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# Incident Database and Macroanalysis to Help Set Safety Direction

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## ABSTRACT

This paper describes the framework of an incident database and how incident data can be used to help set safety direction. It includes history, database design, and data collection and utilization. Examples illustrate how macroanalysis of incidents revealed inherently weak systems.

These systems suffered disproportionate losses. Analyzing data from incident investigations improved the understanding of the risks associated with the processes. In partnership with the product category, corporate process safety organizations initiated equipment design modifications and procedural changes. These changes significantly reduced both the likelihood and consequences of incidents.

When safety incidents occur, most organizations conduct investigations and prepare reports. These reports generate much information. What happens to the collected information? Is the data reviewed frequently? Are incidents in similar systems analyzed on a macro basis? If incidents occur in similar systems, do reviews reveal lessons learned? Answers to these questions may depend on how easily the data can be accessed.

Databases offer an effective option for managing large amounts of information. Used to study process safety trends and underlying causes of incidents, databases can be powerful and effective risk management tools. Macroanalysis of incident data can reveal process safety weaknesses and help risk managers determine where to focus effort and resources.

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## Incident Database and Macroanalysis to Help Set Safety Direction



### Introduction

When safety incidents occur, most organizations conduct investigations and prepare reports in an effort to learn the cause and to determine how to prevent similar incidents from occurring again. What happens to the collected information? Is the data reviewed frequently? If incidents occur in similar systems, do reviews of the data reveal lessons learned? Answers to these questions may depend on how easily the data can be accessed. Databases offer an effective option for managing large amounts of information. Used to study process safety trends and underlying causes of incidents, databases can be powerful and effective risk management tools. Macroanalysis of incident data can reveal process safety weaknesses and help risk managers determine where to focus effort and resources. Three case studies illustrate how Corporate process safety personnel, in conjunction with product category personnel, use incident data to reveal process safety weaknesses; to initiate equipment design modifications and procedural changes; and to improve risk management programs.

### Background

A main objective of the corporate process safety organization is to improve the understanding of risks associated with processes and to reduce the likelihood and consequences of incidents. One strategy is to study incidents and reapply lessons learned. Incident reports have been collected at P&G for almost 20 years to gather information and report findings. Originally, incident reports were used primarily for documentation, but not much was done with the data in the reports. Manually reviewing reports and sorting incidents was not an effective method for analysis of incident data. Consequently, little data analysis was done, and potential lessons learned may not have been revealed. To improve data analysis capabilities, a process safety incident database was designed and developed. The process safety incident database provides an effective tool for managing the large amounts of information found in incident reports.

## Data Collection

What data is important? How will the data be analyzed? What do we want to learn from the data? Answers to these questions help define what data to collect and how to collect it. For process safety incident analysis, the first step is to define what scenarios should be considered process safety incidents. This streamlines the contents of the database, and allows the analyst to focus on scenarios of interest. Procter and Gamble defines a process safety incident as "anything in a process or utility system which caused or could have caused a fire; an explosion; a release of flammable, reactive or hazardous material; or an overpressure condition (positive or negative)".

To develop an accurate and complete picture of process safety history, all incidents need to be investigated and reported. Consistent data reporting from process to process and from site to site maximizes the usefulness of the data. To ensure consistency in data collection and reporting, Procter and Gamble uses a standard incident investigation report form. The incident investigation form contains predefined data fields, including process, equipment, materials, costs, and incident category. The predefined data fields provide consistency and allow for easy queries on specific pieces of data. The report also contains sections for more detailed description of the incident and the causes. These sections provide more detailed information which may reveal critical insight on the incident.

## Data Integrity

Incident investigations and reporting are critical components of process safety management. To reduce the likelihood and consequences of incidents, lessons learned from process safety incidents should be reapplied to similar systems. To do this, we need a complete, company-wide picture of process safety incidents. How do we ensure all process safety incidents are reported? How do we ensure data on the incident reports are complete and accurate? At Procter and Gamble, all risk program leaders are trained in conducting incident investigations and reporting results, including training on the use of incident investigation report forms. Following an incident, site personnel and corporate risk managers review incidents and discuss report content to ensure corporate risk managers fully understand the incident and its causes. Any unclear information or questions are resolved before database entry. Incident reporting is also checked via risk management program audits. Incident reporting is a specific line item in the audit. Auditors compare the number of incidents reported during a specific period of time and compare this with site records.

## Database Design and Future Enhancements

The original Procter and Gamble process safety incident database was developed using commercially available, PC-based database software. Each field in the incident database corresponded to a field on the incident report form. The database structure provided the analyst with flexibility to perform ad hoc queries in addition to producing predefined reports. Flexibility to perform queries on any of the data fields is crucial. This allows the analyst to probe more deeply into cause and effect relationships. The next generation incident database is being developed on commercially available, mainframe-based software. While maintaining the flexibility of the original database, the change in software will align the incident database with our existing industrial health and safety database. This alignment will allow sites to enter data directly into the incident database, eliminating the need for a "hard copy" to be filled out and re-entered by corporate process safety.

## Database Uses

The following Case Studies illustrate how Corporate process safety personnel, in conjunction with product category personnel, use the incident data to reveal process safety weaknesses, improve safety programs, and focus resources effectively.

### Case Study 1: Risk Reduction -- Reactive Releases

As we have pointed out, Procter and Gamble defines an incident as "Anything in a process or utility system which caused or could have caused a fire, explosion, release of flammable, reactive or hazardous material, or an overpressure condition (positive or negative)." The first step in dealing with large numbers of incident reports is to assure, as much as possible, that all incidents are classified into one of these defined categories. Figure 1 is a Pareto chart showing the distribution of the numbers of incidents in each of the defined categories.

*Figure 1. Incident Distribution by Type*

Fires and explosions are combined because the distinction between the two is sometimes hard to make. Though "Release of Reactive Materials" is the third bar on this Pareto, it presents an interesting and fruitful example of how we used incident data to drive a risk reduction project. What does the data represented by the third bar of the chart in Figure 1 tell us? If all of the reactive releases are analyzed, an interesting picture begins to emerge. We took the data from the third bar on the Pareto chart above and created a new Pareto chart from that data.

The new chart is called a "nested Pareto" (Figure 2). The nested Pareto shows how Reactive Releases were distributed across our diverse product sectors.

*Figure 2. Releases by Product Sector*

This chart shows us that over 75% of our releases occurred in one product sector. This is, of course, the classic "Pareto Principal" - 80% of our problems are in 20% of our product sectors. So what should we do with this knowledge? Is there more knowledge to be gained? We repeated the process of developing another nested Pareto from the data represented by Product Sector "A" in the chart above. The incidents from that sector were distributed by the "Product Categories" within the sector. The chart shows this further subdivision of the data (Figure 3).

*Figure 3. Distribution of Incidents Across Product Categories*

This Pareto shows a clearer picture of where our problems were. Product Category "1" is responsible for most of our reactive releases. What did we do with this information? We know where we should act, but as of yet, we don't know how we should act. At this point, further classification of data helped us decide what we should do. The next step was to find out which chemicals were responsible for our releases. Again we used a nested Pareto (Figure 4) to discover that chemical "A" was the chemical of concern.

*Figure 4. Distribution of Incidents by Chemical*

Every time we categorized the data and charted it we learned more. We now knew which product category and which chemical we should focus on. Further, from this information we knew which experts we needed to help us. We also had the information to show those resources why this effort was important to them. These pictures did, literally, say a thousand words. The charts were extremely powerful tools in convincing stakeholders, including upper management and engineering organizations, to dedicate resources to risk reduction efforts.

At this point we went to the leadership in Product Category "1" and presented this analysis, much the way we have presented it in this paper. We requested and were granted the formation of a task force made up of engineering, operations, maintenance and Process Safety personnel. The team had the specific goal of reducing releases of chemical "A".

The formation of the team was a milestone in our efforts to reduce reactive releases. Our analysis of incident data had given us specific direction. We knew which chemical and processes to concentrate on. It gave us an effective presentation tool to convince management to provide us resources. However, we still did not know exactly what we needed to do. This was the work of the task force.

The task force used the same method as we have used up to this point. Review the data, categorize the data, and chart the data. This is a simple concept, but this is not a trivial task. The task force reviewed all of the incident reports of concern and tried to decide how to categorize the different characteristics of the incidents. Several agreements were made on how to categorize data. However, when the data was charted on a Pareto, no clear 80/20 relationship would show up. When this occurred, we would go back and ask ourselves if there was another way to categorize this data. Ultimately we agreed on the categories shown on the chart below. Since all processes using this chemical were essentially the same design, categorizing the incident data by process components (Figure 5) was a successful strategy for us.

*Figure 5. Distribution of Incidents by Component*

We were beginning to zero in on the "what" we needed to do. The data revealed that we had a basic, systemic weakness in either the design or operation of our storage tanks and our piping systems. We further broke this data down and found that over 60% of our tank problems were simple tank over fillings (Figure 6).

*Figure 6. Tank Incidents by Cause*

Now we knew <u>what</u> we needed to do. We needed to stop trying to put two gallons of material in a one gallon bucket. The simple answer, of course, was to make a elementary design change and add a high level switch on the storage tanks. The switch was interlocked to the unloading pump and shut off the pump when the high level switch was made. When the tank is being filled, an input to the unloading pump logic is "High Level Switch Not Made". In retrospect, this seems as if a switch and interlock should have been a basic design feature of our unloading and storage system. But the fact was, a number of processes worldwide did not have this feature. Those without the feature were the source our overflow releases.

Analysis of the piping system failures yielded similar, fruitful information. We found that 70% of our failures were leaks from flanges and the remaining failures were due to corrosion. Further investigation showed that two thirds of our flange leaks occurred in the piping systems from the storage tank to the process. This piping conveys chemical "A" at relatively high pressure (>250 psig) compared to the unloading piping (<20 psig). So we would expect a greater propensity for flange leaks in the higher pressure piping. Similarly, all of our corrosion failures occurred in the low pressure piping from the unloading station to the storage tanks. Since chemical "A" is a corrosive, the procedure of connecting and disconnecting to railcars or trucks provided the perfect opportunity for moisture laden air to contaminate the piping. Again, the data had shown us what we might expect.

For what ever reason, years of Process Safety programs, with qualified engineers at each site and audits conducted biannually, had not revealed these facts to us. Only the analysis of data from our incident database showed us these critical pieces of information. The thrust of our risk reduction effort was focused on tank overflows and increasing the integrity of our piping systems. We began system improvements in 1992.

The results our efforts are shown in the run chart in Figure 7. Prior to our risk reduction effort, we were suffering frequent releases of chemical "A". The range of our release numbers were as large as twice the mean. Since implementation of the task force improvements, our mean number of incidents has dropped by a factor of four. We are suffering only 25% of the releases we experienced prior to our risk reduction effort. Using the incident database and Pareto analysis, we have implemented changes which have reduced our incident frequency by 75%.

*Figure 7. Releases of Chemical "A"; 1977 - 1997 YTD*

Though it will take several more years of data gathering to assure that the reductions shown on the chart above are not attributable to random variation, we are confident our initial results will continue.

### Case Study 2: Risk Reduction -- Process Heaters

Now we will look at a different case study dealing with Fires and Explosions. This case is interesting because it led us to new discoveries about one of our processes and completely changed our strategy for safe design. Several years ago, we suffered a significant incident in one of our processes involving a process heater used to prepare an agricultural commodity for packaging. Fortunately, no one was injured in the incident, but the equipment suffered significant damage due to an explosion. The results of the incident threatened our production capacity and reduced our flexibility. The impact on the process lasted for weeks as repairs and investigation proceeded. In order to fully understand what had happened, we went back to our incident database and began to evaluate all incidents that had occurred in this or similar processes.

We first looked at the numbers of incidents and categorized the incidents according to the process design in which they occurred. Twenty years of data are reflected in the distribution of incidents across three process designs (Figure 8).

*Figure 8. Number of Incidents per Process Type*

The chart in Figure 8 taught us that while there was a much higher likelihood of an incident in two of the three types of processes, no clear 80/20 relationship existed with this categorization of incidents. As with the previous case study, we looked for another way to categorize the data. Our second cut at the data looked at the cost of incidents in each of the three types of processes instead of the number of incidents. Incident cost information began to provide us with more revealing information (Figure 9).

*Figure 9. Losses per Incident Type*

We now knew our problem was in Type "2" processes. As we had done before, we went to management, obtained resources, and established a risk reduction team. We combed the incident data looking for information which would help us understand the problem more clearly. The key piece of information we found was that though most of the incidents occurred during operation, a number occurred shortly after the process was shut down (i.e., when the gas to the hot air furnace burner was shut off). We again went through the distribution of incident numbers and found that incidents during normal operations outnumbered incidents during shutdown (Figure 10).

The chart in Figure 10 shows a fairly promising "Pareto" relationship. However, the decision to examine cost distribution (Figure 11) provided the real breakthrough for our team. This data was so overwhelming, we really had to understand why the data was so skewed.

*Figure 11. Total Incident Costs per Process Type at Various Stages of Operation*

The data shown in Figure 11 initiated a lot of activity from our team, the engineering organization, and the product development organizations. Various theories emerged and were discussed, but no clear hypothesis seemed to explain the data. Finally, process gas analysis revealed that while operating, these processes contained a flammable gas generated by the heating of the agricultural commodity being processed. Further, it was found that during operation the oxygen content in the process gas mixture was only about 12%. A simple schematic of the process is shown in Figure 12.

*Figure 12. Process Schematic*

We now began to investigate our operating procedures and practices. We found that the shutdown sequence simply shut off the gas supply and left the burner combustion air fan running. This allowed fresh air to enter the process gas stream and slowly raise the oxygen level. The process runs at temperatures in the range of 500 to 700° F and there are adequate ignition sources to ignite the flammable gas, if the explosive range is entered. This was our great discovery -- this was a *gas* explosion we were suffering. This was counter to the conventional wisdom for these processes which held that the explosions were *dust* explosions. Across the board, venders supplying the processing equipment had always designed for a dust explosion and provided explosion venting only at the points in the process where dust accumulations were expected (e.g. the cyclones and the heating chamber). The significant damages that we suffered in our incident were due to inadequate venting, and the design bases for the venting of these processes were based on the wrong assumption. From this point on, our strategy was clear. We would redesign our safety features in these processes to minimize the likelihood of an explosion and minimize the consequences of an explosion if one were to occur.

Figure 13 shows a simple diagram of the operating environment to which these processes are subjected. During normal operation, with a depleted oxygen level, the machines operate relatively safely outside of the explosive envelope created by gases generated by heating the product.

*Figure 13. Operating Environment during Normal Operation*

When the unit was shut down, the combustion air fan continued to operate. Introduction of fresh air raised the oxygen content and provided the opportunity for the process to enter the explosive range. Our incident data says this will occur with significant consequences about once in every 40 operating years per unit. Figure 14 illustrates this phenomena.

*Figure 14. Operating Environment at Shutdown -- Entering Explosive Range*

Our first prevention action was to change our shutdown sequence. At shutdown, the gas to the burner is turned off, and the combustion control logics drive the combustion air fan inlet dampers to close. This minimizes the entry of fresh air to the machine. This strategy initially keeps us out of the explosive range. However, we still have an explosive envelope within the process. Our challenge was to figure out how to move from this condition to a safe, complete shutdown. Through research into Bureau of Mines publications on flammable gases, we learned that if we applied a cooling water mist to the process, we could narrow the explosive envelope by lowering temperature, and shrink the envelope by inerting the gas mixture. Cooling water mist gave us the ability to do both. Cooling water rapidly reduced the process temperature, and the resulting steam provided an inerting effect on the process. Figure 15 shows the effect of cooling water mist on the explosive envelope.

*Figure 15. Effect of Cooling Mist on Process Temperature and Explosive Range*

We established a desired cool down temperature set point that, when met, would stop water flow to the cooling mist. This cool down set point was well below the temperature where an ignition source could exist within the machine.

Our next step, with the explosive envelope significantly reduced, was to modify the process shutdown logics. The new logics called for the opening of both inlet and outlet dampers to provide rapid purge of our system. Figure 16 shows how we could move to a safe shutdown condition with normal oxygen levels and bypass the explosive envelope. Obviously, this drawing does not show that as we are introducing fresh air into the system, we are simultaneously removing the explosive gasses.

*Figure 16. Achieving Safe Shutdown Conditions*

These changes in operating procedures and shut down sequences greatly reduced our likelihood of suffering an explosion. However, we are still concerned that we may not understand our process completely and could not guarantee we would never experience another incident. Our next step was to reduce the severity of an explosion if one were to occur. For those who have dealt with explosion venting, it is often difficult to adequately vent an older processes in an existing building and still meet all of the requirements of NFPA 68 "Venting of Deflagrations". What is especially challenging is venting to a safe location (e.g. outside) with the geometry of the processes and their locations within the building. This is exactly the problem we faced. As mentioned, the explosion was assumed to be a dust explosion with venting located only at possible dust accumulation points. What we had discovered is the explosion was a gas explosion and required venting throughout the entire process. It was literally impossible to vent the machine at all of the required locations and direct those vents to the outside. We began to work with Rembe® GmbH, a German firm which manufactures explosion vents and a unique device called a Q-Rohr® Explosion Suppression device. The device is essentially a large flame arrestor attached to a rupture disc. It absorbs the energy of the explosion and quenches the flames. This looked like a promising solution to our venting dilemma.

The Rembe® device was designed for dust explosion and had never been tested for use with explosive gases. Procter and Gamble entered into a joint agreement with Rembe® to test the Q-Rohr® device using a flammable gas which replicated the gases generated during our processing. We completed those tests in early 1996 and proved the devices effectively performed in a flammable gas environment.

With the completion of these test, we had everything we needed to make a step change in the safety design of these processes. We had identified the problem, developed an effective prevention strategy, and determined the Rembe® devices could be utilized to safely vent these machines where we could not direct the venting to the outside.

This was an exciting project to work through. We learned much about our process, and we have made a real difference in assuring safe operation. It is important to note that the discoveries we made were a result of evaluating data. The existence of a database allowed us to review over 200 incidents in these processes and to categorize the data many different ways. The compelling information of the losses associated with a particular design shortly after process shutdown was the driving force of our investigations. We have left many of the details out, but this was a three year effort and we were assisted by some of the outstanding safety firms in the world. What drove us to go to the lengths we did was the data. We could not have tapped that data without an incident database.

### Case Study 3: Strategic Direction -- Hazardous Chemicals

The third case study will illustrate how incident data was used in two different ways to help set strategic direction for hazardous chemical management at Procter and Gamble.

### Part One -- Hazardous Chemicals Management Systems

In the early 1980s, Procter and Gamble developed a hazardous chemicals management system to improve safety and reduce risks associated with handling hazardous chemicals. In 1992 the OSHA Process Safety Management rule (PSM) and EPA Risk Management Program (RMP) rule, both of which established regulations for managing hazardous chemicals, were in the final stages of development and nearing implementation. We believed PSM and RMP represented the best practices for handling hazardous chemicals. The P&G hazardous chemicals management system closely paralleled OSHA PSM and RMP Prevention Programs, and applied to all P&G listed hazardous chemicals. The list of P&G hazardous chemicals included over 100 chemicals. Some of the P&G listed hazardous chemicals were covered by PSM and/or RMP (e.g., fuming acids). Others were not specifically covered by either regulation (e.g., caustics). To prepare our manufacturing sites for implementation of the new OSHA and EPA programs, we wanted to convince the sites that in addition to the legal requirement for implementation, the new management programs would actually improve process safety. Again utilizing incident data, corporate process safety demonstrated that, historically, P&G hazardous systems caused the greatest total losses. The chart in Figure 17 illustrates that 60% of process safety losses occurred in P&G hazardous systems.

*Figure 17. Percentage of Losses for Various Classes of Chemicals*

This data helped convince our sites that these chemical management systems had merit and would help improve safety. Implementation of these management systems across all processes handling P&G listed hazardous chemical was the next step. However, closer examination of the data resulted in an unexpected learning.

Further subdivision of the process safety losses by category -- OSHA listed chemicals, EPA listed chemicals, and "other" P&G listed hazardous chemicals -- revealed that 50% of process safety losses were attributable to the first two categories. The third category, other P&G listed hazardous chemicals (over 80), contributed to less than 10% of total process safety losses. Clearly, not all P&G hazardous systems posed the same level of risk. Did all P&G hazardous systems require identical risk management programs? How should this group of "other" chemicals be managed? Relaxing process safety management requirements for these "other" chemicals was fundamentally a different idea for the risk management organizations. This rarely, if ever, happened. As risk managers, we were good at asking for more. What we did not do so well is determine how to eliminate non value-added work.

However, we were learning that managing all systems with the same set of requirements diluted process safety efforts and resources. We realized our hazardous chemicals management systems needed to be commensurate with the level of risk. The solution was the creation of a "tiered" hazardous chemicals management system, based on the level of risk posed by the particular process or chemical. This was a move away from "one-size-fits-all" risk management. Procter and Gamble now categorizes systems according to the level of risk, based on the chemical properties and quantities present in the system. The number of chemicals managed with the most stringent requirements -- now known as P&G Class 1 chemicals -- dropped from more than 100 to less than 20. This focuses process safety resources on the higher risk systems.

**Part Two -- Flammable Liquids Handling Practices**

Another key learning evolved from this same incident data. Systems handling flammable liquids and gases were responsible for most process safety losses, as shown in Figure 18.

*Figure 18. Process Safety Losses by Material Type; 1980 - 1994*

Why were these systems suffering disproportionate process safety losses? Were company process safety practices effective? Procter and Gamble process safety practices define company requirements for system design and operation. The practices are based on recognized industry standards, such as NFPA, API, and ASME codes, and company experience. A review of the practices for flammable liquids revealed some weaknesses. From a technical standpoint, the flammable liquids practices were written correctly and aligned with codes and current industry best practices, but they needed to be updated to reflect learnings from recent process safety incidents. The real weakness was how the information was communicated. Comments from engineers and plant personnel using the practices indicated there were too many options, and it was difficult to understand exactly what needed to be done. This decreased the overall effectiveness of the practices and resulted in the practices not being fully implemented at every site. Clear delineation of the requirements would improve system design and decrease the frequency of incidents in systems handling flammable liquids. This was clearly an opportunity for a strategic risk reduction effort -- update the practices for flammable liquids to reflect learnings from recent incidents and make them more understandable and "user friendly." A major improvement to the practices was the addition of design checklists. These checklists can be used for both design bases and for assessing compliance of existing facilities and systems. The revised practices were issued in late 1996. Will the number of incidents involving flammable liquids handling systems decrease? As of today, we do not have enough post-revision data to make any assessment of the impact of these changes. However, we have chosen flammable liquids as a focus area for risk reduction efforts, and we will use incident data to track results and evaluate the effectiveness of the practices. We believe properly designed systems reduce overall risk. Use of the design checklists should lead to more consistent application of the design requirements, and hence, properly designed systems.

**Conclusion**

These Case Histories illustrate how much can be learned from process safety incidents and how powerful this information can be. As stated before, many of Procter and Gamble practices and operating procedures are based on company experience. The incident database provided a tool sorting and analyzing information from over 20 years of incident history. Without a database, analysis of this number of incidents would have been much more difficult, if not impossible. The incident data revealed process safety trends and pointed to opportunities for improvement. This allowed corporate process safety to eliminate non value-added work and focus on risk reduction efforts which would have the greatest impact.



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