Linking OII and RMP*Info Data:
Does Everyday Safety Prevent Catastrophic Loss?

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Abstract

We link the Risk Management Program (RMP) database of accident histories collected by the U.S. Environmental Protection Agency for the period 1996-2000 under section 112(r) of the Clean Air Act Amendments and OSHA reported Occupational Illnesses and Injuries (OII) for the same period. We explore various statistical associations between OIIs and RMP-reported accidents. If we think of OIIs as reflecting everyday safety performance and RMP accidents as reflecting major accidents, then the analysis can be considered a test of whether good everyday safety performance is a foundation for preventing or mitigating relatively rare major accidents. We find only weak evidence that this is the case for the U.S. chemical facilities reporting in the RMP database. The paper concludes with some implications of these findings for industrial risk management and research.

Keywords: Accident epidemiology, Chemical Accidents, Occupational Injuries, Process Safety Management

Introduction

Catastrophic chemical process accidents, such as those at Flixborough, UK in 1974 and Seveso, Italy in 1976 led to a major increase in societal concerns about the safety of chemical processing facilities. By and large the initial regulations in response to these concerns, such as the Seveso Directive in the European Union (EU),[1] focused on preventing accidents thru better control of the individual technical aspects of chemical processes covered under these regulations. The continued occurrence of catastrophic chemical process accidents after the initial set of process safety regulations were put in place led to a new industry and regulatory paradigm regarding the causation of low probability-high consequence (LP-HC) accidents. The principle thrust of the 'new' paradigm is that prevention of LP-HC process accidents requires effective process safety management systems on top of appropriate technical practices, since deficiencies in management systems are the underlying cause of most chemical process accidents.[2]

This 'new' paradigm was implicitly incorporated into by OSHA (the U.S. Occupational Safety and Health Administration) in its Process Safety Management standard (PSM) in 1992 and explicitly into the Seveso II Directive in the EU and the U.S. Environmental Protection Agency (EPA) in its Risk Management Program regulation (RMP) in 1996.[3] The RMP regulation 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) that included assessments of hazards, a summary of accidents at the facility during the past 5 years preceding the filing of the RMP, worst-case accident release scenarios, and prevention and emergency response programs (see Kleindorfer et. al. (2003) for details on the RMP Rule). At the time these regulatory initiatives were launched, projections were made that these regulations would result in significant decreases in the incidence of process accidents. However, the process accident data available does not appear to support these expectations in either the US (Elliott et al. 2004, Kleindorfer et al. 2007) or abroad (Rosenthal et al., 2004).

Despite the less than expected decrease in accident incidence, most practitioners continue to believe that an 'effective' management system is the key to prevention. Such practitioners argue that the less than expected decrease in accident incidence exists because the newly adopted regulations have not resulted in the hoped for adoption of 'effective' process safety management systems by industry (Rosenthal et al., 2006).

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[1] The provisions of the Seveso Directive were implemented in the EU member states via national laws, e.g., the CIMAH regulation in the UK. Subsequent revisions of this Directive, such as Seveso II required revision by member states of their regulations, e.g., in the UK the CIMAH regulation was replaced by the COMAH regulation. The Seveso II Directive (Directive 96/82/EC on the Control of Major-accident Hazards) was adopted by the Council of the European Union on 9 December 1996. Following its publication in the Official Journal (OJ) of the European Communities (No L 10 of 14 January 1997), the Directive entered into force on 3 February 1997.

[2] See Rosenthal et al. (2006) for a summary of recent thinking on the role of management systems in promoting chemical process safety.

[3] "Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act, Section 112(r)(7). Guidelines, Final Rules and Notice": Federal Register: June 20, 1996 Volume 61, Number 120, Page 31667.

Testing the validity of this belief requires the ability to define and identify the essential elements of ‘effective’ facility process safety management plans. Among other issues, it will be important to separate out the effects that a given process safety management system has on everyday safety events from the effects, if any, that such a system might have in preventing or mitigating the consequences of larger events, including catastrophic failures. The main point of the present paper is to examine whether there is any relationship between the performance of chemical facilities on everyday safety and major accidents in the US Chemical Industry. For this purpose, we use as a proxy for “everyday safety” reported occupational illnesses and injuries, the so-called “OII rates”, which are regularly reported to OSHA. For “major accidents”, we use the accidents reported under the RMP rule to EPA. The period of the study is 1996-2000, encompassing the first set of accident history data reported under the RMP rule to EPA.

A great deal of research has been done on safety culture and climate survey instruments aimed at predicting the effectiveness of management systems in regard to preventing occupational illnesses and accidents reportable to OSHA (OII) (Carder and Ragan 2003; Donald 1998; Petersen 2005). Key elements required include: a) management commitment to safety, b) workforce educated and knowledgeable with respect to worker safety, c) effectiveness of the supervisory process, and d) employee involvement and commitment. Carder and Ragan, the latter in his capacity as a corporate safety director of a company with about 6,000 employees and 50 plus facilities, developed a diagnostic tool for identifying the areas of an existing management system that needed improvement. The resulting survey instrument was validated statistically as a predictor of OII incidence (survey scores for 12 facilities correlated with three year average OII results with a very high level of statistical significance). The instrument has also served as a diagnostic tool to guide management system improvements.

Unfortunately, acquiring comparable knowledge on the factors underlying major accidents is very difficult because of the low incidence of LP-HC process accidents. We use here the accident history data base reportable to EPA under the RMP Rule. We compare the rates of accidental chemical releases of various sets of facilities under RMP with the rates of OII events reported to OSHA. The motivating idea here is that the more frequent and lower consequence OIIs could serve as a precursor or prior indicator of the likelihood of low-incidence, high-consequence accidents such as those reported under the RMP Rule. If this were so, then existing OII and employee survey data could be used to predict the risk of RMP reportable accidents and, ultimately, might lead to better programs that would reduce both OIIs and major accidents.

The idea of connecting excellence in one risk domain (everyday safety as measured by personal injury rates) with excellence in another (major accident prevention) is certainly not new with this study. Indeed, such “synergies of excellence” have been fundamental to many management systems from quality to maintenance. However, there are also countervailing reasons to believe that there may be no strong relationship between everyday safety performance, as captured by OII reportables, and major accident frequency or severity. Dalzell (2003) notes, for example, that there is a potential “disconnect between the management of occupational safety, health and…environmental risk management and the management of major accident hazard risks." OIIs measure routine injuries, while LP-HC incidents are rare and contribute little to the OII measures in the routine course of events. Hopkins (2001) argues that "firms normally attend to what is being measured, at the expense of what is not. Thus, a focus on lost time injuries (LTI), the most frequent source of OIIs, can lead companies to become complacent about their management of major hazards."

This complacency may well have been present in both the catastrophic ESSO refinery fire at Longford, Australia, a plant that had an otherwise excellent safety record, and the more recent BP Texas City accident (March 2005) which killed 15 people and injured over 170 others. As the Baker Panel Report on the Texas City accident points out (Baker et al., 2007; p. 14): "BP has emphasized personal safety in recent years and has achieved significant improvement in personal safety performance, but BP did not emphasize process safety. BP mistakenly interpreted improving personal injury rates as an indication of acceptable process safety performance at its U.S. refineries. BP's reliance on this data, combined with an inadequate process safety understanding, created a false sense of confidence that BP was properly addressing process safety risks."

While many practitioners are inclined to accept these observations by Dalzell, Hopkins,and the Baker Panel, others continue to believe in the synergies of excellence as arising from a common culture of prudent risk management. However, neither camp's conviction appears to be backed by factual analysis. It is precisely this issue that we examine here. Our approach is to link RMP*Info reporting facilities to OII reports provided to OSHA during the 1996-2000 RMP*Info reporting period where both types of data are available for the same facility. We then consider the following two hypotheses regarding the relationship between RMP accidents and OII or other factors:

1. Management system effectiveness in reducing OII incidence is a sufficient indicator of facility management system effectiveness in reducing RMP reportable accidents.
2. Management system effectiveness in reducing OII incidence is a necessary but not sufficient indicator of facility management system effectiveness in reducing RMP reportable accidents.

Correlation between OII incidence and RMP accident incidence would suggest that effective OII management systems also generate practices that are effective in ensuring safe chemical process operations. Conversely, lack of correlation may indicate the absence of the know-how needed to design an effective chemical process safety system, or perhaps lack of the motivation to do so. In this regard, it should be noted that good OII performance is relatively quickly reflected in significant reductions in Worker Compensation costs, while the savings from avoiding process accidents are less tangible, certainly less predictable, and more long term, and this may reduce management motivation to act.

Data and Methods of Analysis

Data Sources

RMP*Info. Low-probability, high-consequence event data was obtained from the RMP*Info database. The RMP*Info database is set forth in sections 68.42 and 68.168 of the EPA 1996 RMP regulation. With certain exceptions, all facilities storing on-site at least one of 77 toxic or one of 63 flammable substances above a threshold quantity are required to develop a risk management program (RMP). (For details on the RMP Program, see http://yosemite.epa.gov/oswer/CeppoWeb.nsf/content/RMPS.htm). The information contained in the 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), and other descriptive information on the facility. For each of the 140 RMP-regulated chemicals, the EPA determined a "threshold quantity," such that facilities were required to file a report if they stored quantities above the threshold for the listed chemical. The threshold quantity for each regulated chemical was determined by a consideration of its potential toxicity, its potential for dispersion in the event of an unintentional release, and its flammability. Regulated substances were grouped into hazard levels, with thresholds set to values of 500, 1000, 2500, 5000, 10000, 15000, and 20000 pounds. (Threshold levels are inversely proportional to the perceived per-weight hazardousness of the chemical.) The accident-related information includes date and time of accident; number of associated injuries or deaths among workers, public responders, and the public at large; and other consequences such as property damage (on-site, offsite), evacuations, confinement indoors of nearby residents, and environmental damage.

OII. Rates and counts of Occupational Illnesses and Injuries (OIIs) were obtained from the U. S. Occupational Health and Safety Administration (OSHA). OSHA regulations require records of occupational illnesses and injuries (OIIs) be maintained in the workplace. Annually, OSHA contacts and obtains these records a minimum of once every four years among facilities with 40 or more full-time employee equivalents (FTEs) who use one or more of 558 NAICS processes (NAICS = North American Industry Classification System, which provides a classification system that differentiates between agricultural, manufacturing, warehousing, wholesale trade, and medical facilities). Facilities with high OII rates from previous years, or who have had other OSHA regulatory concerns, may be contacted more frequently than once every four years. Government employers are exempt. OSHA attempts to collect establishment information from about 80,000 facilities each year. The data on OII rates in the sample analyzed here were taken from 1996-2000 OSHA surveys, mirroring the same time frame of the first set of RMP data analyzed.

RMP*Info and OII Linkage: As of December 7, 2000, a total of 15,219 facilities reported on their covered facilities to the EPA's RMP*Info database as required by the provisions the RMP regulation. Of these, 3,201 facilities had 40 or more employees and used one or more of the 558 NAICS process codes that OSHA uses to determine whether or not to include a facility in the OII survey. Of these 3,201 facilities, 922 could be linked to the OSHA OII survey list under the criterion that the RMP*Info and OSHA facility street addresses matched, or that the facility name and city matched with a near match on the address. An additional 164 facilities with fewer than 40 employees or with processes that did not match the standard OII survey NAICS process codes were nonetheless matched in the OSHA OII surveys and are included in the analysis below, for a total of 1,086 facilities. We describe the data collected on the matched sample of facilities in more detail below. We also report below on the characteristics of facilities captured in our matched sample versus characteristics of all facilities reporting under the RMP Rule and note that our matched facilities appear to be representative of all eligible facilities.

Data Analysis

We considered one outcome from the OSHA OII data: the total number of occupationally-related illnesses and injuries reported to OSHA during 1996-2000. Because facilities differed in size and might have reported to OSHA for more than one year, OIIs are usually normalized across facilities by measuring the average number per 100 FTE (full-time equivalent employees) per year. This is the approach we use here, as it controls for the number of exposed employees in a facility.

For the RMP data, we considered six outcomes: death, property damage, evacuations, sheltering in place, environmental damage (reported fish/animal kills, defoliation, or other environmental damage), and injury. Because these events are relatively rare, we analyze two broad categories of outcomes:

- First, whether or not an incident took place at the facility in the given time period 1996-2000 that involved any of the following outcomes: a) major property damage, b) evacuations, c) sheltering in place, d) environmental damage, or e) deaths. (To avoid “minor” events that might not have been reported consistently across facilities, we define “major property damage” as any single event resulting in \$100,000 or more in reported total damage, both on- and off-site.)
- Second, whether or not an incident took place at the facility in the given time period 1996-2000 that involved an injury (either on-site or off-site).

Aggregating the types of events, per the above two categories, is advantageous from a statistical perspective, since the power to detect associations increases if the outcome of interest is more common. As we will see below, the second category of events, accidents with injuries, were more common than accidents involving any of the other indicated outcomes a-e above.

Intuitively, more hazardous processes and chemicals might reasonably be expected by their very nature to lead to more frequent or more severe accidents. However, hazardousness might also lead to greater attempts to mitigate underlying risks, and perhaps in ways that lead to the substitution of capital for labor in the control infrastructure of the affected facilities and processes. To account for the fact that more “intrinsically” hazardous processes tend to involve capital-intensive infrastructure that might confound relationships between OII events and LP-HC events, we first developed a "total hazard" measure as a proxy for facility hazardousness. We then included this measure in our statistical analysis as a control to account for the potential effects of both increased mitigation investments and decreased employee/labor exposure to the underlying process hazards.

The "total hazard" is calculated as follows. First, the EPA provided guidance on threshold quantities (in pounds) of each substance that were deemed sufficient to require reporting under the RMP Rule. The higher the toxicity or catastrophic potential of flammable substances, the lower the threshold quantity. We used this threshold quantity together with maximum recorded inventories on site to compute a "total hazard" measure for a facility as the sum over all the chemicals at the facility of $\log_2$(maximum quantity of inventory on site/threshold). Hence a total hazard measure of 0 indicates that only threshold levels of chemicals are kept in inventory, a total hazard 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 a doubling of volume inventoried of a single chemical or an addition of another twice-threshold chemical on-site. Note that threshold levels are inversely proportional to the per-weight hazardousness of the chemical. We also note that worst case scenarios at each facility were required to be developed as part of the RMP Plan. These scenarios were based on specific release and diffusion criteria developed by EPA. As would be expected intuitively, the results of such worst case scenarios are positively correlated with our total hazard measure. However, we were not allowed, for security reasons, to use these worst case scenario results in our statistical studies.[4]

As noted above, only facilities satisfying certain requirements are typically captured in the OSHA OII survey. We call such facilities "apparently OII eligible". A subset of the apparently OII eligible facilities were those facilities, 1,086 in total, in the RMP database for which we were able to link OII records to the associated RMP data. We call these "OII-matched" facilities. We then used various statistical tests to determine whether OII-matched facilities in the RMP database were representative of all OII eligible facilities in this database, i.e. whether "apparently OII-eligible" and "OII-matched" RMP*Info facilities differ.[5] As we will see in our results below, the OII-eligible and OII-matched samples in the RMP database have very similar characteristics, so that our OII-matched sample appears to be representative of OII-eligible facilities.

To consider the association between LP-HC outcomes and OII rates in a more detailed fashion, a logistic regression model is considered. Logistic regression models consider how the how the log of the odds of an outcome are related to a set of predictor variables;

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[4] See Elliott et al. (2003) for a more extensive study of the impact of hazardousness on facility accident characteristics for the RMP data used in the present study.

[5] Wilcoxon rank-sum tests and chi-square tests of association are utilized to determine if statistically significant differences exist in the means of continuous and categorical measures, respectively. Spearman rank correlations and Wilcoxon rank-sum tests are utilized to summarize the bivariate associations between RMP*Info incident rates and OII rates.

consequently the exponentiated regression coefficient associated with a given predictor may be interpreted as the multiplicative change in the odds of an event occurring for a unit change in the predictor if all other predictors are held constant, or the odds ratio for each change in the unit level of the predictor. ("Odds" are the probability of an event occurring divided by one minus this probability; hence if the probability of an event occurring is 50%, the odds of it occurring are 1.) Standard logistic regression models assume a linear relationship between the predictor and the log-odds of the event. Because this relationship may not be linear, a nonparametric generalized additive model (Hastie and Tibsharni 1990) was fit to the present data. This allows a very general functional form to be fit to the log-odds outcome variable, based on predictor variables such as OII rates and Total Hazard Measure. The result may be thought of as a very general polynomial fitting process that captures potential non-linearities linking the underlying predictive factors to the log-odds outcome variable.[6]

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 at similar levels of C shows no association. For example, in the analysis below, a negative association between accident outcomes and OII rates might not be due to something intrinsic to OII behavior at the facility but rather to the underlying hazardousness (or lack thereof) of the processes that tend to be used in facilities where OII rates are high; thus this confounding might mask a positive association between accident risk and OII rates. To account for this particular potential confounding effect, the nonparametric logistic regression model is always adjusted for facility "total hazard" using the total hazard measure described above.

Results

Our data cover the period 1996-2000. For a particular facility, we use the abbreviation ORWRII to denote the total OSHA Reportable Work-Related Illnesses or Injuries for that facility for the time period 1996-2000. Figure 1 provides a histogram of the OII rates among the 1,086 facilities in the RMP*Info database that could be matched to OII surveys during 1996-2000; the mean (SD) OII rate was 3.42 (4.67) ORWRII/Year/100

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[6] The algorithm used was based on a natural cubic *B*-spline basis matrix, whereby 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. The intervals are fixed at the unique values of the OII rates in the sample data, and the cubic spline parameters are obtained via a local scoring algorithm, which iteratively fits weighted additive models by a backfitting algorithm that allows up to 4 degrees of freedom for the spline parameters. The algorithm separates the parametric from the nonparametric part of the fit, and fits the parametric part using weighted linear iteratively reweighted least squares within the backfitting algorithm. Summary statistics and bivariate tests of association were obtained using SAS V8.02 (SAS Institute, Cary, NC); the generalized additive models were fit using R V1.9.1 (See R Development Core Team at www.r-project.org/).

FTE. Table 1 provides descriptive statistics for key measures taken from the RMP*Info database, overall and stratified by OII status (not eligible, eligible but not matched, and matched). We see from Table 1 that facilities that were potentially eligible for OII reporting were generally larger and used more complex processes, and were more likely to be chemical manufacturing or petroleum refining facilities, than other RMP*Info facilities; these facilities had higher rates of LP-HC events, consistent with the positive association between process and chemical complexity (Elliott et al. 2003). The only (small) difference between apparently OII-eligible RMP*Info facilities and those actually matched to the OII data was the size of the average facility (427 FTE for the OII-eligible versus 404 FTE for the OII-matched). The eligible and matched OII facilities had very similar characteristics with respect to process/chemical complexity and risk measures.

The rarity of the LP-HC events of interest is evident from Table 1: one in 900 (0.11%) of 15,219 RMP facilities reported an accident resulting in death; one in 200 (0.5%) of 15,219 facilities reported at least one accident resulting in environmental damage, one in 125 (0.8%) reported at least one accident resulting in property damage of $100,000 or more (on- and off-site), and one in 90 (1.1%) an accident resulting in public evacuation or sheltering in place. The aggregate result is that only one facility in 50 had at least one of the above incidents during 1996-2000. Reported injuries resulting from an RMP-reportable event were more common: one out in 28 (3.6%) of 15, 219 RMP facilities had accidents that led to at least one reportable injury during 1996-2000.

Table 2 shows the five most common processes used by RMP facilities overall, and among OII matched facilities. The OII-matched facilities were much more equally distributed by NAICS codes than the RMP facilities, with the OII-matched facilities focused primarily on manufacturing facilities (except for ammonium refrigeration facilities which are important in both populations).

Table 3 considers the bivariate association between the LP-HC events reported in RMP*Info and the OIIs reported to OSHA. In general, facilities reporting LP-HC events had lower OII rates than facilities without such events: facilities reporting one or more injuries during the period had OII rates 2% lower, and facilities reporting one or more incidents of major property damage, evacuation/sheltering, environmental damage, or death had OII rates 24% lower, than facilities without the given type of LP-HC event. These differences in OII rates are marginally statistically significant in both cases.

However, as Figure 2 shows, facilities with higher OII rates tend to have lower total hazard measures: for example, food processors, particularly poultry processors, are heavily represented among the high OII-rate facilities, but these facilities tend to have much lower total hazard measures than, e.g., petrochemical facilities, which have lower OII rates. This relationship may confound any underlying proclivity of facilities with high OII rates to be at greater risk of LP-HC events. Hence we consider a multivariate regression model that adjusts for total hazard of the facility to account for potential confounding between OII rate, LP-HC event risk, and the underlying complexity of the processes being used by the facility. We also consider stratified analyses by process type among the two most common process types (food processing, chemical manufacturing), which should also largely remove such confounding.

Figure 3 shows the nonparametric regression of the odds of one or more injury or one or more major property damage/evacuation/sheltering/environmental damage/death resulting from a LP-HC events reported to RMP*Info. There is some hint that facilities with very high OII rates (>10 ORWRII/Year/100 FTE) also had higher risk of injuries resulting from LP-HC events (ORWRII = OSHA Reportable Work-Related Illnesses or Injuries). There does not appear to be a consistent trend relating major property damage/evacuation/sheltering/environmental damage/death to LP-HC events. In neither case did the estimates associations reach statistical significance (p=.14 for injury; p=.091 for major property damage/evacuation/sheltering/environmental damage/death).

Figure 4 shows the nonparametric regression of the odds of one or more injury resulting from a LP-HC events reported to RMP*Info, stratified by the two most common NAICS processes at the 3-digit level, food processing and chemical manufacturing, among the facilities that reported only a single RMP*Info reportable process. The overall trend was similar to that obtained across all OII-matched facilities, with facilities with the highest OII rates appearing to have inflated risk of RMP*Info reportable injuries, although again these trends were far from statistical significance (p=.13 for food processors and p=.46 for chemical manufacturers). The outcome of major property damage-evacuation-sheltering-environmental damage-death was not considered for the stratified analysis because of the rarity of these events.

Discussion

There are no strong positive correlations between OII reports and RMP*Info low-probability, high-consequence events. Facilities with injuries, deaths, major property damage, or substantial off-site consequences from RMP*Info-reported events actually tended to have <u>lower</u> OII/Year/FTE than facilities without these types of RMP*Info-reported incidents. However, this negative correlation is a function of RMP-reporting facilities with higher OIIs tending to have lower hazard measures and thus lower rates of RMP*Info-reported accidents. After adjusting for this confounding between OII rates and the underlying hazardousness of the process, no statistically significant associations were found between OII rates and either RMP*Info reported injuries or RMP*Info-reported major property damage/evacuation/sheltering/environmental damage/death. It appeared that facilities with high OII rates (>10 ORWRIIs/Year/100 FTE) might pose a higher risk of an RMP*Info injury report, but this association did not reach statistical significance (p=.14).

One potential limitation of these findings is that there appear to be a large number of RMP*Info reporting facilities that should have been contacted by OSHA for OII reports but which were not available to be matched in the OSHA database. That these facilities failed to appear in both databases may be a function of the failure of these facilities to be contacted by OSHA, failure to self-report to RMP*Info, or failure to match records from both databases because of address errors and other reporting problems. However, there was little difference between apparently OII-eligible RMP*Info facilities and those actually matched with respect to process/chemical complexity or risk of a LP-HC event, suggesting that any failures to match OII reports with RMP*Info facilities may have been largely at random, and consequently unlikely to lead to substantial biases in the analysis above.

Conclusions and Future Research

Our analyses provides no support for the hypothesis that low OII rates translate to low risk of RMP*Info reportable incidents, and only marginal support for the hypothesis that high OII rates might predict further LP-HC events. Thus, there is no support for Hypothesis 1 "low OII rates are sufficient for low LP-HC risks," and limited support for Hypothesis 2 "low OII rates are necessary but not sufficient for low LP-HC risks."[7] Implicit in these hypotheses is the assumption that the culture driving low OII rates is the determining factor and, if present, it reduces risk of LP-HC events, not vice versa.
The OII and RMP data were analyzed cover a wide range of injuries, process accident events and types of facilities. Our results are preliminary and touch only a part of the RMP data (namely larger chemical manufacturing and petro-chemical refinery facilities), and our results do not preclude a more positive finding between process safety and major accident prevention in other segments of the industry. Further effort is needed to explore in detail the impact of other factors as reflected in culture indices (e.g., Carder and Ragan, 2003), Process Safety Certification by ISO or other Management System indices (see Rosenthal et al. 2006), or audited performance on best practices in Environmental Health & Safety (EH&S). These additional factors could well establish a stronger correlations between the incidence of occupational injuries and major accidents, e.g., as reflected in the OII and RMP data analyzed here.

A primary focus of future research in this area should be to link OII data and RMP data more routinely going forward. This would not necessitate a joint data collection effort between OSHA and EPA, but could be facilitated by better linking of facility IDs that would have minimal effect on facility reporting procedures, but would allow a direct link between RMP data and the OII data reported by facilities. This would bypass the arduous process of matching that had to be undertaken for the present study and could provide valuable future insights when integrated with data on other factors that might be advanced as drivers of EH&S performance. Beyond the valuable studies noted just above, there remain many important insights for industry and policy makers related to the continuing assessment of the RMP data. For example, recent results in Kleindorfer et al. (2007) show some significant decreases in injury rates associated with RMP accidents between the first wave of RMP filings studied in this paper (the 1999-2000) and the

[7] Note our interpretation of "necessary" and "sufficient". We interpret good performance on OII rates as necessary for good RMP performance to mean that high OII are associated with higher than average RMP accident frequency and severity. We interpret good performance on OII as sufficient for good RMP performance to mean that low OII rates are associated with lower than average RMP accident frequency and severity.

second wave of RMP filings (filed in 2004-2005). Studying whether these decreases in injury rates are associated with corresponding decreases in the same facilities in their OII rates, and relating both RMP and OSHA trends to changes in technology and management systems in specific sectors, could be an important source of greater understanding of the foundations of process safety and major accident prevention.

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Facility Characteristic	All Facilities (n=15,219)	Not OII Eligible (n=11,854)	*p*-value vs. Matched	OII Eligible, Not Matched* (n=2,279)	*p*-value vs. Matched	OII Matched* (n=1,086)
Mean # FTEs	155 (1179)	80 (1204)	<.001	427(1209)	.004	404 (550)
Mean Total Hazard Measure**	13.8 (19.0)	12.0 (14.0)	.83	20.5 (31.1)	.25	19.3(26.7)
Mean # of Toxics	1.08 (.95)	1.02 (.79)	<.001	1.29 (1.37)	.82	1.30(1.31)
Mean # of Flammables	0.30 (1.14)	0.21 (.86)	<.001	0.67 (1.85)	.12	0.57(1.56)
% Injury	3.6	2.0	<.001	9.8	.71	8.8
% Death	0.11	0.06	.055	0.26	1.00	0.28
% Property Damage***	0.8	0.3	<.001	2.7	.45	2.2
% Evacuation/ Sheltering	1.1	0.6	<.001	2.9	.63	2.6
% Environmental Damage	0.5	0.4	.044	1.0	.75	0.8
% any Property/ Any Sheltering/ Any Env. Damage/ Any Death	2.0	1.1	<.001	5.8	.34	4.9

*OII eligibility and matching status is defined in the data sources section of this paper.
**“Total hazard” is defined in data analysis section of this paper.
***Property damage restricted to reported accidents with $100,000 or more of damage (on- and off-site).

Table 1: Descriptive statistics for facilities reporting to RMP*Info, by OII reporting status. Standard deviations in parenthesis.

All facilities				OII-Matched facilities		
NAICS	N	Percent		NAICS	N	Percent
Farm Supply Wholesalers	4317	28.4		Refrigerated Warehouse And Storage Facilities	99	9.1
Water supply/ Irrigation systems	1975	13.0		Poultry processing	76	7.0
Sewage Treatment Facilities	1410	9.3		Plastics/resin Manufacturing	70	6.4
Refrigerated Warehouse And Storage Facilities	563	3.7		Other organic chemical Manufacturing	61	5.6
Natural Gas Liquid Extraction	478	3.2		Petroleum refineries	35	3.2

Table 2: Five most common processes: among all RMP*Info reporting facilities, and among only those linked to OII data.

	Any RMP-Reported Incidents of the Indicated Type?		
RMP Incident Type	Yes	No	P-value*
Injury	3.36±6.15 (n=95)	3.42±4.51 (n=985)	.057
Property/ Evacuation/Sheltering/ Environmental Damage/ Death	2.62±3.89 (n=53)	3.46±4.71 (n=1027)	.039

*P-value under Wilcoxon rank-sum test of common mean. ORWRII=OSHA Reportable Work-Related Illnesses or Injuries.

Table 3: Comparison of Mean ORWRIIs/Year/100 FTE for firms with and without an RMP reportable accident reporting period that led to: (Row 1) an injury, or to at least one of the following effects: a) property damage >$100,000 (on- or off-site), evacuations or sheltering, environmental damage, or death; standard deviations in parentheses.

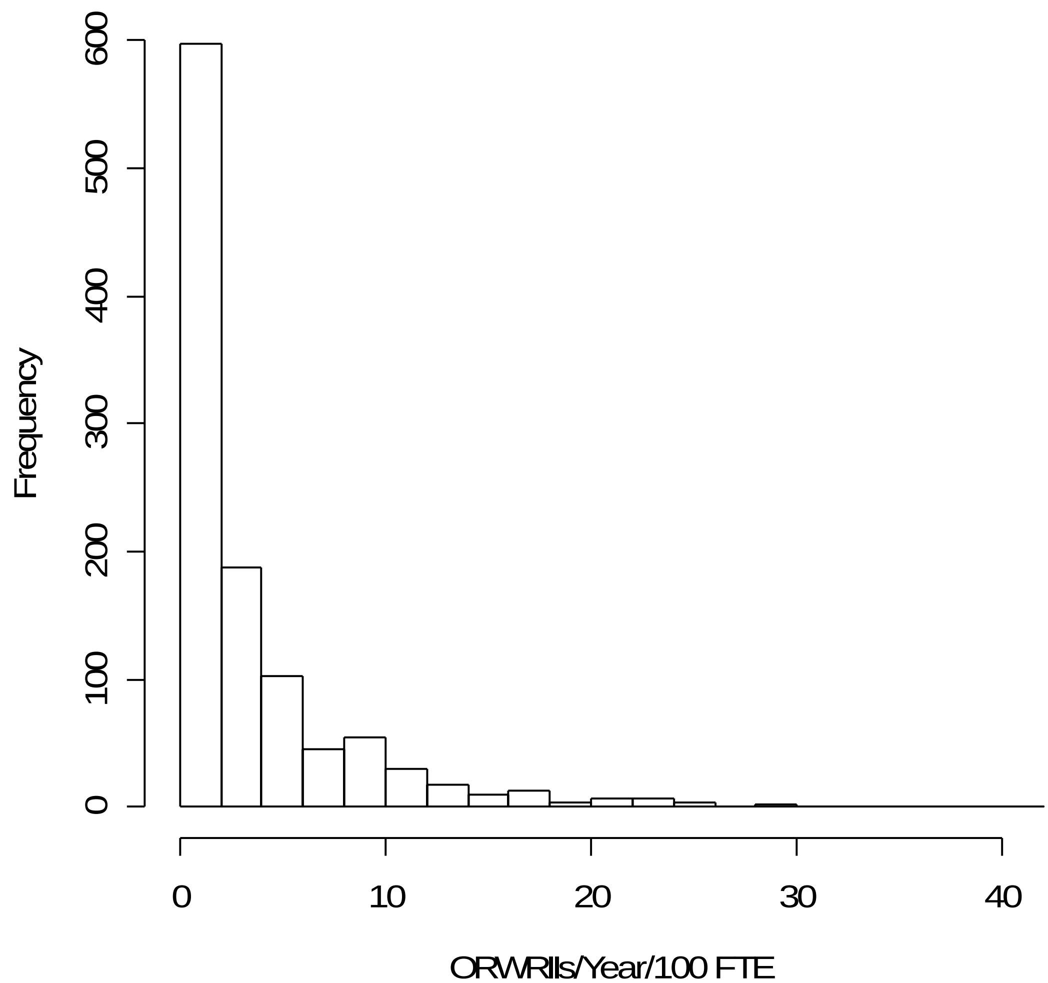

Figure 1: Histogram of ORWRIIs/Year/100 FTE among OII-matched RMP*Info facilities. (ORWRII = OSHA Reportable Work-Related Illnesses or Injuries)

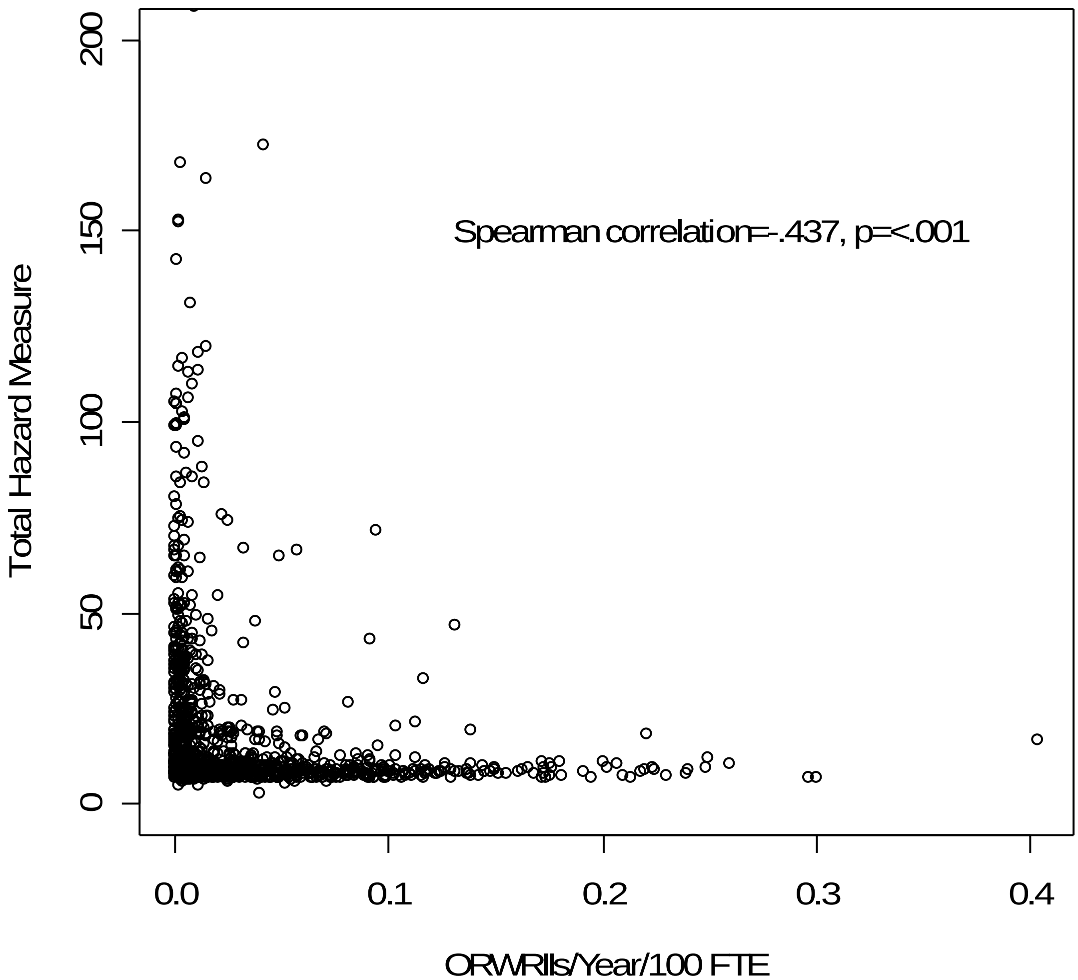

Figure 2: ORWRIIs/Year/100 FTE vs. Total Hazard Measure among OII-matched facilities.

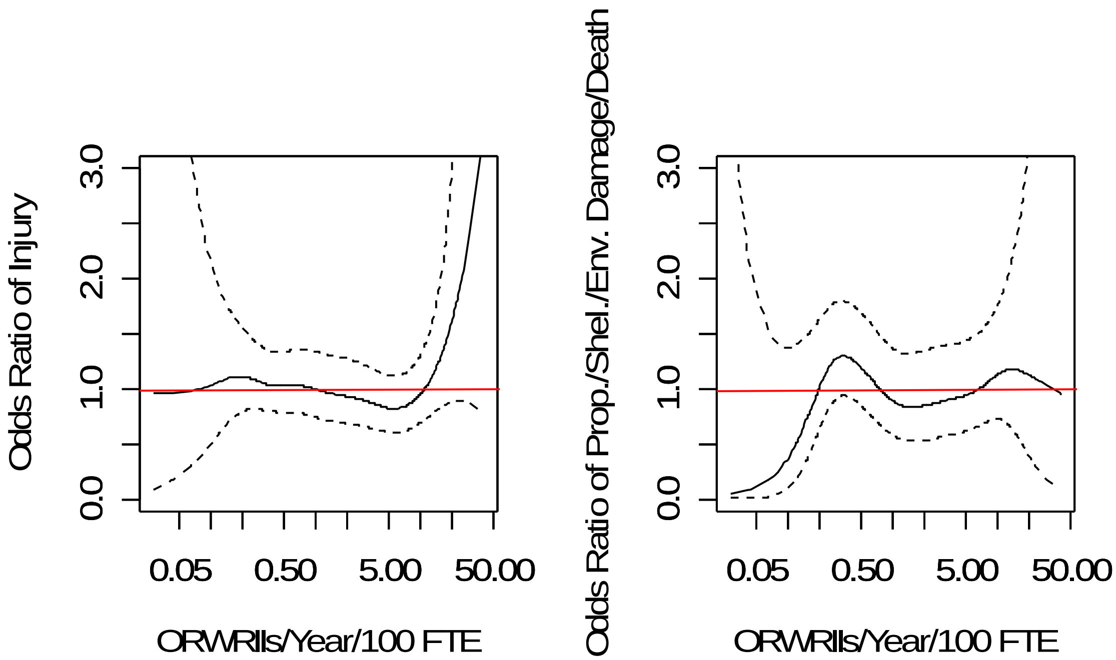

Figure 3: (a) OR of any RMP*Info-reported injury and (b) OR of any RMP*Info-reported property damage, evacuation or sheltering in place, environmental damage, or death; by OII rate. Adjusted for total hazard measure. 95% confidence interval given by (----). OR = Odds ratio of an event occurring, relative to the average odds (probability of the event/[1-probability of the event]).

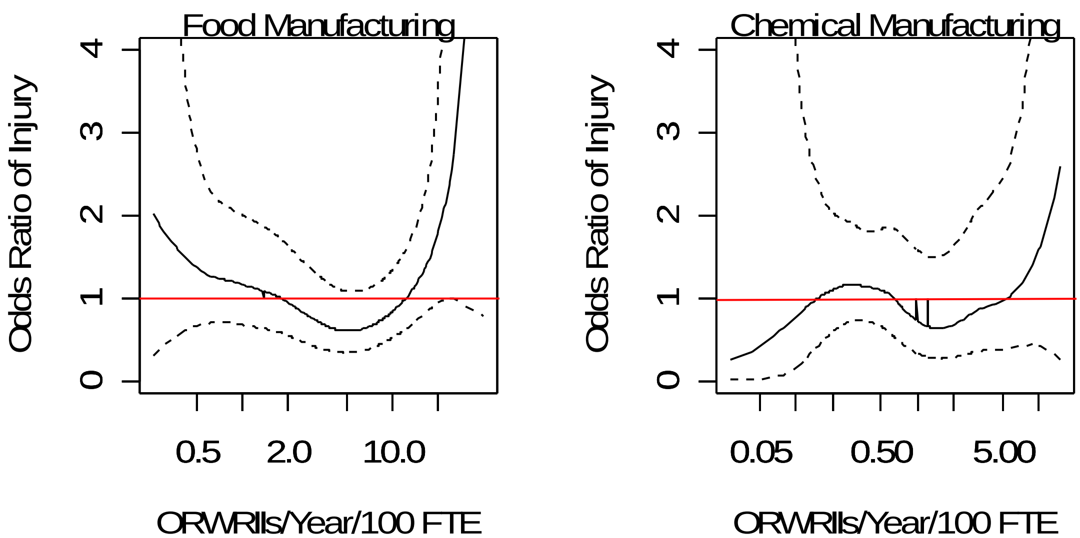

Figure 4: OR of injury by OII rate, among the n=335 facilities involved only in food processing and n=228 facilities involved only in chemical manufacturing. Adjusted for total hazard measure. 95% confidence interval given by (----). OR = Odds ratio of an event occurring, relative to the average odds (probability of the event/[1-probability of the event]).