138
503
THS

LIBRARIES
MICHIGAN STATE UNIVERSITY
EAST LANSING, MICH 48824-1048

3 1293
02876 2

This is to certify that the
thesis entitled

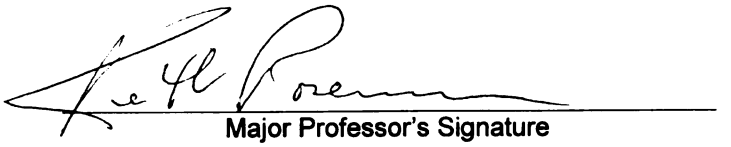
EVALUATING THE MICHIGAN SENSOR SURVEILLANCE PROGRAM FOR WORK-RELATED ASTHMA

presented by

Philip Lee Reed

has been accepted towards fulfillment
of the requirements for the

Master of Science degree in Epidemiology



Major Professor's Signature

11/29/04

Date

MSU is an Affirmative Action/Equal Opportunity Institution

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE

6/01 c:/CIRC/DateDue.p65-p.15

EVALUATING THE MICHIGAN SENSOR SURVEILLANCE PROGRAM FOR WORK-RELATED ASTHMA

By

Philip Lee Reed

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Epidemiology

2004

ABSTRACT

EVALUATING THE MICHIGAN SENSOR SURVEILLANCE PROGRAM FOR WORK-RELATED ASTHMA

By

Philip Lee Reed

Work-related asthma (WRA) surveillance has been a component of the Michigan Sentinel Event Notification System for Occupational Risks (SENSOR) program since 1988. As a first step in the evaluation of the SENSOR WRA program, this study compared 545 worksites inspected as a result of the identification of an index WRA case (SENSOR worksites) with two comparison groups of inspected worksites: (1) a matched comparison group of inspected worksites; and (2) the entire population of 12,268 Non-SENSOR worksites. Data were obtained from the U.S. Department of Labor Integrated Management Information System (IMIS) database. The key outcome variables in this study were the occurrence and types of violations identified and cited during the health inspections, as well as the initial penalties imposed on the organization in conjunction with these violations. The study found SENSOR and Non-SENSOR worksites were similar with respect to the occurrence of citations and the assessment of penalties. Worksites receiving citations were less likely to be represented by a union and tended to have fewer employees. An association was found between citations and penalties and the year of the inspection. Inspections taking place during the period 1993 to 2002 were more likely to have citations and penalties than inspections taking place during 1989 to 1992.

Copyright by
PHILIP LEE REED
2004

DEDICATION

To Marybeth, for never hesitating.

ACKNOWLEDGMENTS

I wish to thank my thesis advisor, Dr. Kenneth Rosenman, for his guidance and support as I completed this work. I also thank my other committee members, Dr. Joseph Gardiner and Dr. Mathew Reeves, for the help they provided along the way, and Dr. James Anthony, for his valuable advice and patience during this process. A debt of gratitude is owed Dr. Nigel Paneth and Dr. Michael Rip for helping to make all of this possible, and to Dr. Naomi Breslau for her intellectual support and encouragement.

This research was supported by Michigan Department of Community Health Grant # U60/CCU515856 to Michigan State University, Dr. Kenneth Rosenman, Principal Investigator. During the completion of this thesis the author received the following financial support: (1) K30 Post Doctoral Fellowship from the from the Heart, Lung, and Blood Institute, Grant # K30 HL 04113 to Michigan State University, Dr. Nigel Paneth Principal Investigator and Training Director; (2) Summer Internship from the Michigan Department of Community Health, April - June, 2003, Grant # 1 U010H07306, Dr. Kenneth Rosenman, Supervisor; and (3) T32 Post Doctoral Fellowship, Grant # T32DA07292 from the National Institute on Drug Abuse to Johns Hopkins University, Bloomberg School of Public Health, Dr. James C. Anthony and Dr. Howard Chilcoat, Principal Investigators and Training Directors.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

With limited resources for health and safety inspections at worksites in the United States, sentinel event surveillance is one of several available strategies for prioritizing the selection of worksites to be inspected. Work-related asthma (WRA) surveillance is part of the Sentinel Event Notification System for Occupational Risks (SENSOR).[1,2] The assumption underlying the sentinel event approach is that index cases of WRA identify worksites where there may be additional disease present, or where workers are at greater risk for developing disease as compared to other worksites. This study compares worksites inspected as a result of the identification of an index WRA case (SENSOR worksites) and worksites inspected in the normal course of implementing the Michigan Occupational Safety and Health Administration (MIOSHA) policy for industrial health inspections (Non-SENSOR worksites). The comparisons of SENSOR and Non-SENSOR worksites focus on a series of outcomes that are derived from records of citations and penalties assessed by industrial hygiene inspectors as a consequence of observed violations of workplace health standards.

The three specific aims of the study are:

> **Aim 1.** To determine if SENSOR WRA identified worksites differ from comparison groups of worksites with respect to citations issued for violations of workplace health standards.

Aim 2. To determine if SENSOR WRA identified worksites differ from comparison groups of worksites with respect to penalties assessed for violations of workplace standards for health.

Aim 3. To determine if SENSOR WRA identified worksites differ from comparison groups of worksites with respect to the qualitative types of citations issued. Citations resulting from inspections are classified qualitatively as 'Serious', 'Willful', 'Repeat', and 'Other.'

In this research the most important issues concern the composition of comparison groups, and the identification of an appropriate statistical model for making comparisons of interest. Factors that impact the choice of sampling strategies for selecting a comparison group include temporal effects influencing the inspection process, and the disproportional representation of certain industries among the SENSOR cases compared to the industries in the reference population of inspected Michigan worksites. Also relevant to WRA surveillance is the lack of workplace standards specific to most exposures that cause WRA. In the absence of specific standards for the causes of WRA, evaluation of inspections must rely on more general indices of hazardous work conditions such as the number of citations issued and the penalties assessed.

Background and Significance

Asthma is a common disease described by the National Heart Lung and Blood Institute as "a chronic inflammatory disorder of the airways...in susceptible individuals, inflammatory symptoms are usually associated with widespread but

variable airflow obstruction and an increase in airway response to a variety of stimuli. Obstruction is often reversible, either spontaneously or with treatment."[3,p. i3] The symptoms of asthma include wheeze, shortness of breath, chest tightness, and cough. These symptoms tend to be variable, intermittent, worse at night, and are provoked by triggers including exercise.[3]

Work-related asthma has been reported to be one of the most prevalent occupational lung diseases in developed countries.[4,5] A recent estimate is that in 1997 there were 784 deaths in the United States attributable to work-related asthma.[6] Estimates of prevalence and incidence vary considerably from country to country.[7,8] This is due to differences in methods of ascertainment and surveillance, as well as differences in the types of industries found across countries. A generally accepted estimate is that 15% of all adult asthma cases are work-related.[9] In Michigan, this would imply as many as 97,000 adults suffered from work-related asthma in 2001.[10]

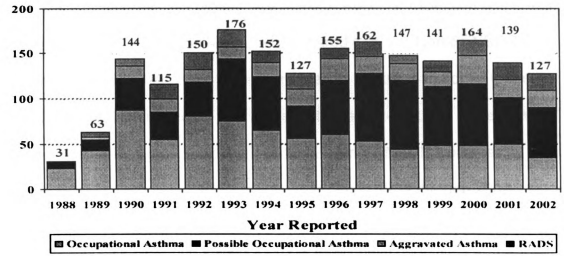
As part of the SENSOR reporting system, in 1988 Michigan began a state-based surveillance program for work-related asthma.[1,2,10,11,12] The SENSOR model targets "...a preventable work-related disease, death, or disability that serves as a signal that other workers in the same workplace, industry, or occupation may be at risk of a similar outcome and may benefit from interventions to abate a hazard or to detect and treat early disease."[2] The SENSOR work-related asthma program in Michigan has confirmed more than 1900 cases of work-related asthma since its inception. These index cases have led to greater than 500

inspections of worksites intended to identify symptomatic coworkers and eliminate hazards that could cause additional illness.

Four categories of WRA were defined as index cases for the SENSOR WRA surveillance program. These were: (1) WRA; (2) Possible WRA; (3) Work Aggravated Asthma; and (4) Reactive Airways Dysfunction Syndrome (RADS).

To be considered a definite 'WRA case' three criteria needed to be satisfied: (A) a physician diagnosis of asthma; (B) the onset of respiratory symptoms improve when the individual is away from the job; and (C) the individual had worked with a known occupational allergen, or there was evidence of association between work exposures and a decrease in pulmonary function testing. The category of 'possible WRA' was used for cases satisfying criteria A & B, but without confirmation of criterion C. The category 'work aggravated asthma' was used in instances when exposures to an agent at work exacerbated asthma symptoms for an individual previously diagnosed with asthma. RADS consists of the immediate development of asthma following an acute exposure at work.[2] Figure 1 presents the distribution of SENSOR WRA index cases broken out by year and the four categories of WRA (1988 was a partial year).[13]

Figure 1
Number of SENSOR WRA Index Cases Per Year



From Rosenman, et al, 2003

The process by which SENSOR WRA surveillance operated began with the referral of a potential WRA case to the surveillance group at the Division of Occupational Medicine of the College of Human Medicine at Michigan State University. The primary sources of referral were physician referral (71%), and hospital discharge data (24%).[13] The referred patient was then interviewed by telephone, and if deemed a probable WRA case a request was made for medical records. The records were reviewed by the program physician who made the final diagnosis and classification of the case. A determination was then made as to whether an inspection of the patient's worksite would be recommended. A total of 545 worksites were subsequently inspected during the period 1989 through 2002 as a result of SENSOR program recommendations. These worksites, designated 'SENSOR worksites', were the focus of this research.

MEASURES AND METHODS

This was a non-concurrent prospective study of worksite inspection outcomes. The SENSOR cohort of worksites was compared with two Non-SENSOR cohorts. The first comparison group consisted of worksites matched to the SENSOR worksites based on year of inspection and 2-digit SIC Code. The second comparison group consisted of all the Non-SENSOR worksites. Complete data were available for the 14-year period 1989 through 2002.

The population of inference for this study is all Michigan worksites under the jurisdiction of the Occupational Safety and Health Administration (OSHA) and potentially subject to inspection. The observational unit or element is the worksite at which a health inspection occurred. The study population was designated to include eligible Michigan worksites for which health inspections were conducted by the Michigan Occupational Safety and Health Administration (MIOSHA) during the period 1989 through 2002. Safety inspections are not included in the population of inference or the study population.

The sampling frame is a list of all industrial hygiene inspections categorized as "health" inspections conducted within Michigan during the study period. The source of the list of worksite inspections is the U.S. Department of Labor Occupation Safety and Health Administration Integrated Management Information System (IMIS). This national database contains worksite inspection information provided by state industrial hygiene inspectors. The information includes "inspection history for specific establishments, citations issued, penalties

assessed and paid, accidents and injuries, standards cited, complaints received and investigated, referrals, cases contested, State Programs activities, Federal Agency Programs activities, consultation visits, and discrimination investigations."[14]

Worksite health inspections are conducted:

(1) as part of a planned series of targeted inspections;

(2) in response to employee complaints (the most frequent reason);[15]

(3) in response to referral from other entities such as other state agencies or a safety inspection; or

(4) in response to a SENSOR recommendation.

Excluded from the eligible population of worksites were all worksites inspected in association with other SENSOR surveillance programs operating during the study time frame.

Construction of Comparison Groups of non-SENSOR Worksite Inspections.

Two comparison groups were used to address the study aims, a matched group and the group of all Non-SENSOR health inspection worksites. The selection of the matched comparison group involved matching selected worksites with SENSOR worksites based the year of inspection and on the two-digit Standard Industrial Classification System (SIC) Code.[16] The two-digit SIC code represents major groups of organizations within a comprehensive classification system based on the primary activities performed by an organization in conducting its business. Codes exist for industries ranging from mining, construction and

manufacturing, to retail, wholesale and government. The resulting matched group of worksites reflects the same industry profile, and associated hazards, as represented by the worksites of SENSOR index cases. The use of a matched comparison group controls for unmeasured, potentially confounding covariates that are associated with SIC Code and time.

Several candidate worksites within the non-SENSOR universe were available for matching. Before undertaking the matching procedure, the SENSOR inspections were first sorted into three time strata, consisting of

(1) 1989 – 1992;

(2) 1993 – 1997; and

(3) 1998 – 2002.

The purpose of stratifying the source population of inspections by time of inspection was to remove the impact of any secular trends in the inspection process. For example, there might have been local inspection emphases in place in a given year, or changes in policy on citations or penalties, or changes in personnel or procedures that could have impacted the process or substance of inspections over the course of the fourteen-year time frame.

The procedure for matching consisted of frequency matching by two-digit SIC Code within each time stratum. The matching protocol first specified, within each time stratum, the frequency of SENSOR worksites having each two-digit SIC Code. Then, for each two-digit SIC Code category, non-SENSOR worksite inspections were randomly selected without replacement until the number of

matching non-SENSOR worksites equaled three times the number of SENSOR worksites. This process was repeated for each SIC Code within each time stratum. There were 78 two-digit SIC Codes represented in the entire study sample of worksites.

For one SIC code in time stratum 3 (SIC 57,Home Furniture, Furnishings, and Equipment Stores), there were insufficient non-SENSOR inspections to achieve the 3 to 1 sampling ratio. To resolve this, SIC 59 (Miscellaneous Retail) was recoded as 57 to allow a random selection of three inspection sites. There were no SENSOR inspections for SIC code 59.

The second comparison group consisted of the entire population of non-SENSOR worksites where health inspections were conducted during the study time period. This comparison group represents the distribution of hazards from worksites across the entire source population of health inspections (excluding SENSOR sites). Thus the two comparison groups, matched and unmatched, permit comparisons with like worksites (as defined by SIC code) and with all worksites, respectively.

Exclusions.

The initial set of worksite inspections for the study period consisted of 13,131, of which 850 were SENSOR worksites. Excluded from the SENSOR worksites were 1 duplicate entry and 304 worksites representing SENSOR programs other than asthma. The 304 non-Asthma SENSOR worksites consisted of 112 Blood

Lead, 109 Noise, and 83 Silicosis SENSOR worksites. This left 545 Asthma SENSOR worksites for inclusion in the study.

There were initially 12,281 Non-SENSOR worksite inspections in the database for the study period. Thirteen were excluded: nine because there was no inspection number or an erroneous inspection number; and four as outliers. The outliers were chosen based on the total penalty assessed (in dollars). The distribution of total penalty was extremely skewed with no obvious break or gap appearing until the four highest values. The fourth highest value was more than eight standard deviations above the mean penalty among the subgroup receiving non-zero penalties, and approximately two standard deviations above the next lower penalty. The thirteen exclusions left a net number of non-SENSOR worksites of 12,268, which is 99.9% of the total number of Non-SENSOR worksites in the database.

Table 1 presents SENSOR and Non-SENSOR inspections included for each of the three time strata. The total of 12,813 represents the entire population of inspections included in the study.

Table 1
SENSOR and Non-SENSOR MIOSHA Health Inspections
Conducted from 1989 Through 2002

Time Stratum	SENSOR	(%)	Non-SENSOR	(%)	Total	(%)
1989 - 1992	146	(26.8)	4,694	(38.3)	4,840	(37.8)
1993 - 1997	217	(39.8)	3,741	(30.5)	3,958	(30.9)
1998 - 2002	182	(33.4)	3,833	(31.2)	4,015	(31.3)
Total	545	(100.0)	12,268	(100.0)	12,813	(100.0)

The overall SENSOR project was reviewed and approved by the institutional review board for protection of human subjects in research at Michigan State University (UCRIHS).

The key outcome variables in this study are the occurrence and types of violations identified and cited during the health inspections, as well as the initial penalties imposed on the organization in conjunction with these violations. Examples of violations that might typically be cited include (1) failure to provide required respiratory protection, a violation of Standard 19100134; (2) failure to provide appropriate ventilation, a violation of Standard 19100094; and (3) failure to maintain a log and summary of occupational injuries and illnesses, a violation of Standard 19040002.

To illustrate potential types of quantitative outcomes, consider that an inspection could result in zero, one, or several citations for observed violations. Each citation could result in no penalty or varying amounts of monetary penalty, as well as generate various qualitative ratings of the violations by the inspector. Numerous options are available for tabulating such measures. Each option represents a composite measure reflecting the presence or level of worksite factors such as the severity of the hazard associated with the violation or the history of past violations at the worksite. The study utilized four quantitative measures of violations and four qualitative measures of the violations cited as a consequence of an inspection. The description of these eight measures follows.

Quantitative Outcome Measures. The four quantitative measures are:

(1) **Citation Event** – (coded 1/0), defined as the occurrence of at least one citation being issued for a violation observed at the inspected worksite;

(2) **Citation Total** – the total number of citations issued to the inspected worksite;

(3) **Penalty Event** – the occurrence of at least one monetary penalty being assessed as a consequence of the worksite inspection (coded 1/0); and

(4) **Penalty Total** – the total number of individual penalties issued to the inspected worksite.

The Quantitative outcome variables are summarized in Table 2.

Table 2
Summary of Quantitative Outcome Variable Characteristics
Data Source: All MIOSH Health Inspections Conducted During 1989 - 2002

Outcome Variable Name	Variable Definition	Variable Type	Value Range: Matched Analysis*	Value Range: All Worksites †
Citation Event	One or more Citations	Dichotomous	0 - 1	0 - 1
Citation Total	Total number of Citations	Count	0 - 37	0 - 51
Penalty Event	One or more Penalties	Dichotomous	0 - 1	0 - 1
Penalty Total	Total number of Penalties	Count	0 - 16	0 - 26

*The lowest and highest values found in the comparisons of SENSOR and the matched comparison group (n=2180)

†The lowest and highest values found in the entire study population of worksites

Qualitative Outcome Measures. Violations are classified by the industrial hygiene inspector with respect to a set of qualitative categories. With only a few rare exceptions, ratings reported in the IMIS database utilized only four categories –'Serious', 'Willful', 'Repeat', and 'Other'. The definitions of these qualitative categories are:

> **Serious** - A serious violation is defined as a violation producing a substantial probability that death or serious physical harm could result, and the employer knew or should have known of the hazard.
>
> **Repeat** - A repeat violation is a violation of any standard, regulation, rule or order where, upon re-inspection, a substantially similar violation is found.
>
> **Other** - An other-than-serious violation is a violation which has a low probability of resulting in an injury or illness.
>
> **Willful** - Willful violations are violations committed with an intentional disregard of, or plain indifference to, the requirements of the OSH Act and regulations. [17]

Each qualitative variable (Serious, Repeat, Other, and Willful) was defined as the occurrence of at least one citation of that type being issued for a violation observed at the inspected worksite, and was coded "1" or "0". For example, if an inspection produced three citations rated as Serious (or any frequency greater than zero), then that worksite was coded "1" for Serious. If a worksite inspection produced no citations for Serious violations, then that worksite was coded "0" for

Serious. This procedure was followed for each of the four qualitative outcome variables.

Covariates. The covariate of central interest is the worksite attribute of having been targeted for a health inspection due to an employee being identified as a SENSOR work-related asthma index case. This will be referred to as a 'SENSOR' worksite (coded 1 or 0). Of the 12,813 eligible worksites in the study, 545 are SENSOR asthma worksites. Three additional covariates of interest include 'Union' – union status (coded 1/0); 'Worksite Employees' – the number of employees at the inspected worksite; and 'Corporate Employees' – the number of employees controlled by the parent corporation. Both employee covariates are multi-category variables utilizing categories commonly employed in Department of Labor (DOL) statistics. These categories are

(1) 1 – 10 employees;
(2) 11-49 employees;
(3) 50 – 249 employees;
(4) 250 – 999 employees; and
(5) 1000 or more employees.

The Worksite Employees and Corporate Employees covariates were entered in the regression models using k-1 dummy-coded variable-specific categories, with category 5, 1000 or more employees, as the omitted reference category.

There were 656 of the 12,813 worksites with zero values for Worksite Employees and Corporate Employees. Of these, 4 were SENSOR worksites. Only two (0.03%) of the "zero-employee" worksites received a citation for a violation. In

contrast, 1,608 (66.0%) of the worksites in category 1 (1 – 10 employees) of the covariate Worksite Employees received citations. It is not possible to meaningfully interpret the meaning of zero employees. The group with zeros for number of employees could consist of a mixture of headquarters locations, sole proprietorships, missing data, and data entry or recording errors. The option of combining the zero group with the group of worksites having 1 to 10 employees is not appropriate because of the large difference between the two groups in the prevalence of violations. Treating "zero-employee" worksites as a separate group added nothing to the analyses because there was essentially no variance in outcome among these worksites. Therefore, it was decided to treat these 656 worksites as having missing data for all regression analyses which included the covariates Worksite Employees and Corporate Employees.

In addition to the above described covariates, two additional covariates were employed in analyses involving the unmatched comparison group. The first additional covariate was the year of inspection (**Year**), with three levels corresponding to each of the three time strata defined above. Regression models used dummy coded variables with stratum 1, 1989-1992, as the reference category. The second additional covariate was the two-digit SIC code (**SIC**) for each worksite. In regression analyses k-1 dummy-coded variables were used for the 78 two-digit SIC codes represented in the study sample.

The guiding conceptual model was one in which each outcome variable of interest was expressed as a function of SENSOR status, with statistical

adjustment for the covariates listed above, including Union, Worksite Employees, and Corporate employees for the matched group analyses, and adding Year and SIC for the analyses of all worksites.

ANALYSIS

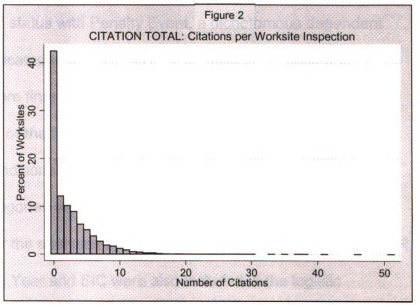
The plan for data analysis began with exploratory steps involving stem and leaf plots and other exploratory descriptive techniques to examine the underlying distributions of each outcome variable and covariate of interest. The following presentation of the analysis strategy and procedures is organized by the three study primary aims. In the case of the analyses addressing Aims 1 and 2, which involve the quantitative outcome variables, each analysis sequence began with a tabulation and examination of the frequency of the occurrence of citations and penalties. Then logistic regression analysis was used to estimate the bivariate association of SENSOR status with the dichotomous outcomes Citation Event and Penalty Event. Unconditional logistic regression was used for the matched group analyses because frequency matching does not require a conditional model.[18] The final steps in each analysis sequence focused on the count variable outcomes, Citation Total and Penalty Total, using regression models capable of taking into account the additional information contained in the count outcome measures. The analyses of the qualitative outcome variables consisted of a slightly different sequence of analyses that is described following the Aim 1 and Aim 2 analysis sections that are presented next.

Analysis: Aim 1. In the initial analysis step addressing Aim 1, the task was to estimate the association of SENSOR status with Citation Event, a dichotomous outcome variable coded "0" to indicate that there were no citations issued, and coded "1" to indicate that one or more citations were issued for violations

observed during the inspection. In comparing SENSOR and matched Non-SENSOR worksites the statistical approach employed unconditional logistic regression. Simultaneous adjustment for Union, Worksite Employees and Corporate Employees was added to the prediction model. When SENSOR and all Non-SENSOR worksites were compared, the covariates Year and SIC were added to the model.

The outcome Citation Total is a count variable with a 'Poisson-like' distribution characterized by a high proportion of zero counts (see Figure 2). The set of analyses attempting to predict Citation Total employed a Poisson regression model in which the dependent variable Citation Total was regressed on SENSOR, with adjustment for Union, Worksite Employees, and Corporate Employees. A Poisson distribution is defined as having a mean equal to the variance.[19] The high zero count for Citation Total required evaluation of the distribution for potential over or under dispersion (variance > or < mean), which would indicate that the underlying distribution of the dependent variable departed from a true Poisson distribution. This proved to be the case (mean=2.2, variance=10.4)

Figure 2



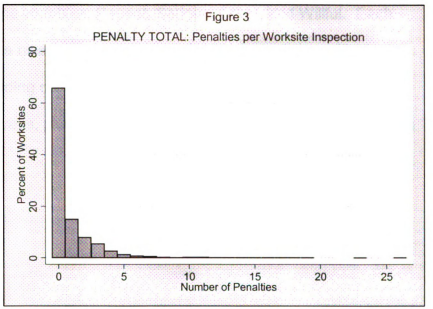
and therefore additional statistical models were explored. The model ultimately used was zero-inflated negative binomial regression (ZINB).[20] ZINB uses a two equation process, with one equation predicting the always zero condition, and a second equation predicting counts greater than zero. Only the results of the prediction of non-zero counts will be presented because the prediction of always zero provides essentially the same information as the logistic regression analysis predicting Citation Event, with reversed scoring (i.e. predicting the zero condition rather than the one condition).

The final exploratory analysis steps involved post hoc explorations of covariate combinations in the Citation Total analyses, and regression diagnostics used to probe for model misspecifications and invalid assumptions.[21]

Analysis: Aim 2. The analyses addressing Aim 2 began with estimating the association of SENSOR status with Penalty Event, a dichotomous dependent variable in which "0" indicated that there were no penalties assessed and "1" indicated that one or more financial penalties were assessed for citations issued during the inspection. For the Matched Group comparison, the statistical approach involved a conditional logistic regression, conditioned on the pooled frequency matched categories defined by time stratum and two-digit SIC code within time stratum. For the analyses comparing SENSOR and all non-SENSOR worksites the covariates Year and SIC were also included in the logistic regression model.

The second stage of analysis pursuing Aim 2 employed a Poisson regression model in which the dependent variable Penalty Total was regressed on SENSOR, with adjustment for Union, Worksite Employees, and Corporate Employees. As with the count of citations, Penalty Total was characterized by a high proportion of zero counts, and a variance substantially greater than the mean (mean=0.7, variance=2.7), indicating that the underlying distribution of the dependent variable departed from a true Poisson distribution (see Figure 3). As with the analysis of citations, only the non-zero count portion of the ZINB analysis is reported.

Figure 3



The final exploratory analysis steps involved post hoc explorations of covariate combinations in the ZINB analyses, and regression diagnostics used to probe for model misspecifications and invalid assumptions.

Analysis: Aim 3. In the initial analysis step addressing Aim 3, the task was to estimate the association of SENSOR asthma worksite status with each qualitative category of citation issued consequent to the health inspections. The

statistical approach involved a separate sequence of analyses for each of the four qualitative outcome variables; Repeat, Serious, Other, and Willful. Each sequence began with a bivariate logistic regression analysis, followed by logistic regression models holding constant the covariates Union, Worksite Employees, and Corporate Employees, plus Year and SIC for comparisons of SENSOR with all Non-SENSOR.

RESULTS

Table 3 presents a description of the study sample and the source population of inspected worksites. For example, in rows 2 and 3 of column 1 (SENSOR worksites), the median and mean number of workers at SENSOR worksites are 200 and 776 respectively. In column 2, row 1, the number of worksites for Comparison Group 2 is 1,635. At the bottom of Table 3 the most common SIC Codes are presented for each group. This description is extended in Appendix A, Tables A1 and A2.

The mean number of employees per worksite was greater for the SENSOR group than for either of the comparison groups: comparing SENSOR with the matched comparison group of Non-SENSOR worksites, $z=-5.4$, $p<0.001$; and comparing the mean employees per worksite for SENSOR and all Non-SENSOR worksites $z = 11.6$, $p<0.001$. The mean number of workers per corporation was also greater for SENSOR worksites than for both comparison groups: comparing SENSOR with the matched comparison group of Non-SENSOR worksites, $z=-4.8$, $p<0.001$; and comparing the mean employees per worksite for SENSOR and all Non-SENSOR worksites $z = 8.8$, $p<0.001$.

The proportion of worksites that were represented by a union also differed for SENSOR worksite as compared with Non-SENSOR worksites. For the matched group comparison X^2 (1 df) = 14.8, $p<0.001$, and for the comparison with all Non-SENSOR worksites X^2 (1 df) = 26.3, $p < 0.001$.

Table 3
Study Sample Sub-Group Characteristics
Data Source: All MIOSH Health Inspections Conducted During 1989 - 2002

	SENSOR Group	Comparison Group 1	Comparison Group 2
	Michigan Worksites Identified by SENSOR Index Cases	Michigan Worksites Matched to SENSOR Index Cases[1]	All Non-SENSOR Michigan Worksites Inspected from 1989 through 2002
Number of worksites	545	1635	12,268
Workers at Worksite			
Median	200	90	37
Mean	776	451	263
SD	1,276	1,186	994
Workers in Corporation			
Median	389	133	60
Mean	10,848	4,213	2,362
SD	41,021	21,962	21,015
Non-Union[2]	264 48.5%	923 58.0%	7,145 59.6%
Union[2]	280 51.5%	668 42.0%	4,846 40.4%
Most common 2-digit SIC codes[3]	SIC Freq. %	SIC Freq. %	SIC Freq. %
	37 218 40.0	37 654 40.0	34 1,421 11.6
	35 49 9.0	35 147 9.0	17 1,253 10.2
	30 40 7.3	30 120 7.3	37 1,240 10.1
	34 40 7.3	34 120 7.3	35 718 5.9
	28 24 4.4	28 72 4.4	80 550 4.9
	33 24 4.4	33 72 4.4	33 453 3.7

[1] Frequency matched for time stratum and 2-digit SIC Code with selection ration of 3 to 1
[2] Union status information was missing for1 SENSOR and 277 Non-SENSOR worksites.
[3] More complete lists of SIC Codes and descriptions are provided in Appendix A.

Results Aim 1: Citations for Violations

Table 4 presents a summary of Citation Event frequencies. For all three groups, SENSOR, Matched non-SENSOR, and All non-SENSOR, the prevalence of worksites receiving at least one citation was between than 53% and 58%. For example, 55.4% (906 worksites) of the Matched comparison group (Comparison Group 1) received at least one citation.

Table 4
Frequency of Citation Event:
Occurrence of One or More Citations at Health Inspections of
Asthma SENSOR Worksites and Two Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	SENSOR Group	Matched Comparison Group 1 [1]	Comparison Group 2 [2]
Zero Citations Issued	254 (46.6%)	729 (44.6%)	5,199 (42.4%)
One or More Citations Issued	291 (53.4%)	906 (55.4%)	7,069 (57.6%)
Total	545 (100%)	1,635 (100%)	12,268 (100.0%)

[1] Frequency matched by Year category and 2-digit SIC Code within each Year Category stratum
[2] All Non-SENSOR Inspected Michigan Worksites

Citation Event: Matched Group Analysis. A bivariate unconditional logistic regression analysis (Table 5) suggests there is no difference in the likelihood that SENSOR worksites received one or more citations as compared with the matched non-SENSOR worksites (OR=0.9, 95% CI: 0.75 – 1.12, p=0.41). Adding covariates to the model to simultaneously adjust for the influence of union status, Worksite Employees and Corporate Employees did not materially alter the

association between SENSOR status and Citation Event (OR=1.0, 95% CI: 0.79 - 1.20, p=0.827).

Table 5
Logistic Regression Predicting the Occurrence of At Least One Citation in SENSOR and Matched Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Odds Ratio	95% CI	p-value
Model A (Bivariate)			
SENSOR	0.9	0.75 – 1.12	0.405
Model B (adjusted)‡			
SENSOR	1.0	0.79 – 1.20	0.827
Union	1.0	0.81 – 1.28	0.864
Worksite Employees			
1 – 10	1.6	0.65 – 3.75	0.316
11 – 49	1.8	0.96 – 3.33	0.069
50 – 249	1.8	1.12 – 2.77	0.014
250 – 999	1.5	0.99 – 2.28	0.052
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	3.3	1.33 – 8.18	0.010
11 – 49	2.1	1.15 – 3.78	0.016
50 – 249	1.7	1.16 – 2.63	0.007
250 – 999	1.4	0.98 – 1.98	0.066
1,000 or more (ref)	1.0		

‡ Adjusted for union status, number of worksite employees, and number of corporate employees

There was a difference in citations by corporation size, Wald $X^2_{(4df)} = 10.4$, p = 0.034 (not presented in the table), but no difference in the occurrence of a citation by numbers of workers at the worksite inspected, Wald $X^2_{(4df)} = 5.3$, p = 0.176.

Citation Event: All Worksites. A bivariate logistic regression analysis of all worksites inspections (Table 6) showed that a Citation Event is less likely at SENSOR worksites than Non-SENSOR worksites. However, this association

becomes null when covariates are added to the model (OR=1.0, 95% CI: 0.79 – 1.14, p=0.603).

Several covariates were associated with the occurrence of a Citation Event (see Table 6). Union worksites were less likely to receive a citation than non-union worksites (OR=0.8, CI = 0.77 – 0.93, p<0.001). Also there was an association between Year and Citation Events. Using Year Stratum 1 (1989-92) as the reference category, the odds for the occurrence of a citation were 50% higher during Year Stratum 2, and 70% higher during Year Stratum 3.

Table 6
Logistic Regression Predicting the Occurrence of At Least One Citation in Asthma SENSOR and All Non-SENSOR Worksite Inspections
(n=12,157)
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Odds Ratio	95% CI	*p*-Value
Model A (Bivariate)			
SENSOR	0.8	0.71 – 1.001	0.051
Model B (adjusted) †			
SENSOR	1.0	0.79 – 1.14	0.603
Union	0.8	0.77– 0.93	< 0.001
Time Strata			
1: 1989 - 1992 (ref.)	1.0		
2: 1993 - 1997	1.5	1.35 – 1.62	< 0.001
3: 1998 - 2002	1.7	1.56 – 1.87	< 0.001
Worksite Employees			
1 – 10	1.7	1.31 – 2.30	< 0.001
11 – 49	1.9	1.50 – 2.43	< 0.001
50 – 249	1.7	1.38 – 2.13	< 0.001
250 – 999	1.4	1.14 – 1.76	0.001
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.4	1.11 – 1.85	0.006
11 – 49	1.4	1.17 – 1.77	0.001
50 – 249	1.2	0.98 – 1.38	0.082
250 – 999	0.9	0.78 – 1.07	0.244
1,000 or more (ref)	1.0		

† Adjusted simultaneously for union status, number of worksite employees, number of corporate employees, Year Category, and 2-Digit SIC Code

There was also an association between the issuing of a citation and both the number of employees at a worksite and at a corporation. Compared with the group of largest worksites (1000+), each of the categories of smaller worksites was more likely to receive a citation (OR's 1.4 to 1.9). The overall Wald chi squared tests for the effect of smaller worksites and corporations were statistically significant ($p<0.001$ for both).

Citation Total: Matched Group Analysis. In order to take into account the information provided by the number of citations issued to a worksite, various "count regression" analytic models were considered.[20] The distribution of number of citations (Citation Total) was characterized by an inflated number of zero values and over dispersion (a variance substantially greater than the mean). These two characteristics suggested that either a negative binomial regression model or a zero-inflated negative binomial regression model might be more appropriate than a Poisson model. The negative binomial regression model (NBREG) takes into account the over dispersion. Zero-inflated negative binomial regression (ZINB) is similar to NBREG, but also posits that the inflated number of zero counts may suggest that different prediction models apply to the condition of always being zero, as compared to the observation of a non-zero count (one or more events).

Table 7 presents the results of this analysis for the Matched group comparison. The zero-inflated negative binomial (ZINB) model was a better fit than the NBREG model (Vuong test: $z=4.26$, $p<.001$).[22]

Table 7
Prediction of Non-Zero Counts of Citations
with Zero-Inflated Negative Binomial Regression: [1]
SENSOR and Matched[2] Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002
(n=1,197)

Predicting non-zero counts of violations			
	PR	**95% CI (RR)** [3]	***p*-value**
SENSOR	0.9	0.76 – 1.01	0.078
Union	1.0	0.85 – 1.12	0.734
Worksite Employees			
1 – 10	2.1	1.21 – 3.64	0.008
11 – 49	1.6	1.07 – 2.53	0.022
50 – 249	1.6	1.16 – 2.31	0.005
250 – 999	1.4	0.99 – 1.95	0.051
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	0.8	0.48 – 1.41	0.473
11 – 49	1.2	0.83 – 1.77	0.311
50 – 249	1.0	0.77 – 1.34	0.912
250 – 999	1.0	0.75 – 1.26	0.823
1,000 or more (ref)	1.0		

[1] Only the model for prediction of the non-zero counts (n=1,197) is presented
[2] Frequency matched by Year category and 2-digit SIC Code within each Year stratum
[3] RR is incident rate ratio

When predicting non-zero counts of citations, the number of worksite employees is associated with the number of citations. Worksites with fewer employees receive more citations. For example worksites belonging to the 1-10 employee category receive about twice as many citations as otherwise similar worksite from the reference category of 1000 or more worksite employees (RR=2.1, 95% CI: 1.2 – 3.6, p=0.008). The overall effect of Worksite Employees is significant (Wald $X^2_{(4df)}$ =9.5, p=0.049). SENSOR status was not associated with the number of citations issued (PR=0.9, CI= 0.76 – 1.01, p=0.078).

Citation Total: All Worksites. Table 8 presents the non-zero count portion of the zero-inflated negative binomial regression analysis predicting Citation Count

for all SENSOR and Non-SENSOR worksite inspections. The principal additional information provided by this analysis as compared with the Matched Group analysis is: (1) As compared with the reference Year category (1989 – 1992) worksite inspected in later years are likely to receive 20% to 30% more citations; and (2) Each of the smaller categories of number worksite employees receives roughly 20% to 30% more citations than the reference category (1000 plus employees). The overall Wald test for number of Worksite Employees was significant ($X^2_{(4df)}$ =12.6, p=0.014), as was the test for number of Corporate Employees ($X^2_{(4df)}$ =14.58, p=0.006).

Table 8
Prediction of Non-Zero Counts of Citations
with Zero-Inflated Negative Binomial Regression: [1]
SENSOR and All Non-SENSOR Worksite Inspections
(n=7,360)

Predicting non-zero counts of violations			
	PR	**95% CI (RR)[2]**	***p*-value**
SENSOR	0.8	0.72 – 0.93	0.002
Union	1.0	0.96 – 1.07	0.646
Time Strata			
Year Category 1:1989 - 1992 (ref.)	1.0		
Year Category 2:1993 - 1997	1.3	1.19 – 1.34	<0.001
Year Category 3:1998 - 2002	1.2	1.18 – 1.32	<0.001
Worksite Employees			
1 – 10	1.2	1.04 – 1.52	0.020
11 – 49	1.3	1.12 – 1.58	0.001
50 – 249	1.3	1.10 – 1.52	0.002
250 – 999	1.2	0.99 – 1.38	0.055
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.3	1.10 – 1.53	0.002
11 – 49	1.2	1.03 – 1.34	0.016
50 – 249	1.1	0.94 – 1.18	0.358
250 – 999	1.0	0.90 – 1.13	0.884
1,000 or more (ref)	1.0		

[1] Only the model for prediction of the non-zero counts (n=7,360) is presented
[2] RR is incident rate ratio

Results Aim 2: Penalties

Table 9 presents a summary of the frequency of receiving at least one monetary penalty (Penalty Event). The prevalence of receiving penalties was approximately 28% for SENSOR worksites, 31% for the Matched Non-SENSOR worksites, and about 34% for all Non-SENSOR worksites. The prevalences of worksites receiving penalties are well below the prevalences for receiving citations – roughly 30% compared with 55%.

Table 9
Frequency of Penalty Event:
The Occurrence of One or More Penalties at Health Inspections of Asthma SENSOR Worksites and Two Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	SENSOR Group Inspected Michigan Worksites Identified by SENSOR Index Cases		**Comparison Group 1** Inspected Michigan Worksites Matched to SENSOR Worksites[1]		**Comparison Group 2** All Non-SENSOR Inspected Michigan Worksites	
Zero Penalties Issued	390	(71.6%)	1,126	(68.9%)	8,045	(65.6%)
One or More Penalties Issued	155	(28.4%)	509	(31.1%)	4,223	(34.4%)
Total	545	(100%)	1,635	(100%)	12,268	(100.0%)

[1] Frequency matched by Year category and 2-digit SIC Code within each Year Category stratum

Penalty Event: Matched Group Analysis. A logistic regression analysis (Table 10) provides no basis for inferring there is a significant difference in the odds of a penalty being issued at SENSOR worksites as compared to matched Non-SENSOR worksites. This was true both for the bivariate model (OR=0.9, 95% CI: 0.75 – 1.12, p=0.405), as well as when simultaneously adjusting for the

influence of union status, and number of employees at the worksite and organization wide (OR=1.0, 95% CI: 0.72 -1.13, p=0.364). Only a smaller number of Corporate Employees was associated with higher odds for a Penalty Event, with the odds increasing significantly to 2 – 2.7 times for the smallest corporation size categories (1-10 and 11-49 employees). However, the Wald X^2 test for overall effects was not statistically significant for number of Worksite Employees (p=0.401) or Corporate Employees (p=0.159).

Table 10
Logistic Regression Predicting the Occurrence of At Least One Citation in SENSOR and Matched Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002
n=2,180

	Odds Ratio	95% CI	*p*-value
Model A (Bivariate)			
SENSOR	0.9	0.75 – 1.12	0.405
Model B (adjusted) ‡			
SENSOR	1.0	0.72 – 1.13	0.364
Union	1.1	0.87 – 1.39	0.416
Worksite Employees			
1 – 10	1.1	0.44 – 2.82	0.809
11 – 49	1.1	0.56 – 2.25	0.730
50 – 249	1.5	0.91 – 2.55	0.107
250 – 999	1.4	0.86 – 2.22	0.186
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	2.7	1.07 – 6.73	0.036
11 – 49	2.0	1.07 – 3.87	0.030
50 – 249	1.5	0.95 – 2.30	0.083
250 – 999	1.2	0.79 – 1.73	0.436
1,000 or more (ref)	1.0		

‡ Adjusted for union status, number of worksite employees, and number of corporate employees

Penalty Event: All Worksites. In the bivariate case, the comparison of SENSOR and all Non-SENSOR worksites (see Table 11) suggested that SENSOR worksites were less likely to experience a Penalty Event. However, this association became null when covariates were added to the logistic regression prediction model for Penalty Event.

Table 11
Logistic Regression† Predicting the Occurrence of At Least One Penalty in Asthma SENSOR and Non-SENSOR Worksite Inspections
(n=12,157)
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Odds Ratio	95% CI	*p*-value
Model A (Bivariate)			
SENSOR	0.8	0.63– 0.91	0.004
Model B (adjusted)‡			
SENSOR	0.9	0.75 – 1.12	0.385
Union	0.9	0.85– 1.02	0.142
Time Strata			
Year Category 1:1989 - 1992 (ref.)	1.0		
Year Category 2:1993 - 1997	1.8	1.64 – 1.99	< 0.001
Year Category 3:1998 - 2002	1.5	1.32 – 1.60	< 0.001
Worksite Employees			
1 – 10	1.1	0.84 – 1.54	0.393
11 – 49	1.2	0.95 – 1.62	0.106
50 – 249	1.3	1.06 – 1.71	0.016
250 – 999	1.1	0.89 – 1.43	0.323
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.5	1.15 – 1.95	0.003
11 – 49	1.4	1.16 – 1.78	0.001
50 – 249	1.2	0.99 – 1.42	0.058
250 – 999	0.9	0.78 – 1.10	0.378
1,000 or more (ref)	1.0		

‡ Adjusted for union status, number of worksite employees, number of corporate employees, Year Category, and 2-Digit SIC Code

Overall, the covariate associations with Penalty Event among all inspected worksites had a similar pattern of associations as the Matched Group analysis. In the adjusted model (Model B, Table 11) only being a smaller corporation (Wald X^2=25.6, p<0.001) and having been inspected during Year Strata 2 or 3 have a statistically significant higher odds of receiving a penalty.

Penalty Total. Penalty Total was defined as the count of all penalties issued to a worksite. The frequency of zero penalties was 8,435 (66%) as compared with 43% for citations. Of the 8,435 worksite not receiving a penalty, 2,982 did receive at least one citation. The high proportion of zero penalty worksites dictated that negative binomial regression models be considered. As was true for the analysis of Citation Total, the zero-inflated negative binomial regression model (ZIBN) was a better fitting model than negative binomial regression (NBREG) for both the Matched group comparison (Vuong test: z=1.98, p=0.0241) and for the analysis of all worksites (Vuong test: z=11.96, p<.0001).

Penalty Total: Matched Group Analysis. Table 12 presents the prediction of non-zero counts resulting from the ZIBN regression analysis of SENSOR and Matched Non-SENSOR worksites. In this analysis conditioned on being a non-zero counts, SENSOR becomes a statistically significant predictor of the number of penalties, with SENSOR worksites tending to have slightly fewer penalties than non-SENSOR worksites (RR=0.8, 95% CI: 0.57 – 0.99, p=0.048). Also associated with number of penalties is Worksite Employees. As the numbers of worksite employees decreases, the association with number of penalties

Table 12
Prediction of Non-Zero Counts of Citations
Using Zero-Inflated Negative Binomial Regression: [1]
SENSOR and Matched Non-SENSOR Groups

Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002
(n=664)

Predicting non-zero counts of penalties			
	RR[3]	**95% C I**	***p*-value**
SENSOR	0.8	0.57 – 0.99	0.048
Union	1.0	0.76 – 1.25	0.867
Worksite Employees			
1 – 10	4.4	1.54 – 12.3	0.006
11 – 49	3.2	1.36 – 7.68	0.008
50 – 249	2.1	1.03 – 4.46	0.041
250 – 999	2.0	1.03 – 3.76	0.039
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	0.5	0.19 – 1.50	0.233
11 – 49	0.9	0.39 – 1.94	0.737
50 – 249	1.0	0.53 – 1.71	0.884
250 – 999	1.0	0.62 – 1.81	0.818
1,000 or more (ref)	1.0		

[1] Only the model for prediction of the non-zero counts of penalties (n=664) is presented
[2] Frequency matched by Year category and 2-digit SIC Code within each Year stratum
[3] RR is incident rate ratio

increases (see Table 12). For example, the smallest worksite size category (1 to 10 employees) has 4 time the number of penalties as the reference category (1000 or more employees) holding when adjusting simultaneously for the other covariates in the model (RR=4.4, 95% CI: 1.5 – 12.3, p=0.006). The Wald test for overall effect for Worksite Employees had a *p*-value of 0.051.

Penalty Total: All Worksites. The analysis of the association of SENSOR status and number of penalties was repeated for the entire study sample of worksite inspections. The results for predicting the non-zero counts of penalties are reported in Table 13. As with the matched analysis, SENSOR status was

associated with the number of penalties (see row 1 of Table 13), with ratio of penalties at SENSOR worksite being about 80% the numbers of penalties assessed at Non-SENSOR worksites (PR=0.8, 95% CI: 0.62 – 1.00, p=0.054).

Table 13
Prediction of Non-Zero Counts of Penalties
Using Zero-Inflated Negative Binomial Regression: [1]
SENSOR and All Non-SENSOR Worksite Inspections
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002
(n=4,378)

Predicting non-zero counts of penalties			
	RR [2]	**95% C I**	***p*-value**
SENSOR	0.8	0.62 – 1.00	0.054
Union	0.9	0.80 – 0.99	0.028
Time Strata			
Year Category 1:1989 - 1992 (ref.)	1.0		
Year Category 2:1993 - 1997	1.1	1.03 – 1.23	<0.008
Year Category 3:1998 - 2002	0.9	0.84 – 1.00	<0.060
Worksite Employees			
1 – 10	1.3	0.89 – 1.77	0.201
11 – 49	1.5	1.09 – 2.06	0.012
50 – 249	1.3	0.93 – 1.73	0.127
250 – 999	1.3	0.95 – 1.75	0.101
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.0	0.73 – 1.32	0.914
11 – 49	0.9	0.69 – 1.11	0.278
50 – 249	0.9	0.74 – 1.15	0.458
250 – 999	1.0	0.82 – 1.21	0.911
1,000 or more (ref)	1.0		

[1] Only the model for prediction of the non-zero counts of penalties (n=664) is presented
[2] RR is incident rate ratio

There were no overall effects for Worksite or Corporation Employees, and there was a marginal finding indicating that individual categories of Worksite Employees received slightly more penalties as compared with the reference category of larger worksites (1000 or more employees). In contrast to results reported for Citation Total, the Year stratum in which the inspection took place was not consistently associated with number of penalties.

Results Aim 3: Quality of Violation

This section presents results for the qualitative assessment of violations at the worksite inspections. The categories used in the qualitative assessment include "Repeat", "Willful", "Serious", and "Other." In the database, each citation had no more than one qualitative rating. Each of these qualitative outcomes is scored "1" to indicate that at least one citation was issued for a violation of that type, and is scored "0" if no citations were issued for violations of that type.

Serious Violations. Table 14 presents the frequencies of 'Serious' violations recorded for SENSOR and Non-SENSOR inspection sites. The prevalence of at least one citation for a 'Serious' violation among SENSOR worksite inspections was 22 percent. The number of SENSOR worksites having at least one Serious citation was 121, which is 42 percent of all SENSOR worksites receiving at least one citation of any type.

The occurrence of at least one 'Serious' violation among Matched Non-SENSOR inspections had a prevalence of 25 percent. The number of matched Non-SENSOR sites with one or more Serious violations was 409. This represents 45 percent of all matched Non-SENSOR worksites that received a citation of any type.

Among all NON-SENSOR worksites the prevalence of receiving at least one Serious citation is 28 percent. The number of Non-SENSOR worksites that

received a Serious citation was 3,452, which is 49 percent of all Non-SENSOR worksites that received a citation.

For both the matched and all worksite analyses, the bivariate analysis of the association between SENSOR status and occurrence of Serious violations suggested a crude OR of less than one. But in each case, when covariates were added to the analyses the association became null.

Table 14
Frequency of Serious Violations per Worksite Inspection
at Health Inspections of Asthma SENSOR Worksites and Two Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002

Number of Serious Violations per Worksite	**SENSOR Group** Inspected Michigan Worksites Identified by SENSOR Index Cases n=545		**Comparison Group 1** Inspected Michigan Worksites Matched to SENSOR Worksites[1] n=1635		**Comparison Group 2** All Non-SENSOR Inspected Michigan Worksites N=12,268	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 per Worksite	424	77.8	1,226	75.0	8,816	71.9
1 per Worksite	38	7.0	126	7.7	1,013	8.3
2 per Worksite	23	4.2	95	5.8	722	5.9
3 per Worksite	21	3.8	53	3.2	516	4.2
4 per Worksite	17	3.1	41	2.5	339	2.8
5 per Worksite	5	0.9	26	1.6	184	1.5
>5 per Worksite	17	3.1	68	4.2	676	5.5
Total Non-Zero Worksites	121	22.2	409	25.0	3,452	28.1

[1] Frequency matched by Year category and 2-digit SIC Code within each Year Category stratum

Table 15 presents the results of the comparison of SENSOR with all Non-SENSOR worksites. SENSOR status was not associated with citations for Repeat violations, but Union worksites were slightly less likely to be cited for a repeat violation than were non-union worksites (OR=0.9, 95% CI: 0.82 – 1.01, p=0.055).

Table 15
Logistic Regression† Predicting the Occurrence of At Least One Citation for a 'Serious' Violation in Asthma SENSOR and Non-SENSOR Worksite Inspections (n=12,157)
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Odds Ratio	95% CI	p-Value
Model A (Bivariate)			
SENSOR	0.7	0.59– 0.90	0.003
Model B (adjusted)‡			
SENSOR	0.9	0.69 – 1.08	0.203
Union	0.9	0.82– 1.01	0.055
Time Strata			
Year Category 1:1989 - 1992 (ref.)	1.0		
Year Category 2:1993 - 1997	2.0	1.79 – 2.19	< 0.001
Year Category 3:1998 - 2002	2.2	1.95 – 2.38	< 0.001
Worksite Employees			
1 – 10	1.1	0.82 – 1.55	0.468
11 – 49	1.3	0.98 – 1.73	0.065
50 – 249	1.4	1.11 – 1.85	0.006
250 – 999	1.2	0.90 – 1.51	0.237
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.5	1.09 – 1.91	0.011
11 – 49	1.4	1.05 – 1.66	0.015
50 – 249	1.2	0.92 – 1.34	0.283
250 – 999	0.9	0.76 – 1.10	0.332
1,000 or more (ref)	1.0		

‡ Adjusted for union status, number of worksite employees, number of corporate employees, Year Category, and 2-Digit SIC Code

With respect to the other covariates, the odds of receiving a 'Serious' citation were about two fold greater for worksites inspected after the reference time stratum, 1989 – 1992 (see Table 15). There was also a weak indication of a

tendency for Serious violations to be cited at smaller small to medium worksites (11 – 250). There was an overall effect for Worksite Employees (Wald $X^2_{(4df)}$ = 12.6, p=0.013) and for Corporate Employees (Wald $X^2_{(4df)}$ =17.1, p=0.002) as compared with the reference categories (1000 or more employees).

Repeat Violations. Table 16 presents the frequencies of 'Repeat' violations recorded for SENSOR and Non-SENSOR inspection sites. The prevalence of the occurrence of at least one citation for a 'Repeat' violation among SENSOR worksite inspections was 2.8 per 100 inspections. The number of SENSOR worksites having at least one Repeat citation was 15, which is 5.5 percent of all SENSOR worksites receiving at least one citation (of any type).

The prevalence of the occurrence of at least one 'Repeat' violation among Matched Non-SENSOR inspections, was 1.9 per 100 inspections. The number of matched Non-SENSOR sites with one or more Repeat violations was 31. This represents 3.4 percent of all matched Non-SENSOR worksites that received any citations.

Among all NON-SENSOR worksites the prevalence of receiving at least one Repeat citation is 2.0 per 100. The number of Non-SENSOR worksites that received a Repeat citation was 240, which is 3.4 percent of the total Non-SENSOR worksites that received a citation.

There was no bivariate (crude) association between SENSOR status and the occurrence of a repeat violation. For the Matched Group comparison using

logistic regression the estimated odds ratio was 1.5 (95% CI: 0.78 – 2.76, p=0.228), and for the analysis of all worksites the estimated odds ratio was 1.4 (95% CI: 0.83 – 2.40, p=0.195). Adding covariates did not effect the SENSOR association with Repeat violations for either the matched group or all worksite comparisons. In the comparison of all worksites, inspections citing Repeat violations were less likely to have occurred during Year Stratum 3 as compared with Year Stratum 1, (OR=0.48, 95% CI: 0.34 – 0.67, p<0.001).

Table 16
Frequency of Repeat Violations per Worksite Inspection
at Health Inspections of Asthma SENSOR Worksites and Two Comparison Groups
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002

Number of Repeat Violations per Worksite	**SENSOR Group** Inspected Michigan Worksites Identified by SENSOR Index Cases n=545		**Comparison Group 1** Inspected Michigan Worksites Matched to SENSOR Worksites[1] n=1635		**Comparison Group 2** All Non-SENSOR Inspected Michigan Worksites N=12,268	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 per Worksite	530	97.2	1,604	98.1	12,028	98.0
1 per Worksite	13	2.4	19	1.2	152	1.2
2 per Worksite	1	0.2	6	0.4	49	0.4
3 per Worksite	1	0.2	3	0.2	22	0.2
4 per Worksite			1	0.1	5	0.0
5 per Worksite			2	0.1	5	0.0
>5 per Worksite					7	0.1
Total Non-Zero Worksites	15	2.8	31	1.9	240	2.0

[1] Frequency matched by Year category and 2-digit SIC Code within each Year Category stratum

Other Violations. Table 17 presents the frequencies of 'Other' violations recorded for SENSOR and Non-SENSOR inspection sites. The prevalence of the occurrence of at least one citation for an 'Other' violation among SENSOR worksite inspections was 44.4 per 100 inspections. The number of SENSOR worksites having at least one Other citation was 242 which is 83 percent of all SENSOR worksites receiving at least one citation (of any type).

The prevalence of the occurrence of at least one 'Other' violation among Matched Non-SENSOR inspections, was 46.5 per 100 inspections. The number of matched Non-SENSOR sites with one or more Other violations was 761. This represents 84 percent of all matched Non-SENSOR worksites that received any citations.

Among all NON-SENSOR worksites the prevalence of receiving at least one Other citation is 46.5 per 100. The number of Non-SENSOR worksites that received a Other citation was 5,734, which is 81 percent of all Non-SENSOR worksites that received a citation.

The bivariate association between SENSOR status and the occurrence of at least one violation rated 'Other' was null for both the Matched and all worksite analyses, and remained null after adding covariates to the prediction models. In the regression analyses the estimated odds ratios were roughly 0.9 to 1.0, with 95% confidence intervals of approximately 0.8 to 1.2, and *p*-values in the 0.25 and higher range (see Table 18 for the regression analyses involving all worksite inspections).

Table 17
Frequency of 'Other' Violations per Worksite Inspection
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002

Number of 'Other' Violations per Worksite	**SENSOR Group** Inspected Michigan Worksites Identified by SENSOR Index Cases n=545		**Comparison Group 1** Inspected Michigan Worksites Matched to SENSOR Worksites[1] n=1635		**Comparison Group 2** All Non-SENSOR Inspected Michigan Worksites N=12,268	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 per Worksite	303	55.6	874	53.5	6,534	53.3
1 per Worksite	74	13.6	247	15.1	1,834	14.9
2 per Worksite	74	13.6	163	10.0	1,219	9.9
3 per Worksite	41	7.5	153	9.4	982	8.0
4 per Worksite	28	5.1	63	3.8	625	5.1
5 per Worksite	11	2.0	55	3.3	442	3.6
>5 per Worksite	14	2.6	80	4.9	632	5.2
Total Non-Zero Worksites	242	44.4	761	46.5	5,734	46.7

While SENSOR status was not associated with 'Other' violations, several covariates were (Table 18). For example, a worksite receiving a citation for the 'Other' violation category was less likely to be represented by a union, more likely to have been inspected after 1992, and more likely to have fewer than 1000 employees. All these associations were small (OR's 1.2 to 2.6) but were statistically significant ($p<0.001$). The overall effect for Worksite Employees was significant ($X^2(4df) = 56.0$, $p<0.001$) as was the effect for Corporate Employees ($X^2(4df) = 21.3$, $p<0.001$).

Table 18
Logistic Regression Predicting the Occurrence of At Least One Citation for an 'Other' Violation in Asthma SENSOR and Non-SENSOR Worksite Inspections (n=12,157)
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Odds Ratio	95% CI	*p*-value
Model A (Bivariate)			
SENSOR	0.9	0.76– 1.08	0.285
Model B (adjusted)‡			
SENSOR	1.0	0.82 – 1.19	0.887
Union	0.8	0.76 – 0.91	< 0.001
Time Strata			
Year Category 1:1989 - 1992 (ref.)	1.0		
Year Category 2:1993 - 1997	1.3	1.22 – 1.46	< 0.001
Year Category 3:1998 - 2002	1.2	1.11 – 1.33	< 0.001
Worksite Employees			
1 – 10	2.5	1.85 – 3.29	< 0.001
11 – 49	2.6	2.00 – 3.30	< 0.001
50 – 249	2.1	1.70 – 2.68	< 0.001
250 – 999	1.8	1.40 – 2.20	< 0.001
1,000 or more (ref)	1.0		
Corporate Employees			
1 – 10	1.2	0.93 – 1.54	0.160
11 – 49	1.3	1.02 – 1.54	0.025
50 – 249	1.1	0.93 – 1.31	0.235
250 – 999	0.9	0.73 – 1.01	0.057
1,000 or more (ref)	1.0		

‡ Adjusted for union status, number of worksite employees, number of corporate employees, Year Category, and 2-Digit SIC Code

Willful Violations. Table 19 presents the frequencies of 'Willful' violations recorded for SENSOR and Non-SENSOR inspection sites. The prevalence of the occurrence of at least one citation for a 'Willful' violation among SENSOR worksite inspections was 1.1 per 100 inspections. The number of SENSOR worksites having at least one Willful citation was 6, which is 2.1 percent of all SENSOR worksites receiving at least one citation (of any type).

The prevalence of the occurrence of at least one 'Willful' violation among Matched Non-SENSOR inspections was 0.6 per 100 inspections. The number of matched Non-SENSOR sites with one or more Willful violations was 10. This represents 1.1 percent of all matched Non-SENSOR worksites that received any citations.

Among all NON-SENSOR worksites the prevalence of receiving at least one Willful citation is 1.1 per 100. The number of Non-SENSOR worksites that received a citation for a Willful violation was 129, which is 1.8 percent of all Non-SENSOR worksites that received a citation.

Matched group analysis was not performed because of the small number of citations for willful violations — 6 to SENSOR worksites and 10 to matched Non-SENSOR worksites. The bivariate logistic regression analysis of all worksite inspections found no evidence to support an association between SENSOR status and the occurrence of a willful violation. When all covariates were added to the model only Year strata were associated with the outcome. As compared with Year stratum 1, the citing of a Willful violation was much less likely to occur

during Year stratum 2 (OR=0.20, 95% CI: 0.11 – 0.34, $p<0.001$) or Year stratum 3 (OR = 0.34, 95% CI: 0.22 – 0.52, $p<0.001$). All other covariate associations with the occurrence of citations for Willful violations had p-values of 0.38 or greater.

Table 19
Frequency of Willful Violations per Worksite Inspection
Data Source: All MIOSHA Health Inspections Conducted During 1989 – 2002

Number of Willful Violations per Worksite	**SENSOR Group** Inspected Michigan Worksites Identified by SENSOR Index Cases n=545		**Comparison Group 1** Inspected Michigan Worksites Matched to SENSOR Worksites[1] n=1635		**Comparison Group 2** All Non-SENSOR Inspected Michigan Worksites N=12,268	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 per Worksite	539	98.9	1,625	99.4	12,139	98.9
1 per Worksite	4	0.7	3	0.2	55	0.4
2 per Worksite	1	0.2	3	0.2	24	0.2
3 per Worksite	1	0.2	1	0.1	12	0.1
4 per Worksite			1	0.1	8	0.1
5 per Worksite			2	0.1	7	0.1
>5 per Worksite					23	0.2
Total Non-Zero Worksites	6	1.1	10	0.6	129	1.1

SIC Code. A post hoc analysis of SIC Code was undertaken to determine if subgroups of industry types might be more at risk for receiving citations or penalties. The 78 two-digit SIC Codes represented in the sample were grouped into seven subgroups: (1) Agriculture and Forestry; (2) Construction and Mining; (3) Transportation & Utilities; (4) Wholesale, Retail and Financial Services; (5) Service; and (6) Public Administration; and (7) Manufacturing. Table 20 presents the number of worksites within each category (range 138 to 6,435), as well as the frequency and prevalence for Citation Event and Penalty Event within SIC sub-group.

Table 20
Frequency of Citation and Penalty Event within Seven SIC Code Subgroups

SIC Category	Number of Worksites	Citation Event[2]		Penalty Event	
		Freq.	Prevalence	Freq	Prevalence
Agriculture & Forestry	138	71	52%	38	28%
Construction & Mining	1,734	1,076	62%	790	46%
Transportation & Utilities	664	378	57%	233	35%
Wholesale, Retail & Financial	933	529	57%	287	31%
Services	2,203	1,296	59%	764	35%
Public Administration	698	372	53%	242	35%
Manufacturing	6,435	3,635	56%	2,023	31%
Total[1]	12,805	7,357	57%	4,377	34%

[1] There were 8 worksites with missing values for SIC Code.
[2] Frequency of Worksites with at least one citation
[3] The percentage of worksites with at least one citation within SIC Category

Table 21 presents the odds ratios for receiving at least one citation with respect of each of six categories of 2-digit SIC Code, using category 7, Manufacturing, as the reference category. The prediction models used logistic regression, predicting first Citation Event, and then Penalty Event. Each model adjusted

Table 21
Summary of Association between SIC Groups
and Two Outcome Measures:
Adjusted[1] Odds Ratios(OR) For All SENSOR
and Non-SENSOR Worksites

Data Source: All MIOSHA Health Inspections
Conducted During 1989 - 2002

(n=12,157)

		Citation Event	Penalty Event
Agriculture & Forestry	*OR* *95% CI* *p-value*	0.7 0.47 – 0.95 0.026	0.8 0.54 – 1.17 0.237
Construction & Mining	*OR* *95% CI* *p-value*	0.9 0.82 – 1.06 0.269	1.5 1.37 – 1.75 <0.001
Transportation & Utilities	*OR* *95% CI* *p-value*	1.0 0.8 – 1.19 0.990	1.2 0.99 – 1.40 0.071
Wholesale, Retail & Financial	*OR* *95% CI* *p-value*	0.8 0.72 – 0.97 0.017	0.9 0.77 – 1.06 0.203
Service	*OR* *95% CI* *p-value*	1.0 0.91 – 1.13 0.782	1.1 1.00 – 1.24 0.053
Public Administration	*OR* *95% CI* *p-value*	0.9 0.75 – 1.06 0.195	1.2 1.00 – 1.42 0.050
Manufacturing (Ref.)	Ref.	1.0	1.0

simultaneously for Sensor, Union, Year, Worksite Employees, Corporate Employees, and SIC Code category. Two categories were less likely to experience a Citation Event as compared with Manufacturing: Agriculture & Forestry (OR=0.7, 95% CI: 0.47 – 0.95, p=0.026) and Wholesale, Retail & Financial (OR=0.8, 95% CI: 0.72 – 0.97, p=0.0176).

For Penalty Event the pattern was different. First, Agriculture & Forestry and Wholesale, Retail & Financial do not differ from Manufacturing with regard to the odds of receiving at least one penalty (Penalty Event). Second, each of the other categories had a greater odds of being assessed a penalty as compared with manufacturing (range of OR's 1.1 to 1.5).

Results Summary. Table 22 presents a summary of the bivariate (crude) odds ratios for five outcomes: Citation Event, Penalty Event, Repeat violations, Serious violations, and Other violations. Each of these is a measure of the occurrence of at least one event of its type, and is coded 1/0. For each outcome the matched (M) group analysis and the analysis of all (A) worksites are presented. The statistical significance level is noted. For example, row two of the first column of Table 22 has an entry of 0.6, indicating that union worksites are less likely to be cited for violations that are non-union worksites. The footnote indicates that the p-value for this odds ratio is less than 0.001. The confidence intervals and p-values for the entries in Table 20 are reported in previous tables or text.

Table 22

Summary of Crude Odds Ratios(OR) between Covariates and Five Outcome Measures

Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Citation Event OR		Penalty Event OR		Repeat OR		Serious OR		Other OR	
	M[1]	A[1]	M[1]	A[1]	M[1]	A[1]	M[1]	A[1]	M[1]	A[1]
SENSOR (ref= Non-SENSOR)	0.9	0.8	0.9	0.8[†]	1.5	1.4	0.9	0.7[†]	0.9	0.9
Union (ref = Non-union)	0.6[‡]	0.7[‡]	0.8*	0.9[‡]	1.5	1.7[‡]	0.8*	0.9[†]	0.6[‡]	0.6[‡]
Worksite Employees										
1 – 10	4.7[‡]	2.9[‡]	3.0[‡]	2.1[‡]	1.0	0.4[†]	3.4[‡]	1.9[‡]	4.7[‡]	3.0[‡]
11 – 49	3.6[‡]	3.1[‡]	2.3[‡]	2.0[‡]	1.6	0.9	2.7[‡]	1.9[‡]	3.6[‡]	3.5[‡]
50 – 249	3.0[‡]	2.1[‡]	2.2[‡]	1.7[‡]	1.2	0.7	2.6[‡]	1.7[‡]	3.0[‡]	2.5[‡]
250 – 999	2.0[‡]	1.4[‡]	1.5*	1.1	1.6	1.7	1.6*	1.1	2.0[‡]	1.7[‡]
1,000 or more (ref)	1.0		1.0		1.0		1.0		1.0	
Corporate Employees										
1 – 10	4.5[‡]	2.3[‡]	2.8[‡]	1.8[‡]	0.9	0.4[‡]	3.0[‡]	1.6[‡]	4.7[‡]	2.2[‡]
11 – 49	3.1[‡]	2.5[‡]	2.2[‡]	1.8[‡]	1.3	0.9	2.3[‡]	1.7[‡]	3.1[‡]	2.5[‡]
50 – 249	2.5[‡]	1.8[‡]	2.0[‡]	1.5[‡]	0.9	0.8	2.0[‡]	1.4[‡]	2.5[‡]	1.8[‡]
250 – 999	1.8[‡]	1.1	1.4*	1.0	0.8	0.6*	1.5[†]	1.0	1.8[‡]	1.2[†]
1,000 or more (ref)	1.0		1.0		1.0		1.0		1.0	

[1] Comparison set "M": SENSOR with Matched Non-SENSOR Worksites (n=2,180)
Comparison set "A": SENSOR with ALL Non-SENSOR Worksites (n=12,813)

* p<0.05

[†] p<0.01

[‡] P<0.001

Table 23 presents a summary of the adjusted associations between seven outcome measures and each of the covariates SENSOR, Union, Worksite Employees, and Corporate Employees. The matched group analyses of the qualitative outcome measures yielded few significant associations and are not included in the summary. The odds ratios and prevalence ratios presented in Table 21 were previously presented in Tables 5, 6, 7, 8, 10, 11, 12, 13, 15, and 18, or in the text, where the confidence intervals and p-values can be observed. Each odds ratio and prevalence ratio was produced by an analysis that simultaneously adjusted for all the reported covariates plus SIC Code and Year.

In Table 24, a summary is presented of the adjusted association between Year of inspection and each outcome measure. Each odds ratio and prevalence ratio was represented previously in tables (6, 8, 11, 13, and 18) or text, which can be referred to for confidence intervals and p-values. Each of the analyses for which results are re-presented employed simultaneous adjustment for SENSOR, Union, Worksite Employees, Corporate Employees, Year, and SIC Code.

Table 23

Summary of Adjusted[1] Associations between Covariates and Seven Outcome Measures:
Odds Ratios(OR) and Rate Ratios (RR) For Selected Study Comparisons

Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002

	Citation Event OR		Penalty Event OR		Citation Total[3] PR		Penalty Total[3] RR		Repeat OR	Serious OR	Other OR
	M^2	A^2	M^2	A^2	M^2	A^2	M^2	A^2	A^2	A^2	A^2
SENSOR (ref= Non-SENSOR)	1.0	1.0	0.9	0.9	0.9	0.8†	0.8*	0.8	1.4	0.9	1.0
Union (ref = Non-union)	1.0	0.8‡	1.1	0.9	1.0	1.0	1.0	0.9*	1.2	0.9	0.8‡
Worksite Employees											
1 – 10	1.6	1.7‡	1.1	1.1	2.1†	1.2*	4.4†	1.3	0.5	1.1	2.5‡
11 – 49	1.8	1.9‡	1.1	1.2	1.6*	1.3†	3.2†	1.5*	1.0	1.3	2.6‡
50 – 249	1.8*	1.7‡	1.2	1.3*	1.6†	1.3*	2.1*	1.3	0.8	1.4†	2.1‡
250 – 999	1.5	1.4†	1.4	1.1	1.4	1.2	2.0*	1.3	1.0	1.2	1.8‡
1,000 or more (ref)	1.0		1.0		1.0		1.0		1.0	1.0	1.0
Corporate Employees											
1 – 10	3.3*	1.4†	2.7*	1.5†	0.8	1.3†	0.5	1.0	0.7	1.5†	1.2
11 – 49	2.1*	1.4†	2.0*	1.4†	1.2	1.2*	0.9	0.9	0.9	1.4*	1.3*
50 – 249	1.7†	1.1	1.5	1.2	1.0	1.1	1.0	0.9	0.9	1.2	1.1
250 – 999	1.4	0.9	1.5	0.9	1.0	1.0	.0	1.0	0.6	0.9	0.9
1,000 or more (ref)	1.0		1.0		1.0		1.0		1.0	1.0	1.0

[1] Simultaneous Adjustment for all covariates including Year and SIC Code

[2] Comparison set "M": SENSOR with Matched Non-SENSOR Worksites (n=2,180)
Comparison set "A": SENSOR with ALL Non-SENSOR Worksites (n=12,813)

[3] RR's for Citation Total and Penalty Total reported only for the Non-Zero Counts

* p<0.05

† p<0.01

‡ P<0.001

Table 24
Summary of Association between Year Stratum and Eight Outcome Measures:
Adjusted[1] Odds Ratios (OR) and Rate Ratios (RR)
For All SENSOR and Non-SENSOR Worksites
Data Source: All MIOSHA Health Inspections Conducted During 1989 - 2002
(n=12,157)

	Citation Event OR	Citation Total RR	Penalty Event OR	Penalty Total RR	Serious OR	Repeat OR	Other OR	Willful OR
Year Category 1: 1989 - 1992 (Ref)	1.0		1.0		1.0	1.0	1.0	1.0
Year Category 2: 1993 - 1997	1.5‡		1.8‡		2.0‡	1.0	1.3‡	0.2‡
Year Category 3: 1998 - 2002	1.7‡		1.5‡		2.2‡	0.5‡	1.2‡	0.3‡
Year Category 1: 1989 - 1992 (Ref)		1.0		1.0				
Year Category 2:1993 – 1997 (Predicting non-zero counts)		1.26‡		1.1†				
Year Category 3:1998 – 2002 (Predicting non-zero counts)		1.25‡		0.9				

[1] Simultaneous Adjustment for all covariates including Year and SIC Code
‡ p<0.001
† P<0.01

DISCUSSION

The main findings of this research can be summarized succinctly. The study found that SENSOR and Non-SENSOR worksites were similar with respect to the occurrence of citations and the assessment of penalties. Worksites receiving citations were less likely to be represented by a union and tended to have fewer employees. There was also an association reported between citations and penalties and the year of the inspection. Inspections taking place during the period 1993 to 2002 were more likely to have citations and penalties than inspections taking place during 1989 to 1992. Finally, manufacturing worksites were less likely to be assessed penalties than were non-manufacturing worksites. This section provides a discussion of these findings, followed by a discussion of the strengths and limitations of the study. In conclusion, a brief overview of possible future research is presented.

SENSOR Status. The occurrence of violations and the assessment of penalties were similar at worksites identified by a WRA SENSOR index case and a typical worksite inspected by MIOSHA under its normal policies and procedures. The fact that SENSOR and Non-SENSOR worksites were found to be similar with respect to the occurrence of citations is noteworthy, because there are very few specific industrial hygiene standards for agents that cause work-related asthma. The similar results indicate that most citations issued by MIOSHA are based on general workplace and not substance specific standards.

While there were several bivariate analyses that suggested that SENSOR status and an outcome were associated, each of these associations typically became null when covariates were added to the prediction model. The only exception to this pattern was when predicting counts of citations and penalties greater than zero using zero inflated negative binomial regression (ZINB).

The ZINB model consists of two prediction equations. First, the so-called inflate equation attempts to predict the condition of having a zero count of the event. The second equation attempts to predict the event counts greater than zero. There were four analyses of this type: (1) predicting Citation Total for the matched groups; (2) predicting Citation Total for all worksites; (3) predicting Penalty Total for the matched groups; and (4) predicting Penalty Total for all worksites. For each analysis, the equation predicting the zero count yielded a null association between SENSOR status and zero events. However, when predicting non-zero counts, SENSOR worksites tended to have slightly lower counts of both citations and penalties (RR's ranging from 0.8 to 0.9). The p-values for the four RR's ranged from 0.002 to 0.078, with two RR's below the traditional significance level of 0.05.

A possible explanation may be related to the lag in time between the identification of the SENSOR index case and the actual inspection. This lag would be greater than the lag between an employee concern or complaint and an inspection, the typical reason a Non-SENSOR inspection was initiated. This would allow more time that some employees might use to implement changes. It

also allows time for an employer to learn that an employee was a WRA case, which might motivate the employer to implement change. Either of these scenarios might account for there being fewer violations observed at SENSOR worksite inspections than at Non-SENSOR worksite inspections among the group of worksites having one or more citations or penalties.

Union Status. In summary, union worksites were slightly less likely to receive a citation than non-union worksites. However, there was no association between union status and the total number of citations or the assessment of penalties.

At the level of crude odds ratios there is evidence to support the inference that unionized worksites are less likely to be cited for violations and be penalized than are non-union worksites. This suggests that unionized worksites may better comply with workplace standards. The crude odds ratios for Repeat violations, however, contradict this pattern. In predicting Repeat violations, the odds ratio for union status indicates that union worksites were more likely to be cited than are non-union worksites. There were only 255 worksites that were cited for Repeat violations cited among the study population of 12,813, and it is possible that this association may be just an anomaly. An alternative explanation might be that unions or their members are more likely to file complaints about repeat violations. Perhaps individual workers feel less vulnerable to reprisals when represented by a union than do their non-union counterparts.

In any case, when covariates were added to the models, only the outcomes Citation Event and Other violations continued to be associated with union status

(OR's=0.8, $p<0.001$). Citation Event differentiates worksites receiving one or more citations from worksites receiving zero citations. There were 7,360 worksites that received one or more citations. 'Other' violation is a qualitative rating of violations characterized as representing less than serious hazards. Most, but not all citations received some type of qualitative rating. There were 5,976 worksites receiving citations for violations rated 'Other', almost 1,400 fewer than the total worksites receiving citations. Yet the odds ratios for union status are the same for both outcomes.

It seems plausible that the difference in the frequencies of these two measures may be due to the failure of the industrial hygiene inspector to complete the qualitative rating in many instances of minor violations, and not because of a meaningful qualitative difference in the observed violations. Two factors provide support for this inference: (1) an examination of the cross-tabulation of 'Other' violations and Citation Event reveals that only 106 worksites of the 5,559 scored 0 for "Other" were scored 1 for Citation Event; and (2) the adjusted odds ratios for Union status in predicting Citation Event was 0.72 when excluding all worksites receiving citations for Willful, Serious, or Repeat violations, very similar to the 0.8 odds ratios reported above.

Number of Employees. Worksites with fewer employees are more likely to receive citations and receive penalties for the violations cited than are worksites with 1000 or more employees. This pattern is also found for corporation size, although to a somewhat lesser extent. Examining the crude odds ratios for

Worksite and Corporate Employees, nearly all size categories have highly significant odds ratios and there is a pattern of the odds ratios increasing as number of employees decreases.

The adjusted analyses retain these patterns to some extent. However, the strength of association is generally lower, evidenced by lower odds ratios and *p*-values. Small companies are more likely to receive both citations and penalties, and among those receiving citations and penalties, higher counts are more likely to be received by smaller than by larger companies.

This finding is consistent with reports suggesting that smaller companies have fewer workplace controls and are more hazardous.[23,24,25,26] One possible explanation for this is that small companies have fewer resources to invest in creating a workplace free of hazards. This could be reflected in less engineering control, less supervision, or less training. For example, small companies would have less capital for investment in the purchase or maintenance of equipment to control the workplace environment, such as adequate ventilation systems.

A second, and probably less plausible explanation, could be that small companies are more frequently cited for violations and assessed penalties because they are easier targets, with fewer resources to resist or appeal enforcement, and because large companies have more political influence. This need not be a conscious bias in the system, but might simply be a reaction to real contingencies faced by those responsible for enforcement of industrial health standards.

Year of Inspection. This findings of this study strongly suggest there was an association between the time period of the inspection and the occurrence of citations and penalties. This was true both with respect to quantitative and to qualitative measures of violations. This is only observable in the analysis of all worksites because Year of inspection is a matching variable for the matched group comparisons.

The outcomes Citation Event and Penalty Event had a 1.5 to 1.8 times greater odds of occurring in 1993 or later, as compared to the reference category — 1989 to 1992. Both number citations and penalties were less strongly associated with the later time periods, and Serious violations were twice as likely to be cited in the later periods. Interestingly, Repeat and Willful violations were much less likely to be cited in the later periods, a reversal in direction of association compared to the other outcome measures.

Without detailed knowledge of patterns of MIOSHA policies and practices during the 14-year period of this study it is difficult to interpret these findings. One speculation is that the higher tendency to issue citations and penalties in the later time periods might have decreased the occurrence of Repeat and Willful violations. Alternatively, MIOSHA practices might have produced higher frequencies of citations in general but fewer of the Repeat and Willful ratings, which typically are associated with more substantial penalties.

SIC Code. The post hoc analysis of categories of SIC Code revealed interesting differences among the categories regarding the relative odds for a Citation Event

as compared with the relative odds for a Penalty Event. Manufacturing worksites had lower odds for receiving penalties as compared with four of the six other categories, and were not different from the other two categories. However, when considering citations, the pattern was reversed. The two categories that had no difference regarding penalties (Agriculture & Forestry, and Wholesale, Retail & Financial) had lower odds for a Citation Event as compared with Manufacturing worksites. The remaining four categories were not different from Manufacturing worksites with respect to the odds of a Citation Event..

In an attempt to simplify and better understand this pattern, an additional exploratory analysis was performed using a recoding of the SIC categories so as to allow comparison of manufacturing worksites with all other worksites. This analysis showed that there was no difference in the odds for a Citation Event (OR=1.06, 95% CI: 0.98 – 1.15, p=0.130). However, manufacturing worksites were less likely than non-manufacturing worksites to be assessed a penalty (OR=0.85, 95% CI: 0.78 – 0.92, p<0.001). The fact that four of the sub-categories of non-manufacturing worksites show this same direction of association suggests that this difference is general, and not unduly influenced by a narrow subgroup of industries.

It is unclear why manufacturing worksites might be less likely to be assessed with penalties than worksites in other industries. Future studies might examine this phenomenon in greater detail, with an eye to covariates not available for this study.

Study Strengths. This research has a number of strengths. First, the sample size for these analyses (12,813) was large relative to the number of covariates under study, which virtually eliminated the issue of power, and substantially reduced the role of chance in the regression analyses. Also, one set of comparisons included all eligible worksites with no sampling. This provided a good benchmark to rule out any bias in the sampling or matching processes.

The large sample also created a favorable environment for the creation of the matched comparison group. With only one minor exception, an adequate number of worksites was available to select three comparison worksites for each SENSOR worksite matched on two-digit SIC Code. The matched cohort provided an indirect control of unmeasured factors that might have influenced the analyses of all worksites.

Finally, other than the zero employee issue, the database had few missing data or other data problems. Only 13 worksites (0.1 per cent) were excluded for reasons such as missing inspection numbers or having extreme values.

Limitations. With regard to limitations, a central concern is the lack of information regarding the characteristics of inspected worksites. The IMIS database contained only limited information describing worksites, such as whether workers were represented by an organized bargaining unit, the number of employees working at the site, and the number of employees in the parent organization if that differed from the number at the inspected worksite. Absent was additional information about worksites that might have been associated with

the outcome measures. Examples include such organizational variables as management and supervisory style, level of investment in training of management and labor, and the financial performance of the company. Additional covariates that might be predictive of violations include the occurrence of workforce reductions in the period preceding inspections, and absenteeism. Workforce reductions may be an indicator of developing financial difficulties that could impact the previously mentioned covariates such as level of supervision or training. Absenteeism could be a consequence of a broad range of organizational factors that may be associated with management practices leading to higher levels of violations, but that are difficult to measure directly.

Another limitation concerned the Worksite and Corporation Employee covariates. In analyses that included these covariates, 656 (5.1%) of the worksites had to be treated as missing because they had zero recorded as the number of employees. Of the 656 worksites, 4 were SENSOR worksites which constituted 0.7% of the total SENSOR worksites. For Non-SENSOR worksites, the 652 scored zero for number of employees constituted 5.3% of all Non-SENSOR worksites. A similar percentage (5.8%) of the matched comparison group had a zero score for number of worksite employees. As previously described, it was not possible to determine which of several alternative explanations of the zero score might be correct. However, if the majority of these worksites did properly belong in the smallest category for number of employees, their omission from the analysis might have inflated the association reported for the smallest company size. This is because only two of the worksites with 'zero' employees received any citations.

Thus, including the 'zero' employee worksites in the smallest size category would have reduced the reported association of the smallest company size with the occurrence of a citation.

Exploratory analyses were undertaken to examine the materiality of this issue with respect to the reported company and corporate size effects. In these exploratory analyses, the covariates Worksite Employees and Corporate Employees were replaced with covariates that included the worksites with 'zero' scores in the smallest categories of the respective replacement covariates. While, as expected, the analyses did yield somewhat smaller associations and higher *p*-values for the smallest category (1-11 employees), there remained a clear pattern that worksites with fewer employees were more likely to receive citations and penalties as compared with the largest worksites (1000+ employees).

An additional limitation was the inability to control statistically for the influence of individual industrial hygiene inspectors. It is possible that inspector level differences in such factors as interpretation and application of standards, attitude toward the SENSOR WRA program, training, level of experience might be associated with patterns in citations and penalties assessed. However, SENSOR staff at MSU observed that SENSOR worksites were assigned inspectors in a manor similar to the assignment of inspectors to worksites in general, suggesting that inspector bias is unlikely to have influenced the study results.

Beyond the aforementioned limitations, is the issue of the difference between SENSOR and Non-SENSOR inspections regarding the lag time between the occurrence of the event initiating an inspection and the time when the actual inspection took place. In the case of SENSOR inspections, significant time often passed between the occurrence of asthma symptoms and a worker seeking treatment. Further time passed until a potential case was reported to the SENSOR program. Following an interview of a potential case, medical records were requested. Additional time passed waiting for records to be received and a review by the study physician. Next a recommendation was made for an inspection. This may or not have resulted in an inspection, and in the instances that it did, a further delay of several months might take place before the actual inspection occurred. This process triggering a SENSOR inspection took much longer than the sequence from employee complaint to inspection that was typical for a large proportion of Non-SENSOR inspections. The longer time lag associated with SENSOR inspections allowed more time for a hazardous condition to be eliminated. This could have created a bias leading to an underestimation of citations at SENSOR worksites.

Finally, there is the issue of the generalizability of the findings of this study. This study focused exclusively on the State of Michigan, and similar studies in other states might yield different results. For example, other states may have industries that are not represented in the Michigan population of worksites. If such industry differences represent differences in hazard patterns that were not controlled for by the current study design or statistical methods, then the

associations reported for Michigan might vary from results obtained by similar studies in other states. Also, the finding that the year of inspection was associated with the outcome suggests the possibility that future time periods may differ from the time period considered in this study.

Future Studies. This study represents the first step in the process of evaluating the SENSOR work-related asthma program. It is now evident that even without the availability of specific standards for agents that cause work-related asthma, inspections triggered by a WRA index case are very much like other inspected worksites in terms of the prevalence of violations observed at the worksite. This means that inspecting SENSOR worksites is at least as valuable with respect to public health as inspections undertaken for other reasons, such as employee complaints. Further examination of the broader impact of SENSOR triggered inspections can only add to their net public health value.

An example of this broader impact is the approximately 1800 coworkers identified at the SENSOR inspections as having WRA symptoms. Roughly 1300 of the symptomatic coworkers were identified through interviews conducted during SENSOR inspections, and the remainder by an examination of logs maintained by employers under mandatory OSHA regulations.[2] The evaluation of the public health impact of the SENSOR WRA must take into account both the identification of these additional cases as well as the potential value of the prevention of additional incident cases of WRA. Such prevention might result from changes in workplace environment occurring as a consequence of the SENSOR inspection.

To assess the broad public health impact of the SENSOR WRA program the following additional steps in the evaluation process are required: (1) an economic evaluation of the cost of identifying SENSOR index cases as well as the cost (and benefit) of identifying additional symptomatic workers at SENSOR worksites; (2) following up at the SENSOR worksites to determine if changes have resulted as a consequence of the SENSOR process; and (3) to the extent that changes are identified at worksites, estimating the probability of reducing the incidence of new cases and the associated economic benefits of such reductions.

The form of follow-up efforts might range from surveys of employees regarding workplace practices and conditions, to follow-up inspections, to the linking of other administrative databases with the IMIS database in order to compare SENSOR and NON-SENSOR worksites with respect to a broader array of covariates. Such covariates might include safety inspection outcomes, workers compensation claims, and health insurance records.

APPENDIX A

Tables of the 25 Most Frequent Two-Digit SIC Codes

APPENDIX TABLE A1 25 Most Frequent SIC Major Codes for SENSOR and Matched Comparison Michigan Worksites Inspected During 1989 through 2002 [1]					
Grp. #	**SIC Major Group**	**Frequency**		**%**	**Cum %**
		SENSOR	**Matched**		
37	Transportation Equipment	218	654	40.0	40.0
35	Industrial And Commercial Machinery And Computer Equipment	49	147	9.0	49.0
30	Rubber And Miscellaneous Plastics Products	40	120	7.3	56.3
34	Fabricated Metal Products, Except Machinery And Transportation Equipment	40	120	7.3	63.7
28	Chemicals And Allied Products	24	72	4.4	68.1
33	Primary Metal Industries	24	72	4.4	72.5
20	Food And Kindred Products	22	66	4.0	76.5
80	Health Services	18	54	3.3	79.8
36	Electronic And Other Electrical Equipment And Components, Except Computer Equip	11	33	2.0	81.8
24	Lumber And Wood Products, Except Furniture	9	27	1.6	83.4
27	Printing, Publishing, And Allied Industries	8	24	1.5	85.0
32	Stone, Clay, Glass, And Concrete Products	8	24	1.5	86.4
38	Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks	8	24	1.5	87.9
72	Personal Services	5	15	0.9	88.8
17	Construction Special Trade Contractors	4	12	0.7	89.5
25	Furniture And Fixtures	4	12	0.7	90.3
39	Miscellaneous Manufacturing Industries	4	12	0.7	91.0
42	Motor Freight Transportation And Warehousing	4	12	0.7	91.7
26	Paper And Allied Products	3	9	0.6	92.3
49	Electric, Gas, And Sanitary Services	3	9	0.6	92.8
50	Wholesale Trade-durable Goods	3	9	0.6	93.4
51	Wholesale Trade-non-durable Goods	3	9	0.6	93.9
54	Food Stores	3	9	0.6	94.5
73	Business Services	3	9	0.6	95.0
75	Automotive Repair, Services, Parking	3	9	0.6	95.6

[1] MIOSHA Health Inspections, only.

APPENDIX TABLE A2 25 Most Frequent SIC Major Codes for All Eligible Michigan Worksites Inspected During 1989 – 2002 [1]				
Grp. #	**SIC Major Group**	**Frequency**	**%**	**Cum. %**
34	Fabricated Metal Products, Except Machinery And Transportation Equipment	1,421	11.6	11.6
17	Construction Special Trade Contractors |	1,253	10.2	21.8
37	Transportation Equipment	1,240	10.1	31.9
35	Industrial And Commercial Machinery And Computer Equipment	718	5.8	37.8
80	Health Services	550	4.5	42.2
33	Primary Metal Industries	453	3.7	45.9
92	Justice, Public Order, And Safety	437	3.6	49.5
82	Educational Services	400	3.2	52.8
30	Rubber And Miscellaneous Plastics Products	389	3.2	55.9
75	Automotive Repair, Services, And Parking	371	3.0	58.95
28	Chemicals And Allied Products	329	2.7	61.63
15	Building Construction General Contractors And Operative Builders	277	2.3	63.89
73	Business Services	263	2.1	66.03
49	Electric, Gas, And Sanitary Services	246	2.0	68.04
24	Lumber And Wood Products, Except Furniture	202	1.6	69.69
50	Wholesale Trade-durable Goods	196	1.6	71.28
16	Heavy Construction Other Than Building Construction Contractors	178	1.4	72.73
27	Printing, Publishing, And Allied Industries	176	1.4	74.17
42	Motor Freight Transportation And Warehousing	174	1.4	75.59
20	Food And Kindred Products	173	1.4	77.00
32	Stone, Clay, Glass, And Concrete Products	165	1.3	78.34
55	Automotive Dealers And Gasoline Service Stations	162	1.3	79.66
36	Electronic And Other Electrical Equipment And Components, Except Computer Equip	153	1.2	80.91
72	Personal Services	145	1.9	82.09
25	Furniture And Fixtures	137	1.1	83.21

[1] MIOSHA Health Inspections, only.

REFERENCES

1. Matte T, Hoffman R, Rosenman K, Stanbury M. Surveillance of occupational asthma under the SENSOR model. *Chest*. 1990; Supplement, 98:173S-178S.

2. Rosenman K, Reilly MJ, Kalinowski D. *2002 Annual Report on work-related asthma in Michigan.* A joint report of the Michigan State University Department of Medicine and Michigan Department of Consumer & Industry Services. 2003, Lansing, Michigan.

3.International consensus report on the diagnosis and treatment of asthma. National Heart, Lung, and Blood Institute, National Institutes of Health. Bethesda, Maryland 20892. Publication no. 92-3091, March 1992. *Eur Repir J* 1992;5:601-41, as cited inThorax 2003; 58 Suppl I, p. i3.

4. Chan-Yeung M, Malo J-L. Occupational asthma. *The New England Journal of Medicine*. 1995; 333(2), 107-112.

5. Kogevinas M, Anto JM, Sunyer J, Tobias A, Kromhout H, Burney P, and the European Community Respiratory Health Survey Study Group. Occupational asthma in Europe and other industrialized areas: a population-based study. *Lancet*. 1999; 353:1750-54,

6. Steenland K, Burnett C, Lalich N, Ward E, Hurrell J. Dying for work: The magnitude of US mortality from selected causes of death associated with occupation. *American Journal of Industrial Medicine*. 2003; 43:461-482.

7. Meridith S, Nordman H. Occupational asthma: measures of frequency from four countries. *Thorax*. 1996; 51: 435-440.

8. Contreras GR, Rousseau R, Chan-Yeung M. Occupational respiratory diseases in British Columbia, Canada in 1991. *Occupational and Environmental Medicine*. 1994; 51:710-712.

9. Balmes J, Becklake M, Blanc P, Henneberger P, Kreiss K, Mapp C, Milton D, Schwartz D, Toren K, Viegi G. American Thoracic Society Statement: Occupational contribution to the burden of airway disease. *American Journal of Respiratory and Critical Care Medicine*. 2003; 167:787-797.

10. Rosenman K, Reilly MJ, Kalinowski D. *2001 Annual Report on work-related asthma in Michigan.* A joint report of the Michigan State University Department of Medicine and Michigan Department of Consumer & Industry Services. 2002, Lansing, Michigan.

11. Rosenman K, Reilly MJ, Kaliowski D. A state-based surveillance system for Work-related asthma. *Journal of Occupational and Environmental Medicine.* 1997; 39:415-425.

12. Rosenman K, Reilly MJ. Asthma. In Maizlish N.(ed.) *Workplace health surveillance: An action-oriented approach.* 2000; Oxford University Press. Pp. 172-184.

13 Rosenman K, Reilly MJ, Kalinowski D. 2003 Annual Report on work-related asthma in Michigan. A joint report of the Michigan State University Department of Medicine and Michigan Department of Consumer & Industry Services. 2004, Lansing, Michigan.

14. Occupational Safety and Health Administration, United States Department of Labor; http://www.dol.gov/osha/gils/records/000227.htm;

15. Personal communication with Dr. Kenneth Rosenman, 2003.

16. United States Department of Labor; Occupational Safety & Health Administration. Standard Industrial Classification System. http://www.osha.gov/cgi-bin/sic/sicser5.

17. *MIOSHA Overview.* Document SP-20 (Rev. 4-02). 2002. Consultation Education and Training Division, Bureau of Safety and Regulation, Department of Consumer and Industry Services, State of Michigan.

18 Kleinbaum, D.G., Klein, M. *Logistic regression: A self-learning text.* (Chapter 8: Analysis of matched data using logistic regression). 2002. Springer-Verlag, New York, pp. 227-242.

19. Rosner, B. *Fundamentals of Biostatistics,* 5th Edition. 2000, Brooks/Cole, Pacific Grove, CA.

20. Cameron, A.C., Trivedi, P.K. *Regression analysis of count data.* 1998, Cambridge University Press, Cambridge, UK.

21. *STATA Base Reference Manual: Volumes 1-4, Release 8.* 1985 – 2003, Stata Press, College Station, TX.

22. Vuong, Q.H. Likelihood ratio tests for model selection and non-tested hypothesis. *Econometrica.* 1989; 57:307-333.

23. Morse, T., Dillon, C., Weber, J., Warren, N., Bruneau, H., Rongwei, F. Prevalence and reporting of occupational illness by company size: Population trends and regulatory Implications. *American journal of Industrial Medicine.* 2004; 45:361-370.

24. Okun, A., Lentz, T.J., Schulte, P., Stayner, L. Identifying high-risk small business industries for occupational safety and health interventions. *American Journal of Industrial Medicine*. 2001; 39:301-311.

25. Ashley, M.J., Eakin, J., Bull, S., Pederson, L. Smoking control in the workplace: Is workplace size related to restriction and programs? Journal of Occupational and Environmental Medicine. 1997;39:866-873.

26. Huang, J., Shibata, E., Takeuchoi, Y., Okutani, H. Comprehensive health evaluation of workers in the ceramics industry. *British Journal of Industrial Medicine*. 1993; 50: 112-116.

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 02504 0423