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Incident Database-based Framework for Establishing Industrial Safety Performance Assessments

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Abstract
Many organizations collect data on industrial incidents. These organizations differ from each other in their interests, data collection procedures, definitions, and scope, and each of them is analyzing its data to achieve its goal and to accomplish its mission. However, there were no attempts to explore the potential hidden in integrating data sources. Extensive efforts are required in order to integrate information from different data sources as well as to identify the effects of the individual aspects of data collection procedures on the quality and completeness of the data. This work presents a methodology for incident data collection from various sources, and the opportunity that exists in a combined data mart for industrial safety performance assessment and identification of trends. It also presents the major challenges associated with utilizing databases, furthermore integrating these data sources for conducting industry-wide performance assessments. The study also discusses how the proposed analysis can be used to determine the areas for major reduction of losses and number of incidents.

Introduction
The fallout of dioxin caused by a runaway reaction at Seveso, Italy, in 1976, and the 1984 disaster of Bhopal, India, led to major changes in laws over the world. Federal and industrial entities devoted major efforts toward risk reduction and hazard control. Most of the organizations in the chemical industry integrated their systems for safety.

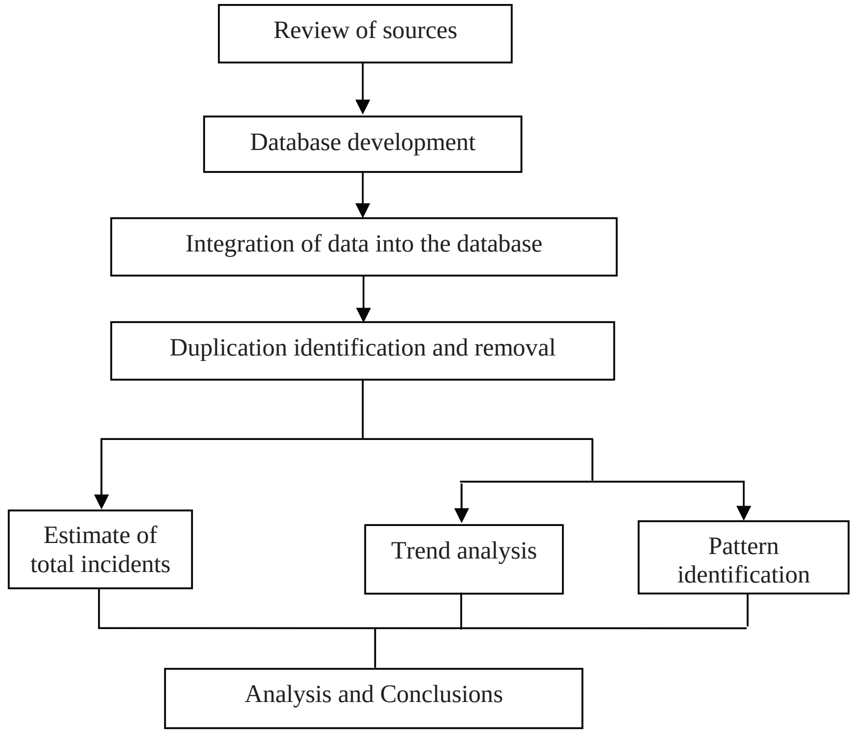
Beyond measuring performance within facilities (Keren, 2003, 2009), and among facilities (Keren, 2002, 2005), most of the efforts in the development of safety performance measurements are invested toward measuring the industry as a whole and with some efforts directed toward performance measurements of federal agencies.

The Occupational Safety and Health Administration (OSHA) is a federal agency under the authority of the Department of Labor (DOL) and is responsible for the safety and health of employees in the work place. OSHA's incident rate is a statistical index that measures illnesses and injuries per 100 worker years (DoT, 2009). The Fatality Accident Rate (FAR) is a European index mostly used by the British and is a statistical index that measures the number of fatalities per 1000 employees working their entire lifetime (50 working years per employee). Indices such as FAR and Incident Rate, which represent failure to effectively control risks, are called Trailing Indicators. These indices are important, and can be used to measure performance in industries. While OSHA's Bureau of Labor Statistics produces several such indices, these indices are normalized, and are per industrial sectors. There is still a need for a framework that will allow to conduct estimation of variety of performance indices for more specific, yet inclusive, industrial arenas. A most desirable type of arenas are performance indices for product-based (e.g., Chlorine, Ammonia, etc.).

Newell (2001) presents a very well developed concept of process safety performance measurements. In his work, he analyzes in detail OSHA's database as a sole source of data for performance measurements. Newell recommends using the OSHA rates for measurements only as part of comprehensive balanced assessments that include other key information. Newell calls for use of leading, trailing and financial indicators rather than trailing indicators only. His work is based on the balanced scorecard, which is best emphasized by "Accentuate the positive to eliminate the negative." This concept has been widely used since the early nineties and is common to many suggestions for performance measurement systems. Newell's work describes the features of the trailing, and leading indicators, but it does not actually develop the indicators. Although this work does not introduce the indicators, its contribution is significant in the phase where data sources are considered and in the phase of defining the indicators. Similar works have been done by Ritwik (2001), Walker, D. S., Schoolcraft, M., Casada, J. Leonard, & W. Hanson (2001), Morrison (2001), and Toellner (2001). All of these works contributed to some of the safety performance measurement in the process industry; however, none of them is comprehensive, well defined, and developed.

The European Organization of Economic Co-operation and Development (OECD) launched a project related to the development of Safety Performance Indicators for Chemical Accidents Prevention, Preparedness and Response (Clement, & Lacoursiere, 2001; Grenier, Jacobson, Jennings, & Schulberg, 2001). OECD distinguishes between the industry and the public. It discusses the Canadian stakeholder view of accident prevention, emergency preparedness, and response. Its indicators have many similarities to the OSHA's Voluntary Protection Program (VPP). OECD introduces the general concept for safety performance indicators in the process industry (Clement, & Lacoursiere, 2001). According to this work the project interim report should have been published in 2002, however, the report is yet not available.

Figure 1. Methodology flow chart



Incident Data

Overview

Many organizations collect data on industrial incidents. These organizations differ from each other in their interests, data collection procedures, definitions, and scope, and each of them is analyzing its data to achieve its goal and to accomplish its mission. There is an increased interest in using data on incidents to improve safety in the last 20 years. In the late 1980s, Marshal (1987) consolidated incident data from sixty or so years and harnessed it toward loss reduction, and loss prevention. Today the interest is bigger than ever, because of the development of information technologies that look promising in their abilities to see what "unarmed human eye" cannot see. Major efforts are being invested toward collection of incident related data. The US Department of Health and Human Services, The Agency for Toxic Substances and Disease Registry (ATSDR) maintains Hazardous Substances Emergency Events Surveillance (HSEES) and publishes annual and cumulative reports (http://www.atsdr.cdc.gov/HS/HSEES/), and is only one among many other type of data collection projects that is maintained by the Centers for Disease Control and Prevention (CDC). The US Department of Transportation repository consists of a large number of transportation safety related databases, and many reports are available on their website (http://www.transtats.bts.gov/). The last are only two from at least 15 sources of information of incident related data that have been analyzed and incorporated in assessments of industrial safety performance.

Assessment that is based on a methodology of incident data collection from various sources is a thorough process that has to be done carefully and in several stages. Figure 1 presents a simplified process for utilizing incident data collection from various sources for industrial safety performance assessment.

The primary focus of industrial safety performance assessments that use the methodology presented herein is to establish a baseline metrics for the universe (scope of the dataset) under inves-

Table 1. Sources of Information and Databases

Source	Database
Federal Emergency Management Agency (FEMA)	National Fire Information Reporting System (NFIRS)
U.S. Consumer Product Safety Commission (CPSC)	* National Electronic Injury Surveillance System (NEISS) * Death Certificates * Investigation Summary * Incident Summary
Mary Kay O'Connor Process Safety Center (MKOPSC)	News Clipping Database
States Associations	Iowa and Florida
State Agencies	State of Texas
National Response Center (NRC)	Incident Reporting Information System (IRIS)
US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry	Hazardous Substances Emergency Events Surveillance (HSEES)
U.S. Department of Transportation (DOT)	* Hazardous Material Incident Reporting System (HMIRS) * Integrated Pipeline Information System (IPIS) also known as Hazardous Liquid Accident Data (HLAD).
U.S. Environmental Protection Agency (EPA)	*Risk Management Program (RMP) 5-year Accident History *Accidental Release Information Program (ARIP)
U.S. Department of Labor, Occupational Safety and Health Administration (OSHA)	Accident Investigation System and several other databases.

tigation with regard to safety. This requires identification of incident trends, distribution of number of incidents, number of injuries, property damage costs, releases of materials, hospitalizations, and evacuations. These should then be analyzed and correlated across the causes of incidents, equipment involved, initiating events, location, and other indicators. Several of the sources of information that are publicly available collect only part or a sample of the information. Further use of information from databases for safety performance assessments, (not industry-wide) are demonstrated by Keren and colleagues (Keren, West, Rogers, Gupta, & Mannan, 2003; Anand, Keren, Tretter, Wang, O'Connor, & Mannan, 2006; Keren, Anand, & Mannan, 2006, Mannan, O'Connor, & Keren, (2008), and Mills, O'Neil, Seider, Oktem, & Keren (2007)).

Among the major conclusions from this study is to not be "misled" by the amount of data that a certain source may consist of. One of the sources of information provided about two-third of the data; however, it failed to collect significant data (e.g., failed to collect data with severe consequences). This conclusion justified the efforts that were required to broaden the search and combination of sources of information. A novel data collection methodology, based on News Clippings, is using search engines to query newspapers according to a predetermined set of keywords. The information is collected and submitted to the datamart. This method has several advantages including the ability to further investigate the incident or to verify the information if required.

The study herein presents the development of a methodology to assess industry-wide safety performance by applying the methodology above and by utilizing Set Theory applications on publicly available incident databases.

Sources of Information

The process of integration of data from several sources requires a thorough analysis of the databases that collect information on industrial incidents. Table 1 consists of a list of more than a dozen databases from ten sources that were integrated for an assessment project for a certain industry sector.

These databases were selected because they contain information that could be used to establish safety performance metrics for the industry sector. The form of the data reflects the interest, purpose, and scope of the organization collecting the data. Thus, a through review of each one of the databases was required. Tables 2 and 3 present the results of reviews of NFIRS and News Clippings, respectively. Keren (2003a) presents an Analysis of all sources.

The lack of national and international standard of reporting incidents, as Johnson (2002) mentions, has led to a lack of consistency among the sources with regard to coding used in the variety of fields. As a result, major efforts are needed to create an infrastructure that will allow data from variety of sources to "sit" together in a datamart.

Table 2. An overview of NFIRS

Dimension	Description
Covered Universe	In 1974 the USFA was authorized to gather data on US fire incidents. About 2 million incidents are collected annually from about 17,000 fire and emergency departments. The National Directory of Fire Chiefs and Emergency Department is the most updated list of fire departments in the US. This list consists of about 35,000 fire departments and about 6,900 emergency departments. About 50% of these departments are currently reporting to NFIRS from 50 states.
Collection Method	Fire and emergency departments report on events that required their involvement. Some of the departments report directly to the system, others report to the state fire marshal, and his office submits the information to NFIRS.
Principal Data Elements	Data collected on incidents for this database include the following: Time and date Address Consequences Damage estimation Material involved Fire/emergency department details Location categories Number of emergency personnel in the site Equipment involved Causes
Strengths	NFIRS is a very extensive data collection source of material incidents. It is able to capture a large amount of data, and includes a very detailed location code. The damage estimation is quite unique.
Weaknesses	Even though NFIRS consists of a large number of incidents, it fails to capture many of the most significant incidents, and therefore is not as comprehensive as it might seem.

Table 3. An overview of news clippings database

Dimension	Description
Collection Method	Collection methods vary somewhat among the sources. The archival sources present a short description of the clipping. Cases that are of interest are purchased/downloaded. Information was extracted from the sources and entered into the News Clipping database. The free real-time sources gather articles from a much larger number of sources but only retain information for about 30 days. Google searches more than 4,000 sources.
Principal Data Elements	The news-clipping database consists of several fields as well as an area for text descriptions. The information that is extracted is input to the following fields: Name and address of facility, company or dealer Date of incident Fatalities, injuries, hospitalizations, evacuations, and sheltering Distribution of the above among employees, contractors and general public
Principal Data Elements (continued)	Number of response units in the incident site Release location Nature of release Cause Material involved, and State of material released
Strengths	The news clipping procedure has several strengths: News clipping provides real-time information that can be used to follow up on incidents. Quite often the name of the local responder, investigator, or reporter is available. Allows direct contact to gain or confirm information, obtain investigative reports, etc. Gives text description of what happened Focuses on notable incidents Not just fires and explosions, but includes some near-misses as well Internet search getting better with time
Weaknesses	Information can be inaccurate or ambiguous, thus extensive efforts are required at times to clarify the information Some of the sources retain the information for a short period of time Converting news clipping to electronic form requires extensive human resources

Figure 2 demonstrates the information flow until it reaches its final destination. At almost every node the data is being converted, and the process must be done diligently in order to avoid misinterpretation of the data.

It is important to emphasize that the sources do not release the information as it becomes available. A real-time data collection from various sources is a long process that takes at least three years, as can be seen in Figure 3. Because of its real-time nature, the news clipping data collection system creates several opportunities: 1) Development of procedures for incident investigation for the real-time data collection; 2) Identification of a need for incident investigation and performing investigation; and, 3) Follow-up on information to validate causes of incidents and long-term consequences.

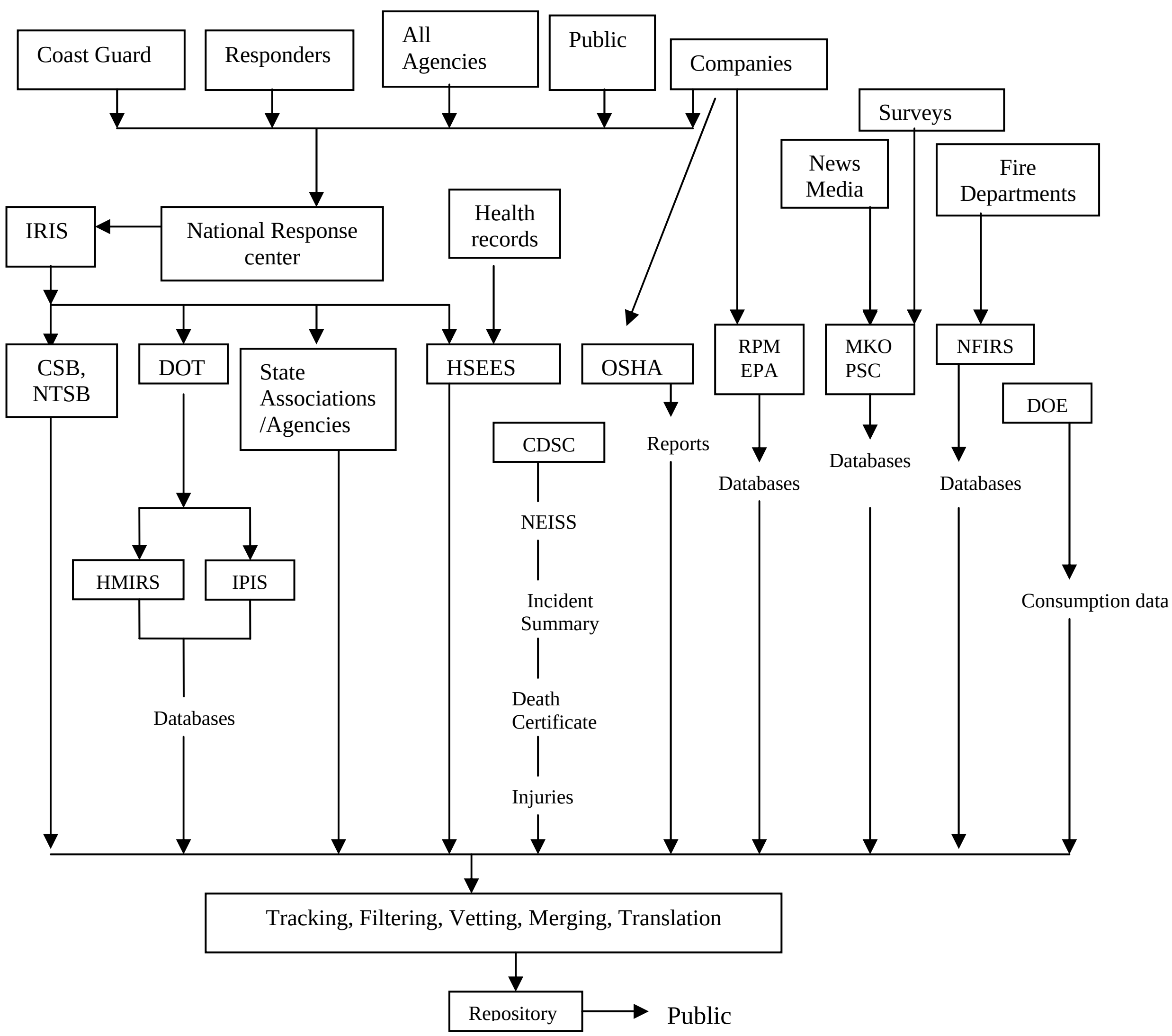
In many of the records that were examined, question arose that could have been answered quite easily if a real-time data collection process had been in place. In several of the records, it was hard to determine what the cause is, or what the initiating event was. As an example, one of the records contained data for an incident in Alaska. The record indicated 99 fatalities for a single incident. Since it is reasonable to assume that an incident with such large number of fatalities would be covered by the media as well as by incident investigation reports, a thorough research was conducted, which revealed that the incident actually resulted in a single fatality and 99 injuries.

<u>Method of Duplication Identification and Removal</u>

At the end of the data submission stage (Figure 3), it is required to identify and remove duplications. Johnson (2002) discusses many of the problems involved in automation of the process of duplication identification.

There are two categories of duplications that are encountered during the

Figure 2. Information flow chart.



consolidation of incident information from a variety of sources:

- Duplications within the sources; and,
- Duplications among different sources.

In general, it is much easier to identify duplications within the sources than amongst different sources. However, the process of identification of duplications is similar in both cases. Duplication within the same source has the same type of information and is much easier to identify. The duplication identification process is illustrated in Figure 4.

The number of records in the list of 'Suspected as Duplications' is sensitive to the timeframe that is employed. However, in order to verify that the time frame used is not arbitrary, an algorithm was written to conduct sensitivity analysis of the number of suspected as duplications to the time frame. The results are presented in Figure 5. As Figure 5 reveals, the number of incidents that are suspected as duplications is highly correlated with the width of the time frame (RMS= 0.98).

The slope of the correlated line can serve as a qualitative relative indicator for the comprehensiveness of the database. Under the estimation that the probability of an incident to occur is not time dependent, the number of suspected duplication in a given time frame would increase as the portion of the universe of incidents increases. The slope of the curve becomes steeper as the comprehensiveness of the database increases.

Once the system creates a list of records that are suspected as duplications, the records are reviewed manually, and a decision with regard to these records are made. Records that are identified as duplications are marked, so queries will reveal only one of them. Identification of duplicates becomes quite difficult in cases where time of incident is not given.

As for duplicate identification within the databases, the process of verification of whether incidents are duplications varies according to characteristics of the incidents. NFIRS for example contains two types of duplications: 1) Fire department that reported the same incident more than once; and, 2) Incidents that were suspected as duplicates, because more than a single fire department reported the incident.
In the first case, the verification process is not complicated. In the second case, however, it was necessary to conduct an Internet search for county maps in order to determine if it is reasonable that a fire department from an adjacent county would assist another fire department and also report to NFIRS. In the majority of the cases the distance between the counties was too far to assume that the reports are duplicates.
An important criterion for identifying duplications is the number of injuries

Figure 3. Timetable of real-time data collection and analysis.

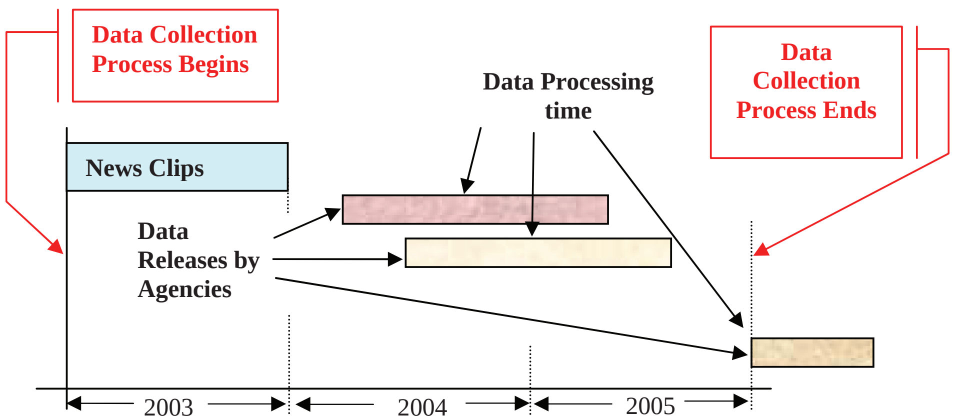
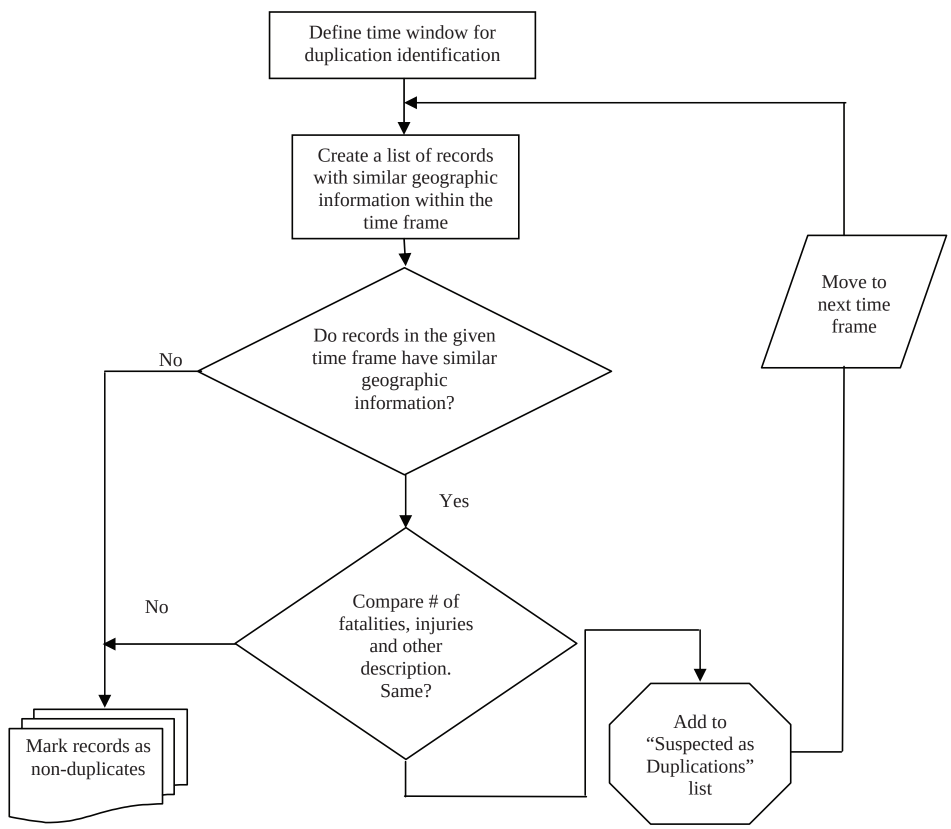


Figure 4. Procedure for identification of duplications.



and fatalities. If two incidents that have other similar characteristics also show exactly the same number of fatalities and injuries, there is a high likelihood that one of these incidents is a duplicate. The algorithm ignored incidents that have different number of injuries or fatalities. A thorough manual verification and quality control procedures were implemented to ensure that duplicates were identified accurately and that non-duplicates were not eliminated inadvertently.

As for duplications amongst different databases, the process required relatively more extensive efforts, and each of the cases needed to be treated separately.

Methodology for Estimation of Total Number of Incidents

The process for estimating the total number of Industrial incidents in the Unites States can be done by applying Set theory rules. Figure 6 qualitatively illustrates a Venn diagram of the situation with incident databases: The gray area represents the total number of industrial related incidents in the US. The white areas represent the actual number of incidents in each of the respective databases. The number of incidents from each of the databases is a subset of the total number of incidents that this database would consist of if all incidents were reported to the source (the set). For example, NFIRS, which is a database that consists of reports from emergency departments, contains records from about 14,000 fire departments from 42 states. The records in NFIRS are a subset of a set, which is the number of records that NFIRS would consist of if all 29,000 fire departments as well 6,900 emergency departments from the 50 states reported every Industrial incident to NFIRS (in 1999).

Figure 7 is an illustration of the relation between a set and a subset.

The Universe is a collection of all incidents that have the potential to be reported. Therefore, Universe is a composition of sets. The translation of

Figure 5. Sensitivity to time frame.

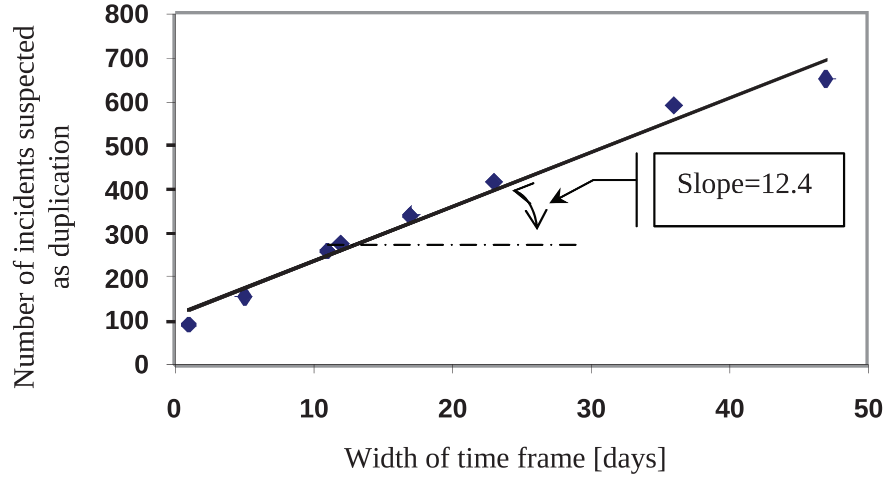


Figure 6. Illustration of relation between total number of incidents and number of incidents in the Sources.

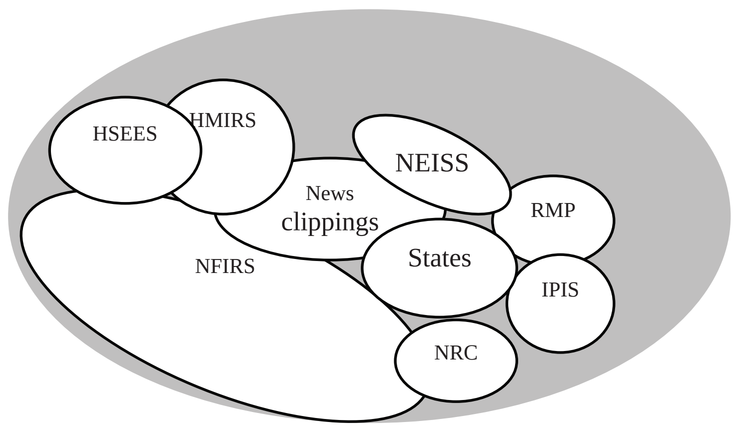
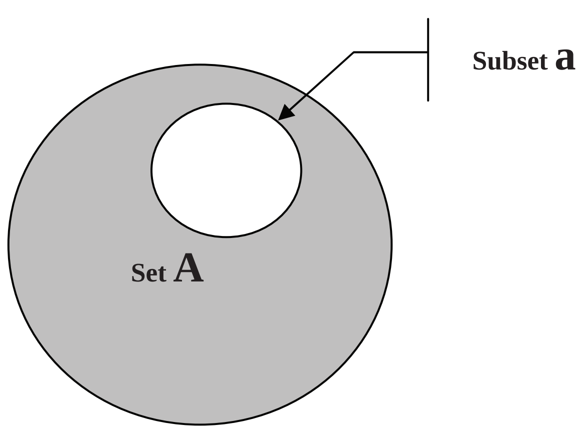


Figure 7. Relation between a set and a subset



the above to the theory of set language is as follows:

a_1 - is current records in database **DB1**

A_1 - is the potential number of record in the database DB1, if all incidents targeted by this database were reported.

a_1 is a subset of **A_1** → **$a_1 \subset A_1$**

a_2 - is current records in database **DB2**

A_2 - is the potential number of record in the database **DB2**, if all incidents targeted by this database were reported.

a_2 is a subset of **A_2** → **$a_2 \subset A_2$**

The same principles applies to a_3, a_4,......, a_n or all the databases. The Universe S (Figure 8) is a composition of all the sets.

However, there are overlaps among the sets, and therefore U is a union of the sets, as equation 1 in Figure 9 shows. Figure 10 presents the sequence of obtaining the information required to solve equation 1.

The following paragraphs describe the process for extrapolating the sets **A_i** according to the characteristics of each of the sources. The assumptions that were required in order to extrapolate the intersections between the sets are presented later.

Extrapolation of Sets A_i: The purpose of collection of information is not the same for all the sources, and therefore the characteristics of each of these sources should be incorporated in order to calculate the number of incidents that the source database would consist of if it were to capture all the incidents that belong in its category. A set of considerations, as well as the methods for extrapolating of information from the sets, A_i is developed individually.
Extrapolation of Duplicates: The ideal way to extrapolate the number of duplications is to extract several samples of sub-sets and to identify number of duplicates for combination of sizes. By using this methodology it is possible to study how the number of duplications increases with increase of the size of subsets. However, in cases where the databases consist of relatively low

Figure 8. The universe is a union of the sets (Venn Diagram).

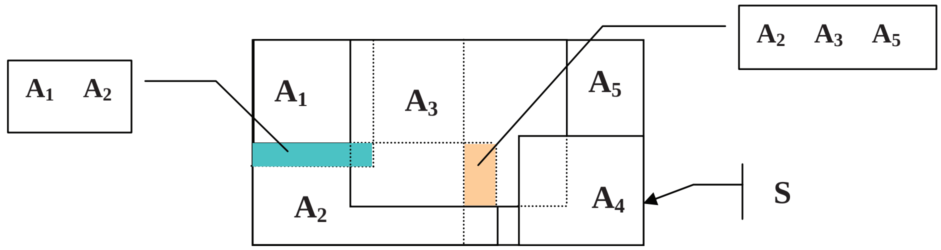
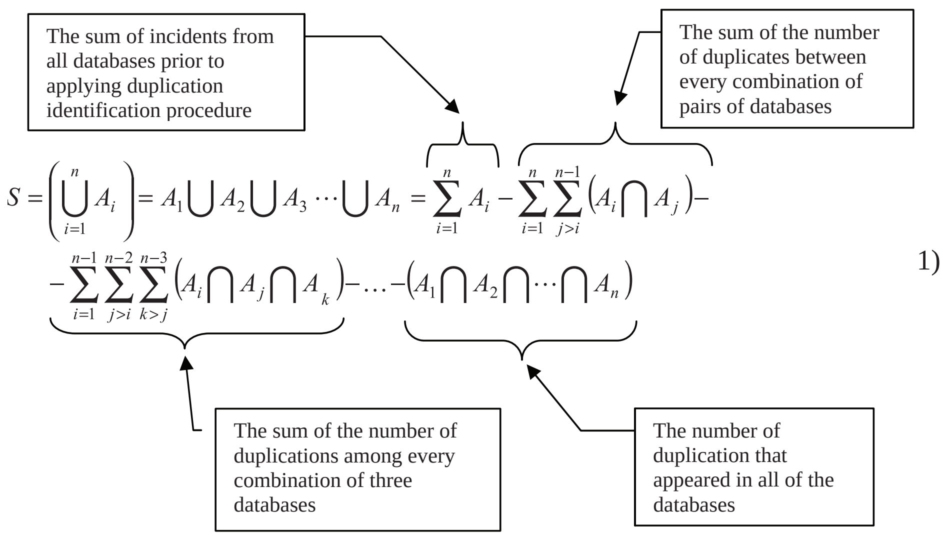
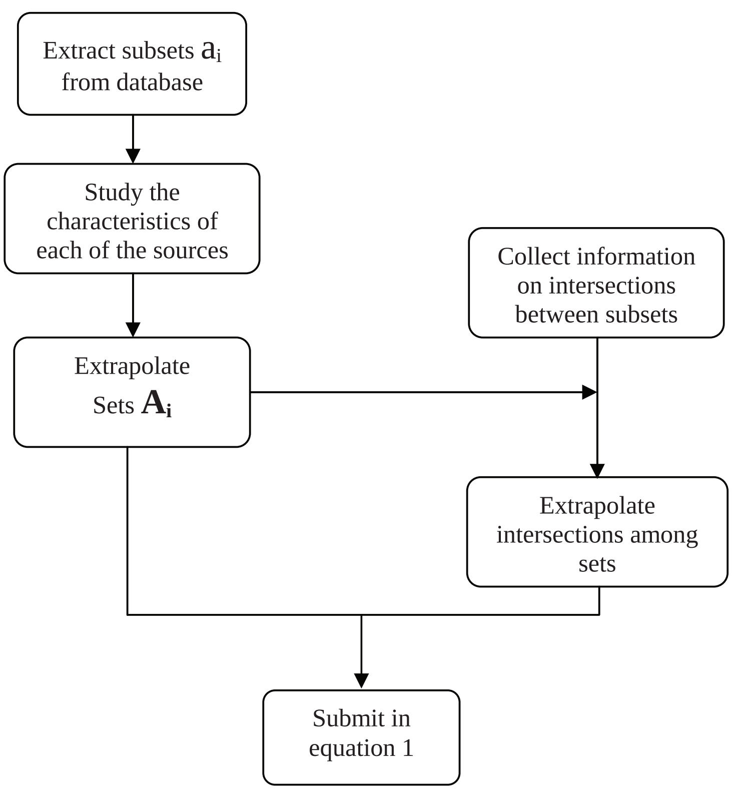


Figure 9. Union of sets.



$$S = \left(\bigcup_{i=1}^{n} A_i \right) = A_1 \bigcup A_2 \bigcup A_3 \cdots \bigcup A_n = \sum_{i=1}^{n} A_i - \sum_{i=1}^{n} \sum_{j>i}^{n-1} \left(A_i \bigcap A_j \right) - \sum_{i=1}^{n-1} \sum_{j>i}^{n-2} \sum_{k>j}^{n-3} \left(A_i \bigcap A_j \bigcap A_k \right) - \ldots - \left(A_1 \bigcap A_2 \bigcap \cdots \bigcap A_n \right) \quad 1)$$

+Figure 10. Sequence of estimation universe S.



number of duplicates, an approximation can be done by multiplication of the number of duplicates between sources by the ratio of the sum of the extrapolated number of the incidents and the sum of the actual number of incidents in the database.

Calibration of Information from Sources

When reviewing sources it is important to verify that the data represents the relevant population uniformly. The Consumer Product Safety Commission (CPSC) - National Electronic Incidents Surveillance System (NEISS) is a collection of injury data that are gathered from the emergency departments of 100 hospitals selected as a statistical sample of all 5,300 U.S. hospitals with emergency departments. NEISS surveys sample of hospitals that represent all ethnic groups and concentrations of population, and it is statistically valid to extrapolate this data. However, the Federal Emergency Management Agency, National Fire Information Reporting System (NFIRS) database, is a collection of incident reports from fire departments. About 50% of the fire departments in the US, from 50 states and the District of Columbia are reporting incidents to NFIRS (http://www.usfa.dhs.gov/fireservice/nfirs/about.shtm). These fire departments vary in size, ranging from departments that protect several dozen individuals (rural areas) up to departments that protect millions. Extensive efforts have been devoted to normalize the number of incidents from NFIRS based on population protected. Then, the inventory of all firefighting departments in the country was used to extrapolate the data and gain the total number of incidents. The process of extrapolation was repeated for each one of the sources based on the characteristics of the source.

Results

Figure 13 presents the result of implementation of the methodology of data collection from various sources on a petrochemical product (due to confidential agreement, the name of the product could not be survived) for 1999. The number of fatalities in Figure 13 is 136. The number of fatalities prior to the implementation of the methodology was 276 (98 from the 276 have been reported in one incident).

Table 5 present the distribution of fatalities and injuries by victim category. Figure 14 presents the age distribution of the fatalities.

Figure 15 demonstrates patterns of causes of incidents for the same product. Similarly, further analyses can be done to determine the distributions above as well as other distributions for sub categories (i.e., distribution of fatality categories for fires, for explosions, etc.).

The ability to conduct these types of analyses is very critical to determine effective lines of action and to develop intervention programs and regulations. Should the majority of the victims be emergency responder, the intervention program will be different than the program that will be developed for the general public. Similarly, programs that address different age groups will vary in nature.

Figure 13. Distribution of fatalities by cause of death.

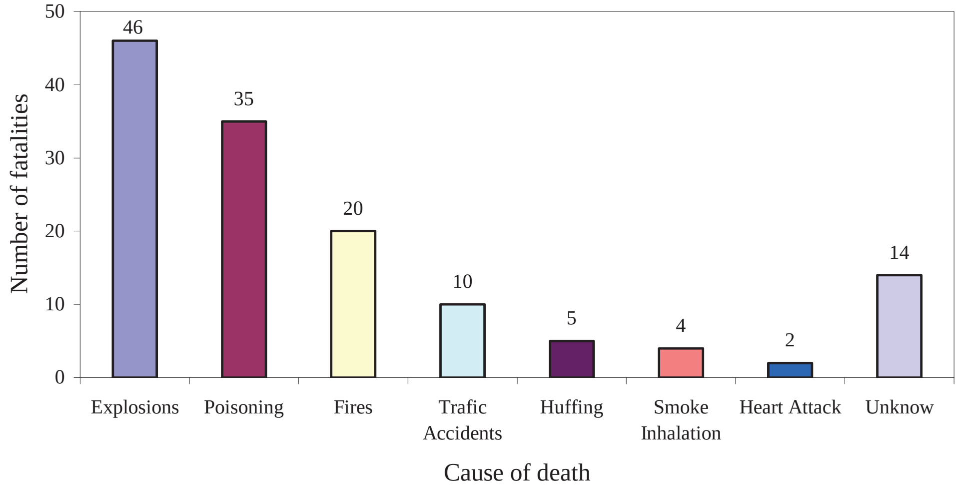
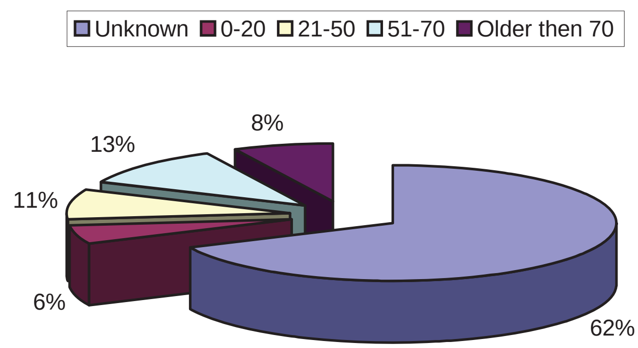


Table 5. Distribution of fatalities and injuries by victim category

Victim Category	Number of Fatalities	Number of Injuries
General Public	122	740
Worker/ Contractors	8	95
Fire Fighters/ Public responders	2	126
Unknown	5	51

Figure 14. Age distribution of the fatalities.



Further Research And Development

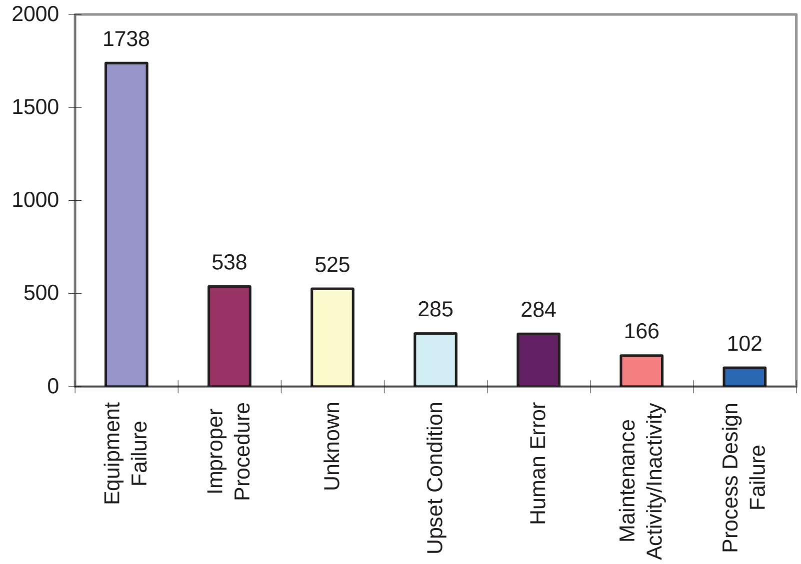
Extensive efforts are required to integrate information from a variety of data sources as well as to identify the effects of the individual aspects of data collection procedures on the quality and completeness of the data. A holistic approach that suggests an innovation of tools, methods, techniques, and procedures in order to extract information from the large variety of sources of information is required. The principles as well as the methods of such a holistic approach will be applicable to many disciplines such as civil engineering and insurance entities.
In an era where information processing power increases exponentially, it is hoped that the processes associated with the methodology above will be automated. Establishment of an automated procedure will tremendously reduce the efforts of integrating data sources, and make the process common.

Summary

The methodology herein was utilized to conduct several safety performance assessments studies. These studies demonstrated that it is worthwhile to collect data from a variety of sources, and that much can be learned from the consolidated database. However, in order to accomplish the ultimate goals of safety performance assessment, the consolidated database must include root cause information. Conducting root cause analyses will be more effective if data is collected 'real-time'. The need for a real-time data collection process is critical due to the short time that news clipping are stored in news archives and due to the need of further investigating incidents at times. The reliability of information gathered decreases significantly with time.

Implementation of the proposed methodology yield an opportunity to develop educated intervention programs, a capability that industries strive for.

Figure 15. Distribution of number of incidents by cause.



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