Accident Epidemiology and the U.S. Chemical Industry: Preliminary Results from RMP*Info[**]

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Accident Epidemiology and the U.S. Chemical Industry: Preliminary Results from RMP*Info[1]

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Abstract

This paper presents preliminary results on accident frequencies and severities available from RMP*Info, the database set up to store Risk Management Plans (RMPs) and Accident History data filed under Rule 112(r) of the Clean Air Act Amendments. The paper first analyzes which facilities actually filed under the Rule, and then presents results for various segments of the U.S. chemical industry on observed accident frequencies for the period June 21, 1994 through June 20, 1999, covered by the initial filing requirements under 112(r).

1. Introduction

The tragedy at Bhopal in December, 1984, followed by a subsequent release of the same substance, methyl isocyanate, from a facility in Institute, West Virginia resulted in great public concern in the United States about the potential danger posed by major chemical accidents. This public concern was translated into law in section 112(r) of the 1990 Clean

[1] This work is part of on-going work by the Wharton Risk Management and Decision Processes Center under a Cooperative Agreement with U.S. EPA/CEPPO on risk management in the chemical industry and, specifically, on the implementation of Rule 112(r) of the Clean Air Act Amendments. Center Co-Director Howard Kunreuther and the Center's EPA Cooperative Agreement Project Manager Patrick McNulty have played important roles in shaping and guiding this research. This report has benefited greatly from discussions with and comments on an earlier draft by Russell Localio of the the Center for Clinical Epidemiology and Biostatistics (CCEB) at the University of Pennsylvania School of Medicine. The authors are particularly grateful for the advice of Dr. I. Rosenthal of the Chemical Safety Board for his early leadership in launching this project and for the assistance of Breeda Reilly and Karen Schneider of U.S. EPA/CEPPO and informaticians Al Crawford and John Holmes of the CCEB.. None of the above individuals should bear the blame for any errors or omissions in this report. Comments on this report may be sent to kleindorfer@wharton.upenn.edu. Readers who wish to have access to other materials on the Wharton Risk Center's work on accident prevention in the chemical industry should consult the Center's website at http:\\grace.wharton.upenn.edu/risk/.

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Air Act Amendments. Section 112(r) sets forth a series of requirements aimed at preventing and minimizing the consequences associated with chemical accidental releases. These requirements are the basis of EPA's rule on "Risk Management Programs for Chemical Accidental Release Prevention" (hereafter the "Rule"). The federal regulations promulgated under 112(r) apply to facilities (both public and private) that manufacture, process, use, store, or otherwise handle regulated substances at or above specified threshold quantities (which range from 500-20,000 pounds).

The U. S. Environmental Protection Agency (EPA) estimated in its original economic impact analysis justification study (CEPPO, 1996) to the Office of Management and Budgeting (OMB) that about 66,000 facilities nationwide would be regulated under the Rule, including many facilities not covered under the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) standard or Title III of the Superfund Amendment and Re-authorization Act of 1986, [SARA Title III also known as the Emergency Planning and Community Right-to-Know Act, (EPCRA)]. With some exceptions, the Rule requires all regulated facilities to prepare and execute a Risk Management Program (RMP) which contains the following elements:

1. A hazard assessment to determine the consequences of a specified worst case scenario and other accidental release scenarios on public and environmental receptors and provide a summary of the facility's five-year history of accidental releases.

2. An accidental release prevention program designed to detect, prevent and minimize accidental releases.

3. An emergency response program designed to deal with any accidental releases in order to protect both human health and the environment.

The Rule also specifies the requirement (68.42) that regulated facilities maintain a five-year history of accidental releases and submit this history to the EPA (beginning June 21, 1999 and covering therefore the period June 21, 1994 through June 20, 1999)[5]. While as noted above, the original estimate of covered facilities expected to file under the Rule was 66,000, we will see in the data reported below that the number of facilities actually filing was, in fact, 14,500 (22%), with 1,145 of these facilities (7.9%) reporting some 1,913 accidents over the five-year period of interest.[6] A further temporary restriction in information available to the public was that worst case data, in the form of the required

[5] In actuality the time window represented by RMP*Info is not uniform for all facilities. A facility, for example, that filed its RMP on May 10th could have interpreted the five-year history covered by the Rule to be May 11, 1994 through May 10, 1999. Other facility owners interpreted more precisely as given above, and anticipated filing updated RMPs if their facility had an accident between the time they filed and June 20, 1999. Clearly, some ambiguity remains; however, it seems reasonable to think of the data as representing accident histories for the period mid-1994 to mid-1999.

[6] Reasons for the significant decreases in the number of filings will be reviewed in more detail below, but they include the recent exclusion of flammable fuels from RMP reporting under the Chemical Safety Information, Site Security and Fuels Regulatory Relief Act (PL 106-40) passed in August, 1999.

off-site consequence analysis (OCA) noted under (1) above, was not to be made available to other than "covered persons" except in summary form in order to reduce the possibility that these data might be used by terrorists to target specific facilities. Covered persons, as defined by the new law, include federal, state, and local government employees, agents and contractors; entities given planning and prevention responsibilities by state and local governments; and qualified researchers. The database itself has been named RMP*Info and, except for the OCA worst case data, has been available to the public since August 1999. The purpose of this paper is to provide a preliminary analysis of the data in RMP*Info. An important caveat to keep in mind is that this database is constantly in the process of revision, as companies submit updated RMPs or correct errors that come to their attention in their filings of RMP information. The data reported here reflect the state of the RMP*Info database as of October 21, 1999, corrected for a few additional known errors (as described below). Besides correcting for errors and accommodating RMPs from new facilities with covered processes, RMP*Info may also change as a result of legal proceedings clarifying which facilities must file or what information may be required of covered facilities.[7] For all these reasons, the data in RMP*Info may change over time with potential consequences for the findings reported based on these data.

The basic approach followed in this study has been the epidemiologic methodology known as [retrospective] cohort study design. Epidemiology is the study of predictors and causes of illness in humans. Its use in studying industrial accidents 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 present study is only a first step in a longer-term research project. Our sole interest in this paper is to present descriptive statistics associated with RMP*Info and not to undertake analytic studies to determine precursors of accidents or their sequellae. The latter studies will be important elements of future research.

As several commentators have already noted, RMP*Info represents a significant step in understanding the scope of accidents in the chemical industry and in promoting more effective accident prevention and mitigation.[8] New business models have emphasized the importance of learning across facilities, based on benchmarking and best practices. Using data in RMP*Info, together with other organizational and financial data on the

[7] The most recent such instance involved the lifting by the U. S. Court of Appeals for the District of Columbia on January 5, 2000 of the judicial stay exempting certain propane facilities from the requirement to file under the Rule. Owners of these facilities, perhaps believing that P.L. 106-40 might ultimately be interpreted to exempt them from filing RMPs, had awaited the outcome of the Court's decision before filing. This process alone has led to some 150 additional RMPs being filed since December 1, 1999. [Breeda Reilly, CEPPO, personal communication, February 2, 2000].

[8] See, for example, Rosenthal (1997) and Mannon and O'Connor (1999) for recent discussions of the promise of using large-scale comparative data to determine robust predictors of accidents in the chemical industry.

facilities and companies involved, is taking this approach to another level. Indeed, looking across the entire U.S. chemical industry, as well as across specific segments, technologies and chemicals therein, clearly holds the potential for detecting and validating factors predictive of severity and frequency of accidents. These models can then provide input for rational prioritization of risk management and regulatory policy initiatives designed to prevent future accidents. New data can then be used to update predictive models. Thus, coupling the methodology of epidemiology with RMP*Info, with periodic updates to these data as planned, has immense potential for promoting a deeper understanding of the causes of accidents and their prevention.

The paper proceeds as follows. In section 2 we describe the nature of RMP*Info and the preliminary data screening undertaken to assure data quality for RMP*Info. Section 3 then describes the nature of the facilities that filed, with the Top 20 by chemical use and by the North American Industry Classification System (NAICS) Code listed explicitly. Section 4 presents results on accident frequency and severity, including details by chemical and NAICS Code. Section 5 presents some simple univariable studies on timing and location of accidents as well as on the size of plants (measured by number of full-time equivalent (FTE) employees involved in these accidents. Conclusions are offered in section 6.

2. Introduction to RMP*Info and Preliminary Data Screening

This section describes the information collected under the Rule. We also discuss data quality issues here as a necessary precursor to our analysis in the rest of the paper.

As promulgated in 112(r) and supporting documentation, the following are the data elements required to be filed and recorded in RMP*Info for each covered facility:

- Executive Summary: This must cover the nature of facility and its policies for prevention and emergency response, as well as a verbal summary of the facility's five-year accident history.

- Section 1: Facility identification information and basic demographics on the facility, its parent company and its covered processes, including a listing of regulated chemicals above threshold quantities at the facility and indications of whether the source is covered by various other regulatory processes (OSHA Process Safety Management (PSM) Standard, Emergency Planning and Community Right-to-Know Act (EPCRA) Section 302, Clean Air Act (CAA) Title V).

- Sections 2 and 4: Description of worst-case release scenarios for regulated toxic (2) and flammable (4) substances above threshold quantities at the facility.

- Sections 3 and 5: Description of alternative release scenarios for regulated toxic (3) and flammable (5) substances above threshold quantities at the facility.

- Section 6: Five-year Accident History for the facility, including a separate record for each accidental release from covered processes that occurred during the five-year reporting period for the facility.

- Sections 7 and 8: Prevention Program descriptions for Program 3 processes (7) and Program 2 processes (8), including details on risk assessment and training procedures used, together with a list of the major hazards identified for these processes.

- Section 9: Details on the emergency response plan at the facility are required, including indications of which of several federal and state regulations on emergency response apply to the facility.

This paper is primarily concerned with data provided under sections 1 and 6 of RMP*Info, i.e. the basic demographics of the facilities that filed under the Rule and the accidents they reported in their Accident History data. Other data were used primarily for crosschecking the accuracy and consistency of the demographic and accident data. As noted earlier, off-site consequence data has not been released yet in a form suitable for statistical analysis (Sections 2-6).

Concerning accuracy and consistency, a first step in any epidemiologic study is the screening of data, and we therefore note some of the steps taken with respect to this critical issue in data quality assurance. In this regard, it is important to note that nearly all submissions under the Rule were electronic, with 97% of the final RMP submissions having been entered by diskette and mailed to the EPA. While manual submissions using a standard paper form were allowed, these accounted for only 3% of total.[9] Electronic submission is critical to data quality since the data submission system, called RMP*Submit, used a standard data entry template and had a number of self-correcting and checking mechanisms built into it to assure that the data submitted was in a standard format and met other consistency checks (such as range checks).[10] Notwithstanding the significant effort undertaken by EPA/CEPPO to assure the overall quality of the data, the research team also undertook its own data cleaning and screening checks. In particular, the following two steps were undertaken by the research team:

1. Extensive interviews with plant-level and corporate managers responsible for submitting the RMP data were undertaken during the period November, 1998 through June, 1999, to determine whether there were ambiguities in the minds of facility managers as to what data were required. The primary difficulties were with understanding the requirements for the OCA, both worst case and alternative scenarios, and not with the data of interest in this initial report. The managers at both

[9] Personal communication of 01/24/00 from Karen Schneider, who guided much of CEPPO's effort in data input and the quality assurance program surrounding RMP*Submit.

[10] It is not our purpose to review or comment on the extensive effort undertaken to assure data quality in the RMP process and the details of the software developed to assure data quality under the RMP*Submit system. The details of this can be found by consulting the extensive documentation provided by CEPPO at their website http://www.epa.gov/ceppo/.

large and small facilities generally exhibited a clear understanding of the requirements of the Rule and they showed a positive and constructive attitude towards the RMP process, where smaller companies typically relied on trade associations and consultants to assist them in this process. The effort expended on complying with the Rule was generally quite considerable. Indeed, data on some 10 companies collected as part of this pre-screening process indicated that, including internal and external consultants' time, person-hours dedicated to putting the data together for RMP*Info ranged from 200 hours for some small companies to nearly 3,000 hours for some large facilities.

2. Standard approaches for quality assurance of data, commonly employed in epidemiologic studies, were employed to look for data errors. For all variables included in this report, frequency distributions were reviewed to look for unusual or unexpected values ("outliers.") Where appropriate, cross-tabulations were performed to look for internal inconsistencies in the data. Outliers were discussed with EPA staff, who reviewed these cases to determine their validity.[11]

   Particular attention was focused on reviewing accidents in which substantial numbers of deaths or injuries were reported. In each of these cases, EPA staff were provided with the data for review before reports were finalized. In two cases, it was discovered that a facility had changed its report since October 21, 1999, the day on which EPA provided the database to the University of Pennsylvania. In one case, 9 public deaths had been reported and in the other case 5 deaths among public responders were reported; in both cases, these reports were resubmitted and changed to 0 deaths. Because the number of reported deaths is such an important data element, we have incorporated these corrections into our analysis. However, we must note that there may be corrections and revisions to RMP*Info at any time via the submission of a corrected RMP by any facility; other, less obvious changes to the database since October 21, 1999, will not be reflected in this report. Thus, in interpreting results from RMP*Info, it is critical to know the date of the last update incorporated in the analysis.

[11] An example of this quality assurance process may be informative. A frequency distribution of the number of full-time equivalent employees (FTEs) reported at each facility revealed a range from 0 to 48,000 FTEs. Eight hundred eighty-eight plants reported 0 FTEs and 14 plants reported over 15,000 FTEs. The authors of this report queried EPA staff about these outliers. EPA staff noted that all 14 of the facilities with over 15,000 FTEs were military bases and confirmed that these values were plausible. EPA staff hypothesized that the facilities with 0 FTEs might be related to specific industries. That led the authors to determine the NAICS codes of the facilities reporting 0 FTEs. The commonest processes were Water Supply and Irrigation Systems (246 facilities), Farm Supplies Wholesalers (229), and Farm Product Warehousing and Storage Facilities (186). EPA investigated whether it is plausible for such facilities to report 0 FTEs. EPA staff responded, in part, to this question as follows: "Coops are usually large organizations, frequently covering several states, but certainly serving many communities with individual outlets. They reported having zero FTEs because they are reporting on a storage facility that is unmanned except for certain seasons. According to the way FTEs are calculated, if they have one person there for five months, they have less than 0.5 FTE and report zero employees." [Breeda Reilly, CEPPO, personal communication, December 14, 1999.] Further discussion with EPA staff addressed other categories of processes associated with 0 FTEs, until EPA staff were satisfied that the data were accurate.

3. Overview of Plant Demographics for Facilities Reporting in RMP*Info

This section considers the basic demographics of the facilities that filed under RMP*Info. There are 14,500 facilities in RMP*Info and there are 1,913 reported accidents in RMP*Info, with 1,145 facilities reporting at least one accident. However, the sample size for various statistics will not remain constant at 14,500 and 1,913, since some sites have multiple processes and some processes use multiple listed chemicals.

Tables 1-3 below list various characteristics of filers under the Rule. Table 1 lists the 20 most commonly reported chemicals, along with the number of plants using each chemical and the number of FTE employees at these facilities. Also listed are the total numbers of facilities reporting use of at least one listed toxic or one flammable chemical. In Table 1, if the same chemical is used in more than one process at a facility, it is only listed once in the Table; however, the same facility may appear more than once in this Table if more than one of the Top 20 chemicals are present at the facility. For the same reason, the number of facilities indicating the use of at least one toxic or flammable will exceed the total number of filers since some facilities have both toxic and flammables on site. The average facility size among facilities reporting to RMP*Info, as measured in employee FTEs, is 163 FTEs, ranging from facilities with less than 0.5 FTEs (recorded as 0 FTEs in RMP*Info) to 48,000 FTEs. Half of facilities have 11 FTEs or fewer. Of the Top 20 chemicals in terms of reporting facilities, note that 9 are toxics (T) and 11 are flammables (F).

Table 2 lists the 20 most commonly reported industrial sectors, along with the number of plants reporting each process and the number of FTE employees at these facilities. Industrial process is specified by the NAICS code of the facility reporting. In Table 2, if a facility has multiple processes with the same NAICS code, it is reported only once. However, the same facility may appear more than once if it supports processes in more than one NAICS code.

Table 3 lists the numbers and percentages of reporting facilities which indicated that they were covered under various state and federal regulatory programs covering process safety, notification requirements and emergency response regulations. Table 3 also lists the maximum Prevention Program Level of any process at reporting facilities (this was computed by considering all processes at each reporting facility and taking the maximum of the Prevention Program Levels across all processes at a given facility).[12] We note that 6,672 (or 46%) of the reporting facilities had at least one process at level 3, requiring therefore a full Process Hazards Analysis to be undertaken and reported in the facility's RMP.

[12] EPA has defined three different Prevention Program Levels to reflect the potential for public impacts and the level of effort needed to prevent accidents. Only minimal requirements are imposed on Program Level 1 processes, while Program Level 3 processes are subject to much higher compliance requirements; Progam Level 2 processes face intermediate requirements. Program 3 processes are those processes that are either subject to OSHA's PSM standard or belong to nine specific SIC codes placed in Program 3 by the EPA.

As noted in the introduction, there is a significant difference in the number of facilities who originally projected to file under the Rule (66,000) and the number of actual filers (14,500). While a full study of this matter is beyond the scope of the present paper, a few reasons should be noted. First, the original estimate was intended to be a conservative estimate to OMB to assure that the full costs of the regulatory burden imposed by the Rule would not be underestimated. Second, as noted, several large groups including propane distributors, were excluded by P.L. 106-40. Third, a number of companies are likely to have responded to the Rule by reducing their inventories below the specified threshold limits required for reporting. Finally, non-compliance is always a possible explanation for the observed results. Which of these or other explanations are valid in various industrial sectors is clearly an important area for future research.

Section 4: Facility Accident Rates and Severities

Corresponding to the demographics given in the previous section, we now consider the accident rates in RMP*Info (over the entire five-year reporting period). These are given in Tables 4-6. Table 4 provides data on the frequency of accidents at facilities in RMP*Info. In particular, we note that 1145 facilities (or 7.9% of the 14,500 filers) had at least one accident during the reporting period, and 346 facilities (or 2.3% of the 14,500 facilities filing) had multiple accidents during the five-year reporting period. The cumulative incidence of accidents, expressed as a fraction of total reporting facilities, was 1913/14500 (or 13.2%). Thus, there was an average of just over 380 accidents per year over the period (we consider the time pattern of these accidents further below).

Table 5 reports all accidents by listed chemical involved in the accident. These ranged from 656 accidents for anhydrous ammonia facilities to a single accident for 22 listed chemicals. Exactly half (80) of the 160 chemicals listed under the Rule were involved in at least one accident during the reporting period.

Table 6 lists accidents by NAICS Code of the process involved in the reported accident. Two of the total of 1,913 reported accidents in RMP*Info do not report an NAICS Code in the Accident History Database.

Severities of accidents, according to various measures, are summarized in Tables 7-9. Tables 7 (employees/contractors) and 8 (non-employees) are concerned with statistics regarding injuries and deaths. For each category listed, we first provide the totals over all accidents for the reporting period. From this, we note that there were a total of 1,897 injuries and 33 deaths to workers/employees, and there were 141 injuries and 42 deaths to non-employees, including public responders. Half of accidents (956 of 1912 reporting this data) resulted in worker injuries. Most accidents did not involve other injuries to humans. Of the 1911 accidents that included data on these elements, 19 (1%) resulted in deaths to workers; 18 (0.9%) resulted in injuries to public responders; 3 (0.2%) resulted in deaths to public responders; 14 (0.8%) resulted in injuries to members of the public on-site in the facilities; one (0.2%) resulted in deaths to members of the public on-site in the

facilities; and there were no off-site deaths reported. Note, however, that there were 217 total hospitalizations and 6,025 individuals given other medical treatments.

Table 9 notes the damages to property and the non-medical off-site consequence analysis resulting from accidents during the reporting period. Note that the property damages alone are in excess of $1 Billion, and they do not include business interruption costs, including losses in shareholder value and lost business associated with accidents.[13] Table 9 records a number of other off-site effects besides the injuries and deaths noted in Table 8. In particular, we note both the large number of community residents who have been affected by accidents (over 200,000 involved in evacuations and shelter-in-place incidents) as well as the ecological consequences. On the other hand, only 21% of accidents resulted in any on-site property damage; 2.8% resulted in off-site property damage; 8.3% resulted in evacuations; and 5.3% resulted in individuals being sheltered in place.

5. Preliminary Analytic Studies

Analytic studies are concerned with establishing statistical associations between predictor variables such as facility characteristics and outcome variables such as frequency and severity of accidents of facilities having various characteristics. We will only pursue the simplest such studies here, in the spirit of merely describing the basic characteristics of RMP*Info in this paper. We report only univariable studies here (see Tables 10-12), relating overall accident rates to the time or location of their occurrence and to the size of plants as measured by FTEs. We begin by noting the frequency of accidents by year of occurrence and by the day of the week on which accidents occurred.

Table 10 displays the incidence of reported accidents over the five years in RMP*Info.[14] The significantly lower numbers for 1994 and 1999 are the obvious result of the fact that these years were only partly within the reporting window for most companies.[15] There is a natural tendency to compute accident incidence rates based on these data, e.g., accidents per plant year. However, this cannot be reliably done since there is no information in RMP*Info indicating the age of facilities reporting to it. All we know is that, if facilities reported, they existed as of June 21, 1999, but we do not know if they existed during the entire reporting time period. Without this information, it is not possible to compute the incidence rate of accidents per plant per year, nor to deduce

[13] These latter costs are likely to be larger, and perhaps much larger, than losses due to property damage. For a study of the full shareholder costs of environmental accidents, see Klassen and McLaughlin (1996).

[14] Three accidents are omitted from this table because they were reported to occur in 1992 (2 cases) or 1993 (1 case). It is unclear if these represent data entry errors in the submissions, with the wrong date reported, or unnecessary reporting of accidents that occurred prior to requirements of the Rule.) They have been included in the other analyses in this report.

[15] See also footnote 5, *supra*.

anything about the general trend in accidents per plant per year.[16] If we make the assumption that all facilities in RMP*Info existed during the entire reporting period, then the data in Table 10 suggest a small upward trend in accidents over time. But it should be noted that if accident-prone plants from the early days of the reporting period went out of business prior to June 21, 1999 (and are therefore omitted from the database), then the actual trend in accidents over time could well be negative even though reported accidents in RMP*Info indicate the opposite. Given these uncertainties, we cannot state whether the incidence rate of accidents has increased or decreased over the last five years.

Table 11 reports the day of the week on which accidents in RMP*Info took place. A small peak in accident rates is noticeable in mid-week. Of course, one should not infer from this anything about "safe weekend operations" since we do not know how many of the facilities in RMP*Info operated as intensively on weekends as they did during weekdays. Similarly, we do not know whether the lower number of accidents on Mondays and Fridays is a result of shorter periods of operation on these days, different work attitudes on these days, or other factors. Additional data would be required in order to study this issue. A number of other factors should also be considered in analyzing the temporal pattern of accidents, including seasonal manufacturing facilities, continuous versus batch operations, and specific process characteristics. None of these is accounted for in the simple univariable analysis presented here.

Next, we report results related to the size of plant, as measured by FTEs at the plant, and accident rates during the reporting period. Several caveats must be kept in mind in reviewing these data. First, these data do not account for many possible confounders with plant size. For example, we do not control for the inherent hazards in the processes in question and this could be a significant confounding influence on the statistical association of plant size and accident frequency and severity. Generally, a much more detailed analysis controlling for such factors as process hazard, OSHA PSM membership, and so forth, would be required in order to understand the etiology of the association of plant size with accident frequency and severity.

With these cautions in mind, Table 12 shows the association of increasing plant size with a higher frequency of accidents. We separated the data into those facilities reporting 0 FTEs, between 1 and 10 FTEs and more than 10 FTEs. Plants with more employees are significantly more likely to have accidents ($p < 0.001$, chi-square for trend). As explained earlier (see footnote 11), the FTE category "0" represents mostly seasonal or part-time farm operations that have less than 0.5 FTEs and, therefore, report 0 FTEs.

Again, it is to be emphasized that these analyses are provided by way of example of the sort of analyses that will be conducted as this project continues. They are limited in scope and should not be used for policy-making until additional analyses are conducted, adjusting for confounding variables. Furthermore, different outcome measures may be more appropriate in support of different regulatory and risk management policies. For

[16] Of course, this might done be done for particular sectors or technologies if plant ages for these sectors or technologies can all be reliably determined.

example, in evaluating risks from chemical accidents to the workforce, the incidence of deaths and injuries ***per FTE employee*** is a more informative measure of risk than is accidents ***per plant***. If most accidents involve few injuries or deaths, the direction of the association between plant size and adverse events might reverse in such an analysis.

The results of a final analysis, provided in Table 13, indicate the frequency of accidents by EPA Region. The differences in accident frequency across Regions are again highly statistically significant ($p < 0.001$, Chi-Square), which is certainly not unexpected since there are large differences in the types of processes located in various EPA Regions.

6. Conclusions and Directions for Future Research

Clearly this paper is only the beginning of our analysis of the informational value of the data collected under the RMP Rule. Certainly, a very important area in this regard is continuing research on how complete RMP*Info is, i.e., to what extent does RMP*Info capture the entire population of plants covered by the Rule. Another important area, going forward, will be to evaluate desirable changes in RMP*Info for the next reporting of accident history data, presumably to take place in 2004.

Focusing on the present data in RMP*Info, a number of analyses of interest remain. Foremost amongst these will be studies based on the critical additional information soon to become available on Off-site Consequence Analysis and Worst Case Scenarios. In addition, our own near-term research will be focused on:

- Basic modeling frameworks for accidents and accident precursors; in particular, this would provide an analysis of the effects of such plant characteristics as size on accident frequency and severity, controlling for other demographic and process characteristics such as Prevention Level, EPCRA Requirements, inherent hazard of the chemicals involved and other factors that might effect accident outcomes;

- Individual sector-specific and process-specific studies (e.g., chlorine plants) to allow more focused questions to be raised and more reasonable inter-plant comparisons to be drawn. This approach would allow, in particular, a more careful assessment of which facilities actually responded to RMP*Info for that specific sector or process, and whether there is a significant nonresponse bias for that sector or process in RMP*Info.

Besides the above studies focused on RMP*Info itself, there exist opportunities for connecting RMP*Info data to other collateral databases that may provide answers to questions of organizational and financial determinants or precursors of major accidents. The key question, of course, is this. Are there sectors or groups of sectors in the chemical industry for which RMP*Info, possibly coupled with other data, provides robust predictors of accident frequency and severity? Using Accident Epidemiology to discover such patterns, if they exist, seem a particularly fruitful approach given the growing availability of comparative, cross-industry data. The Wharton Risk Center looks forward

to cooperating with other research centers and industrial partners in shaping these studies.[17] As we proceed to mine the data in RMP*Info, we are mindful of the tremendous effort that went into collecting it and of the opportunities that it provides for understanding precursors of major industrial accidents and for prioritizing mitigation and regulatory strategies for preventing such accidents in the future.

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[17] Readers interested in sharing information about their own studies or in suggesting hypotheses to be tested using RMP*Info data may find our Hypotheses Bank website of interest. This website provides access to an interactive program that enables users to learn more about what the Center and others have done in studies related to RMP*Info as well as suggesting hypotheses to be tested. For additional information, please consult the website: http://epihb.wharton.upenn.edu.

Table 1: Twenty Most Commonly Reported Chemicals and Characteristics of the Facilities Reporting Them[18]

Chemical Name	Chem Type	Chem ID	Number of Filers	Avg FTEs of Filing Facilities	StDev FTEs
Ammonia (anhydrous)	T	56	7540	124	356
Chlorine	T	62	4241	233	2068
Propane	F	98	1451	243	740
Flammable Mixture	F	155	770	144	368
Sulfur dioxide (anhydrous)	T	49	730	189	1053
Ammonia (conc 20% or greater)	T	57	475	146	351
Butane	F	118	310	240	446
Formaldehyde (solution)	T	1	263	292	1123
Hydrogen fluoride/Hydrofluoric acid (conc 50% or greater) [Hydrofluoric acid]	T	55	259	283	415
Isobutane [Propane, 2-methyl]	F	107	229	256	535
Propylene [1-Propene]	F	129	158	506	900
Methane	F	93	157	401	892
Pentane	F	125	157	262	358
Toluene diisocyanate (unspecified isomer) [Benzene, 1,3-diisocyanatomethyl-]	T	77	154	276	796
Vinyl acetate monomer [Acetic acid ethenyl ester]	T	29	143	225	289
Hydrogen	F	149	138	684	1502
Acrylonitrile [2-Propenenitrile]	T	25	114	304	641
Ethylene oxide [Oxirane]	T	9	107	375	725
Isopentane [Butane, 2-methyl-]	F	115	107	312	405
Propylene oxide [Oxirane, methyl-]	T	12	103	335	698
Total Facilities Reporting at Least One Toxic Chemical	T		12738	16336	1240
Total Facilities Reporting at Least One Flammable Chemical	F		2698	242	761

[18] If the same chemical is used in more than one process at a facility, it is only listed once in Table 1; however, the same facility may appear more than once in this Table if more than one of the Top 20 chemicals are present at the facility. For the same reason, the number of facilities indicating the use of at least one toxic or flammable will exceed the total number of filers since some facilities have both toxic and flammables on site.

Table 2: Twenty Most Commonly Reported NAICS Codes and Characteristics of the Facilities Reporting Them

NAICS Code	NAICS_DESCRIPTION	Filers with the specified NAICS Code	Avg FTEs of Filing Facilities	StDev of FTEs of Filing Fac's
42291	Farm Supplies Wholesalers	4034	7	11
22131	Water Supply and Irrigation Systems	1892	196	2259
22132	Sewage Treatment Facilities	1361	240	2264
49312	Refrigerated Warehousing and Storage Facilities	504	200	320
211112	Natural Gas Liquid Extraction	450	15	23
42269	Other Chemical and Allied Products Wholesalers	356	25	39
49313	Farm Product Warehousing and Storage Facilities	326	5	17
454312	Liquefied Petroleum Gas (Bottled Gas) Dealers	307	16	88
11511	Support Activities for Crop Production	283	8	8
325211	Plastics Material and Resin Manufacturing	250	272	525
325199	All Other Basic Organic Chemical Manufacturing	244	264	515
311615	Poultry Processing	216	811	512
115112	Soil Preparation, Planting, and Cultivating	185	9	10
325188	All Other Basic Inorganic Chemical Manufacturing	185	237	563
32411	Petroleum Refineries	166	379	405
32512	Industrial Gas Manufacturing	134	58	164
49311	General Warehousing and Storage Facilities	121	648	4444
221112	Fossil Fuel Electric Power Generation	120	85	115
325311	Nitrogenous Fertilizer Manufacturing	116	92	145
311612	Meat Processed from Carcasses	115	423	411

Table 3: Reporting Facilities Covered by Various Regulatory Programs

Name of Regulatory Program	Number of Facilities Covered (from a Total of 14,500 Reporting)	Percent of Total Facilities Reporting under the Rule Covered by Each Specific Program
Process Safety and Hazards Permitting Programs		
OSHA-PSM	7,045	49%
CAA-Title V	2,181	15%
EPCRA-302	11,921	82%
Emergency Response Programs		
OSHA 1910.38	12,189	84%
OSHA 1910.12	8,696	60%
RCRA (40 CFR 264, 265, 279.52)	3,040	21%
OPA 90 (40 CFR 112, 33 CFR 154, 49 CFR 194, 30 CFR 254)	1,365	9%
State EPCRA Rules/Law	10,544	73%
Prevention Program Level		
Level 1	626	4%
Level 2	7,202	50%
Level 3	6,672	46%

Table 4: Frequency of Accidents at Individual Facilities

Number of Accidents at Facility	Number of Facilities in RMP*Info with the Indicated Number of Accidents in the Reporting Period	Total Accidents Represented
1	799	799
2	193	386
3	66	198
4	28	112
5	26	130
6	11	66
7	7	49
8	4	32
9	1	9
10	3	30
11	2	22
13	1	13
14	1	14
15	1	15
17	1	17
21	1	21
Totals	1145	1913

Table 5: Accidents Reported in RMP*Info by Chemical Involved in the Accident for the Entire Period 1994-1999

Chemical Name	Chemical ID	Number of Accidents
Ammonia (anhydrous)	56	656
Chlorine	62	518
Hydrogen fluoride/Hydrofluoric acid	55	101
Flammable Mixture	155	99
Chlorine dioxide [Chlorine oxide (ClO2)]	71	55
Propane	98	54
Sulfur dioxide (anhydrous)	49	48
Ammonia (conc 20% or greater)	57	43
Hydrogen chloride (anhydrous) [Hydrochloric acid]	54	32
Hydrogen	149	32
Methane	93	30
Butane	118	26
Ethylene oxide [Oxirane]	9	19
Hydrogen sulfide	63	19
Formaldehyde (solution)	1	17
Isobutane [Propane, 2-methyl]	107	17
Pentane	125	17
Titanium tetrachloride [Titanium chloride (TiCl4) (T-4)-]	51	15
Phosgene [Carbonic dichloride]	10	12
Nitric acid (conc 80% or greater)	58	12
Ethane	94	12
Oleum (Fuming Sulfuric acid)	69	11
Ethylene [Ethene]	95	11
Vinyl chloride [Ethene, chloro-]	101	11
Trichlorosilane [Silane, trichloro-]	153	11
Methyl chloride [Methane, chloro-]	5	10
Toluene diisocyanate (unspecified isomer)	77	10
Propylene [1-Propene]	129	10
Acrylonitrile [2-Propenenitrile]	25	8
Hydrochloric acid (conc 37% or greater)	53	8
1,3-Butadiene	120	8

Table 5 (Cont.): Accidents Reported in RMP*Info by Chemical Involved in the Accident for the Entire Period 1994-1999

Chemical Name	Chemical ID	Number of Accidents
Epichlorohydrin [Oxirane, (chloromethyl)-]	21	7
Bromine	60	7
Isopentane [Butane, 2-methyl-]	115	7
Propylene oxide [Oxirane, methyl-]	12	6
Sulfur trioxide	50	6
Trimethylamine [Methanamine, N,N-dimethyl-]	113	6
Carbon disulfide	8	5
Ethylenediamine [1,2-Ethanediamine]	26	5
Vinyl acetate monomer [Acetic acid ethenyl ester]	29	5
Hydrocyanic acid	6	4
Cyclohexylamine [Cyclohexanamine]	31	4
Dimethylamine [Methanamine, N-methyl-]	133	4
Silane	152	4
Chloroform [Methane, trichloro-]	4	3
Methyl mercaptan [Methanethiol]	7	3
Phosphorus oxychloride [Phosphoryl chloride]	70	3
Acetylene [Ethyne]	96	3
Methylamine [Methanamine]	97	3
2-Methylpropene [1-Propene, 2-methyl-]	131	3
Methyltrichlorosilane [Silane, trichloromethyl-]	16	2
Allyl alcohol [2-Propen-1-ol]	27	2
Hydrazine	38	2
Crotonaldehyde [2-Butenal]	48	2
Acetaldehyde	104	2
Isopropylamine [2-Propanamine]	109	2
Isoprene [1,3-Butadiene, 2-methyl-]	116	2
Dichlorosilane [Silane, dichloro-]	150	2
1,1-Dimethylhydrazine [Hydrazine, 1,1-dimethyl-]	2	1
Dimethyldichlorosilane [Silane, dichlorodimethyl-]	15	1
Toluene 2,6-diisocyanate [Benzene, 1,3-diisocyanato-2-methyl-]	20	1
Acrolein [2-Propenal]	22	1
Chloromethyl methyl ether [Methane, chloromethoxy-]	28	1
Toluene 2,4-diisocyanate [Benzene, 2,4-diisocyanato-1-methyl-]	44	1

Table 5 (Cont.): Accidents Reported in RMP*Info by Chemical Involved in the Accident for the Entire Period 1994-1999

Chemical Name	Chemical ID	Number of Accidents
Boron trifluoride [Borane, trifluoro-]	52	1
Hydrogen selenide	64	1
Arsine	67	1
Nitric oxide [Nitrogen oxide (NO)]	72	1
CBI Acids	78	1
Ethyl chloride [Ethane, chloro-]	100	1
Ethyl mercaptan [Ethanethiol]	105	1
Vinylidene fluoride [Ethene, 1,1-difluoro-]	112	1
1-Butene	119	1
Vinyl methyl ether [Ethene, methoxy-]	123	1
Tetrafluoroethylene [Ethene, tetrafluoro-]	132	1
Propadiene [1,2-Propadiene]	135	1
2-Butene-cis	142	1
2-Butene-trans [2-Butene, (E)]	145	1
Butene	154	1
Nitrogen Tetroxide	160	1

Table 6: Accidents Reported in RMP*Info by NAICS Code of the Process Involved in the Accident for the Entire Period 1994-1999

NAICS_DESCRIPTION	NAICS Code	Number of Accidents
Petroleum Refineries	32411	192
Water Supply and Irrigation Systems	22131	116
Sewage Treatment Facilities	22132	110
All Other Basic Inorganic Chemical Manufacturing	325188	89
All Other Basic Organic Chemical Manufacturing	325199	89
Other Chemical and Allied Products Wholesalers	42269	87
Farm Supplies Wholesalers	42291	85
Alkalies and Chlorine Manufacturing	325181	80
Nitrogenous Fertilizer Manufacturing	325311	68
Poultry Processing	311615	67
Petrochemical Manufacturing	32511	55
Pulp Mills	32211	54
Refrigerated Warehousing and Storage Facilities	49312	50
Animal (except Poultry) Slaughtering	311611	47
Natural Gas Liquid Extraction	211112	34
Plastics Material and Resin Manufacturing	325211	34
Frozen Fruit, Juice and Vegetable Manufacturing	311411	32
Meat Processed from Carcasses	311612	31
Paper (except Newsprint) Mills	322121	25
Industrial Gas Manufacturing	32512	24
Other Basic Organic Chemical Manufacturing	32519	24
Other Basic Inorganic Chemical Manufacturing	32518	22
Pesticide and Other Agricultural Chemical Manufacturing	32532	22
Ice Cream and Frozen Dessert Manufacturing	31152	19
Frozen Food Manufacturing	31141	17
Paper Mills	32212	17
All Other Miscellaneous Chemical Product Manufacturing	325998	17
Fluid Milk Manufacturing	311511	15
Aluminum Sheet, Plate and Foil Manufacturing	331315	13
All Other Chemical Product Manufacturing	32599	12
Other Warehousing and Storage Facilities	49319	12

Table 6 (Cont.): Accidents Reported in RMP*Info by NAICS Code of Process Involved in the Accident for the Entire Period 1994-1999

NAICS_DESCRIPTION	NAICS Code	Number of Accidents
Frozen Bakery Product Manufacturing	**311813**	**11**
Fertilizer (Mixing Only) Manufacturing	325314	11
Secondary Smelting and Alloying of Aluminum	331314	11
Dairy Product (except Frozen) Manufacturing	31151	10
Cheese Manufacturing	311513	10
Animal Slaughtering and Processing	31161	10
Paperboard Mills	32213	9
Cyclic Crude and Intermediate Manufacturing	325192	8
Fertilizer Manufacturing	32531	8
Polystyrene Foam Product Manufacturing	32614	8
Pharmaceutical and Medicine Manufacturing	32541	7
Toilet Preparation Manufacturing	32562	7
Fossil Fuel Electric Power Generation	221112	6
Flour Milling	311211	6
Inorganic Dye and Pigment Manufacturing	325131	6
Phosphatic Fertilizer Manufacturing	325312	6
General Line Grocery Wholesalers	42241	6
Farm Product Warehousing and Storage Facilities	49313	6
Support Activities for Crop Production	11511	5
Wineries	31213	5
Organic Dye and Pigment Manufacturing	325132	5
Surface Active Agent Manufacturing	325613	5
Iron and Steel Mills	331111	5
Corn Farming	11115	4
Other Grain Farming	11119	4
Broilers and Other Meat Type Chicken Production	11232	4
Seafood Product Preparation and Packaging	31171	4
Ethyl Alcohol Manufacturing	325193	4
Waste Treatment and Disposal	56221	4
Soil Preparation, Planting, and Cultivating	115112	3
Frozen Specialty Food Manufacturing	311412	3
Dried and Dehydrated Food Manufacturing	311423	3
Fresh and Frozen Seafood Processing	311712	3
All Other Petroleum and Coal Products Manufacturing	324199	3
Pharmaceutical Preparation Manufacturing	325412	3
Urethane and Other Foam Product (except Polystyrene) Manufacturing	32615	3

Table 6 (Cont.): Accidents Reported in RMP*Info by NAICS Code of Process Involved in the Accident for the Entire Period 1994-1999

NAICS_DESCRIPTION	NAICS Code	Number of Accidents
Cold-Rolled Steel Shape Manufacturing	331221	3
Primary Aluminum Production	331312	3
Electroplating, Plating, Polishing, Anodizing and Coloring	332813	3
All Other Miscellaneous Manufacturing	339999	3
Hazardous Waste Treatment and Disposal	562211	3
Space Research and Technology	92711	3
Unclassified Establishments	99999	3
Postharvest Crop Activities (except Cotton Ginning)	115114	2
Oil and Gas Extraction	21111	2
Electric Power Generation	22111	2
Wet Corn Milling	311221	2
Fats and Oils Refining and Blending	311225	2
Creamery Butter Manufacturing	311512	2
Cookie and Cracker Manufacturing	311821	2
Other Snack Food Manufacturing	311919	2
All Other Food Manufacturing	31199	2
Perishable Prepared Food Manufacturing	311991	2
Breweries	31212	2
Fiber, Yarn, and Thread Mills	31311	2
Newsprint Mills	322122	2
Synthetic Rubber Manufacturing	325212	2
Other Plastics Product Manufacturing	32619	2
Flat Glass Manufacturing	327211	2
Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	331419	2
Aluminum Foundries	331524	2
Other Nonferrous Foundries	331528	2
Printed Circuit Board Manufacturing	334412	2
Motor Vehicle Brake System Manufacturing	33634	2
Motor Vehicle Fabric Accessories and Seat Manufacturing	33636	2
Gasket, Packing, and Sealing Device Manufacturing	339991	2
Liquefied Petroleum Gas (Bottled Gas) Dealers	454312	2
All Other Pipeline Transportation	48699	2
Other Services to Buildings and Dwellings	56179	2
Total of Other NAICS Sectors with 1 Accident		63
Total Accidents from All NAICS Sectors Identified		1911

Table 7: On-Site Injuries and Deaths Resulting from Accidents During Reporting Period

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
On-Site Injuries to Workers/Contractors					
Total On-Site Injuries	1,897				1,912
Injuries per Accident	.9922	2.810	0	67	1,912
Injuries per FTE per Acc.	.0202	.0784	0	1	1,896
On-Site Deaths to Workers/Contractors					
Total On-Site Deaths	33				1,911
Deaths per Accident	.0173	.2224	0	6	1,911
Deaths per FTE per Acc.	.0003	.0071	0	0.25	1,895

Table 8: Non-Employee Injuries and Deaths Resulting from Accidents During Reporting Period

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
Non-Employee Injuries					
Total Injuries to Public Responders for All Accidents	58				1,911
Injuries to Public Responders Per Accident	.0304	.5568	0	21	1,911
Total On-Site Injuries to Other Members of the Public for All Accidents	83				1,911
On-Site Injuries to Other Members of the Public Per Accident	.0434	1.369	0	59	1,911
Total Hospitalizations for All Accidents	217				1,909
Hospitalizations Per Accident	.1137	1.964	0	80	1,909
Total Other Medical Treatment for All Accidents	6,025				1,910
Other Medical Treatment/Accident	3.154	106.09	0	4,624	1,910
Non-Employee Deaths					
Total Public Responder Deaths	40				1,911
Total On-Site Deaths by Other Members of the Public	2				1,911
Total Non-Employee Deaths	42				1,911
Public Responder Deaths/Accident	.0209	.6263	0	25	1,911
On-Site Deaths by Other Members of the Public Per Accident	.0010	.0457	0	2	1,911
Overall Non-Employee Deaths/Accident	.0220	.6444	0	25	1,911

Table 9: Property Damage and non-Medical Off-Site Consequences Resulting from Accidents During Reporting Period

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
On-Site Property Damage ($ Millions)					
Total On-Site Damage	$1,006				1,907
Damage per Accident	$0.528	$6.716	$0	$219	1,907
Off-Site Property Damage ($ Millions)					
Total Off-Site Damage	$11				1,907
Damage per Accident	$0.006	$0.109	$0	$3.8	1,907
Off-Site Consequences					
Total Number of Evacuations	154				1,908
Total Number of Evacuees in all Accidents	25,745				1,908
Number of Evacuees per Accident	13.49	122.02	0	3,000	1,908
Total Number of Accidents Involving Shelter in Place	97				1,909
Total Number of Individuals Confined to Shelter in Place in All Accidents	198,460				1,909
Number of Individuals Confined to Shelter in Place per Instance	104.0	1,956.4	0	55,000	1,909
Number of Accidents with Effects on the Eco-System					
Fish or Animal Kills	17				1,913
Minor Defoliation	54				1,913
Water Contamination	24				1,913
Soil Contamination	31				1,913
Any Environmental Damage	101				1,913

Table 10: Pattern of Accidents over the Five-Year Period

Year	Number of Accidents in the Year	Percent of Total Accidents
1994	157	8.2%
1995	336	17.6%
1996	390	20.4%
1997	426	22.3%
1998	431	22.6%
1999	170	8.9%
Totals	1910	100.0%

Table 11: Day-of-the-Week Pattern of Accidents

Day of the Week	Number of Accidents	Percent of Total Accidents
Sunday	153	8.0%
Monday	301	15.7%
Tuesday	313	16.4%
Wednesday	333	17.4%
Thursday	333	17.4%
Friday	271	14.2%
Saturday	209	10.9%
Totals	1913	100.0%

Table 12: Plant Size vs. Accident Frequency

FTEs at Facility	Proportion of Facilities with Accidents	Number of Facilities
0	1.7%	888
1-10	2.9%	6,304
>10	13.0%	7,308
Total	7.9%	14,500

Table 13: Accidents by EPA Region

	Proportion of Reporting Facilities with Accidents	Number of Reporting Facilities in Region
Region		
I	8.2%	220
II	9.2%	465
III	10.2%	811
IV	9.4%	2,360
V	7.3%	3,149
VI	11.0%	2,266
VII	4.5%	2,619
VIII	4.8%	955
IX	7.5%	1,161
X	10.3%	494
Total	7.9%	14,500