Developing an Incident Response Process Model for Chemical Facilities

Stephen C. Fortier
George Washington University
sfortier@gwu.edu

ABSTRACT

This research project investigated the incident response mechanism used by the chemical industry for handling extremely hazardous chemicals. The mechanism was described as the policies, procedures, practices, tools, and methods used to conduct incident response. The results from the study determined what technologies, specifically software and information systems, could be utilized to improve the chemical facility incident response mechanism. The chemical industry is responsible for process safety management at all of its facilities, especially those that have off-site consequences in the event of an unplanned release.

The processes and procedures of local, regional and national emergency responders have been studied thoroughly. An area of research that is lacking is the study of incident response policies and procedures within the boundaries of a chemical site. Results of the analysis determined that the chemical industry, in general, does not take advantage of available information technology when responding to unplanned releases.

Keywords

Information technology, requirements engineering, emergency management, information technology, business process modelling, incident response, chemical facility, hazardous substances, emergency response team.

INTRODUCTION

This research concentrates on understanding the chemical industry's ability to respond to unplanned extremely hazardous chemical (EHS) releases that were caused by man-made or natural phenomena. This research characterized the methods, practices, experiences and problems when chemical facilities respond to chemical incidents potentially caused by operator error, system fatigue, terrorism, insider threats, or natural disasters. Special interest was paid to small- and mid-sized production facilities where reports have indicated that these facilities generally lack the resources to implement rudimentary safety and security precautions. A specific concern was to identify how information technology is used to provide the situational awareness of the inherent risks in the environment. Many of the chemical facilities use the "acceptable risk" method for protecting their assets without consulting with people in the surrounding communities.

Chemical facilities have inherent risks associated with the type and quantity of hazardous or toxic chemicals on their site. The threat of terrorism, potentially on chemical sites, heightens the risk of loss to the local population, property and the environment.

The attack of the USA on 11 September 2001 brought to focus how ill-prepared this nation was to protect itself from terrorist attacks. The Federal Government was unable to cohesively work together to respond to the attack (Kean, 2004); recovery efforts suffered from inefficiencies; and health and safety issues affected the emergency responders. The Government established the Department of Homeland Security (DHS) in January 2003 to provide a coordinated national response to the issues of emergencies, disasters and terrorism. The goals of DHS are to provide awareness, prevention, protection, response, recovery, and service to this country. As part of DHS' charter, the nation's critical infrastructure was categorized into 16 key elements. The Critical Infrastructure Protection (CIP) elements included threats to the power grid (Kluepfel, 2004), the chemical industry, finance and banking systems, and maritime domain (NSPD-41, 2004). It also became clear that the Government could not achieve its goals alone. It needed the cooperation of industry, private citizens and others to tackle this difficult threat to the nation's security. Industry groups, like the American Chemical Council (ACC), rallied its member companies to respond to the threat. According to the ACC, its members are required to conduct vulnerability assessments, design and put in place plans to mitigate vulnerabilities, and have independent validation and verification that security measures were implemented (ACC, 2005).

It is interesting to note that the ACC member companies are providing safety and security internally with an eye on government regulations. The ACC (2001) pointed out:

In the chemical industry, incident response and crisis management functions are especially complicated, and the way in which they are performed is to a great extent dictated by government regulation. This section, therefore, does not attempt to specify how a company should respond to emergencies and manage crises.

This comment suggests that the chemical industry is required to learn how to effectively respond to potential hazards and threats to their assets. There are published reports that ACC members spend millions of dollars annually on facility safety and security, with the emphasis on safety — but the industry still needs to work on the security aspects.

Other related industry associations, such as the Chlorine Institute, the National Petrochemical and Refiners Association and the Adhesive and Sealant Council, have also developed best practices, security guidelines, methodologies and tools to support their member companies' unique requirements.

The DHS has developed a chemical sector-specific plan that would coordinate stakeholders from national, state, local, and private sector chemical facilities. This plan focuses on assessing vulnerability of "high target" chemical facilities and developing programs to protect against terrorist attacks. High target chemical facilities are defined as facilities that produce or store EHS as defined by the Environmental Protection Agency (EPA) under SARA Title III "List of Lists" (EPA, 2001); and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The CERCLA was passed into law on 11 December 1980 (CERCLA, 2009).

The problem with this approach is that smaller chemical facilities may not have the resources to implement these security measures and will remain vulnerable to a terrorist attack.

In the field of safety management there is an emphasis on managing the modes of risk, hazards and loss. These modes therefore are the major thrusts of safety managers. Risk is a function of the probability of a hazardous state resulting in a mishap or incident (Fortier and Michael, 1993). "Hazards are states of a system…when combined with certain environmental conditions could lead to a mishap" (Levenson, 1995). When there is a harmful contact incident (mishap) the result is a loss of humanity (injury or death), property or efficacy. "Losses involved with different areas of a business activity can be classified as minor, serious, major or catastrophic" (Fortier, et.al., 1993).

Emergency response for chemical facilities requires the confluence of pre-planned and "ad hoc" coalitions to respond to the emergency event (harmful contact incident). The more "familiar" emergency situation tends to be handled by a pre-planned coalition. For example, the CHEMTRAC (ACC, 2007) response mechanism is currently used by the chemical industry to handle these types of incidents. As the severity of the incident escalates, however, the response tends to be a mixture of pre-planned and ad hoc components.

The U.S. Government considers the chemical industry as one of its critical infrastructure elements. Other critical infrastructure elements include banking and finance, transportation, water systems, the power grid, etc. If there is a cyber-attack on the banking industry, there may be loss of property and efficacy, but no human loss. Incidents at chemical facilities can easily escalate into situations where human life is at stake. The chemical industry is special in that when an incident occurs at one of its facilities, the consequences of the event can be catastrophic and become an extreme event, as described by Sarewitz and Pielki (2001).

What would the impact on an incident response be if the chemical facility used sensors for early warning of unplanned chemical releases? Given a release, do chemical facilities use atmospheric dispersion models to determine who in the general public is at risk of injury or death? What are the policies and procedures for communicating a chemical release to the local authorities and the general public? Are decision support systems currently used in the decision making process when there is an incident? These questions were explored during this research project.

Every chemical facility is required by law to have an emergency response plan. The question is — how effective are the incident response mechanisms? The probability that a chemical facility will experience an extreme event[1] due to man-made or natural disasters is low. So, what is the optimal and most cost effective solution for a problem that one may never face? This research looked at this problem and the results will support the development of future incident response systems.

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[1] An extreme event arises when a man-made hazard or natural phenomena occurs that overwhelms the local emergency response's ability to effectively respond to the incident. Extreme events are usually a rare occurrence.

LITERATURE REVIEW

A literature review was conducted to research the existing literature that addressed incident response mechanisms for chemical facilities. There is a lot of literature published for generic (non-domain specific) incident response such as National Response Framework (FEMA, 2008) and the National Incident Management System (NIMS, 2008). These documents are written from the perspective of the local authority response to emergencies and disasters. I could not locate any research papers that studies incident response from the chemical facility perspective. When there is an unplanned chemical release, the true first responders are the operators and maintenance workers on site.

Hence, an area of research that is lacking is the study of incident response policies and procedures within the boundaries of a chemical site. This situation is exacerbated for a number of reasons:

- Chemical companies do not publicly share their emergency response plans due to security reasons
- Chemical facilities that manufacture or store EHS are prohibited by EPA and DHS law from publically disclosing actual quantities and types of chemicals
- Concerns about trade secrets

Since there is not a lot of published academic research, it became necessary to examine the current state of practices for securing chemical facilities and the information technology involved in supporting preparedness and response to emergencies. Key elements of response mechanisms were reviewed, such as situational awareness, information technology support for incident management in a dynamic environment, dynamic response information systems, information technology effectiveness, and system of systems methods. System process modeling methods were also researched.

After an initial review, the literature search was focused on:

- Chemical Facility Posture
- Citizens' and Workers' Right-to-Know
- Information Technology for Emergency Response
- Early Warning Systems
- System Process Modeling and System Engineering
- Critical Path Analysis

The chemical facility posture literature search describes the current state-of-the-practice and highlights the issues and concerns of the industry. This is closely related to the citizens' and workers' right-to-know literature search. The literature described the legal basis for chemical facilities first, to have a mechanism to respond to incidents and second, to compel them to report hazardous incidents to the public.

The literature search for information technology for emergency response provided background on the critical elements when developing or maintaining an incident response mechanism. This is closely tied to the early warning systems (EWSs) literature search, since technologies (specifically information technologies) provide the components of the EWSs. Early warning systems are the critical component in an emergency response mechanism.

The literature search on process modeling of systems provided the front end of the modeling and simulation effort. The systems simulation literature search provides the context for creating accurate and effective simulation models.

METHODOLOGY

This research followed a concurrent method similar to the sequential exploratory design mixed method approach. The following were the core activities and the sequence of execution.

1. Interview Industry Experts. Developed an understanding of the problem through the use of informal interviews. Critical industry issues were discussed and theoretical questions were formulated.
2. Formulate and Test Questions. Designed of initial set of questions that were vetted by industry experts.

3. Develop Integration Definition for Function Modeling (IDEF0) Model (IDEF0, 1993). Used IDEF0 modeling to bound the domain of discourse for incident response at chemical facilities
4. Set Qualifications for Chemical Facility Participation. The qualification for participating in the study was that the facility had to have a potential for off-site consequence from an EHS and one of the following:
   a. At least one Risk Management Plan[2] (RMP) process listed in the EPA RMP* database (RMP, 1999)
   b. At least one EHS chemical listed in the CFATS database
   c. Obtain a Seveso[3] Low- or High-Tier designation for chemical facilities in Europe
5. Develop Questionnaire. A web-based form was developed.
6. Chemical Facilities Agree to Participate in the Study. Facilities that participated were required to supply their current Emergency Response Plan. Efforts to enlist facilities included:
   a. Discussions with the American Chemistry Council
   b. Joining industry trade organizations such as ChemITC
   c. Email recruitment campaign, including cold calling of chemical facilities
7. Site Visits and Data Collection. Administration of questionnaire to statistically representative population of mid- to senior-level chemical facility workers. Created workflows for each of the chemical sites that participated in the study.
   a. Used Business Process Modeling Notation (BPMN) tool to create workflows for each of the chemical sites that participated in the study (BPMN, 2006)
   b. Identified "actors" during incident response
   c. Identified information exchanged between activities during incident response
   d. Determined tools and technologies used during incident response
   e. Determine the timing and sequencing of activities during incident response
8. Generation and aggregation of descriptive and inferential statistical analysis of the questionnaire results.
9. Conclusions and Interpretation of Qualitative and Quantitative Results.

The researcher conducted an initial round of interviews with industry experts to scope the problem area. Based on this early research, it was determined that a formal questionnaire would be developed to capture the data. A web-based form was used to facilitate the capture of the data. Business process modeling was used to capture the incident response workflows from each of the 12 chemical sites. This method was selected because it provided the stakeholders with a visual model, which was the preferred method of the sample set.

RESEARCH RESULTS

Twelve facilities participated in the research project. Table 1 highlights the characteristic of each of the sites. The facility name, specific location, and actual number of employees were obfuscated to protect the identity of each of the chemical facilities. Participants were located throughout the United States and Europe.

The goal of the research was to study how chemical facility personnel respond to unplanned chemical releases. This paper focuses on the process modeling aspect of the research, but there were also mechanisms used to affect a response (where a mechanism is an instantiation of the methods, policies and tools used by each location). The following data were analyzed:

Validation of the Emergency Response Plans (ERPs). Each of the 12 sites provided their ERP. Some

[2] Risk Management Plan (RMP) database developed by the Environmental Protection Agency. The processes indicated the number of processes the facility has that involves an extremely hazardous chemical (EHS).

[3] Seveso Level is based on the European Community Seveso Directive. The directive lists hazardous chemicals and quantities of those chemicals.

participants redacted their ERP to exclude information about the worst case scenarios or the EHS used at the facility.

Facility Name	Area	Employee Range	# RMP Processes	CFATS	Seveso Level
Alpha	Southwest, US	50-100	5		
Beta	West, US	50-100		X	
Gamma	Southwest, US	0 to 50	5		
Delta	East, US	50-100	5		
Epsilon	South, US	0 to 50	3		
Zeta	South, US	100-500	3		
Eta	England	0 to 50			Low-Tier
Theta	England	0 to 50			Low-Tier
Iota	Ireland	100-500			Low-Tier
Kappa	South, US	100-500	4		
Lambda	South, US	500+	8		
Mu	Belgium	100-500			High-Tier

Table 1. Characteristics of Participating Chemical Facilities[4]

Expert Interview Qualitative Data Analysis. A questionnaire was developed but the interviews were open-ended. These interviews identified elements of qualitative incident response heuristics, methods and processes. The results of the analysis were collected in an aggregated data set.

The main finding were the development of site specific incident response process models, a calculation of critical path analysis for each of the process models, analysis of information technology used during incident response, and recommendations to make improvements to incident response.

Questionnaire Statistical Analysis. The questionnaire was executed to test the research hypotheses, and to elicit judgment and advice from mid- to senior-level chemical facility incident response personnel. The analysis of the questionnaire results produced a statistically representative delineation of how incident response personnel operate during unplanned releases.

There were three hypotheses that were tested, where the null hypothesis is H_0 and the alternate hypothesis was H_1. The following hypotheses were developed from the research sample:

(1) H_0: Emergency Response Managers can accurately predict the average time required to create a go forward plan after an unplanned release of an EHS has been detected.

(1) H_1: Emergency Response Managers cannot accurately predict the average time required to create a go forward plan after an unplanned release of an EHS has been detected.

(2) H_0: Decision support tools are used during incident response to assist in problem resolution.

(2) H_1: Decision support tools are not used during incident response to assist in problem resolution.

(3) H_0: Chemical facilities use integrated an IT solution to support incident response.

(3) H_1: Chemical facilities do not use integrated an IT solution to support incident response.

The research questions were answered using quantitative analysis of the questionnaires. The first hypothesis was tested using the Paired t-test, or Student's test.

The other hypotheses [(2) and (3)] were tested based on the quantitative analysis of specific questions from the questionnaire. The researcher asserted that a majority (> 50 percent) of the respondents utilized decision support tools, and used an integrated information technology solution to support incident response: Therefore, H_0: $x > 50$ percent, where x is the test statistic. A reject region of $x > 35$ percent would strongly reject the H_0 in favor of the H_1 (Devore, 2004).

In all three cases, the null hypothesis was rejected!

Quantitative Analysis of Critical Path. The results of the ERP reviews, interviews with industry experts and

[4] A qualified chemical facility required at least one RMP process, OR be a CFAT facility, OR be a Low- or High-Tier Seveso rated facility.

answers to the questionnaire contributed to the development of critical path analysis for each of the facilities in the research project. The analysis was necessary to statistically determine the time it would take for the Emergency Manager to react to an unplanned release and develop the "go forward" plan for on- and off-site consequences.

A critical path analysis was conducted at each site to determine the time required to render a go forward plan. The evacuation of personnel was a critical factor in this analysis and could potentially lead to delays in responding to incidents. The critical path included personnel disposition in 83 percent of all the incident response workflows. This indicates that the activities surrounding shelter-in-place, evacuation, muster and roll call are important factors in the incident response process. The analysis found that response times varied from 21 to 53 minutes in the sample.

Incident Response Assessment. The results of the ERP reviews, interviews with industry experts and answers to the questionnaire, and critical path analysis contributed to defining an best practice incident response mechanism for chemical facilities when responding to unplanned releases. This analysis led to a recommendation of an industry model for incident response, best practices during the response and tools and technologies to assist in incident response.

Based on the analysis, the essential elements of an effective and efficient incident response mechanism include:

- Trained personnel with well-defined roles for when they are called to perform incident response. Although the preparation phase of incident response was out of scope for this research, it was clear that facilities that performed regular training had better results in the critical path analysis
- A proven repeatable process. The process must be integrated; and not a mere execution of a set of loosely connected (or unconnected) checklists
- Personnel disposition. The processes used for muster, shelter-in-place, evacuation, and roll call should be analyzed to ensure that personnel are quickly accounted for in a safe manner
- Information management. The response mechanism must collect and share information in a timely and efficient manner. None of the sites had an automated incident response process, but the researcher suggests that it would improve efficiency. This assertion is based on the results of the interviews with the industry experts.
- Decision support tools for the mission.
- Integrated communications. Communication equipment must be standardized throughout the facility; and protocols for emergency communications should be consistent among different operating groups

Validation of Results

An incident response process model was developed as a result of the research. This model was an amalgamation of the 12 incident response process models that were developed for each of the chemical facilities. The research developed a process model for each of the sites. Each site individually reviewed their respective models to validate that they were correct. After all of the process models were reviewed the researcher developed a unified incident response process model.

The goal for developing a best practice incident response process model was to share the findings within the chemical manufacturing industry. This model could be used for the following:

- Tool to evaluate an existing chemical facility incident response mechanism
- Template for creating an incident response mechanism for a new chemical facility
- Potential industry standard for incident response to unplanned chemical releases

All of the participating chemical company representative reviewed the amalgamated incident response process model and provided feedback to the researcher. One of the goals of the researcher is to present these findings at an chemical industry conference in the near future.

The EXPRESS G[5] model highlights the physical attributes used during incident response at a chemical facility. Figure 1 illustrates the attributes and workflow of a standard incident response process model for chemical facilities. The elements include:

[5] EXPRESS G is an international standard for graphical notation for information modeling.

- Chemical container. This is an abstract super-type of (one of many) the process control system, storage unit, and transportation element. These containers hold the chemicals of interest. The incident response mechanism is unique for each chemical facility, no two are the same:
  - The process control system includes the mixers, scrubbers, separators, distillation, pumps, compressors, and piping
  - A storage unit includes portable or fixed tanks, drums and containers for dry chemicals
  - A transportation element includes trucks, rail and water borne that move chemicals in and out of the facility
- Distribution Control System (DCS). The DCS controls and monitors the activities of the chemical manufacturing system. The DCS provides indications and warnings when there is a potential for an unplanned release

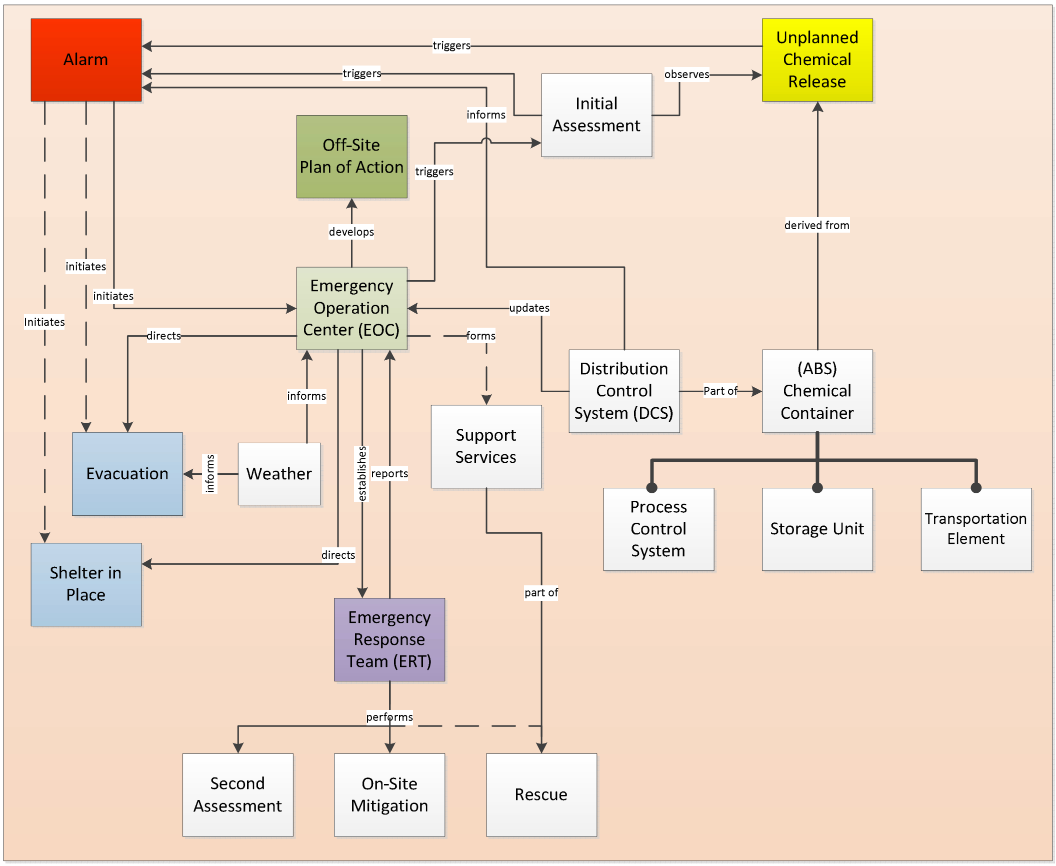

Figure 1. Best Practices Incident Response Process Model

- Initial Assessment. The true first responders, when there is an unplanned chemical release, are the maintenance, process control, and general work force at the facility.
- Unplanned chemical release. This includes the EHS chemical or chemicals that are release into the environment
- Alarm. The alarm could be automatically triggered or initiated through observation of a chemical release
- Weather. Windsocks provide wind direction, but weather instrumentation provides wind direction and speed, temperature, and humidity
- Emergency Operations Center. The EOC is the location on the facility where the command and control of the response activities are managed
- Emergency Response Team. The ERT are the true first responders. Whether operators, maintenance personnel, or full time fire brigade, these individuals diagnose the problem, affect rescues, and mitigate the problem

- Evacuation. One of the critical elements during response is to quickly and safely remove personnel from the danger zone. This needs to be accomplished while accurately accounting for all personnel. This is a personnel disposition activity
- Shelter in Place. One of the personnel disposition activities is shelter in place. The incident response manager makes the determination to either shelter in place or evacuate
- Support services. This includes the assignment of a safety officer, health officer, logistics, traffic controller, etc. Typically, the larger the facility, the more likelihood that more support services will be available

This model is not limited to the size of the chemical facility. It could be applied to small, medium or large chemical facilities. By implementing a model, described in Figure 1, a chemical facility would be less likely to have ad hoc or unplanned responses to unplanned chemical releases.

ANALYSIS OF RESEARCH FINDINGS

The findings were validated by analyzing the site visits, interviews with stakeholders and responses to questionnaires.

The incident response process model (Figure 1) supports both the safety and security aspects of incident response. The model is applicable to both smaller chemical facilities, with fewer resources to implement security measures, and larger chemical sites.

In the USA chemical facilities are required by law to have up-to-date emergency response plans. It was determined from the interviews that a majority of chemical facilities provide ad hoc response to unplanned chemical releases. In other words, every chemical facility has an ERP, but it usually sits on the shelf and is not used during an incident.

Reviewing the suggestions offered by the participants, to improve incident response, physical items such as cameras and sensors were the lead suggestions. This indicated to the researcher that there is a lack of information technology influence in the management of the incident response process. In other words, IT professionals do not have an active role in defining the incident response mechanism.

There is a notion of "integrated incident response" that really was not present at the 12 chemical sites. Although incident response was coordinated, it lacked a cohesiveness that would normally be associated with an automated information system. A common theme was the lack of attention paid to company ERPs. "Most of the time the emergency response plans sit on the shelf," according to a chemical industry expert. "Plans need to be actionable." This would be an area for improvement for all 12 sites.

Another area for improvement would be personnel disposition (evacuation) during an incident. Ten of the 12 sites had personnel disposition in their critical path. The processes used for muster, shelter-in-place, evacuation, and roll call should be analyzed to ensure that personnel are quickly accounted for in a safe manner. This is an area for further research.

One of the discussion points with the industry experts was the use of information technology during incident response. The consensus from the group of experts was the following statement, "The key to optimization is an integrated information system with decision support components that can contribute to the overall situational awareness, and can continuously update information about the incident. The information flow should be dynamic and all information related to the incident should be collected in a central repository."

Figure 2 illustrates the information flow during incident response.

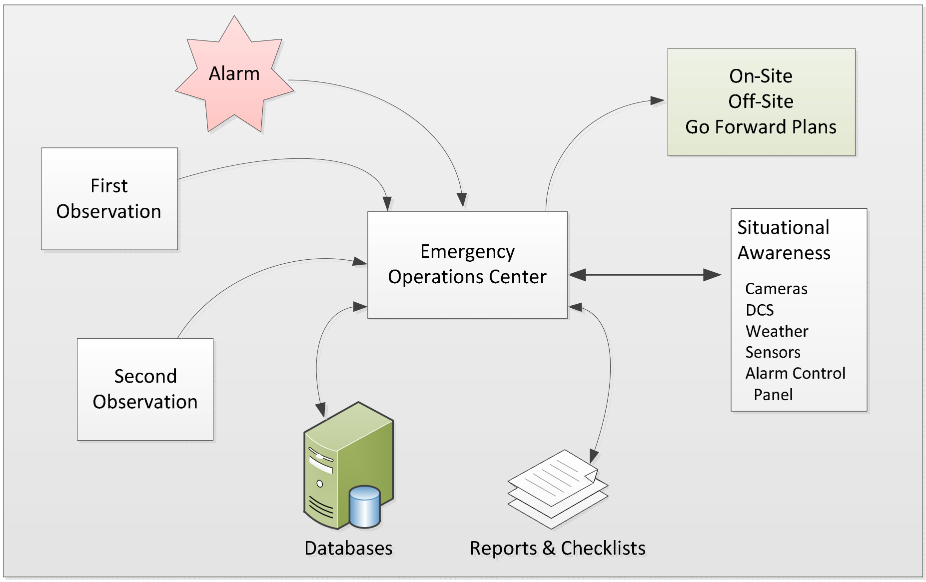

Figure 2. Information Flow during Unplanned Chemical Release

The information flow problem, above, would be an ideal candidate to develop and implement a business process modeling solution.

Although this research was limited to response, there are implications to preparedness and recovery. The researcher observed that participating chemical facilities who conducted regular training drills were more effective in their incident response processes. These same companies had a history of performing better during recovery from unplanned chemical release incidents. The improvements to response implicitly would improve preparedness while lessening the impact on recovery.

Chemical facilities that share information about their hazardous chemicals, site maps and worst-case scenarios with the local fire departments appear to be better prepared to respond to unplanned releases. This best practice is especially true when chemical facilities with fire brigades have a close working relationship with the local fire department. There were a couple of fire brigades, which participated in the study, that claimed they were better prepared to handle hazardous chemical releases and enclosed rescues than the local fire departments.

There needs to be a balance between the integration of information technology and common sense, according to the Plant Manager of one of the chemical sites participating in the study. "Don't be overly prescriptive because you are going to affect response times. Modeling the wind slows things down." This may be true for his location, but not necessarily true for other chemical sites.

CONCLUSION

This research highlights the need to define an effective and efficient incident response mechanism for chemical facilities. The research is unique and valuable to both the research community and industry. Rinaldi (2004) called for researchers to develop simulation models in the area of critical infrastructure protection, and this research contributes to the general body of knowledge. This research defined a standard incident response mechanism for chemical facilities, but the onus is on the chemical industry to build the infrastructure to be more responsive to harmful chemical incidents.

Areas for further research include:

Develop an information model of the information required during incident response. The model could be the basis for chemical facilities to define their information requirements for incident response. The information model would adopt an ontology that is currently used in the industry. The model could be used as a specification for developing an information system for a new incident response organization. The model could also be used by chemical companies to retrofit their incident response information systems.

Expand and implement one or more of the incident response process models at a chemical facility. Chemical sites regularly conduct training exercises. The researcher suggests that one or two sites be selected to implement the process models that were developed during the study. This would include the development of forms (from paper checklists) that would be used during the process and establish interfaces with available corporate databases to automate the process and improve information sharing and situational awareness.

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