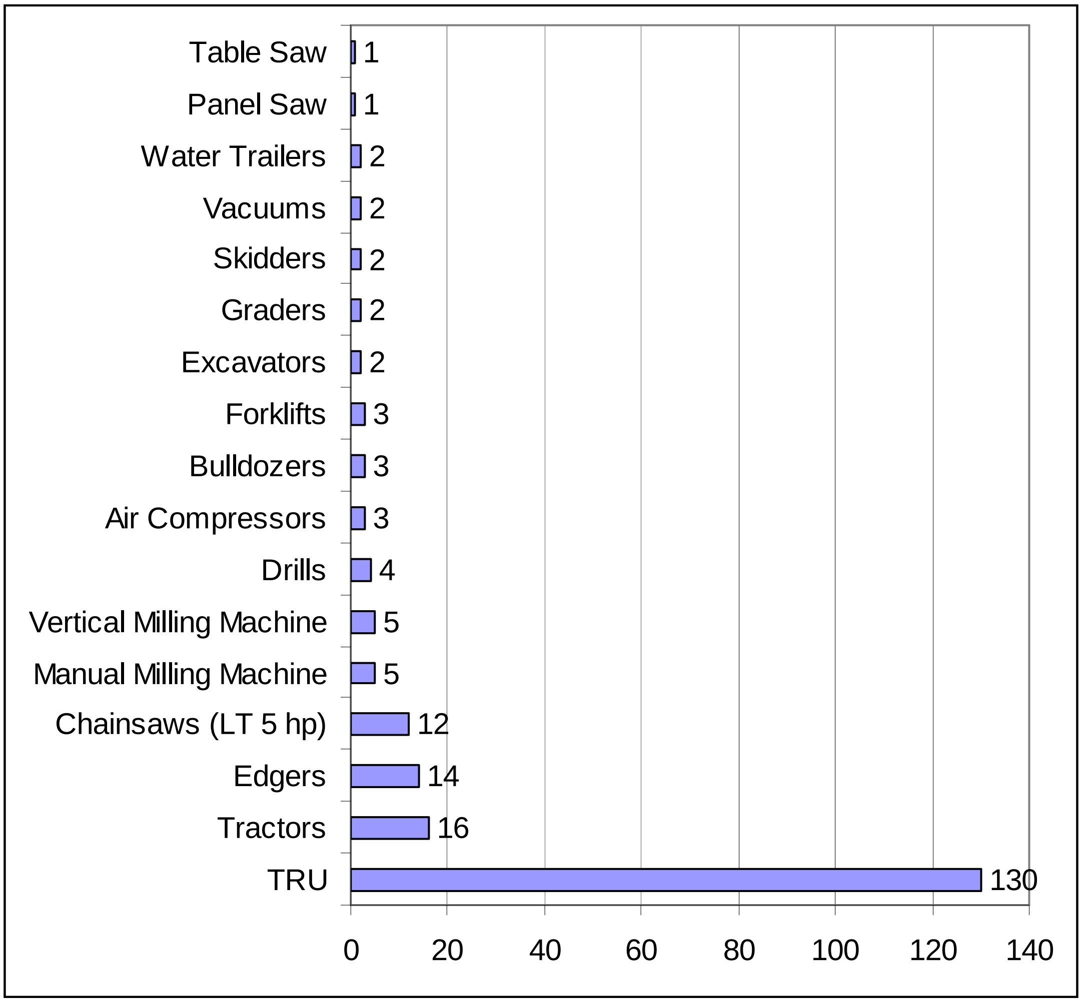
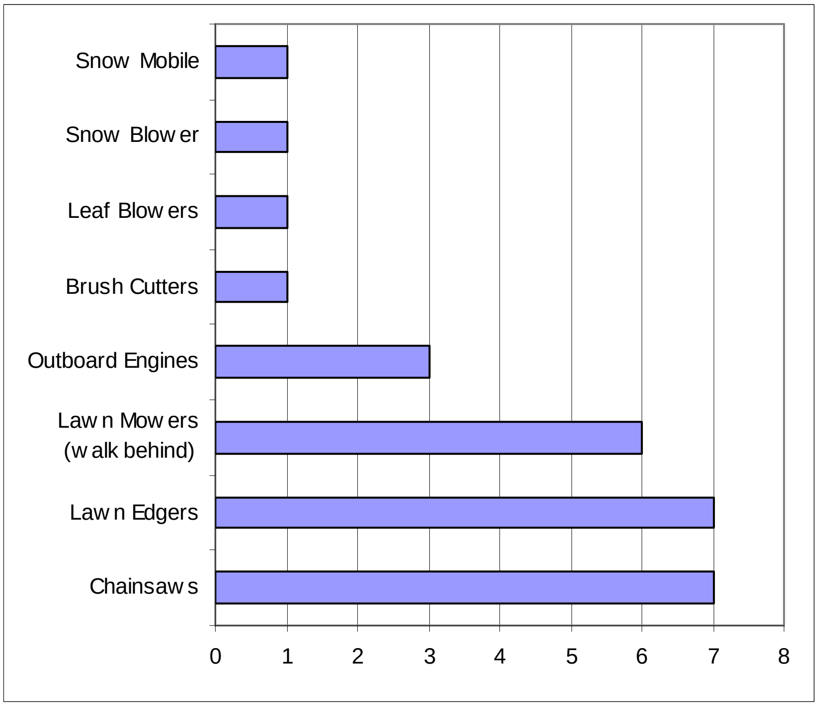


Figure 15. Number Of Pieces By Equipment Type -- Residential Category



The observed equipment type distributions follow generally expected trends, with a few exceptions, as summarized below:

- Equipment used in the agricultural sector is dominated by tractors, with other specialty agricultural equipment such as sprayers, bailers, and harvesters commonly appearing as well;
- The relatively large number of ATVs (reported to be used for on-farm transportation during cognitive interviews), and sweepers/scrubbers was perhaps unexpected for the agricultural sector;
- The agricultural sector had seemingly anomalous reports of lawn mowers and edgers being used in agricultural applications;
- The number of pumps (2 of 114 pieces) may be under-reported among agricultural respondents;
- The range of equipment types reported for the construction and mining sector was consistent with many of the common construction equipment types included in the OFFROAD model, with the exception of 2 lawn and garden tractors;
- The equipment types reported for the Residual category covered a wide variety of common as well as specialty categories. This finding is consistent with the very wide variety of SIC codes included in the Residual sample;
- Residential respondents reported a narrow range of equipment types, all of which would reasonably be expected at private residences.

With the possible exception of the agricultural sector, it appears that the number of observations within each sector is too small to perform a meaningful statistical test (such as Chisquare) to compare the observed equipment type distributions with those from alternative data sources such as the OFFROAD model.

Application Types

Respondents were asked to estimate the percentage of time they used each piece of off-road equipment in the following applications:

- Agriculture
- Building/construction
- Warehousing
- Automotive
- Industrial
- Recreational
- Personal/residential

Of the 308 pieces of equipment with corresponding answers to this question, all but 5 reported 100% use in the equipment operator's primary sector, that is, agricultural for the Agriculture sector, personal for the Residential sector, and construction for the Construction and Mining sector. (Residual sector respondents indicated a range of responses, corresponding to their primary SIC code, such as "Industrial", "Warehousing", and "Logging".) Of the 5 equipment pieces that indicated multiple applications types, the splits were as follows: 1) personal – 5% / agricultural 95%; 2) industrial 10% / construction 90%; 3) warehousing 25% / industrial 75%; 4) building 50% / agricultural 50%; and 5) agricultural 99% / "other" 1%.

Activity Estimates

Respondents were asked to provide an estimate of the total hours of use in 2005 for each piece of equipment. As show in the Figures 16 - 19 show the distribution of reported hours per year for each sample strata.

Figure 16

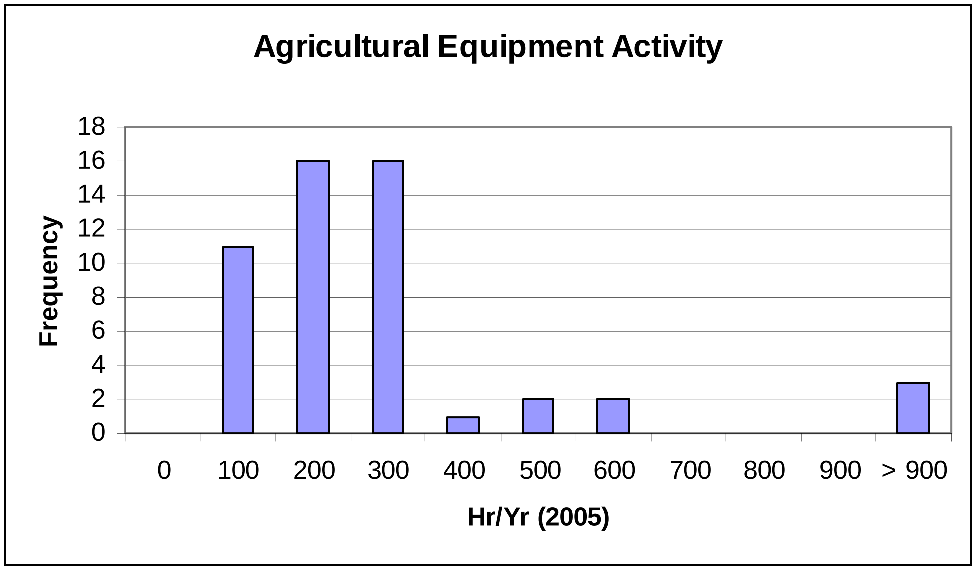


Figure 17

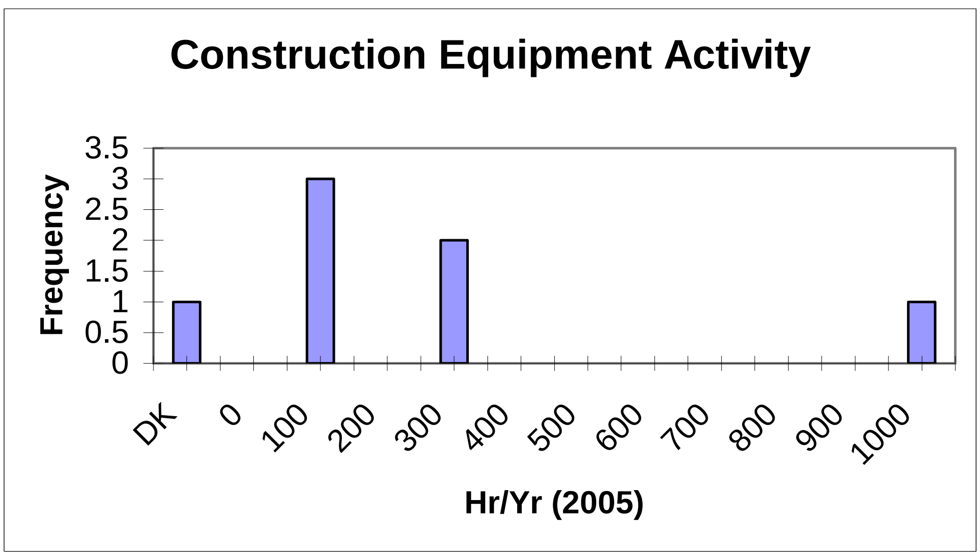


Figure 18

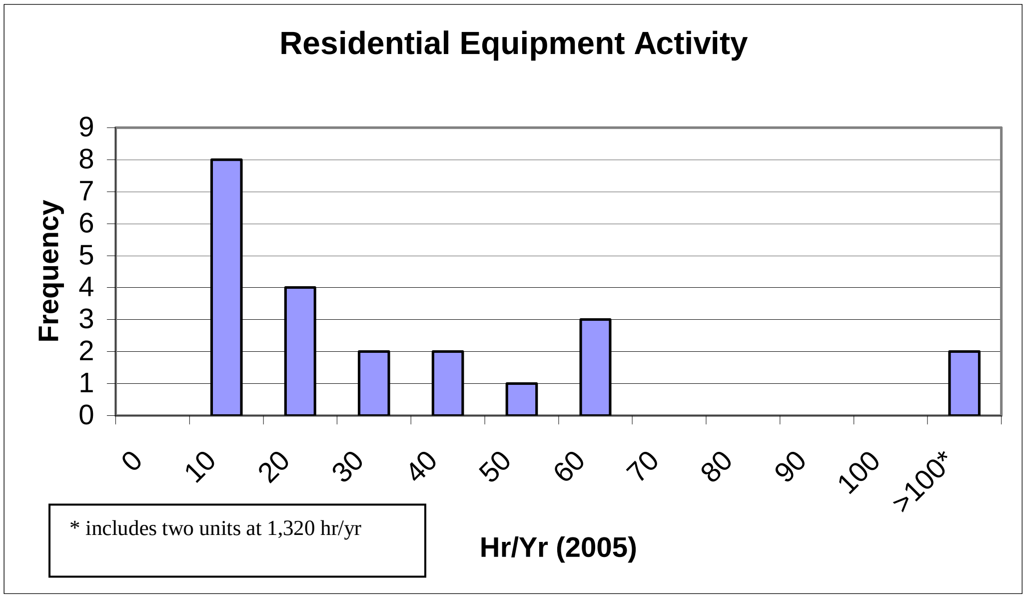
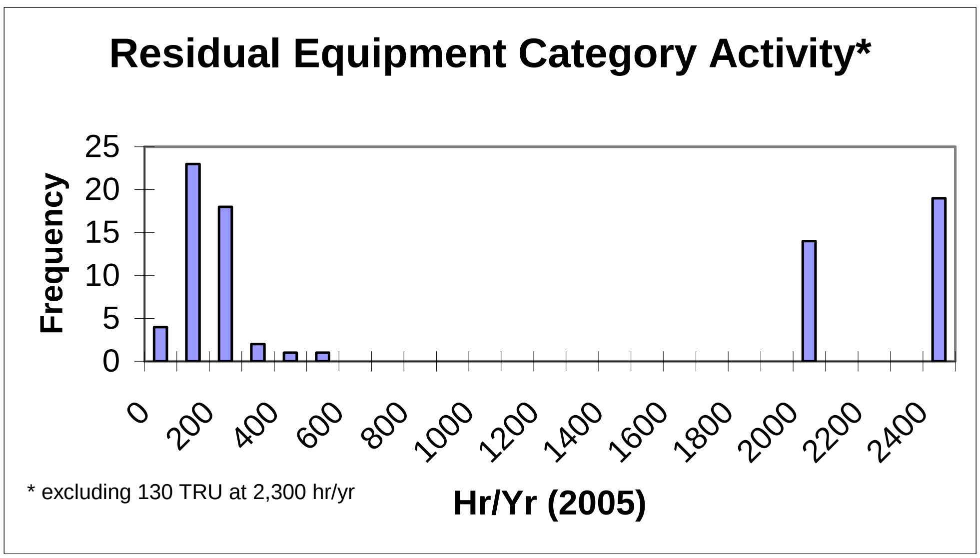


Figure 19



As might be expected, the Residential strata featured the lowest activity rates, with almost all equipment less than 100 hr/yr. And perhaps reflective of the diversity of operators, the Residual category featured the broadest range of activity, ranging from less than 100 hr/yr to 2,400 hr/yr. Equipment counts were lowest in the Construction sector, making it difficult to infer patterns from the few activity estimates in this category. Finally, equipment in the agricultural sector featured a relatively low amount of activity, on average.

Seasonal Distribution Of Equipment Use

Seasonal use varied by sample type, as shown in Table 9 below. While use varied little within the construction and mining and residential samples, the agriculture sample shows high usage in summer months (32% compared to 22%-23% in other months). The residual sample also showed a summer and fall increase in use (29% and 28% respectively) coupled with a very distinct dip in winter (18%).

Table 9. Seasonal Distribution - % of Time (Aggregate Across All Equipment)

Sample Type	Spring	Summer	Fall	Winter
Agriculture	23%	32%	22%	23%
Construction and Mining	25%	25%	25%	25%
Residual	25%	29%	28%	18%
Residential	25%	26%	24%	25%
Total	**26%**	**30%**	**24%**	**20%**

Portable Equipment

Table 10 shows the percentage of equipment designated as “portable” by sector.

Table 10. Portable Equipment

Sample Type	Number	Percentage*
Agriculture	16	25%
Construction and Mining	6	14%
Residual	53	25%
Residential	8	38%
Total	**83**	**27%**

* Considers only definitive (Y/N) responses

Although the sample sizes are small, these results are generally as expected, with the highest percentage of portable equipment found in the Residential sector, and the lowest in the Construction and Mining Sector.

Auxiliary Equipment

Less than one percent of reported equipment was found to feature auxiliary engines (one piece of agricultural equipment).

Fuel Type

Table 11 summarizes the fuel type distributions reported for each sector.

Table 11. Fuel Type Distribution

Sample Type (N)	Diesel	Gasoline	CNG	Propane	Electric	Other
Agriculture (65)	82%	17%	0%	0%	0%	1%
Construction and Mining (7)	29%	43%	14%	0%	14%	0%
Residual (84)*	25%	41%	0%	4%	25%	6%
Residential (22)	0%	91%	0%	0%	9%	0%

* Less 130 gasoline-powered TRU

As expected, the agricultural sector is dominated by diesel use, the Residential sector has a preponderance of gasoline powered units, and the Residual category shows the greatest diversity in fuel types. Again, the low number of construction equipment responses with data makes generalizations regarding fuel type distributions impossible.

Horsepower Distribution By Sector

Respondents were asked to provide estimates for their equipment hp values. Respondents that could not provide a point estimate were asked to identify a likely hp range. The standard hp bins were as follows:

- 0 – 2 hp
- 3 – 5 hp
- 6 --10 hp
- 11 – 24 hp
- 25 – 49 hp
- 50 – 74 hp
- 75 – 119 hp
- 120 – 174 hp

The resulting hp distributions are provided in Figures 20 - 23 for each sector.

Figure 20

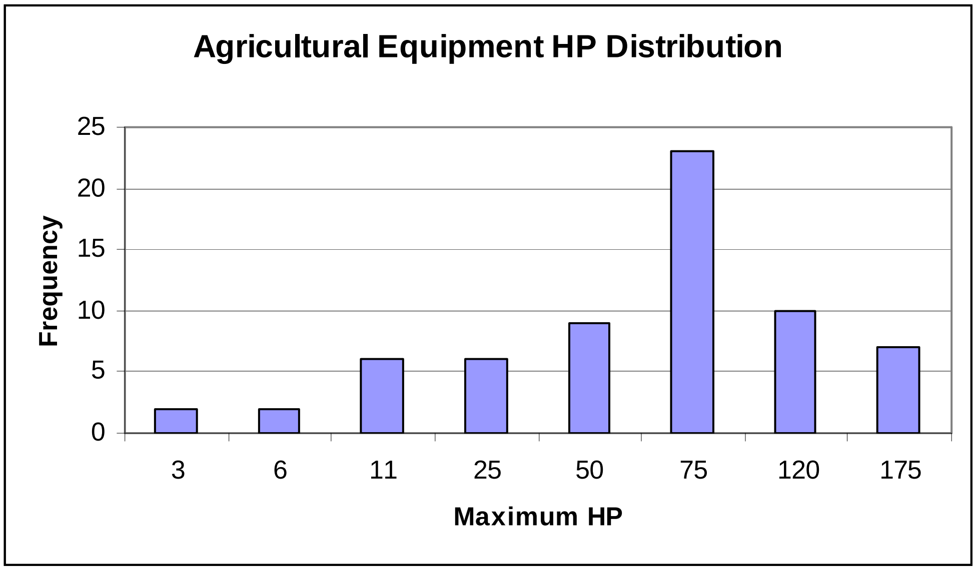


Figure 21

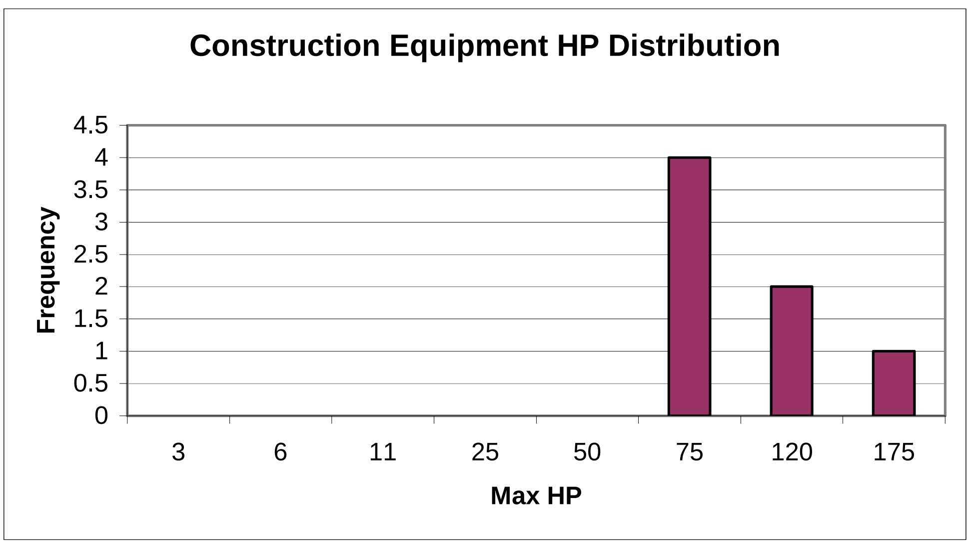


Figure 22

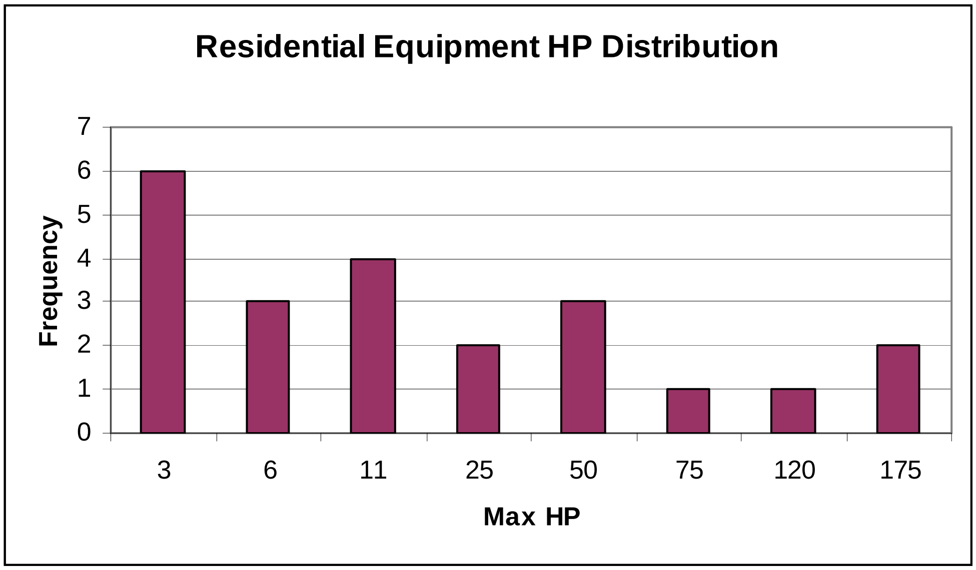
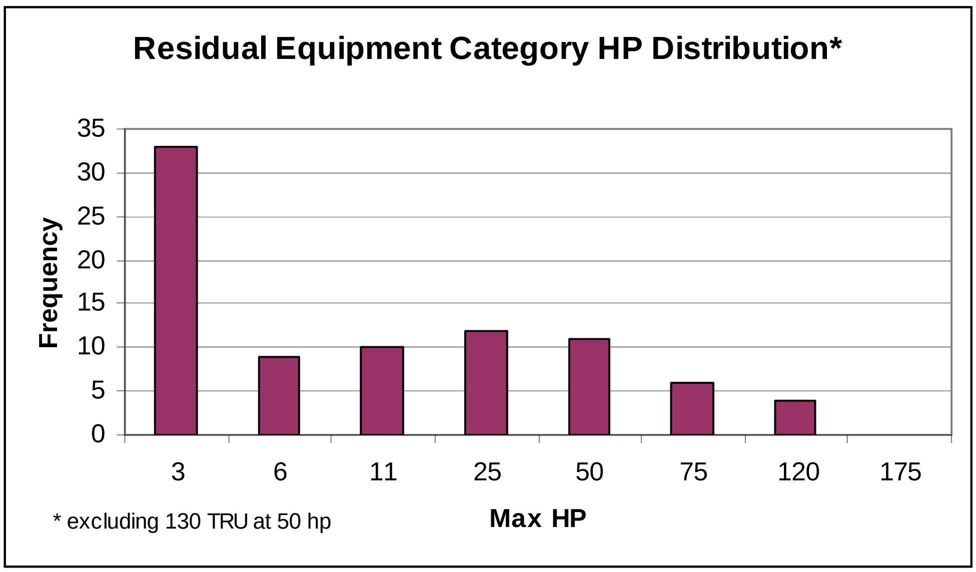


Figure 23



The above figures indicate a preponderance of heavier equipment in the agricultural and construction sectors, and a broader, more even distribution of engine sizes in the residential and residual categories.

Model Year By Equipment Type

Figures 24 - 27 provide the reported model year distributions of the equipment, by sector.

Figure 24

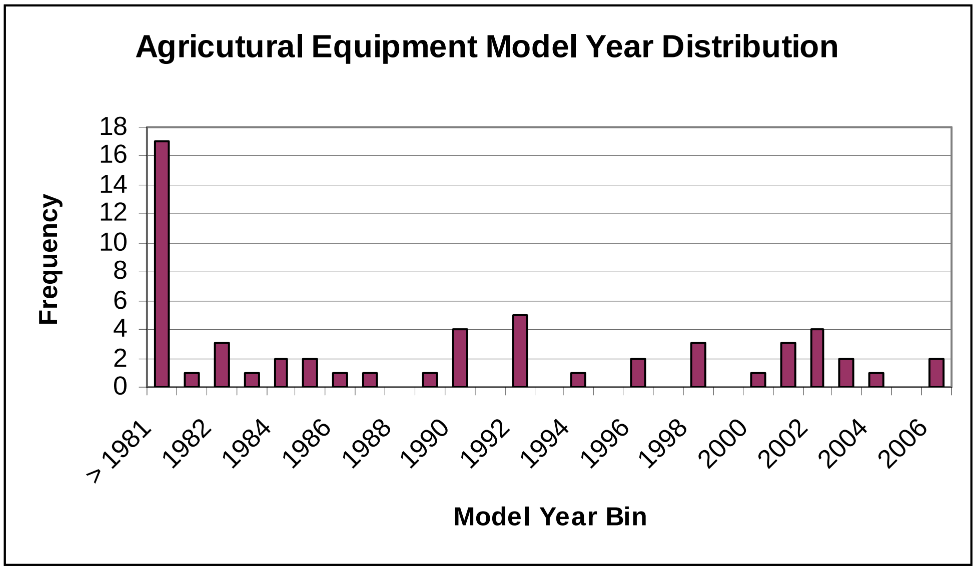


Figure 25

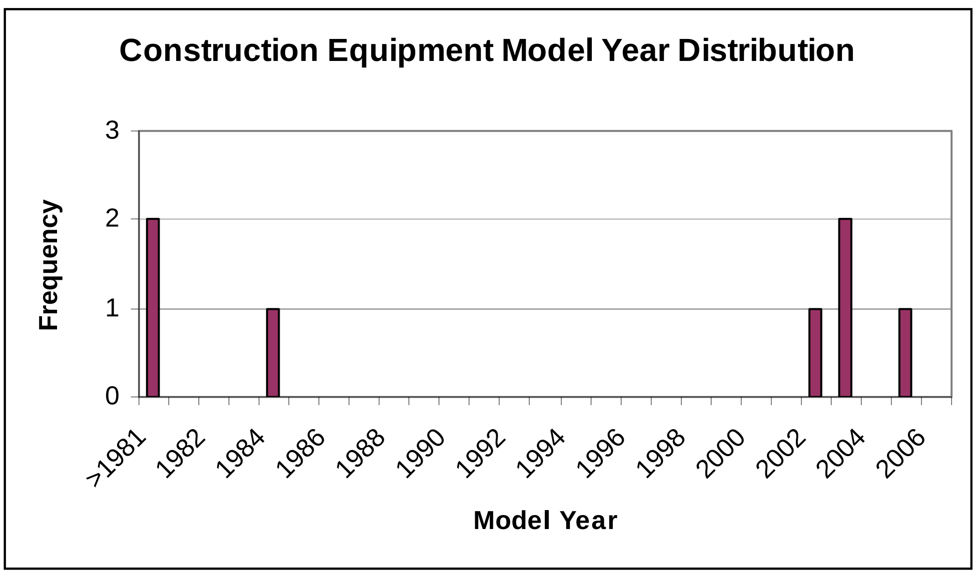


Figure 26

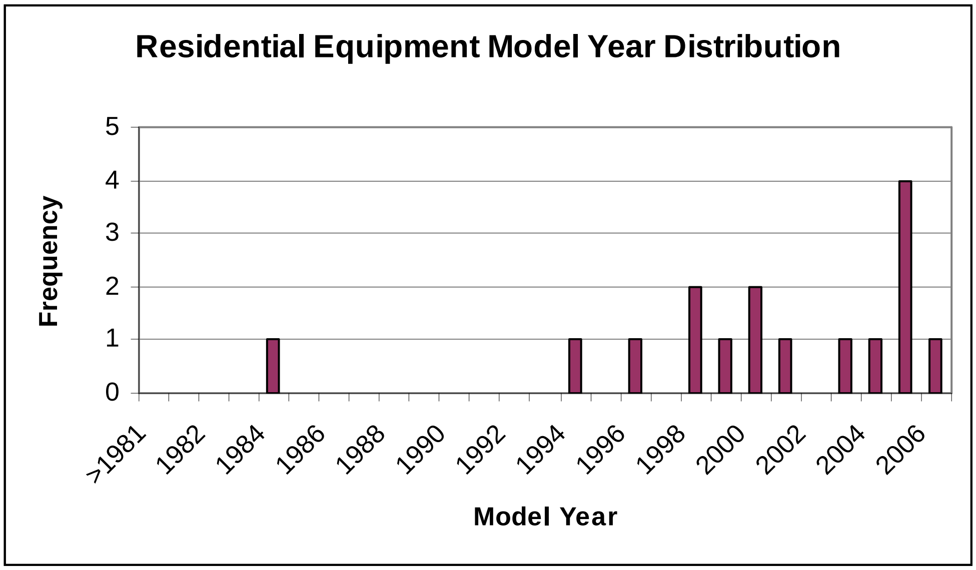
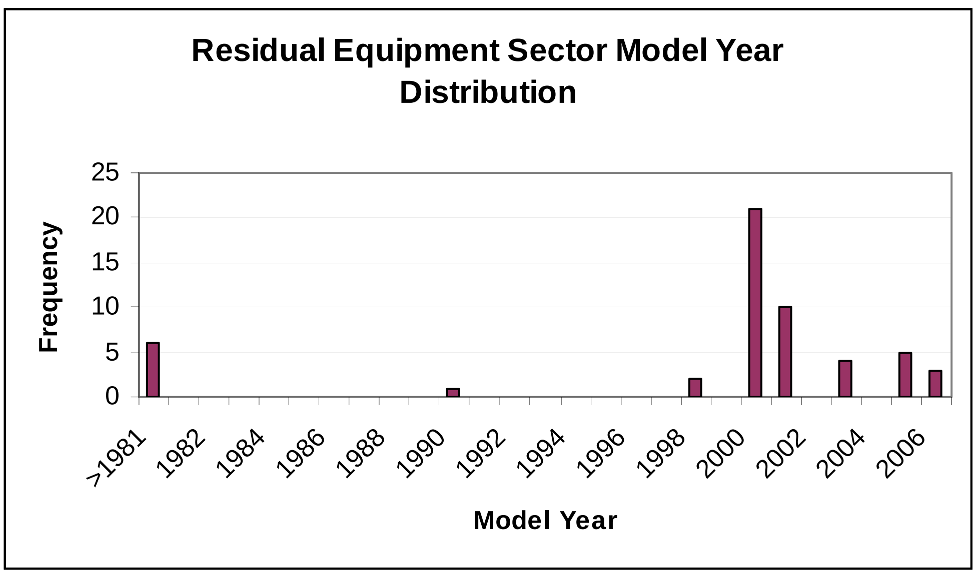


Figure 27



The agricultural sector equipment exhibits a markedly older model year distribution than the other sectors. While all sectors reported at least some equipment older than 1990, the preponderance of units in the residual and residential sectors were less than 10 years old.

Other Survey Findings

In conducting surveys requiring itemization of very specific details on equipment, non-response for specific questions typically results when a respondent does not know, or refuses to provide, the answer (reported as DK or RF, respectively). For this reason, when drafting the survey instrument, significant effort was placed in careful wording of questions with the goal of increasing the likelihood the respondent will not select a "don't know" or "refuse" response.

Based upon the project team's past experience in conducting similar studies, respondents frequently do not know the exact horsepower rating of their equipment. In an effort to improve response for horsepower data, those respondents replying "don't know" or "refuse" were provided a range of horsepower ratings to choose from in a follow-up question. This provides, at a minimum, a response that can be useful for end-use and analytical purposes. In the case of the pilot study, just over three-fourths of respondents could provide a precise horsepower rating while 19% could not. Of those persons who could not provide a rating, more than half were able to provide a hp range, as indicated in Table 12.

Table 12. Improvement in Non-response for Horsepower Rating

Horsepower Rating Questions	Percentage of Responses	
What is the horsepower for that equipment?	Answer Provided	80.7%
	No answer	19.3%
We don't need to know exactly, but just roughly, could you tell me if the horsepower is…	Below 11	3.0%
	11-24	1.4%
	25-49	1.9%
	50-74	3.8%
	75-119	0.5%
	120-174	1.9%
	No answer	6.8%

One question posed greater difficulty for survey participants, namely estimating engine displacement, as shown in Table 13. This finding is typical of other surveys the study team has conducted. In such instances the missing data can be gap-filled to some extent by matching equipment specifications with reported make and model information.

Table 13. Item Non-response for Displacement

Question	Percentage of Responses	
What is the displacement?	Answer Provided	14.4%
	No Answer	85.6%

An issue of concern in conducting this study is the reliability of respondents to accurately recall and provide detailed information on equipment. For example, while most persons were able to provide a response regarding hours of operation, about one out of ten could not (see Table 14). Efforts to improve the respondent's ability to provide an answer could include prompting from the telephone interviewer that "an estimate is ok."

Table 14. Item Non-response for Hours of Operation

Question	Percentage of Responses	
How many hours did you operate your piece of equipment?	Answer Provided No Answer	90.7% 9.3%

Impact of Advance Mailing of Letter about the Survey

Advanced letters are often incorporated in survey research design to increase participation rates. For the pilot study, the impact of mailing an advance letter to all prospective respondents prior to initiating the telephone interviews was tested for its effectiveness. Overall, it was found that the advance letter did not have a significant impact on a person's willingness to participate in the survey. Nearly two-thirds of survey respondents (60%) who agreed to participate in the survey reported they did not receive a copy of the advance letter (see Table 15).

Table 15. Impact of Advance Mailing

Recall Advance Letter?	Total Sample*	Agriculture	Construction & Mining	Residuals	Residential
Yes	34%	17%	44%	36%	58%
No, Continue	60%	79%	48%	56%	40%
No, Send it again	5%	4%	8%	8%	2%

*Categories do not sum to 100% due to rounding.

3.2 Equipment Instrumentation Results

Evaluation of the Roller's RPM Data

The Clēaire logger was installed for a 7-day period beginning July 21 and ending July 28, 2006. No work was performed on Sunday, July 23, so no RPM data was obtained for that day. The plot in Figure 28 shows the cumulative hours of operation spent by the roller on each of the seven days. The day of maximum usage was July 24, 2006, when the roller operated for a total of a little over 9 hours. This includes all times when the engine was turning, including idle time. As shown by the cumulative curve, the roller operated for nearly 35 hours during the 7-day period.

Figure 28. Daily Operation (In Hours) of the Roller

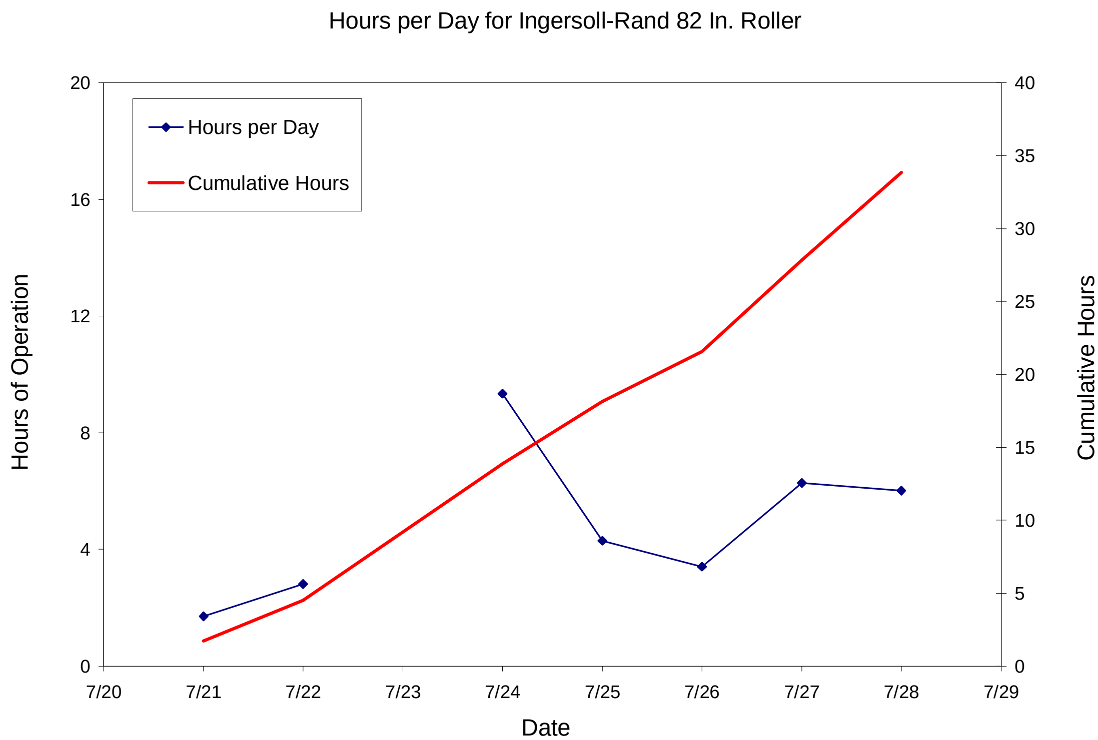
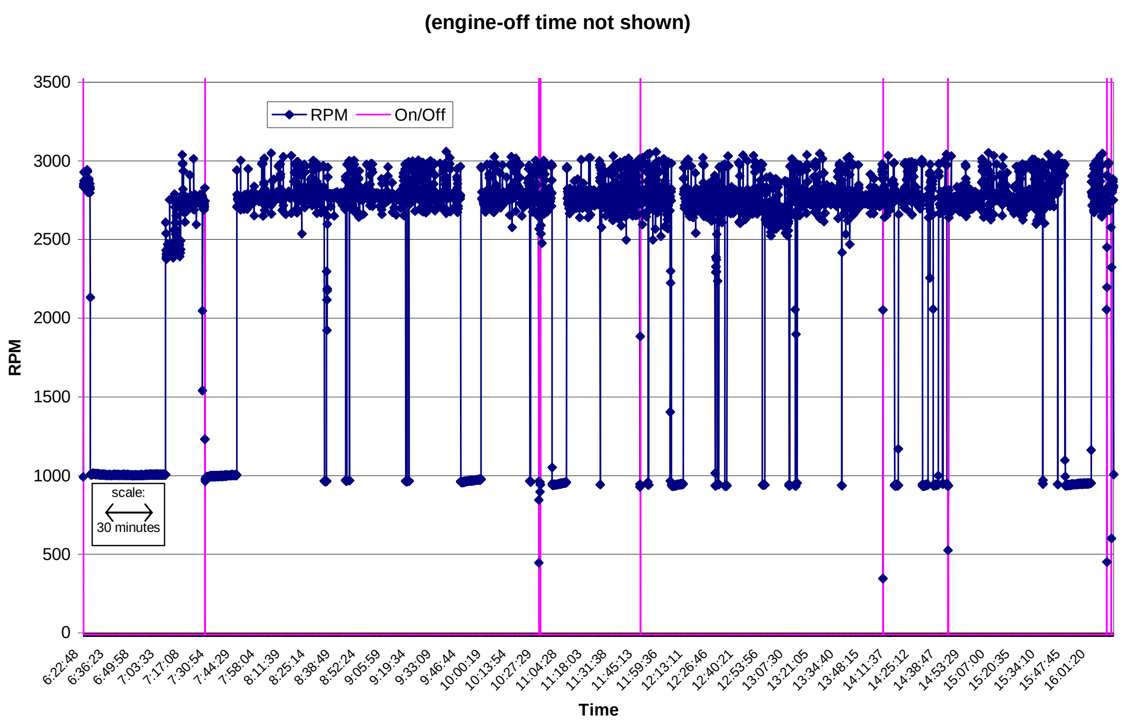


Figure 29 shows the roller's activity during its day of maximum usage (July 24, 2006). Each data point represented an instantaneous "snap shot" of engine RPM, recorded every 5-seconds while the engine was operating. Time scale is shown on the plot by the double-headed arrow near the bottom left of the plot area. The length of the arrow is 30 minutes. Times when the engine was off are not shown.

On July 24 the engine was turned on nine times, which are represented by the vertical lines across the plot. [14] Periods of engine idle are the lower, horizontal series of data points.

The scraper was turned on at 6:22 and within 5-seconds began high RPM operation. This immediate, high RPM operation lasted for almost 4 minutes, and was followed by an extended idle of almost 41 minutes. The rest of the day the roller was used extensively, with relatively few, short idle periods. At 16:28 the scraper was turned off for the day.

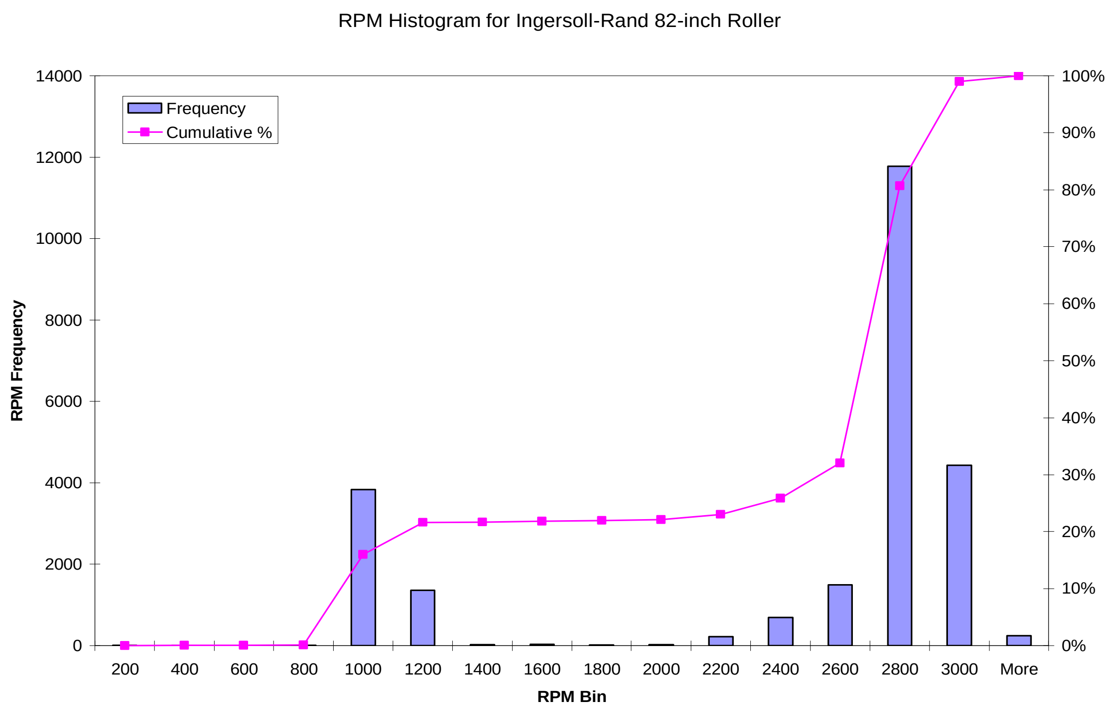
Figure 29. RPM Activity for the Roller on July 24, 2006 (5-second sample rate)



[14] Engine-off instances were recorded in quick succession at approximately 11:00 and at about 14:00. Two vertical lines appear essentially together at both times in the Figure.

The activity of the roller on July 24 appears to be representative of its overall activity during the week. A summary of the operating modes for the roller during the 7 days of monitoring is shown in Figure 30. The columns show the frequency of data points in each RPM bin. The first bin is from 0 to 200 RPM, the second bin is from 201 to 400 RPM, and so on. This plot shows that the majority of operation for this roller was spent in two modes, idle and high-RPM. About 1/3 of the operating time was spent in idle mode. When rolling and compacting fill, the roller engine tended to operate between about 2400 RPM and 3000 RPM, with the 2800 RPM bin being the most populated by far. This fairly narrow range of operating RPM indicates (though, not conclusively) a similarly narrow range of loads on the engine. This was anecdotally confirmed by ERG personnel who watched the roller during a brief period as it operated. It typically operated on level, moderately packed fill material, with few significant sloping areas. The roller would often stop for relatively brief periods of idling as it waited for fill to first be leveled by a grader or scraper before being compacted by the roller. It therefore seems reasonable that a bimodal RPM distribution would be observed in the roller data.

Figure 30. Histogram of RPM Activity for the Roller



Evaluation of the Scraper's RPM Data

The logger was installed for a 7-day period beginning July 29 and ending August 5, 2006. No work was performed on Sunday, July 30, so no RPM data was obtained on that day. The plot in Figure 31 shows the cumulative hours of operation spent by the scraper on each of the seven days the logger was installed. The day of maximum usage was August 2, 2006, when the scraper operated for a total of about 8 hours. This includes all times when the engine was turning, including idle time.

Figure 31. Daily Operation (In Hours) of the Scraper

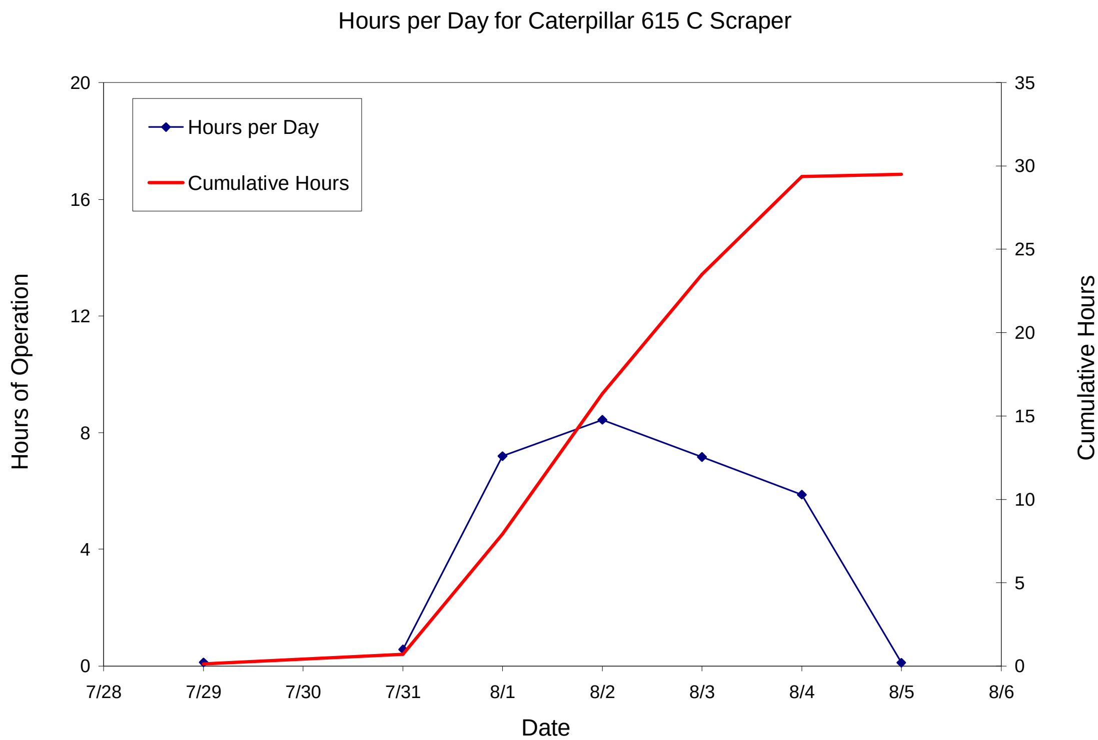
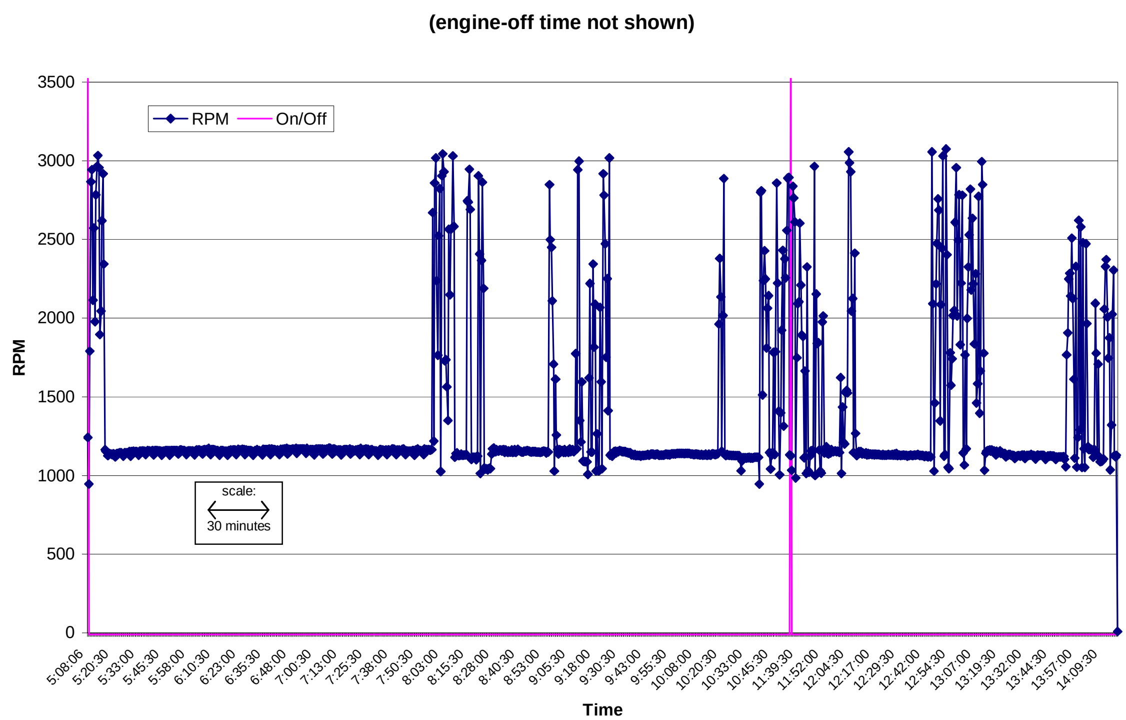


Figure 32 shows the scraper's activity during its day of maximum usage (August 2, 2006). The logger was set to record a sample every 30 seconds. The time scale is shown on the plot by the double-headed arrow near the bottom left of the plot area. The length of the arrow is 30 minutes. Times when the engine was off are not shown.

On August 2, the engine was turned on twice, once to begin the day and once apparently after the lunch break. Engine starts are represented by the vertical lines across the plot. Periods of engine idle are the lower, horizontal series of data points. Brief periods of even lower RPM were often recorded after a period when the engine had been operating at a high RPM.

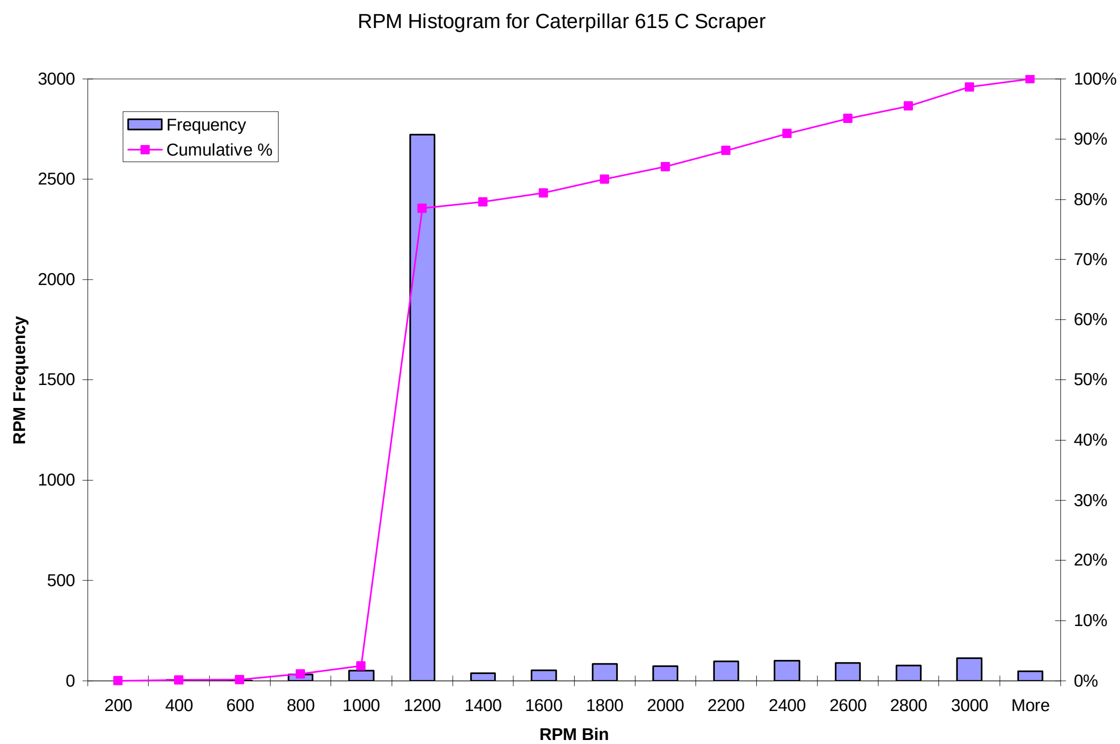
The scraper was turned on at 5:08 and within one minute began high RPM operation. The scraper spent a considerable amount of time idling on August 2. Early in the day it idled for over 2-hours continuously (from 5:16 to 7:58). Then it began a series of intermittent high RPM and idle operations until 10:54, when it was turned off. At 11:36 the scraper was turned back on and began another series of high RPM operations, separated by two periods of idling of over 30-minutes each. At 14:17 the scraper was turned off for the day.

Figure 32. RPM Activity for the Scraper on August 2, 2006 (30-second sample rate)



A summary of the operating modes for the scraper during the 7 days of monitoring is shown in Figure 33. The columns show the frequency of data points in each RPM bin. The plot shows the majority of operation for this scraper was at idle. When moving and leveling fill, the scraper engine tended to operate between about 1800 RPM and 3000 RPM, with the 3000 RPM bin being the most populated, by a very slim margin. This wide range of operating RPM indicates (though, not conclusively) a wide range of loads on the engine. This was anecdotally confirmed by ERG personnel who watched the scraper during a brief period as it operated. For example, ERG saw that as the scraper's blade engaged the fill material, its RPM appeared to vary over a wider range than was observed in the roller that had been previously monitored.

Figure 33. Histogram of RPM Activity for the Scraper



4.0 Conclusions And Recommendations

The following summarizes the strengths and limitations of the data collection methodology developed and executed under Phase I of this study, for both the equipment characterization survey and the data logger instrumentation tasks. An assessment is also provided of the implications for successful completion of the full-scale study under Phase II, along with recommendations for improving data collection methods.

4.1 Equipment Characterization Survey

Based on observations from the survey and subsequent data analysis, the following summarizes the overall performance of the survey administration:

- It is clear that the overall response rate and sample (prospective participant) eligibility was much lower than anticipated in the proposed study design criteria. This was observed for each of the sample types. This meant that more effort was required to obtain a completed survey than originally anticipated.
- The response rate of 17% was below the expected response rate of 23%.
- The completes per hour (CPH) of the study was 0.26, compared to an expected (budgeted) CPH of 0.5. It took between two and three times as much effort to complete a survey than originally estimated.
- Seven percent of all sample (prospective respondents) were eligible to participate in the survey.
- The large number of substrata and set quotas resulted in lower interviewer productivity, and a corresponding higher cost to obtain a completed interview.
- Telephone interviewing is the most practical and feasible approach for survey administration. The preferred method for completing a survey was telephone, for all sample type respondents. Alternative survey modes (Internet and mail) did not significantly increase response rates and should not be pursued for the full study.
- The advanced letter did not influence a prospective survey respondent's decision to participate in the survey. The majority who did NOT receive the letter agreed to continue the survey without it.
- In most instances the survey data collected on equipment characteristics appears to be representative of equipment types, horsepower and model year distributions, and fuel types.
- Reported activity estimates may be low, although independent validation would be needed to verify this assessment. An estimate of fuel consumption could be obtained during Phase II to help validate reported hours of use.
- The sample size for equipment operated in the construction sector was too low to draw substantive conclusions for the most part.
- Item non-response was relatively low for this type of survey. Measures have been successful to minimize non-response for the key data field of engine horsepower.

The above-mentioned metrics and existing budgetary resources are equally important in reviewing the full study design options. Given the findings and resources available for the Full

Study, the project team recommends the following methodological and design modifications for the full study design.

1. ***Suspend the use of the advanced letter; instead, provide the letter and paper version of the survey only upon request**.* The cost of administering the advance letter (approximately $35,000 for postage, return mail postage (BRM), and printing of 60,000 surveys, envelopes and return envelopes) is not justified by the resulting, small increase in willingness to participate. During the pilot test prospective respondents were willing to continue with the survey even without having received the letter. Because the advance letter was a good medium to demonstrate survey endorsement of trade associations, we recommend revising the survey introduction to include the endorsement of appropriate trade associations.
2. ***Clarify eligibility in the screening portion of the interview.*** When surveys require screening to determine eligibility, such as this study, the largest portion of overall non-response occurs at the screening stage of the survey. In the original study proposal, the project team anticipated eligibility to range between 60-80% for this study. As such, we believe there is a problem with the respondent's interpretation of the eligibility question. In other words, we believe that many eligible respondents are reporting that they have no off-road equipment less than 175 hp when in fact they do. Therefore we recommend that the subsequent, primary question to determine eligibility ("Do you own at least one piece of off-road equipment") should be modified to be more clear to the prospective respondent: "How many pieces of *motorized* equipment do you have that do not operate on the road? [Examples include….]." We believe this modification will increase respondents' understanding of what constitutes off-road equipment.
3. ***Set minimum quotas for sample subtypes.*** Setting quotas by sample subtype ensures the study collects data from respondents representative of the sample frame. The pilot test demonstrated difficulty in reaching the set quotas, particularly within the agriculture sample. While we do not suggest removing quotas, we do recommend relaxing the quota by setting a *minimum* level for each substrata. This approach would retain the desired affect of ensuring representation of sample within a sample type, within the available budget.
4. ***Reduce the overall number of completes by 100.*** Even with the above recommended modifications, the total number of completes would need to be reduced in order to remain within the currently available survey budget. This reduction could be distributed across all sample types, reducing the full study from 1,200 to 1,100 completed surveys, as shown below in Table 16. The Table also presents the sampling error (precision) at a +/-5% half-width confidence band, at the 95% confidence level. Reducing the overall number of completes by 100 would increase the aggregate sampling from 2.9% (for 1,200 completed surveys) to 3.0%.

Table 16. Recommended Revision to Full Study Completes by Sample Type and Sub-strata

Sample Type	Pilot Completes	PROPOSED FULL STUDY			REVISED FULL STUDY		
		Full Study	Total Pilot + Full	Precision	Full Study	Total Pilot + Full	Precision
Agriculture	29	271	300	5.8	246	275	6.4
Construction and Mining	10	240	250	6.3	215	225	6.7
Residual	12	288	300	5.8	263	275	6.2
Residential	12	348	350	5.3	313	325	5.7
Total	**63**	**1,147**	**1,200**	**2.9**	**1,037**	**1,100**	**3.0**

The following are additional considerations for the Phase II study design.

Consider creating crop type-specific acreage cutoffs for small and large acreage farms. During the pilot data collection it became apparent that the 50 acre cut point used to delineate small from large farms was not adequate for all crop types. Therefore, we recommend conducting further analysis of available crop type data to further refine these cut points. Obtaining more specific and reliable acreage data from the sample provider, at the level of precision required for the large amount of sample is cost-prohibitive. Therefore, we recommend adding a survey question on acreage size to capture acreage. We do not recommend making this an additional "screening" question to establish eligibility; rather, the acreage data will be incorporated into the analysis as a potential weighting variable.

Include Concentrated Animal Feeding Operations (CAFOs) as a specific sample type within Agriculture. In order to ensure that adequate data is collected on these operations, we recommend including CAFOs as its own sample type, potentially further stratified by animal type and animal quantity (which is available from the sample provider). While adding another substrata to the agriculture sample type will increase the level of effort for survey administration, setting minimum quotas can offset this effect. We have determined, as with the acreage data for crop types, obtaining more specific and reliable data on herd size from the sample provider is cost prohibitive. Similarly, we recommend adding a survey question on herd size. We do not recommend making this an additional "screening" question to establish eligibility; rather, the data will be incorporated into the analysis as a potential weighting variable. Alternatively, a question can be added in the survey to capture herd size, but we caution against making this a mandatory response (and thus reducing eligibility to participate in the survey).

Include a consistency flag for equipment application by sector. Some equipment applications reported within certain sectors appears questionable. For example, some farmers reported using lawn edgers for agriculture activity. It is quite likely that this equipment is used for residential applications instead. To minimize potential errors of this sort, we recommend flagging any responses where the reported equipment application does not match the primary application category (e.g., balers are agricultural equipment, lawn mowers are residential, graders are construction equipment, etc.) Whenever an application does not match the standard category the interviewer will prompt the respondent to verify the equipment is indeed used for the reported application.

Change "compressed natural gas" to "natural gas" as an option for the Fuel Type question. The current response options lists compressed natural gas as a fuel option. Because some equipment operators may use pipeline gas to power their off-road equipment, we recommend revising the terminology to the more general "natural gas."

Exclude nurseries from the agricultural sample frame. While no nurseries responded to the Pilot Survey, it was determined that these entities did fall within the potential sample frame. Therefore we recommend excluding nurseries from the sample frame for the full study in order to focus on standard agricultural activities.

Determine if there is likely under-reporting of agricultural pumps, and modify survey if needed. The number of pumps reported (2 of 114 pieces) may be under-reported among agricultural respondents. We recommend consulting with agricultural experts to determine if the agricultural respondent pool summarized in Tables 6 and 7.

4.2 Equipment Instrumentation

The study team found the Clēaire system to be relatively easy to install on the equipment with which it was compatible "off the shelf." Except for minor problems that could be avoided by keeping a small inventory of redundant systems available, the Clēaire logger worked as advertised. We have developed a list of suggestions and trouble-shooting procedures learned during the Phase I instrumentation, presented in Appendix D. The list is not exhaustive and should be expanded as further experience is gained with these installations.

When installing loggers at construction sites we found it important for installers to obtain an understanding of how the equipment is used at each site, and the expected schedule of equipment usage. An initial inventory of equipment is necessary to help the installers plan, but they will need to remain flexible since equipment needs can change quickly, especially at small and moderately sized work sites. Therefore, it will be important to develop standard operating procedure, with standardized checklists and forms for installers to use for Phase II of this effort.

Based upon experience gained during the pilot task, ERG estimates the following average times will be required during the Phase II project for inspecting equipment, installing and removing data loggers. This does not include travel to and from construction sites.

- Inspecting vehicles: about 15 minutes per vehicle;
- Installing data logger: about 90 minutes per vehicle;
- Removing data logger: about 45 minutes per vehicle.

While budgetary constraints are a concern, given the above resource requirements we believe that the goal of 75 completed intrumentations stated in the original project proposal can be met in the Phase II study. Nevertheless, meeting this target will still require careful coordination of field technician deployment to minimize travel time, and recruitment of large fleet operators where multiple installations can be made at the same location. To the extent that eligible pieces of equipment cannot be readily located, or that they are more difficult to identify and travel to, the likelihood of meeting the instrumentation target is diminished. The following sections discuss these limitations and options for reducing this concern.

Comments on the Applicability of the Clēaire Logger System

"Off the shelf" the Clēaire logger is not as universally installable as hoped. From our experience in Phase I of the project we have learned that directly monitoring engine RPM would require significant modifications or disassembly of a significant fraction of off-road equipment. About half of the equipment inspected fit this description. These types of disassemblies and modifications require a level of skill that is not readily available with standard field technicians.

Nevertheless, it has been determined that the Clēaire system provides a good platform upon which to build a more universal engine activity monitoring system. The Clēaire logger will accept a wide range of inputs, including analog inputs, which are applicable to monitoring various kinds of engine activity. However, "off the shelf," the Clēaire system is not easily installed on about half of off-road construction equipment. It could be modified to be so, but this would require a moderate amount of research and development, as discussed below.

Recommended Alternative Methods for Monitoring Off-Road Engine Activity

The project team consulted with personnel from Clēaire, fleet operators, previous users of the Clēaire system, and expert diesel mechanics to develop feasible strategies for monitoring the activity of a wider range of equipment types. The requirements established for consideration were that the option be installable by moderately trained technicians on a wide range of equipment, that the method record data that reasonably correlates with engine load, that the data be of sufficient resolution to distinguish between idle and working operation, and that the system be of roughly equal or lower cost than the current Clēaire system. The following methods are offered as a result of these considerations.

Intake Airflow

A rotary vane anemometer with analog output and DC power requirement could monitor the intake airflow to the air filter. System output could be recorded using the current Clēaire equipment. Such a system would be installed in the intake snorkel, before the air filter. Diesel RPM is roughly proportional to intake flow rate, with small confounding influences of ambient conditions, turbo-charger speed, and intercooler effect, so engine idle could be determined from the low-flow condition.

To implement this option anemometer systems appropriate for this application would need to be purchased, the interface between the anemometer the data logger would need to be established, and an installation method to adapt the anemometer into the intake ducting of the various equipment configurations would need to be developed. The research and development effort required should be approximately $5,000. Appropriate anemometer systems can be purchased on-line for between $250 and $400 each.

Exhaust Temperature

The temperature of the diesel exhaust is hotter when the engine is under load (i.e., more fuel is being injected) than when it is not under load. It should be possible to monitor exhaust temperature and to roughly infer engine load from the temperature variations. However, the residual heat of the exhaust system might cause a delay in the temperature decay after an extended, high-load event. This effect would have to be accounted for in the post-processing of the data. It would be important to use fast response (i.e. low thermal inertia) thermocouples to counteract this effect as much as possible. Monitoring exhaust temperature near the exhaust system exit should improve the response time and sensitivity of this method. Previous work in this area by ARB (see http://www.arb.ca.gov/regact/porteng/porteng.htm) and others has shown this to be feasible. Also, by monitoring ambient temperatures with another thermocouple, data analysts should be able compare exhaust temperature levels to more precisely estimate the moment of engine idle and engine off events.

The Clēaire system already has several thermocouple inputs and comes with two thermocouples. These could be adapted easily to monitor exhaust temperature near the exit of the exhaust system, as well as ambient temperature. A universal system mounting the exhaust thermocouple near the exit of the exhaust system could be developed with minimal effort. Conclusive proof-of-concept would require a few installations, and analysis of the data. But previous work has already shown this to be a feasible alternative. We estimate that a small research and development effort could be integrated into the initial installations during Phase II of the project. As RPM is being monitored, the exhaust and ambient temperatures could also be monitored. Analysis of the resulting data would enable development of the relationships between RPM, exhaust temperature, and ambient temperature of various equipment configurations. So the research and development of this option could probably be incorporated into the existing budget. There would be no significant incremental effort unless the R&D were to be done separately, before Phase II of the project.

Engine Rotational Acceleration

If mounted on the engine directly above the crankshaft, a three-axis accelerometer could monitor engine vibration in the direction circumferential to the crankshaft of the engine. This would give an indication of RPM, and the frequency of the back and forth accelerations should be proportional to the RPM. A three-axis accelerometer could also monitor vehicular motion in the axial direction to the engine crankshaft (vehicle forward/backward) and in the radial/vertical direction to the engine crankshaft (vehicle up/down).[15]

Engine Vibration

A vibration meter could monitor vibration in the engine that could possibly be correlated to engine RPM. However, conversations with engineering staff of several manufacturers indicates that this would require significant experimentation.

[15] This particular measurement would be most useful for wheeled equipment that regularly "cruises" as part of their normal operation (e.g., graders and scrapers) rather than excavators, trenchers, etc.

Conclusions

The following provides an assessment of the overall utility of the logger data collected to date, and the implications for Phase II.

While logistical uncertainties remain regarding operator participation rates, construction site access, equipment availability, and equipment configurational constraints, the Clēaire logger system itself is likely to provide an efficient, reliable means of collecting engine on-time and RPM for a number of different construction and mining equipment types and applications in Phase II of this study. However, we believe that substantial uncertainty remains regarding the ultimate utility of the data collected. By itself, engine RPM does not correlate one-to-one with engine load and/or exhaust temperature. Without more direct measurements of load and/or temperature, conclusions cannot be drawn confidently regarding duty-cycles (for refining engine load and emission estimates), or retrofit potentials. On the other hand, engine-on time can be used to help validate and adjust survey results regarding equipment activity estimates. Therefore we recommend working with ARB to quantify precise, end-use goals for the instrumentation data before initiation of Phase II. Alternative data collection methods such as those outlined above could be adopted or modified, with corresponding modifications to the number of samples collected, in order to meet ARB's goals for this task.

Appendix A
Crop Type Assignments for Agriculture Sector

Crop	**Crop Type**
Almonds	Nut Crop
Chestnuts	Nut Crop
Macadamia	Nut Crop
Nuts (S)	Nut Crop
Nuts Other/Non-Specific	Nut Crop
Pecans	Nut Crop
Pistachios	Nut Crop
Walnuts	Nut Crop
(Turf and Ornamental) Golf Course - Military	Other Crop
(Turf and Ornamental) Golf Course - Private	Other Crop
(Turf and Ornamental) Golf Course - Public	Other Crop
(Turf and Ornamental) Golf Course - Resort	Other Crop
(Turf and Ornamental) Landscape - Contract	Other Crop
(Turf and Ornamental) Landscape - Architect	Other Crop
(Turf and Ornamental) Lawn Maintenance	Other Crop
(Turf and Ornamental) Memorial Park	Other Crop
Berries Other/Non-Specific	Other Crop
Blackberries	Other Crop
Blueberries	Other Crop
Cascadeberries	Other Crop
Cranberries	Other Crop
Foliage	Other Crop
Fruit (S)	Other Crop
Fruit Other/Non-Specific	Other Crop
Gooseberries	Other Crop
Grass	Other Crop
Huckleberries	Other Crop
Loganberries	Other Crop
Marionberries	Other Crop
Mushrooms	Other Crop
Nurseries Other/Non-Specific	Other Crop
Nurseries Retail	Other Crop
Nurseries Wholesale	Other Crop
Office Park	Other Crop
Oil Crops (S)	Other Crop
Oil Crops Other/Non-Specific	Other Crop
Passion Fruit	Other Crop
Raspberries	Other Crop
Seed	Other Crop
Sod & Sodding Service	Other Crop
Strawberries	Other Crop
Tropical Fruit (S)	Other Crop
Tropical Fruit Other/Non-Specific	Other Crop
Turf & Ornamental (S)	Other Crop
Turf & Ornamental Other/Nonspecific	Other Crop
Alfalfa	Row Crop

Crop	Crop Type
Artichokes	Row Crop
Asparagus	Row Crop
Barley	Row Crop
Beans Other/Fresh	Row Crop
Broccoli	Row Crop
Brussel Sprouts	Row Crop
Burley Tobacco	Row Crop
Cabbage	Row Crop
Canola	Row Crop
Carrots	Row Crop
Castor Beans	Row Crop
Cauliflower	Row Crop
Celery	Row Crop
Cigar Wrap/Filler	Row Crop
Clover	Row Crop
Corn/Soy - (S)	Row Crop
Cotton	Row Crop
Cucumbers	Row Crop
Dry Beans	Row Crop
Eggplant	Row Crop
Endive	Row Crop
Field Corn	Row Crop
Flax	Row Crop
Flowers	Row Crop
Flue Cured Tobacco	Row Crop
Garlic	Row Crop
Grain Sorghum	Row Crop
Green Beans	Row Crop
Hay (S)	Row Crop
Hay Other/Non-Specific	Row Crop
Herbs/Spice	Row Crop
Jojoba	Row Crop
Kale	Row Crop
Kohlrabi	Row Crop
Leeks	Row Crop
Legumes	Row Crop
Lespedezas	Row Crop
Lettuce	Row Crop
Lupine	Row Crop
Melons	Row Crop
Millet	Row Crop
Mixed Hay	Row Crop
Mustard Greens	Row Crop
Oats	Row Crop
Okra	Row Crop
Onions	Row Crop
Parsley	Row Crop

Crop	Crop Type
Parsnip	Row Crop
Peanuts	Row Crop
Peas	Row Crop
Peppers	Row Crop
Pop Corn	Row Crop
Potatoes	Row Crop
Pumpkin	Row Crop
Radish	Row Crop
Rhubarb	Row Crop
Rice	Row Crop
Rutabaga	Row Crop
Rye	Row Crop
Safflower	Row Crop
Small Grains Other/Non-specified	Row Crop
Small Grains (S)	Row Crop
Soybeans	Row Crop
Specialty Hay	Row Crop
Spinach	Row Crop
Squash	Row Crop
Sugarbeets	Row Crop
Sugarcane	Row Crop
Sunflower	Row Crop
Sweet Corn	Row Crop
Timothy	Row Crop
Tomatoes	Row Crop
Turnips	Row Crop
Vegetables (S)	Row Crop
Vegetables Other/Non-Specific	Row Crop
Vetch	Row Crop
Wheat	Row Crop
Yams/Sweet Potatoes	Row Crop
Apples	Tree Crop
Apricots	Tree Crop
Avocados	Tree Crop
Bananas	Tree Crop
Cherries	Tree Crop
Citrus (S)	Tree Crop
Citrus Other/Non-Specific	Tree Crop
Dates	Tree Crop
Figs	Tree Crop
Grapefruit	Tree Crop
Guava	Tree Crop
Kiwi	Tree Crop
Kumquat	Tree Crop
Lemons	Tree Crop
Limes	Tree Crop
Mangos	Tree Crop

Crop	Crop Type
Nectarines	Tree Crop
Olives	Tree Crop
Oranges	Tree Crop
Papaya	Tree Crop
Peaches	Tree Crop
Pears	Tree Crop
Persimmons	Tree Crop
Pineapple	Tree Crop
Pome Fruit (S)	Tree Crop
Pome Fruit Other/Non-Specific	Tree Crop
Pomegranate	Tree Crop
Prunes	Tree Crop
Quince	Tree Crop
Stone Fruit (S)	Tree Crop
Stone Fruit Other/Non-Specific	Tree Crop
Tangelos	Tree Crop
Tangerines	Tree Crop
Tree Fruit (S)	Tree Crop
Tree Fruit Other/Non-Specific	Tree Crop

Appendix B
SIC Codes by Survey Sector

Agricultural - Farm Management

SIC Code	Text Description
0711	Soil Preparation Services
0721	Crop Planting, Cultivating and Protecting
0722	Crop Harvesting, Primarily by Machine
0762	Farm Management Services

Construction

SIC Major Group	Text Description
15	Building construction general contractors and operative builders
16	Heavy construction other than building construction contractors
17	Construction special trade contractors

Mining

SIC Major Group	Text Description
10	Metal Mining
12	Coal Mining
14	Mining and Quarrying of nonmetallic minerals except fuels

Logging

SIC Industry Group	Text Description
241	Logging

Residual (other)

Every SIC not grouped in Ag_Farm Management, Construction, Mining or Logging AND not in one of the SICs listed below

4724 Travel Agencies
4725 Tour Operators
482: Telegraph And Other Message Communications
483: Radio And Television Broadcasting Stations
5441 Candy, Nut, and Confectionery Stores
5461 Retail Bakeries
5499 Miscellaneous Food Stores
Major Group 56: Apparel And Accessory Stores
5719 Miscellaneous home furnishings Stores
5735 Record and Prerecorded Tape Stores
5736 Musical Instrument Stores
Major Group 58: Eating And Drinking Places
Major Group 59: Miscellaneous Retail (EXCEPT INDUSTRY GROUP 598 - FUEL DEALERS)
Division H - Finance, Insurance, and Real Estate - Major Groups 60-65, 67)
Major Group 72: Personal Services (EXCEPT 7216 Drycleaning Plants)

Major Group 73: Business Services (EXCEPT Industry Group 734: Services To Dwellings And Other Buildings, AND Industry Group 735: Miscellaneous Equipment Rental And Leasing
7521 Automobile Parking
Major Group 76: Miscellaneous Repair Services
Industry Group 783: Motion Picture Theaters
Industry Group 784: Video Tape Rental
793: Bowling Centers
792: Theatrical Producers (except Motion Picture),
791: Dance Studios, Schools, And Halls
7993 Coin-Operated Amusement Devices
Major Group 80: Health Services
Major Group 81: Legal Services
Major Group 83: Social Services
8412 Museums and Art Galleries
Major Group 86: Membership Organizations
Major Group 87: Engineering, Accounting, Research, Management, And Related Services
Major Group 89: Miscellaneous Services
Industry Group 921: Courts
9222 Legal Counsel and Prosecution
Major Group 93: Public Finance, Taxation, And Monetary Policy
Major Group 94: Administration Of Human Resource Programs
Major Group 95: Administration Of Environmental Quality And Housing Programs
Major Group 96: Administration Of Economic Programs
9111 Executive Offices
9121 Legislative Bodies
9131 Executive and Legislative Offices Combined

Appendix C
Mail-Out Packet Materials

Questionnaires

California Agricultural Off-Road Equipment Study

SURVEY FORM

Thank you for participating in the survey!

Please use the Instruction Sheet to help you fill out this Survey Form.

1. How would you describe your primary Agriculture business activity?

- ○ Nut crop
- ○ Tree Fruit (apricots, peaches)
- ○ Pasture
- ○ Row crop
- ○ Vineyards
- ○ Other: ____________
- ○ Citrus Fruit (lemons, oranges, tangerines)

2. Do you own, rent or lease at least one piece of off-road equipment?

- ○ Yes
- ○ No ➔ Stop here and return the survey to us
- ○ Don't Know ➔ Please give this survey to the person who would know

3. Does at least one of the pieces of off-road equipment, whether owned, rented, or leased, have a maximum horsepower rating of less than 175hp?

- ○ Yes
- ○ No ➔ Stop here and return the survey to us
- ○ Don't Know ➔ Please give this survey to the person who would know

4. What is the total acreage of the land owned or leased by you? ________ *# acres*

5. Is your business a Farm Management Company?

- ○ Yes
- ○ No

6. How many TOTAL pieces of off-road equipment or vehicles with a maximum horsepower rating of less than 175 does your business currently own, rent or lease that operates in California?

________ *# of equipment* ➔

Use the Instruction Sheet to help answer the questions in the Grid below about EACH piece of equipment.

If you have more than 15 pieces of equipment, go to *http://surveys.nustats.com/Start/NUSTATS/arbw.htm* to enter your information using the PIN# on the SURVEY FORM label or call 800-275-2209 to request an additional form.

EQUIP #	TYPE	MAKE	MODEL NAME OR NUMBER	PERCENTAGE (%) OF THE TIME YOU USE THIS EQUIPMENT FOR EACH TYPE OF WORK OR ACTIVITY (TOTAL = 100%): AGRICULTURE	BUILDING/ CONSTRUCTION	WAREHOUSING	AUTOMOTIVE	INDUSTRIAL	RECREATIONAL	PERSONAL/ RESIDENTIAL	OTHER WORK/ACTIVITY (SPECIFY & WRITE PERCENT)	MODEL YEAR (YYYY)	HORSE-POWER AMOUNT OR CODES A-F	DISPLACEMENT CCS, LITERS, OR CUBIC INCHES AND AMOUNT	HAVE AUXILIARY ENGINE?	FUEL TYPE CODES 1-5 OR WRITE OTHER TYPE	TOTAL HOURS USED IN 2005	SEASONAL USAGE: WINTER (Oct-Nov-Dec-Jan) % OF TIME USED	WINTER AVG # DAYS USED PER WEEK	SPRING (Feb-Mar-Apr) % OF TIME USED	SPRING AVG # DAYS USED PER WEEK	SUMMER (May-June-July) % OF TIME USED	SUMMER AVG # DAYS USED PER WEEK	FALL (Aug-Sept) % OF TIME USED	FALL AVG # DAYS USED PER WEEK	POR-TABLE EQUIP?
EX:	Tractor	John Deere	6420	95	3					2	= 100%	2006	110	○ ccs: ___ ● Liters: 4.63 ○ Cubic inches: ___	○ Yes ● No	1	960	25%	5	25%	5	25%	5	25%	5	○ Yes ● No
1											= 100%			○ ccs: ___ ○ Liters: ___ ○ Cubic inches: ___	○ Yes ○ No											○ Yes ○ No
2											= 100%			○ ccs: ___ ○ Liters: ___ ○ Cubic inches: ___	○ Yes ○ No											○ Yes ○ No
3											= 100%			○ ccs: ___ ○ Liters: ___ ○ Cubic inches: ___	○ Yes ○ No											○ Yes ○ No
4											= 100%			○ ccs: ___ ○ Liters: ___ ○ Cubic inches: ___	○ Yes ○ No											○ Yes ○ No
5											= 100%			○ ccs: ___ ○ Liters: ___ ○ Cubic inches: ___	○ Yes ○ No											○ Yes ○ No

Finished? If so, please return the survey in the enclosed business reply envelope. Thank you!

Do you have more than 5 pieces of equipment? If so, please continue on the back ➔

EQUIP #	TYPE	MAKE	MODEL NAME OR NUMBER	PERCENTAGE (%) OF THE TIME YOU USE THIS EQUIPMENT FOR EACH TYPE OF WORK OR ACTIVITY (TOTAL = 100%)								MODEL YEAR	HORSE-POWER	DISPLACEMENT	HAVE AUXILIARY ENGINE?	FUEL TYPE	TOTAL HOURS USED IN 2005	SEASONAL USAGE								POR-TABLE EQUIP?
																		WINTER (Oct-Nov-Dec-Jan)		SPRING (Feb-Mar-Apr)		SUMMER (May-June-July)		FALL (Aug-Sept)		
				AGRICULTURE	BUILDING/ CONSTRUCTION	WAREHOUSING	AUTOMOTIVE	INDUSTRIAL	RECREATIONAL	PERSONAL/ RESIDENTIAL	OTHER WORK/ACTIVITY *(SPECIFY & WRITE PERCENT)*	(YYYY)	AMOUNT OR CODES A-F	CC'S, LITERS, OR CUBIC INCHES AND AMOUNT		CODES 1-5 OR WRITE OTHER TYPE		% OF TIME USED	AVG # DAYS USED PER WEEK	% OF TIME USED	AVG # DAYS USED PER WEEK	% OF TIME USED	AVG # DAYS USED PER WEEK	% OF TIME USED	AVG # DAYS USED PER WEEK	
6				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
7				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
8				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
9				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
10				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
11				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
12				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
13				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
14				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No
15				+	+	+	+	+	+	+	= 100%			cc's ____ Liters ____ Cubic inches ____	Yes / No											Yes / No

QUESTIONS?	DO YOU HAVE MORE THAN 15 PIECES OF EQUIPMENT?		DID YOU ANSWER ALL THE QUESTIONS FOR EACH PIECE OF EQUIPMENT?
Call NuStats: 800-275-2209	Go to http://surveys.nustats.com/Start/NUSTATS/arbw.htm Use the PIN# *(on the label on the front of the survey)* to enter your information online, OR print out an additional form.	Call NuStats at 800-275-2209: Provide your information, OR request an additional form.	Thank you, fax (800-518-8249) your completed survey, OR mail it back in the enclosed postage-paid envelope.

California Agricultural Off-Road Equipment Study

SURVEY INSTRUCTIONS

STEP 1: Answer questions 1-6 on the SURVEY FORM.

STEP 2: Use the list of Grid Questions (on the right) to record information about each piece of equipment on the SURVEY FORM Grid.

If you have more than 15 pieces of equipment, go to http://surveys.nustats.com/Start/NUSTATS/arbw.htm to enter your information or to print out another form.

STEP 3: Report your information in one of three ways:

Enter your information online at http://surveys.nustats.com/Start/NUSTATS/arbw.htm using your PIN# located on the SURVEY FORM label.

Fax your completed SURVEY FORM to 800-518-8249.

Mail the completed SURVEY FORM to us in the enclosed postage-paid envelope.

QUESTIONS? Call NuStats at 800-275-2209.

Off-Road Equipment is:

Any equipment with a motor not intended for use on roadways or highways and is self-propelled or portable.

Tell us about EACH piece of Off-Road Equipment:

- you own, rent or lease,
- has a maximum horsepower of less than 175, AND
- you operate in California.

Examples of Agricultural Off-Road Equipment:

- 2-wheel tractor
- Agricultural mower
- Agricultural tractor
- Baler
- Combine
- Harvester
- Hydro power unit
- Irrigation pump
- Sprayer
- Stripper
- Swather
- Tiller

GRID QUESTIONS:

Answer the following questions about each piece of equipment on the SURVEY FORM Grid.

EQUIP#:

Record each piece of equipment on its own row *(e.g., if you have 3 tractors, record each one separately).*

If any of your equipment has an auxiliary engine, please record it as a separate piece of equipment. Under the "Type" column, describe its use *(e.g., auxiliary engine for air compressor)*.

TYPE:

Type of equipment. Remember: we need information on ALL the off-road equipment you own, rent or lease, that has a maximum horsepower of less than 175, and that you operate in California - not just the most common types.

MAKE:

Make or brand name of the piece of equipment *(e.g., John Deere, New Holland, Case IH, etc.)*

MODEL NAME OR NUMBER:

Manufacturer's model name or number *(e.g., 6420, etc.)*

PERCENTAGE (%) OF THE TIME YOU USE THIS EQUIPMENT FOR EACH TYPE OF WORK OR ACTIVITY:

Of the total amount of time you use this piece of equipment, what percentage of that time do you use it for each type of work or activity listed:

Agriculture	Industrial
Building/Construction	Recreational
Warehousing	Personal/Residential
Automotive	Other Type *(specify)*

The percentage of time used for each type of work/activity combined should equal 100%.

MODEL YEAR:

Year the equipment was manufactured.

HORSEPOWER:

Write the exact horsepower if possible. If not, write the code for the range:

A = Below 11	C = 25-49	E = 75-119
B = 11-24	D = 50-74	F = 120-174

DISPLACEMENT:

Fill in the bubble for the units *(e.g., cc's, liters, or cubic inches)* and then write the exact displacement amount.

HAVE AUXILIARY ENGINE?

Does this piece have equipment have an auxiliary engine.

If YES: please also record the auxiliary engine as a separate piece of equipment. Under the "Type" column, describe its use *(e.g., auxiliary engine for air compressor).*

FUEL TYPE:

Type of fuel used for this piece of equipment.
Write the code from the list or specify the other type of fuel.

1 = Diesel	4 = Propane
2 = Gasoline	5 = Electric
3 = Compressed Natural Gas	7 = Other Fuel Type *(specify)*

TOTAL HOURS USED IN 2005:

TOTAL hours you operated this equipment in 2005.

SEASONAL USAGE:

% OF TIME USED:

Of the TOTAL annual hours you operated this piece of equipment in 2005, what was the percentage you operated it in each season *(Winter, Spring, Summer and Fall)*. The total percentage for all seasons combined should equal 100%.

AVG # DAYS USED PER WEEK:

On average, how many days per week, do you typically use this piece of equipment during each season *(Winter, Spring, Summer and Fall).*

PORTABLE EQUIP?

Equipment is defined as "portable" if it is moved at least once per year and is NOT self-propelled (e.g., irrigation pumps, compressors or generators, etc.).

Advance Mail Letter

<FNAME> <LNAME>
<ADDRESS>
<CITY>, < ST> <ZIP>
Dear <FNAME>:

We need your help! The Air Resources Board (ARB), a department of the California Environmental Protection Agency, with industry support from the California Cotton Ginners and Growers Associations, Nisei Farmers League, California Grape & Tree Fruit League, California Citrus Mutual, and the Fresno County Farm Bureau, is requesting your help with the California Off-Road Equipment Study. In this study, agriculture business owners share information on the numbers and types of off-road equipment they own, rent or lease. This includes any equipment with a motor not intended for use on roadways/highways and is self-propelled or portable. ARB has contracted with NuStats Partners, a research organization, to administer the survey. The information collected in the survey will provide more accurate data on off-road equipment used in California so that state air quality estimates can be updated.

The study process involves three steps.

1. Please review the enclosed SURVEY INSTRUCTIONS and complete the SURVEY FORM. The survey contains questions about the off-road equipment you own, rent or lease that has a horsepower of less than 175, and that you operate in California.

If you have any questions or need assistance completing the survey, please call NuStats at 1-800-275-2209. NuStats is managing the survey on behalf of the Air Resources Board.

2. If you are not the person most knowledgeable about your business' off-road equipment inventory, forward this packet to the appropriate person. Please call NuStats at 1-800-275-2209 with the name and phone number of the appropriate contact.

3. Report your information in one of three ways:

   Enter your information online at http://surveys.nustats.com/Start/NUSTATS/arbw.htm using this PIN#: <<XXXXXX>>.

   Fax your completed SURVEY FORM to 800-518-8249.

   Mail your completed SURVEY FORM to us in the enclosed postage-paid envelope.

Your help in this study is voluntary, but we urge you to participate. The information you provide is completely confidential, as required by law. No individual business or business owner is identified in reports or data files released by ARB. Again, we appreciate your assistance in this important study. If you would like to verify the information you've been told in this letter, please feel free to contact Dr. Tao Huai, ARB Research Division, at 916- 324-2981.
Sincerely

Richard Corey, Chief
Research & Economic Studies Branch, Research Division
(916) 322-7077

Surveyed Equipment Types

1 2-wheel tractor(s)

2 Agricultural mower(s)

3 Agricultural tractor(s)

4 Air compressor(s)

5 All terrain vehicle(s)

6 Backhoe(s)

7 Bailer(s)

8 Brush cutter(s)

9 Bulldozer(s)

10 Chainsaw(s)

11 Chainsaw(s) (LT 5 hp)

12 Combine(s)

13 Drill(s)

14 Excavator(s)

15 Forklift(s)

16 Generator set(s)

17 Grader(s)

18 Harvester(s)

19 Lawn edger(s)

20 Lawn mower(s) (walk behind)

21 Leaf blower(s) (back pack)

22 Loader(s)

23 Outboard engines

24 Panel Saw

25 Paving Equipment

26 Pipe Threading Machine

27 Pruning Tower

28 Pump(s)

29 Riding lawn mower(s)

30 Skid steer Loader(s)

31 Skidder(s)

32 Sprayer(s)

33 Snow blowers

34 Snow Mobiles

35 Sweeper(s)/Scrubber(s)

36 Table Saw

37 Tiller(s)

38 Tractor(s)

39 Transportation Refrigeration Unit(s)

40 Vertical Milling Machine

41 Vacuum

42 Water Truck(s)

43 Welder(s)

44 Other

Appendix D
Suggestions and Notes on Installing the Clēaire Logger System

Tips for Installing:

- Only need RPM and Power (+/-). Therefore, unroll those and re-roll other cables before starting install
- Inventory the available equipment and their schedules for usage during the coming week.
- While checking the available equipment, note the location of access holes. Lots of equipment has hard to reach holes. Build database of equipment noting easy and difficult access.
- Positioning RPM transducers: Check depth to flywheel teeth with the flat end of a pen or pencil. Make sure the transducer has been treaded in to that depth before backing it out ½ a turn. Do not force the transducer if it won't easily thread into the bell housing - its threads will be damaged because it is probably stopping on a burr in the threaded port. Use a bolt the same size as the RPM transducer to clear out the threads in the port.
- To check that an RPM sensor is working: Need a nultimeter with frequency function or oscilloscope. Wiggle a metal object almost touching the magnetic end of sensor very fast (like gear teeth passing by). Should get a reading of 5-10 hz
- Alternative RPM source is sometimes the alternator. Sometimes you can find a stator terminal that has the sine wave signal (before the rectification to DC). If you find this, connect the RPM umbilical as follows: Connect the positive lead (A on the 2-prong weatherpack connector) to the stator terminal. Connect the negative lead to engine ground. Adjust the RPM scale to about 16 to get a close RPM reading.

Tools for Install

- Wenches (various sizes open end)
- Small electrical nippers
- Adjustable pliers and wrenches (various sizes)
- Multi-tool with screw drivers, pliers, knife, etc.
- Multimeter with Ohms, VDC at least
- ¾ inch, fine thread bolt to clean out bell-housing port for RPM transducer
- 5/8 inch, fine thread bolt to clean out bell-housing port for RPM transducer

Consumables for Install

- Zip ties various sizes
- Locktite (non-permanent)
- Touch up paint to mark bolts/nuts
- Wire terminals for power/ground
- Extra wire for power/ground
- Electrical tape
- Wire nuts
- "No strip" 2nd wire tap for power/ground