# The Role of Hazardousness and Regulatory Practice in the Accidental Release of Chemicals at U.S. Industrial Facilities

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# The Role of Hazardousness and Regulatory Practice in the Accidental Release of Chemicals at US Industrial Facilities

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## ABSTRACT

This paper presents the results of an analysis of the accident history data reported under Section 112(r) of the Clean Air Act Amendments. This data provides a fairly complete record of the consequences of reportable accidental releases occurring the time frame 1995-1999 in the U. S. chemical industry and covering 77 toxic and 63 flammable substances subject to the provisions of 112(r). As such, these results are of fundamental interest to affected communities, regulators and insurers, as well as to owners and managers in the chemical industry. The results show the statistical associations between accident frequency and severity and a number of characteristics of reporting facilities, including their size, the hazardousness of the processes and chemicals inventoried, and the regulatory programs (in addition to 112(r)) to which these facilities are subject. The results are interpreted in light of economic drivers of protective activity and regulatory priorities for monitoring and enforcement.

KEY WORDS: Accident Epidemiology, Risk Management Plans, Hazardous Chemicals, Clean Air Act

# 1. INTRODUCTION

Section 112(r) of the 1990 Clean Air Act Amendments set forth a series of requirements aimed at preventing and minimizing the consequences associated with accidental releases of chemicals at U.S. manufacturing facilities. Its implementation in EPA regulation, 40 CFR 68, required all facilities storing on-site any of 77 toxic or 63 flammable substances above a threshold quantity (ranging from 250 to 20,000 lbs)) to develop a risk management program (RMP). (There were certain exceptions: e.g., farmers using ammonia as an agricultural nutrient. See http://www.epa.gov/swercepp/pubs/potw/part6899.pdf for details on the chemicals regulated under 112(r)). These RMPs include assessments of hazards, details on accident histories during the past 5 years, worst-case accident release scenarios, and prevention and emergency response programs. The focus of this article is on the five-year accident tracking records available from the Chemical Emergency Preparedness and Prevention Office (CEPPO) for 1995-1999 in the RMP*Info™ database (CEPPO 1999). A total of 15,219 facilities reported to this database. All facilities were to report accidental releases of covered chemicals or processes that resulted in deaths, injuries, significant property damage, evacuations, sheltering in place, or environmental damage (see the above website for details).

The wealth of data assembled in the RMP*Info database presents a challenge and an opportunity. The challenge is that the scores of data elements on each of 15,219 facilities render any simple presentation of the raw data impossible. The opportunity is to use the tools of epidemiology and statistics to summarize the data in a manner useful to practitioners and policy-makers and, in addition, to test specific hypotheses about facility characteristics that might render facilities safer, or less safe.

Epidemiology is the study of predictors and causes of illness in humans. Its use in studying industrial accidents – termed "accident epidemiology" – has been proposed in a number of quarters (e.g., Saari (1986), Rosenthal (1997)). The motivating idea is to study the demographic and organizational factors of those facilities whose accident histories are captured in RMP*Info to determine whether any of these factors have significant statistical associations with reported accident outcomes, positive or negative, just as one might use demographic or life-style data for human populations to determine factors that might be associated with the origin and spread of specific illnesses. The basic approach followed in this study has been the epidemiologic methodology known as retrospective cohort study design.

The results of this analysis provide an important record on the accident propensity of facilities in the U.S. chemical industry, and on the consequences of these for the five-year period of the late '90s. These results are significant not just because of the relative completeness of the data records, but also because they allow analysis by specific facilities, sectors, processes and technologies of the magnitude of the risks faced by communities and insurers from chemical facilities. We explore these issues in detail in evaluating the results of our analysis.

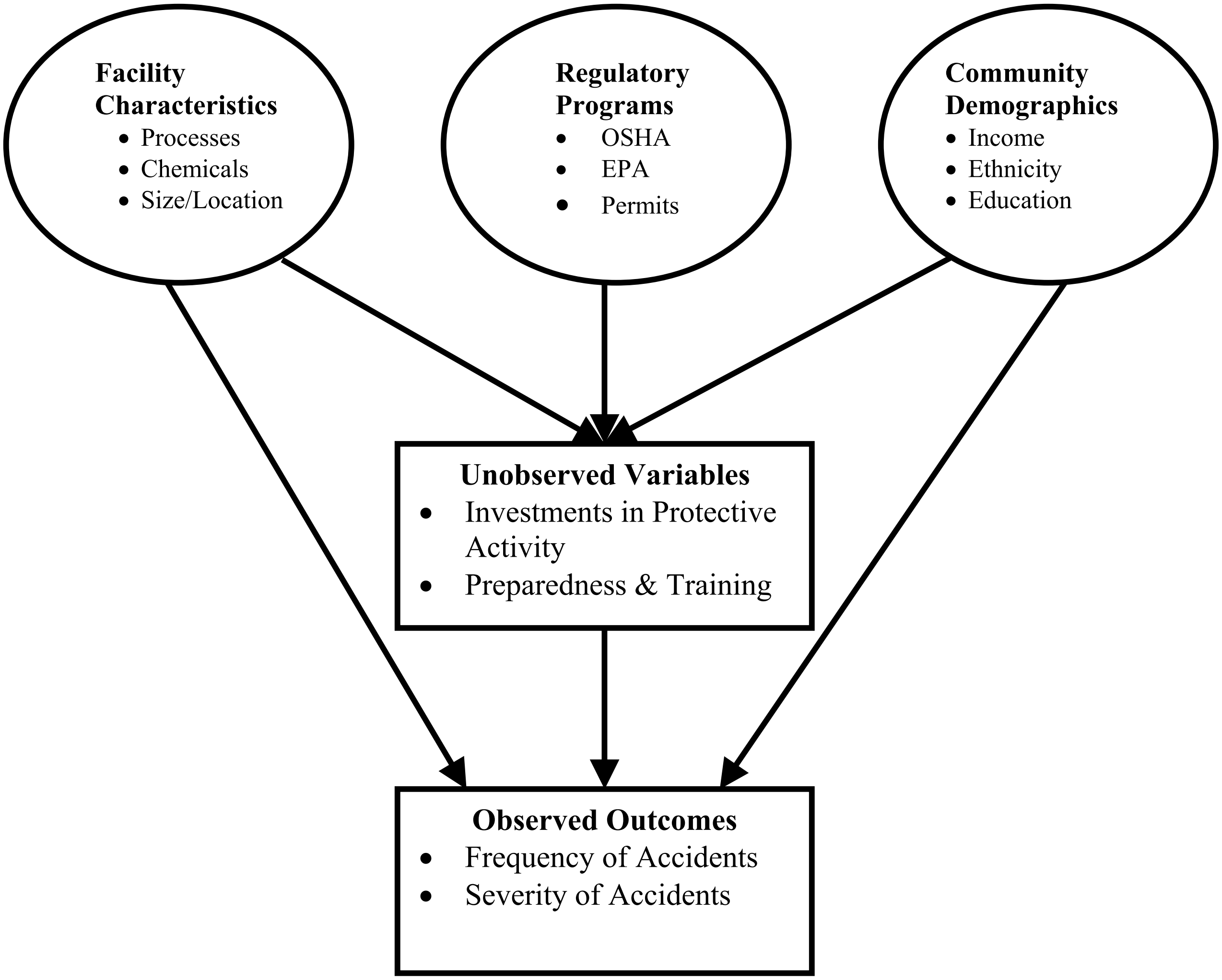
In order to develop plausible and important hypotheses to test concerning predictors of facility safety, we first developed a conceptual model for predictors of frequency and severity of accidents (Figure 1). The following factors are proposed as potential predictors:

1. The characteristics of the facility itself, including facility location, size and the type of hazard present;

2. The nature of regulations in force that are applicable to this facility and the nature of enforcement activities associated with these regulations;

3. The socio-demographic characteristics of the host community for the facility, which characteristics may represent the level of pressure brought on the facility to operate safely and to inform the community of the hazards it faces. (The "community" may be defined in multiple ways: the region that would be impacted by accidental releases or explosions at the facility; the political jurisdiction in which the facility is located (e.g., city); a larger political jurisdiction [e.g., county or state]; or an even larger region [e.g., EPA region] with common regulatory policies.)

**Figure 1: Framework of Analysis**



The present paper focuses on the first two factors, leaving to future work the study of underlying socio-demographic factors. We also restrict attention here to those facility and regulatory factors that are contained in the RMP*Info database. Other facility characteristics, not included in RMP*Info, might be important predictors of accidents but are less accessible for study. For instance, we do not analyze the effects of financial variables of parent companies on facility accident rates, leaving this study for future work.

Specifically, we test the hypotheses that facility characteristics and regulatory programs are associated with facility accident history. The facility characteristics that we study are the following: geographic region; size of facility; and chemicals used at facility. The quantity and nature of chemicals used at each facility are summarized for our statistical analyses by a single "total hazard measure," defined in Section 2. The regulatory programs studied are OSHA-PSM; CAA Title V; and EPCRA-302, which are described in more detail below. The direction of the statistical association between more stringent regulatory structures and accident rates is not clear ex ante. On the one hand, more stringent regulations might serve to reduce accident rates; however, more hazardous facilities might be the focus of more stringent regulations. The statistical associations identified here will reflect the combined effects of investments and regulatory oversight in preparedness/prevention activity and underlying factors driving accident propensity. Such hypotheses, if proven, could provide important insights on the impact of different regulatory programs for particular sectors and types of facilities.

The paper proceeds as follows. Section 2 describes the sources of data and methods used to analyze them. Section 3 presents our results relating facility characteristics to the probability of accidents, and resulting property losses and worker injuries from accidents in the time period covered. These results indicate strong statistical associations between hazardousness of facilities and frequency and severity of accidents, but these associations are modified in interesting ways by size, location and regulatory factors affecting the facility. The concluding section 4 describes the implications of these results for the several stakeholders concerned with the safe operation of chemical facilities.

## 2. METHODS

### 2.1 Sources of Data

The information contained in RMP*Info™ database is extensive and includes details about on-site chemicals and processes; regulatory program coverage; geographic location; and number of full-time employees (FTE). The accident-related information includes date and time of accident; number of associated injuries or deaths among workers, public responders, or the public at large; and off-site consequences such as property damage (on-site, offsite), evacuations, confinement indoors, and environmental damage. Our main outcomes of interest were frequency of accidents and severity of accidents, with the latter measured as injuries to workers and property damage to facilities. Our main facility predictors of interest were number of full-time employees together with hazard measures given by number of regulated chemicals present above threshold measures at the facility (toxic, flammable, and both combined) and a "total hazard" measure defined as the sum over all chemicals of $\log_2$(maximum quantity of inventory on site/threshold), or, alternatively, as the number of chemicals times $\log_2$ of the geometric mean of the maximum-to-threshold quantity ratio. Hence a total hazard measure of 0 indicates that only threshold levels of chemicals are kept in inventory, a measure of 1 means 1 chemical is kept at up to twice threshold level, 2 means 2 chemicals kept at up to twice threshold level or 1 chemical at up to 4 times threshold level, and so forth; unit changes in this measure can thus be interpreted as either an doubling of volume inventoried of a single chemical or an addition of another twice-threshold chemical on-site.[1] Note that the "total hazard measure" employed measures both the total quantity of the chemical on site as well as its inherent risk, the latter as captured through the threshold level in the denominator. Another predictor of interest is region, defined by the 10 EPA regions[2]. Table 1 shows the 20 most commonly reported types of chemicals used in excess of the reporting threshold level.

More than 97% of the RMP*Info™ filings are submitted electronically, permitting consistency and range checks during the submission process. The data obtained were screened for accuracy and consistency by the research team via interviews with plant-level and corporate managers responsible for submitting RMP data and via examination for outliers and internal inconsistencies in the data (Kleindorfer, Feldman, and Lowe 2000). Managers generally exhibited a clear understanding of the RMP process and devoted considerable effort toward its completion, suggesting data quality was likely to be high. The data were also subject to detailed reviews by both EPA staff and by facilities before their release; a review of the data by the researchers revealed no major remaining outliers or inconsistencies.

## 2.2 Regulatory Programs

We tested the hypotheses that three regulatory programs were associated with the frequency and severity of accidents. Reporting facilities are required to note if they are regulated under process safety and hazards permitting programs OSHA-PSM, CAA Title V, and EPCRA-302; under emergency response programs OHSA 1910.38 and 1910.12, RCRA, OPA 90, or state EPCRA rules; and what prevention program level (PPL) that they are assigned. For the purposes of these analyses we will concentrate on risk differences associated with process safety and hazards permitting programs OSHA-PSM, CAA Title V, and EPCRA-302. OSHA-PSM or Process Safety Management regulations are designed to protect worker health and safety in the presence of toxic or flammable substances; Title V of the Clean Air Act (CAA) regulates point source air emissions from industrial facilities, and EPCRA-302 (the Emergency Planning and Community Right-to-Know Act, is designed to give surrounding communities information regarding use of toxic or flammable substances by local manufacturing facilities.

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[1] While the measure proposed seems to be a reasonable measure of hazard computable from the available RMP*Info data, it would have been desirable to include also "worst case consequences" from each facility, either in our measure of hazardousness or as an additional measure. Such worst-case consequences, defined and reported under 112(r) filings using prescribed methods, are intended to assess the maximum damage that could reasonably occur from accidental releases at a facility. Because of security concerns related to terrorism, this data was made available to the public only in paper form through reading rooms and could not therefore be incorporated into the statistical analysis that follows. For similar reasons, the RMP*Info data itself has also been temporarily removed from the Internet, although to the best of our knowledge it remains accessible to qualified researchers. For a discussion of worst case consequences and descriptive statistics on these contained in RMP*Info, see the companion paper Kleindorfer et al. (2002).

[2] Region I: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut; Region II: New York, New Jersey, Puerto Rico, Virgin Islands; Region III: Pennsylvania, Delaware, District of Columbia, Maryland, West Virginia, Virginia; Region IV: North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Kentucky; Region V: Ohio, Indiana, Michigan, Illinois, Wisconsin, Minnesota; Region VI: Arkansas, Louisiana, Texas, Oklahoma, New Mexico; Region VII: Missouri, Iowa, Nebraska, Kansas; Region VIII: North Dakota, South Dakota, Montana, Wyoming, Utah, Colorado; Region IX: Arizona, Nevada, California, Hawaii, Guam, American Samoa, Trust Territories, Northern Mariana Islands; Region X: Idaho, Oregon, Washington, Alaska.

As described on the RMP*Info™ website, http://www.epa.gov/swercepp/ap-lere.htm, the OSHA Process Safety Management (PSM) standard is a set of procedures in thirteen management areas designed to protect worker health and safety in case of accidental releases. Similar to EPA's 112(r) rule, PSM applies to a range of facilities that have more than threshold quantities of certain listed substances. To avoid duplication, EPA has incorporated the OSHA PSM Standard as the chemical accident prevention program for certain facilities subject to both the PSM standard and the 112(r) rule. Given the importance of the PSM standard for worker health and safety, it is obviously interesting to investigate whether facilities subject to the PSM standard have different accident frequency or severity characteristics than other facilities subject to RMP*Info reporting but not PSM standards.

CAA (Clean Air Act) Title V establishes minimum requirements for state and local regulation of point source air emissions from industrial facilities, including monitoring and reporting requirements, permit fees and civil penalties, and public participation in the regulatory process.

EPCRA Community Right-to-Know legislation was passed as part of the Superfund reauthorization (SARA) legislation in 1986, shortly after the devastating Bhopal incident on December 3, 1985. Similar legislation has been passed in other countries. The basic aim of this legislation was to assure that community residents would be advised of hazards in their vicinity and of emergency response procedures in the event of an accidental release that might threaten their health. It is generally believed[3] that such regulations help to assure safer operations by hazardous facilities by providing appropriate pressure by an informed community to influence the level of protective activity in a facility before the fact and to mitigate losses, especially off-site, in the event of an incident.

### 2.3 Data Analysis

This section will describe the statistical methods used for the analyses. Readers with less interest in statistical methodology may safely skip this section and move to the Results section. We present these methodological notes for completeness and for those interested in the rationale for the modeling approaches that were selected.

The unit of analysis in this manuscript is the facility. The RMP*Info™ dataset could be viewed as a census of the entire population of relevant facilities. Thus, with respect to population values, this assumption would imply that no sampling variability is present. However, a more conservative statistical approach is to view the existing facilities as representative of an essentially infinite "superpopulation" of possible US facilities and to perform standard statistical tests for association. This analysis follows the latter, more conservative approach.

A caveat for all statistical analyses is that finding a statistical association between two factors does not prove that one causes the other. For instance, one might view an association between Factors A and B as being due to confounding by Factor C. That is, A and B might have no association at a given level of C, but, due to a common association between A and C and B and C, the unadjusted analysis shows an association between A and B, while the adjusted analysis which compares A and B and similar levels of C shows no association. For example, a positive association between accident outcomes and regulatory practice might not be due to something

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[3] See, e.g., Kleindorfer and Orts (1998) for a summary of the background literature and rationale for the efficacy of "informational regulation" as a basis for informing communities and influencing company safety, health and environmental policies.

intrinsic to the regulatory structure but rather to the underlying hazardousness of the processes that give rise to the facility being governed under the regulation; alternatively, this confounding might mask a negative association between accident risk and regulation. To account for this confounding, multivariate logistic regression models are employed (Hosmer and Lemenshow 2000). Logistic regression models the log-odds of, e.g., a facility reporting one or more accidents during the five-year period, and can "adjust" for confounders. Thus multivariate logistic regression analyses estimate the effect of geographic region or regulatory structure among facility of comparable size and "hazardousness."

There are other reasons that association may not prove causation, especially in observational studies that observe events rather than test interventions. However, it is often impossible to conduct intervention trials. For instance, it would be impossible and unethical to randomly assign some facilities to have more hazardous chemicals on-site, or to randomly remove regulatory coverage at some facilities. Confidence in a cause-and-effect relationship is enhanced by finding associations that support hypotheses that were specified before beginning data analysis, by strong statistical associations, by the plausibility of the postulated cause and effect, and by repeated studies demonstrating the same association. Because this study is the first to use a large database to evaluate association between facility and regulatory characteristics and accidents, the associations found must be viewed as preliminary. However, we took great care to specify our hypotheses in advance of data analysis in order to minimize the possibility of obtaining spurious results.

Because of the non-normal distribution of both the outcome and predictor data, several semi- and non-parametric techniques are utilized to summarize the bivariate and multivariate associations of interest. First, Wilcoxon rank-sum tests (Sprent 1993) are utilized to determine if statistically significant differences exist in the means of continuous predictors between facilities with and without accidents; for categorical variables such as geographic region, chi-square tests of association are performed. Among facilities with one or more accidents, Spearman rank correlations (Sprent 1993) are utilized to summarize the bivariate associations between the predictors of interest and three different outcome variables: the number of accidents, the number of injuries, and the value of property damage. For nonparametric regression relating the log-odds of selected outcomes to total hazard, a generalized additive model (Hastie and Tibsharni 1990) is fit using a cubic *B*-spline basis matrix: that is, separate cubic polynomials are fit between disjoint intervals of the predictor, with constraints imposed so that the estimated log-odds are equal at the "knots" where the intervals meet.

To model this highly skewed outcome data in a fashion that takes into account not only whether or not an incident occurred, but the quantity of incidents, a three-level ordinal scale was constructed for the frequency of accidents (0, 1, 2 or more), number of people injured (0, 1, 2 or more), and the amount of property damage (none, \$1-\$100,000, greater than \$100,000). Extensions of logistic regression models termed proportional odds (PO) models (Agresti 1990) are typically used to estimate the relative change in odds of a facility being at level $j$ rather than $j$-1 for a unit change in a covariate. These models assume that this relative change is the same for each change from level $j$-1 to $j$; when we tested this assumption on these data using a score test, we found that the assumption was generally not valid. Therefore, separate logistic regression models were fit to estimate the odds of being in the lower category versus the upper two and the lower two versus the upper category (Bender and Grouven 1998). Confidence intervals for odds ratios are obtained via profile likelihood.

## 3. RESULTS

A total of 1,945 chemical-release accidents between 1995 and 1999 were reported among the 15,219 facilities, resulting in 1,973 worker injuries and $1,018,000,000 in on-site property damage. One thousand one hundred eighty-six facilities (7.8%) reported at least one accident (range: 1-15). Of these accidents, 670 (4.3%) involved worker injuries (range: 1-69); and 316 (2.0%) involved facility property damage (range: $10-$219,000,000). Table 2 reports the facility, hazard, and regulatory variables of interest. Facilities reporting accidents were more likely to be located in the Region III, corresponding to the Mid-Atlantic (8% versus 5%), Region IV, corresponding to the Southeast (18% versus 15%), and Region VI, corresponding roughly to the South Central (22% versus 15%); and were less likely to be located in Regions VII (10% versus 19%) and VIII (4% versus 7%), corresponding to the Great Plains and Rocky Mountain regions. Facilities reporting accidents were also more likely to have more full-time employees (mean=345 vs. 139), to use more toxic and flammable chemicals (mean=1.6 and .8 vs. 1.0 and .3), and to have higher total hazard measures (mean=27 vs. 13). Facilities with accidents were also somewhat more likely to be regulated under the Right-to-Know Act (EPCRA-302) (86% vs. 82%) and substantially more likely to be regulated under OSHA-PSM (79% vs. 47%) and CAA Title V (32% versus 13%).

Table 3 shows, for facilities with at least one reported accident, Spearman correlations between characteristics of the facility and three outcome variables: number of accidents, number of injuries, and property damage. Readers with less interest in statistical measures may skip this Table, noting that facilities with more full-time employees, more hazardous chemicals in use, and greater total hazard measure were at greater risk of accident, worker injury, and property damage. The number of toxic chemicals was more strongly associated with worker injury (Spearman's $\rho$=.13) than was the number of flammable chemicals (Spearman's $\rho$=.07), whereas the number of flammable chemical was more strongly associated with property damage (Spearman's $\rho$=.13) than was the number of toxic chemicals (Spearman's $\rho$=.04).

Figure 2 plots the probability of accident, worker injury, and property damage versus number of full time employees. The probability of accident climbs from less than 3% for facilities with fewer than 10 employees to near 30% for firms with 1,000, then levels off for firms larger than 1,000. The probability of accident actually appears to decline for the very largest facilities (those with 5,000 or more employees), but this decline is not statistically significant. Similar trends are seen for injury risk and property damage risk.

Figure 3 plots the probability of accident, worker injury, and property damage versus the total hazard measure for the facility. The probability of any chemical accidents during 1995-1999 climbs from less than 4% for firms with a total hazard measure less than 5 (i.e., the equivalent of five chemicals at twice the threshold level, or one chemical at 32 times [i.e., $2^5$ times] the threshold level) to approximately 40% for firms with a total hazard measure of 50-150. The probability of a chemical accident approaches 100% as the total hazard measure reaches the 300-400 range. Similarly the probability of worker injury climbs from about 3-4% for firms with a total hazard measure less than 5, then levels off around 30%, for firms with a total hazard measure of 50-150, then climbs to 50-60% as the total hazard measure reaches the 300-400 range. The probability of property damage appears more linearly related to total hazard measure. Results are similar for the more serious outcomes.

Adjusting for size of facility reduces but does not eliminate this relationship between total hazard measure and risk of accident, injury, and property damage. Similarly, adjusting for total hazard measure reduces but does not eliminate this relationship between size of facility and risk of accident, injury, and property damage.

Table 4 shows bivariate analyses of the association between plant characteristics and the outcomes of interest. This somewhat complex table can be summarized as follows. Facilities in Region VI (South Central), IV (Southeast) and III (Mid-Atlantic) were at the greatest risk of accident (adds ratio (OR)=5.0, 4.1, and 4.0 respectively for 2 or more vs. 0 or 1 accidents when compared with Region VII [Central Plains], 95% CI=3.2-8.1, 2.6-6.7, and 2.3-7.1). Region III and Region VI were also at substantial additional risk of reported worker injury (OR=3.7 and 3.8, 95% CI=2.1-6.4 and 2.5-6.1 for 2 versus fewer than 2 injuries when compared with Region VII), but only Region VI was at substantially greater risk of large scale property damage (OR=8.0, 95% CI=4.3-16.6 for >$100K vs. $0 to $100K in facility damage when compared with Region VII). Table 5, however, shows that facilities in Regions VII and VIII (Great Plains and Rocky Mountains) were substantially smaller and had lower total hazard measures, on average, while facilities in the Region III (Mid-Atlantic) and IV (Southeast) had larger numbers of employees and somewhat higher total hazard measures; facilities in Region VI (South Central) were not exceptionally large on average, but had extremely high total hazard measures. Consequently, after adjusting for size of facility and total hazard, no significant regional differences remain with respect to risk of accident or injury ($\chi^2$=4.22 on 9 df for risk of any accident, p=.90; $\chi^2$=11.42 on 9 df for risk of any worker injury, p=.25) However, the high levels of large-scale property damage in Region VI are not entirely explained by number of employees and total hazard measure ($\chi^2$=23.382 on 9 df, p=.005) for risk of facility damage of over $100,000, although only a portion of the excess risk remains unexplained [OR =5.1, 95% CI=1.2-21.2 compared with Region II, which has the lowest risk after adjusting for number of employees and and total hazard measure]).

Table 4 also shows that heavy users of toxic chemicals covered under 112(r) (3 or more vs. none) were at greater risk of accidents and injuries (OR=9.0 [95% CI 6.8-12.0] and 10.6 [95% CI 7.4-15.6], respectively) than property damage (OR=3.4 [95% CI=2.3-5.1]), while the reverse was true for heavy users of flammables: OR for those using 3 or more flammables versus none were 5.2 [95% CI 4.0-6.6] and 5.9 [95% CI 4.5-7.8] for accidents and injuries and 15.4 [95% CI 11.0-21.1] for property damage. Note that those using one toxic chemical appeared to be at substantially lower risk of property damage than those using no toxics: this is a “selection bias” effect due to firms using a single toxin tending not to use flammables, causing single-toxin users to appear protected against property damage. This is clearer when we consider the relationship among toxic and flammable users given by Table 6. Nearly three-fourths of facilities (11,320) used only a single toxic chemical. Each increase in toxin use for a given level of flammables increased risk of accidents and injuries more than an increase in flammable use for a given level of toxins; the reverse was true for risk of property damage. Going from one to two toxins for a given level of flammables or from one to two flammables for a given level of toxins generally doubled the risk of accident, injury, or property damage; beyond this the risk of using additional chemicals began to level off. A comparison of the observed risk with that predicted under a model that assumes independent effects of toxins and flammables shows reasonable fit for accidents and injuries, with the exception of firms that employed three or more flammable chemicals with only one toxin appears to have higher risk of accidents than other facilities. Further examination of the 62 facilities that used three or more flammables but only one toxin shows that 25 (40%) were petroleum refineries, which had higher accident and injury rates than other facilities using this mix of chemical types (1.6 and 1.3 per refinery, respectively, versus .5 and .6 for other facilities).

Firms regulated under the Right-to-Know act (EPCRA-302) were at somewhat elevated risk of accidents (OR=1.3, 95% CI=1.1-1.6), injuries (OR=1.7, 95% CI=1.3-2.2), and property damage (OR=1.3, 95% OR=0.9-1.8). Those regulated under OSHA Process Safety Management (OSHA-PSM), however, were at more than four times the risk of accident (OR=4.4, 95% CI=3.8-5.0) and injury (OR=4.7, 95% CI=3.9-5.8) and eight times the risk of property damage (OR=8.4, 95% CI=5.9-12.2). Finally, those regulated under CAA Title V and also at increased risk of accident (OR=3.1, 95% CI=2.7-3.5), injury (OR=3.6, 95% CI=3.0-4.2), and property damage (OR=5.1, 95% CI=4.0-6.4). See Table 4. Table 7 shows that facilities regulated under the Right-to-Know act had significantly higher total hazard measures, and firms regulated under Process Safety Management and CAA Title V had significantly higher number of full-time employees and total hazard measures, than facilities not under these process safety and hazards permitting programs. However, as Table 8 shows, after adjusting for number of full-time employees and total hazard, firms regulated under the Right-to-Know Act and CAA Title V were no more likely than other firms to have experienced accidents or property damage, and only marginally more likely to have worker injuries. Somewhat more than one-half of the excess risk for firms regulated under Process Safety Management appears to be accounted for by number of employees and total hazard measure: for firms of similar employee size and hazard load, OSHA PSM-regulated firms are at about twice the risk of accidents or worker injures, and three times the risk of facility damage, than non-PSM-regulated firms.

## 4. DISCUSSION

The risk of an accidental chemical release and of attendant worker injuries or property damage increases ten-fold as firms grow in size from less than 10 to 1,000 FTEs, then levels off. Similarly, risk of accident, injury, and property damage increases ten-fold as "total hazard" measure increases from 0 to 50, then levels off, then climbs again as total hazard reaches the 300-400 range that characterize the very largest chemical manufacturers.

Facilities in the Mid-Atlantic, Southeast, and South Central had the highest risk of accident, injury, and property damage, and facilities in the Great Plains the lowest. Most of these regional differences are explained by the larger number of employees and greater total hazard measures at facilities in the Mid-Atlantic, Southeast, and South Central regions. However, the much higher rate of property damage in excess of $100,000 among facilities in Region VI (South Central) cannot be entirely explained by the number of employees or the total hazard measure.

Toxic chemicals were more strongly associated with worker injury, whereas flammables were more strongly associated with property damage, which makes sense because fire is obviously capable of causing a much greater degree of damage to property than release of acids or poisonous gases, which are either more contained or less damaging to property.

Facilities regulated under the Right-to-Know Act had a modestly higher risk of accident, injury and property damage than other RMP*Info facilities, while facilities regulated under OSHA Process Safety Management and CAA Title V had a much higher risk. Nearly all of this excess risk for Right-to-Know and CAA Title V facilities could be explained by their larger size and greater total hazard measures, whereas only about one-half of the excess risk for OSHA-PSM facilities could be explained in this manner. This makes sense in that EPCRA-302 and CAA Title V targets facilities with hazards having significant off-site consequences, while the OSHA-PSM standard is focused on on-site hazards, which may not be directly related to inventory levels or numbers of processes, as captured in our hazardousness measure.

## Limitations of the Study

It was originally estimated by the U.S. Office of Management and Budget (OMB) that over 64,000 facilities would be required to submit RMPs for the 1995-1999 time period; however, only 15,219 ultimately did so. While the OMB estimate was intended to be conservative, there are several other possible reasons for this discrepancy. Most likely the greatest cause of this discrepancy was that in 1999 legislation was passed exempting flammable fuel when used as a fuel or held for sale as fuel by a retail facility (e.g., propane dealers). In addition, facilities may have reduced their inventories below the threshold limits required for reporting. Finally, some facilities meeting the RMP*Info reporting requirements may have simply refused to respond. These non-responders may differ is significant ways from the responding facilities used in these analyses.

A more structural missing data problem than simple non-compliance stems from the fact that facilities shut down between 1995 and 1999 are missing from the RMP*Info™ database. Similarly, those that went on-line during this period report for only the latter part of 1995-99; but since this information is not captured, it is impossible to determine which facilities were at risk during the 1995-99 time period without recontact. Consequently we do not consider secular trends in our analyses. Recontact efforts and secular trend analyses are the focus of future research efforts.

## Conclusions and Future Research

These results provide important insights into the overall accident rates and consequences in the U.S. Chemical Industry for the period 1995-1999, including the key relationship between these outcomes and the hazardousness of these facilities. The results obtained from this first round of RMP and accident history data are rich in findings. First and foremost, they provide the most complete benchmark statistics to date on deaths, injuries and direct property damage at U.S. chemical facilities. They underline the expected interactions between regulatory oversight and level of hazard at facility. However, contrary to much popular theorizing, it is not the small facilities per se that are the primary sources of accidents. Rather, it is the interaction of the underlying hazard at the facility with size and location that provides the explanatory power for accident and injury rates. In many ways, these results will appear intuitive to the risk analysis community, but it is important to note that this is the first time in the history of the U.S. Chemical Industry that we have had the data to back up our intuition and to provide benchmark results for regulators, the insurance industry and the chemical industry as they attempt to assess the magnitude of the risks arising from chemical facilities.

Future research in this project will consider several areas. First, we intend to link the accident history analysis presented here to demographic data to determine whether socio-economic characteristics of surrounding communities have any statistical association with accident rates and severities. Second, we intend to integrate our analysis of facility characteristics with financial information on the companies that owned these facilities to determine whether financial characteristics of parent companies have an effect on the observed accident frequency and severity of facilities they own. Third, we are pursuing an extension of the hazardousness measure studied here to include worst-case off-site consequences (the OCA data). This last study is being done in cooperation with the EPA, since the OCA data is not accessible to the research community outside of EPA. A longer-term objective of this research will be comparative analyses, including trends, between the first five-year analysis period covered in this paper and the next, expected tranche of data under 112(r) which should become available in 2004. These studies, together, should provide a valuable record of accidents in the U.S. Chemical Industry and the impact of regulation on accident propensity.

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## REFERENCES

Agresti A. *Categorical Data Analysis*. New York: Wiley; 1990.

Bender R, Grouven U. (1998). Using Binary Logistic Regression Models for Ordinal Data with Non-Proportional Odds. *Journal of Clinical Epidemiology*, Vol. 51, 809-816.

CEPPO, *RMP*Info*™, Envirofacts Data Warehouse, U.S. Environmental Protection Agency, 1999.

Hastie, T.J., Tibshirani, R.J. (1990). *Generalized Additive Models*. London: Chapman and Hall.

Henneknes, C.H., Burings, S.L. (1987). *Epidemiology in Medicine*. Boston: Little, Brown and Co.

Hosmer, D.W., Lemeshow, S. (2000). *Applied Logistic Regression*, 2nd Edition. New York: John Wiley and Sons.

Kleindorfer P. R., Feldman H., Lowe R. A. (2000). Accident Epidemiology and the US Chemical Industry: Preliminary Results from RMP*Info. Wharton Risk Management and Decision Processes Center Working Paper 00-01-15. See http://opim.wharton.upenn.edu/risk/downloads/00-1-15.pdf.

Kleindorfer P. R., Belke J. C., Elliott M. R., Lee K., Lowe R. A., Feldman, H. “Accident Epidemiology and the U.S. Chemical Industry: Accident History and Worst-Case Data from RMP*Info”, Risk Management and Decision Processes Center Working Paper 02-04-PK, August, 2002. See http://opim.wharton.upenn.edu/risk/downloads/02-04-PK.pdf.

Kleindorfer P. R. and Orts, E. W. (1998). Informational Regulation of Environmental Risks. *Risk Analysis*, Vol. 18, No. 2, 155-170.

Rosenthal, Isadore (1997). “Investigating Organizational Factors Related to the Occurrence and Prevention of Accidental Chemical Releases”, in A. Hale, B. Wilpert and M. Freitag (eds), *After the Event: From Accident to Organisational Learning*, Pergamon: Elsevier Science, New York, 41-62.

Saari, J. (1986). “Accident Epidemiology”, in M. Karvonen and M. I. Mikheev (eds), *Epidemiology of Occupational Health*, European Series No. 20, World Health Organizations Regional Publications, Copenhagen, 300-320.

Sprent P. *Applied Nonparametric Statistical Methods*, 2nd Ed. London: Chapman and Hall; 1990.

**Table 1 -- Twenty Most Commonly Reported Chemicals and Threshold Reporting Levels**

| Chemical Name | Chem Type | Threshold (lbs) | % of Facilities |
|---|---|---|---|
| Ammonia (anhydrous) | Toxic | 20000 | 53.9 |
| Chlorine | Toxic | 2500 | 29.2 |
| Propane | Flammable | 10000 | 8.7 |
| Flammable Mixture | Flammable | 10000 | 5.4 |
| Sulfur dioxide (anhydrous) | Toxic | 5000 | 5.0 |
| Ammonia (conc 20% or greater) | Toxic | 20000 | 3.4 |
| Butane | Flammable | 10000 | 2.1 |
| Formaldehyde (solution) | Toxic | 15000 | 1.8 |
| Hydrogen fluoride/Hydrofluoric acid (conc 50% or greater) [Hydrofluoric acid] | Toxic | 1000 | 1.8 |
| Isobutane [Propane, 2-methyl] | Flammable | 10000 | 1.6 |
| Pentane | Flammable | 10000 | 1.1 |
| Propylene [1-Propene] | Flammable | 10000 | 1.1 |
| Toluene diisocyanate (unspecified isomer) [Benzene, 1,3-diisocyanatomethyl-] | Toxic | 10000 | 1.1 |
| Methane | Flammable | 10000 | 1.1 |
| Vinyl acetate monomer [Acetic acid ethenyl ester] | Toxic | 15000 | 1.0 |
| Hydrogen | Flammable | 10000 | 0.9 |
| Isopentane [Butane, 2-methyl-] | Flammable | 10000 | 0.8 |
| Acrylonitrile [2-Propenenitrile] | Toxic | 20000 | 0.8 |
| Ethylene oxide [Oxirane] | Toxic | 10000 | 0.7 |
| Propylene oxide [Oxirane, methyl-] | Toxic | 10000 | 0.7 |

**TABLE 2 – Characteristics of RMP reporting facilities and associated counties, overall and by whether or not an accident was reported in 1995-1999.**

| | All Facilities (n=15,219) | No Accident (n=14,033) | 1/+ Accidents (n=1,186) |
|---|---|---|---|
| Geographic region§** | | | |
| % Region I | 1.5 | 1.5 | 1.7 |
| % Region II | 3.2 | 3.1 | 3.8 |
| % Region III | 5.6 | 5.4 | 8.0 |
| % Region IV | 15.7 | 15.5 | 18.8 |
| % Region V | 21.4 | 21.5 | 19.5 |
| % Region VI | 15.8 | 15.3 | 22.0 |
| % Region VII | 18.6 | 19.4 | 10.3 |
| % Region VII | 6.6 | 6.8 | 4.1 |
| % Region IX | 8.2 | 8.3 | 7.8 |
| % Region X | 3.4 | 3.3 | 4.2 |
| Number of FTEs** | 155 | 139 | 345 |
| Number of Chemicals | | | |
| Toxic** | 1.07 | 1.04 | 1.56 |
| Flammable** | .30 | .26 | .79 |
| All covered chemicals** | 1.38 | 1.30 | 2.35 |
| Total Hazard**+ | 13.8 | 12.7 | 26.6 |
| % EPCRA-302** | 82.2 | 81.9 | 85.9 |
| % OSHA_PSM** | 49.2 | 46.6 | 79.2 |
| % CAA Title V** | 14.6 | 13.2 | 31.9 |

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*=*p*<.05, **=*p*<.01by Pearson chi-square or Wilcoxon rank test.

§=EPA-defined geographic region; see footnote 2.

+ Methodology for calculating "total hazard" is defined in statistical methods section of this paper.

**TABLE 3 – Spearman correlations between number of accidents, number of injuries, and property damage in 1995-1999 and characteristics of facility, among facilities with at least one accident.**

| | Number of Accidents | Number of Injuries | Property Damage |
|---|---|---|---|
| Number of FTEs | .23** | .20** | .14** |
| Number of Chemicals | . | | |
| Toxic | .15** | .13** | .04** |
| Flammable | .10** | .08** | .13** |
| All covered chemicals | 20** | .17** | .13** |
| Total Hazard | .13** | .12** | .10** |

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*=$p$<.05; **=$p$<.01.

**TABLE 4 – Unadjusted odds ratios (ORs) for having any versus none or 2 or more versus fewer than 2 accidents; any versus none or 2 or more versus fewer than 2 worker injuries; and any versus no or more than $100,000 versus less than $100,000 in facility property damage in 1995-1999, by region, chemicals used, and regulatory oversight**.

| | N | Accidents | | Injuries | | Property Damage | |
|---|---|---|---|---|---|---|---|
| | | 0 vs. 1+ | <2 vs. 2 | 0 vs. 1+ | <2 vs. 2 | 0 vs. 1+ | <100K vs. 100K+ |
| Region (vs. VII) § | 2837 | | | | | | |
| I | 232 | 2.08 (1.24 -3.33) | 2.70 (.90-6.61) | 3.08 (1.62-5.45) | 2.99 (1.10-6.90) | 1.59 (.47-4.06) | 1.22 (.07-6.43) |
| II | 484 | 2.26 (1.57-3.21) | 2.58 (1.17-5.31) | 2.50 (1.51-4.01) | 1.89 (.79-4.04) | 1.52 (.65-3.17) | 1.18 (.18-4.47) |
| III | 850 | 2.78 (2.10-3.67) | 4.01 (2.29-7.09) | 3.44 (2.37-5.01) | 3.69 (2.13-6.43) | 1.85 (1.00-3.31) | 2.01 (.68-5.43) |
| IV | 2392 | 2.28 (1.82-2.87) | 4.12 (2.63-6.73) | 2.62 (1.92-3.62) | 2.94 (1.87-4.78) | 1.70 (1.07-2.72) | 2.02 (.94-4.59) |
| V | 3253 | 1.69 (1.36-2.18) | 2.46 (1.54-4.04) | 1.87 (1.37-2.58) | 1.97 (1.24-3.22) | 1.50 (0.97-2.37) | 2.37 (1.18-5.14) |
| VI | 2402 | 2.70 (2.17-3.38) | 4.98 (3.21-8.07) | 3.28 (2.43-4.50) | 3.82 (2.47-6.14) | 3.77 (2.54-5.76) | 7.99 (4.30-16.6) |
| VIII | 1007 | 1.13 (.80-1.57) | 1.10 (.48-2.31) | 1.67 (1.08-2.56) | 1.36 (.65-2.66) | 1.37 (.72-2.50) | 1.13 (.31-6.97) |
| IX | 1251 | 1.77 (1.34-2.34) | 3.21 (1.88-5.57) | 1.58 (1.04-2.37) | 2.01 (1.12-3.59) | 1.62 (.92-2.80) | 2.97 (1.30-6.97) |
| X | 511 | 2.39 (1.68-3.35) | 2.94 (1.41-5.84) | 2.99 (1.88-4.66) | 2.70 (1.30-5.31) | 2.18(1.07-4.16) | 2.79 (.87-7.90) |
| All Chemicals (vs. 1) | 12548 | | | | | | |
| 2 | 1757 | 2.58 (2.20-3.02) | 4.30 (3.23-5.66) | 2.67 (2.16-3.29) | 3.73 (2.77-4.99) | 1.85 (1.29-2.60) | 2.31 (1.32-3.86) |
| 3-4 | 546 | 5.07 (4.09-6.28) | 10.7 (7.7-14.6) | 5.55 (4.24-7.20) | 7.60 (5.26-10.8) | 6.28 (4.33-8.89) | 12.1 (7.5-19.0) |
| 5+ | 368 | 10.4 (8.3-13.0) | 23.4 (17.2-31.6) | 11.9 (9.2-15.4) | 17.8 (12.8-24.5) | 17.0 (12.4-23.2) | 34.3 (22.9-51.1) |
| Toxics (vs. 0) | 1677 | | | | | | |
| 1 | 11864 | 1.06 (.86-1.32) | 1.21 (.76-2.05) | 1.23 (.91-1.71) | 1.28 (.80-2.20) | .38 (.28-.52) | .24 (.16-.37) |
| 2 | 1234 | 3.28 (2.56-4.25) | 7.77 (4.79-13.3) | 4.37 (3.10-6.27) | 6.41 (3.86-11.3) | 1.10 (.73-1.63) | .93 (.55-1.56) |
| 3+ | 444 | 9.00 (6.80-12.0) | 21.5 (13.1-37.3) | 10.6 (7.38-15.6) | 15.3 (9.0-27.2) | 3.43 (2.28-5.12) | 3.64 (2.22-5.96) |
| Flammables (vs. 0) | 12612 | | | | | | |
| 1 | 1867 | 1.49 (1.25-1.76) | 1.75 (1.29-2.33) | 1.26 (.99-1.59) | 1.59 (1.14-2.17) | 2.96 (2.19-3.95) | 6.15 (4.03-9.35) |
| 2 | 372 | 2.46 (1.82-3.26) | 3.32 (2.04-5.14) | 2.72 (1.87-3.84) | 2.58 (1.45-4.26) | 6.16 (3.93-9.30) | 12.8 (7.08-22.1) |
| 3+ | 368 | 5.17 (4.05-6.55) | 8.94 (6.41-12.3) | 5.94 (4.46-7.80) | 8.13 (5.68-11.4) | 15.4 (11.0-21.1) | 37.2 (24.3-56.9) |
| EPCRA-30 (vs. no) | 12509 | 1.35 (1.14-1.60) | 2.36 (1.65-3.51) | 1.68 (1.32-2.15) | 2.10 (1.46-3.15) | 1.31 (.95-1.830) | 1.72 (1.06-2.95) |
| OSHA_PSM (vs. no) | 7484 | 4.35 (3.77-5.03) | 11.1 (7.8-16.4) | 4.72 (3.88-5.78) | 12.1 (8.2-18.7) | 8.38 (5.95-12.2) | 38.7 (16.4-125.9) |
| CAA Title V (vs. no) | 2255 | 3.10 (2.72-3.53) | 5.43 (4.38-6.72) | 3.57 (3.02-4.21) | 5.34 (4.24-6.71) | 5.10 (4.04-6.42) | 8.00 (5.79-11.1) |

§=EPA-defined geographic region. 95% confidence intervals in parentheses.

**Table 5 – Mean number of full time employees and total hazard measure, by region.**

| EPA Region | Mean FTEs** | Mean Total Hazard§§** |
|---|---|---|
| I | 181 (392) | 12.5 (14.6) |
| II | 189 (795) | 13.2 (13.2) |
| III | 272 (1486) | 14.3 (14.8) |
| IV | 303 (2032) | 13.0 (16.7) |
| V | 105 (402) | 12.9 (16.6) |
| VI | 128 (374) | 20.2 (33.6) |
| VII | 54 (307) | 11.4 (6.7) |
| VIII | 45 (222) | 12.0 (7.5) |
| IX | 288 (2485) | 12.7 (20.1) |
| X | 132 (247) | 13.0 (11.5) |

*=$p<.05$, **=$p<.01$ by Kruskal-Wallis rank-test. §§=sum of $\log_2$(maximum quantity of inventory on site/threshold). Standard deviations in parenthesis.

**Table 6 – Risk of accident, worker injury, facility property damage, by number of flammables and toxics used: observed and predicted under main effect logistic regression model that simultaneously adjusts for number of toxics and number of flammables. Odds ratios versus reference category of none and 95% CIs given in parentheses.**

Total number of facilities and % reporting accidents [predicted in brackets]

| | Flammables | | | |
|---|---|---|---|---|
| Toxics | None (1.00) | One (2.36; 1.91-2.90) | Two (3.23; 2.26-4.57) | Three or more (5.37; 3.99-7.21) |
| None (1.00) | --- | 1228<br>5.1%<br>[4.9%] | 257<br>6.2%<br>[6.6%] | 192<br>9.4%<br>[10.5%] |
| One (2.79; 2.12-3.68) | 11320<br>5.6%<br>[5.7%] | 441<br>12.7%<br>[12.5%] | 41<br>26.8%<br>[16.4%] | 62<br>45.2%<br>[24.6%] |
| Two (7.58; 5.65-10.19) | 1059<br>14.9%<br>[14.2%] | 116<br>21.6%<br>[28.0%] | 25<br>32.0%<br>[34.8%] | 34<br>47.1%<br>[47.0%] |
| Three or more (13.3; 9.9-18.1) | 233<br>26.6%<br>[22.5%] | 82<br>45.1%<br>[40.6%] | 49<br>42.9%<br>[48.4%] | 80<br>47.5%<br>[60.9%] |

% reporting worker injuries [predicted in brackets]

| | Flammables | | | |
|---|---|---|---|---|
| Toxics | None (1.00) | One (1.95; 1.47-2.56) | Two (3.41; 2.21-5.15) | Three or more (5.69; 4.02-7.98) |
| None (1.00) | --- | 2.1%<br>[2.0%] | 2.7%<br>[3.4%] | 5.7%<br>[5.6%] |
| One (2.99; 2.05-4.42) | 2.9%<br>[3.0%] | 5.4%<br>[5.7%] | 19.5%<br>[9.6%] | 30.6%<br>[15.0%] |
| Two (9.28; 6.29-13.88) | 9.1%<br>[8.8%] | 12.9%<br>[15.9%] | 28.0%<br>[24.8%] | 35.3%<br>[35.5%] |
| Three or more (13.7; 9.3-20.5) | 16.7%<br>[12.5%] | 25.6%<br>[21.8%] | 26.5%<br>[32.8%] | 32.5%<br>[44.9%] |

**Table 6 – cont.**

% reporting facility property damage [predicted in brackets]

| | Flammables | | | |
|---|---|---|---|---|
| | None | One | Two | Three or more |
| | (1.00) | (4.00; 2.77-5.68) | (7.42; 4.42-12.09) | (15.4; 10.3-23.0) |
| Toxics | | | | |
| None | --- | 3.1% | 3.1% | 5.2% |
| (1.00) | | [2.3%] | [4.3%] | [8.4%] |
| One | 1.0% | 2.7% | 17.1% | 25.8% |
| (1.82; 1.21-2.74) | [1.1%] | [4.2%] | [7.5%] | [14.4%] |
| Two | 1.9% | 7.8% | 24.0% | 29.4% |
| (3.73; 2.38-5.80) | [2.2%] | [8.2%] | [14.2%] | [25.7%] |
| Three or more | 6.0% | 7.3% | 10.2% | 27.5% |
| (4.64; 3.01-7.14) | [2.7%] | [10.0%] | [17.1%] | [30.1%] |

**Table 7 – Mean number of full time employees and total hazard measure, by regulatory status.**

|  | Regulated Under |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Right-to-Know Act |  | Process Safety Management |  | CAA Title V |  |
|  | Yes | No | Yes | No | Yes | No |
| Mean FTEs | 170<br>(1291) | 87<br>(332) | 281**<br>(1630) | 34**<br>(366) | 488**<br>(2191) | 99**<br>(886) |
| Mean Total Hazard§§ | 14.2**<br>(20.5) | 12.2**<br>(9.5) | 16.7**<br>(26.2) | 11.1**<br>(5.5) | 24.6**<br>(31.3) | 12.0**<br>(15.2) |

*=*p*<.05, **=*p*<.01 by Wilcoxon rank-test. §§=sum of $\log_2$(maximum quantity of inventory on site/threshold). Standard deviations in parenthesis.

**Table 8 -- Odds ratios (ORs) for having any versus no accidents; any versus no worker injuries; and any versus no facility property damage in 1995-1999, by regulatory oversight, adjusted for number of full-time employees and total hazard measure.**

|  | Accidents | Injuries | Property Damage |
|---|---|---|---|
| EPCRA-302 (vs. no) | 1.15 (.96-1.37) | 1.33 (1.03-1.70) | .94 (.67-1.32) |
| OSHA_PSM (vs. no) | 1.81 (1.53-2.16) | 1.66 (1.31-2.11) | 3.06 (2.03-4.61) |
| CAA Title V (vs. no) | .90(.11-7.14) | .91(.11-7.31) | 1.22(.15-9.77) |

**Figure 2—Probability of having (a) any versus none or (d) 2 or more versus fewer than 2 accidents; (b) any versus none or (e) 2 or more versus fewer than 2 worker injuries; and (c) any versus no or (f) more than $100,000 versus less than $100,000 in facility property damage in 1995-1999, by number of full-time employee equivalents. Solid line represents mean estimates obtained from cubic spline model with knots at 5, 10, 100, 500, 1000, and 10000 employees; dotted line represents associated 95% confidence interval. Points are observed percentages for <10, 10-99, 100-199,…, 900-999, 1000-1999,…,9000-9999, and >10000 employees. Tick marks represent facility FTE measures (truncated at 10000).**

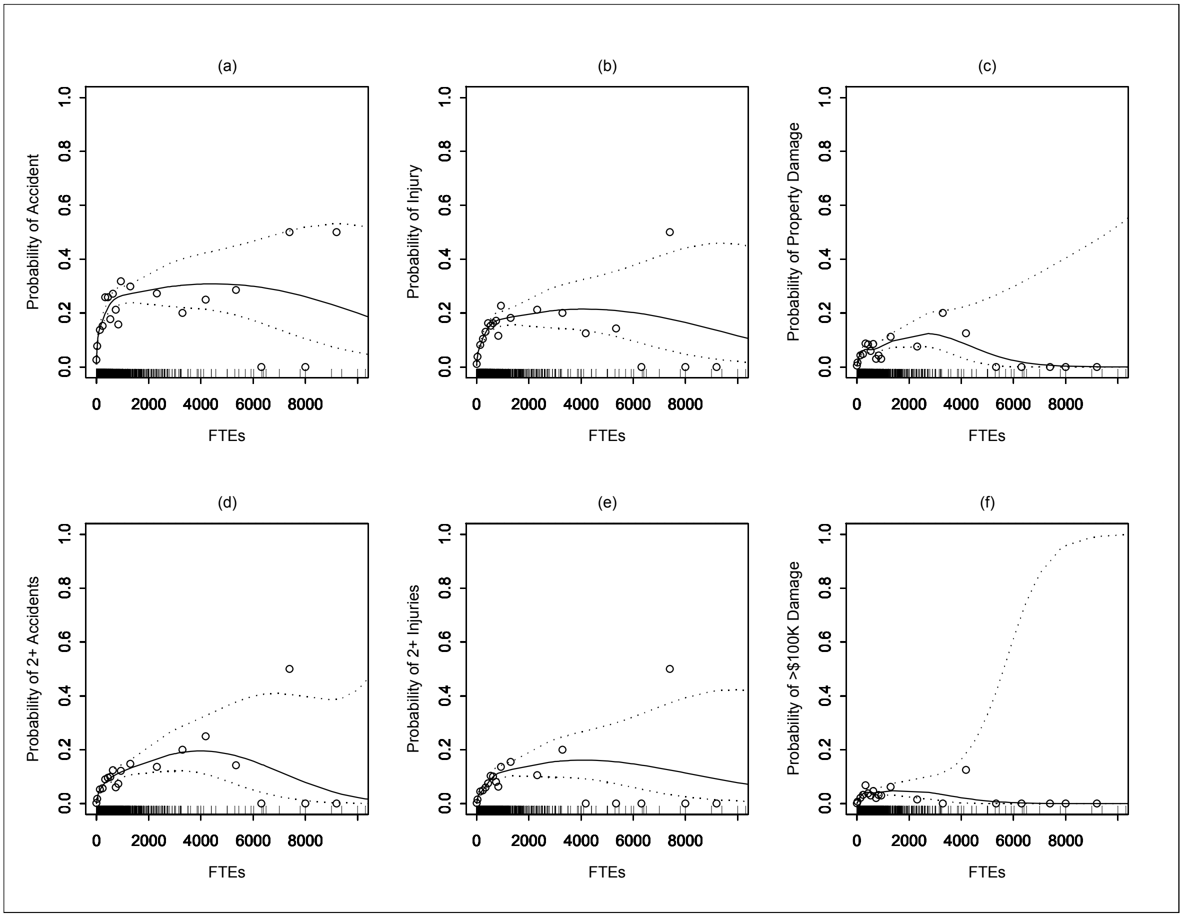

**Figure 3— Probability of having any versus none (a) or 2 or more versus fewer than 2 accidents (d); any versus none (b) or 2 or more versus fewer than 2 worker injuries (e); and any versus no (c) or more than $100,000 versus less than $100,000 in facility property damage (f) in 1995-1999, by total hazard measure. Solid line represents mean estimates obtained from cubic spline model with knots at total hazard measures of 5, 10, 20, 40, and 100; dotted line represents associated 95% confidence interval. Points are observed percentages for total hazard measures of <5, 5-10, 10-19,…, 90-99, and >100. Tick marks represent facility total hazard measures (truncated at 400).**