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Chemical Process Accident Severity Index

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Abstract: Even though chemical process accidents do not have the same severity, they are usually reported without a (semi) quantitative indication of severity. Sometimes attempts are made to identify those accidents where significant injuries and/or in a major financial impact resulted. However, it is generally the case that those interested in the details are left to seek out the published reports and deduce a severity level based on their own judgment.

There is another consequence of not providing accident severity information. Thorough accident reporting often means that attention is being paid to the minor accidents and incidents indicating increased compliance with the process safety program. Without knowing the severity of each accident and incident, the increasing number of reported accidents could be interpreted as decreased compliance with the process safety program.

The Accident Severity Index project addresses this paradox of an increased number of accidents actually being a sign of a healthy and active program. Being in possession of an objective indicator of accident severity allows management to judge the effectiveness of the process safety program. It also provides the necessary details about the extent to which company personnel pay attention to the process safety details concerning handling and use of hazardous chemicals. The goal of this project is to provide a tracking and evaluation system for process safety incidents and accidents. In order to accomplish this it is necessary to assess the actual and potential severity of an accident, in an objective manner, using the information obtained during the accident investigation. The severity information is then used by the program to derive a two-part severity rating that addresses the actual and potential severity.

This presentation will describe a prototype database and assessment system that will accomplish these criteria.

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1. Background

Even though chemical process accidents do not have the same severity, they are usually reported without a (semi) quantitative indication of severity. Sometimes attempts are made to identify those accidents where significant injuries and/or in a major financial impact resulted. However, it is generally the case that those interested in the details are left to seek out the published reports and deduce a severity level based on their own judgment.

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2. Overview of Incident Severity Index

The goal of this project is to provide a tracking and evaluation system for process safety incidents and accidents. In order to accomplish this it is necessary to assess the actual and potential severity of an accident, in an objective manner, using the information obtained during the accident investigation. The severity information is then used by the program to derive a two-part severity rating that addresses the actual and potential severity.

The information from an accident event may be classified into five main areas:

1. *Incident data* - AH, T & P observed, duration of T/P excursions.
2. *Financial data* - damage, cleanup, business interruptions.
3. *Nature of incident* - location, vessel type, incident type.

4. *Cause and effect contributors* - root and side effects.
5. *Potential seriousness of the incident* - health, property, business, and containment losses.

The package, currently in the form of an Excel® workbook, is used to gather and rate the accident data. The data gathering is carried out during an accident investigation by a member of the investigation team. The data entry requirements are, for the most part, a matter of selecting the appropriate and relevant entry from a list of possible situations that cover the five areas of concern listed above.

The program also provides summary statistics derived from the facts of each accident. These trend statistics provide some insight into the frequency and nature of activities that correlate with the raw accident statistics. Which unit operations are associated with a high accident frequency? Are particular pieces of equipment involved more often others? Are certain classes of products or raw materials potentially more difficult to handle without having an accident?

These data may also be used to (re-)train and (re-)educate all personnel involved in chemical manufacture, including R&D, in the elements of a company's Chemical Hazards Evaluation Program and/or the process safety implications of the particular process chemistry and unit operations.

3. Basis of the Approach

There are three major parts to the program for assessing the actual and potential severity of an incident. These are:

A. Gathering general information regarding the chronology of the event(s), processing area, product being manufactured, and main chemicals involved.

B. Entering information regarding the process details (the temperature and pressure, desired and attained during the incident; reaction heats and simple hazards testing data) and the financial costs incurred throughout the incident.

C. Entering information regarding the incident location, vessel type, incident type, and cause and effect contributors; the health and business impacts, and containment losses. Data regarding the potential seriousness of the incident is also entered provided.

The information for Part A is gathered using a series of fill-in tables. This information is used classify the accident into the general product line (SIC code), record geographical location, and record other general information.

The information for Part B is obtained from a single menu. The data required is shown in Table 1. It is used to estimate the total energy content of the system under study. The conditions experienced during the incident are entered here; i.e., temperature, pressure and duration of T/P excursions. Items F and K are used to enumerate the duration of the incident. These data are also used to distinguish between a 'normal' exotherm, a fast reaction lasting no more than

0.25 hours, and an explosion (deflagration or detonation) lasting no more than 0.05 hours.

Table 1. Data for the Thermal Nature and Extent of the Incident

Incident Data

A.	Mass of Chemical(s) Involved [lbs]	____________
B.	Total delta H for Reaction(s) [cal/gm]	____________
C.	T (onset) from DSC Data (Desired reaction) [C]	____________
D.	T (onset) from DSC Data (Desired reaction) [C]	____________
E.	Process Temperature [C]	____________
F.	Temperature Above Process Temperature [C]	____________
G.	How Long Above Process Temperature [hrs]	____________
H.	Process Pressure [psia]	____________
I.	Vessel Rated Pressure [psia]	____________
J.	Pressure Relief Device Set Pressure [psia]	____________
K.	Pressure Above Process Pressure [psia]	____________
L.	How Long Above Process Pressure [hrs]	____________
		____________
Financial Data		
A.	Property Damage [$, thousands]	____________
B.	Site Cleanup [$, thousands]	____________
C.	Environment Remediation [$, thousands)	____________
D.	Business Interruption Losses [$, thousands)	____________
5	Other Losses [$, thousands]	____________

Comments

1 *Total* mass of chemicals in the vessel, Incident Data, item A, since we are referring to the total energy content of the vessel, including solvents.

2. *Total* heat, for the same reasoning as note 1. This information is available from the hazard assessment package and/or from tests that may have been run for the incident investigation.

3. Use the actual temperature reached, above the desired process temperature, not the difference between the two temperatures.

4. The financial data need only be good to within i 50%.

The data for Part C are gathered in tables that represent the twelve subject areas (listed in Table 2), which describe the events leading up to, surrounding, and immediately following an accident. Within each category are a number of keywords or phrases that, taken together, permit an accurate description of the particular category.

Table 2. Subject Areas to Provide Detailed Incident Data

Incident Location	Vessel Damage
Incident Type	Vessel Type
Critical Instruments	Relief System
Raw Material ID	Operating Procedures
Related Causes	Involvement
Potential Seriousness	Health Effects

An example of one category showing the various options used to provide extra definition of the category is shown in Table 3. The "Rating" column provides the relative severity of an accident occurring each type of vessel. The term "vessel" is used broadly to include locations where chemicals can collect, or be inventoried, in quantities large enough to lead to problems in the event of a runaway reaction or ignition.

Table 3 Vessel Type Categories

CATEGORY	EXPLANATION	RATING
Distillation Column	Any equipment that provides distillation or refluxing action for an extended period on a process mixture.	0.2
Drum, 55 gal	Self-explanatory	0.5
Exchanger	All types of heat exchangers	0.3
In-line Reactor	Including Kenix mixers, tubular reactors.	0.7
Laboratory Rig	Any type of production facility housed within a laboratory environment.	0.7
Line, Valve	Any line, or valve, intended, or not intended, to act as a reactor.	0.2
Pump, Compressor	Any pump or compressor, including vacuum pumps	0.4
Rail Car	Self-explanatory	0.8
Reactor	Any equipment designed for reactions to occur and not specifically referenced in other vessel categories.	1.0
Storage Tank	Conventional storage tanks.	0.7
Storage, Other	Any other facility used to store materials.	1.0
Sample/Reagent Bottle	Self-explanatory.	0.5
Truck	Self-explanatory.	0.7
Waste Container	Any container planned or otherwise, used to contain/store waste materials.	0.4

This is the final step in cataloging the events of the incident. This is best carried out at the accident investigation. At this point, the program calculates and displays the numerical summary of the incident analysis, for example, an incident rating will be displayed as 2A or 3c, etc.

The incident rating has two parts. The numerical part describes the actual severity, on a scale of one through five. The significance of the values are shown below:

1 Learning Experience,
2 Minor accident
3 Moderate accident
4 Major accident
5 Severe accident

The second part of the rating indicates the potential of the accident to have caused a greater disruption, injury, or loss of containment than actually occurred. The potential rating is set on a scale of A through D and has the following significance:

A implies that all that could happen actually did happen
B implies that the accident could have been significantly more severe
C implies that the accident had the potential to become a major accident
D implies that major injury and/or loss of live was a definite possibility

A rating number of 3C indicates that the accident was of Moderate severity and that there was a significant potential for the incident to have been much worse than the actual events.

The data from the particular accident under investigation is entered is linked to a Microsoft® Access database. This enables accident history to be correlated with any of the major data elements, such vessel type, location, mass of chemicals involved, etc.

1. Use of the chemical Process Accident Severity Index to Rate a Hypothetical Accident

The following hypothetical accident is presented in bullet format to indicate the major facts and how the final rating of an accident is influenced by the occurrence of some events. The accident is described, in outline, as follows:

1. The first chemical is added to mixed to the batch reactor and heated to 40^0C;

2. The reactor is stirred for 3 hours rather than 30mins. The change in the procedure happened without approval from management

3. The second reactant was added and the reactor closed up;

4. The mixture was heated with steam until the temperature was 70^0C;

5. The reaction proceeds spontaneously without additional heat;

6. The temperature rises to 90^{0}C, as planned;

7. Cooling is applied to hold the temperature at 90~ - 100^{0}C;

8. The reactor temperature continues to rise to above 1 20^{0}C, despite full cooling (supervision is not notified);

9. The temperature rises to 180^{0}C;

10. Process workers started running from the reactor building;

11. One worker receives minor burns;

12. One minute later the reactor vents through the relief devise; the man way is blown off;

13. Thirty seconds later there is a flash fire that extensively damages the building;

14. Four other reactors, not involved in the runaway are damaged by the flash fire.

The incident investigation, hazards testing specifically directed toward understanding the incident, and information regarding financial impact, provided the additional data:

15. Environmental clean up costs were $240,000;

16. Business interruption costs (covered by insurance) were $1,100,000;

17. The product was thermally unstable above 1 30^{0}C, the runaway reaction becoming uncontrollable at 170^{0}C;

18. The nature and extent of possible runaway reaction(s) was not part of known process information;

19. The available cooling was limited by a hot humid day (lowers performance of cooling tower) and three other reactors were running at the same time using the cooling water loop.

The Chemical Process Accident Severity rated the accident as *3D.* The actual events rating number, 3, implies a moderate accident. There was no explosion, the mass of chemicals involved was not very large, and the reaction and decomposition heats were moderate. However, it is reasonable to assume that the accident could have been more severe, hence, the rating of D for the potential aspects of the accident. For example, the worker injury was relatively minor and could have easily been much worse. The damage and costs could also have been higher.

However, the rating for the accident could have been different. For example making a couple of changes to the events of the accident, such as:

9. The temperature rises to 220^{0}C;

10. Process workers attempt to run from the reactor building;

11. Two workers receive major burns.

The increase in the severity of the accident re-classifies the incident as *4D.* However, the incident could have also resulted in fatalities given that the workers did not escape from the building uninjured and a flash fire resulted.

Changing fact 11 to include a fatality generates an accident rating of SB. This is mainly because at least one fatality occurred and although more fatalities could have occurred the threshold of at least on fatality limits the potential rating. The rating of B indicates that the accident could have been somewhat more severe.

1. Summary

This paper has presented an approach useful for assessing the severity of chemical process accidents that is centered on the events of the accident. The potential of the accident for additional damage and greater impact is included in the rating of the incident. This involves expert opinion as to alternate outcomes and may be subject to some bias. All of the data of the incident, including the outputs from the severity index are entered into a Microsoft ® Excel workbook that is linked to a Microsoft ® Access database.

Appendix A. Algorithms Used to Determine Incident Score

There are three components to the incident score. Arithmetic operations are used to scale the score at various points during the estimation. The following explanation of the derivation of the incident rating is presented in outline form only. The internal equations, used to compute individual parts of a score are not shown.

The incident rating is a number and letter concatenated together. The number reflects the severity of what happened; the letter indicates the severity of what could have happened.

The final stage of the calculation is shown as follows:

Incident _Rating = Actual_Rate:: Potential_Rate
(where:: means concatenate)

Actual_Rate is determined from the logic table shown below:

If Total_Score < 3.8 then Actual_Rate = 1
If 3.8 < (Total_Score) < 5.4 then Actual_Rate = 2
If 5.4 < (Total_Score) <6.2 then Actual_Rate = 3
If 6.2 < (Total_Score) < 8.0 then Actual_Rate = 4
If Total_Score > 8.0 then Actual_Rate = 5

Where Total_score is defined by:

Total_Score = Rating_Score * HPDI_Factor*(Graded_Score + 1)

HPDI_Factor Graded_Score and Rating_Score will be described in the following sections.

The HPDI_Factor is used to significantly increase the Total_Score for high financial impact and overall multi-case incidents.

The Potential_Rate, that is the letter part of the rating, is obtained from the following logic table:

If Potential_Score < 3.0 then Potential_Rate = A
If 3.0 < (Potential_Score) < 7.0 then Potential_Rate = B
If 7.0 < (Potential_Score) < 15.0 then Potential_Rate = C
If Potential_Score >15.0 then Potential_Rate = D

An example of the Rating_Score that reflects the qualitative aspects detailed in the categories, is shown in Tables 3. The second score is the Graded_Score that derives from the incident numerical data, as illustrated in Table 1.

Tables 3 shows, in the right hand column, a number from 0 to 1. This number is a measure of the relative seriousness of each member of that particular category relative to each other. The Rating_Score is computed from the formula:

$$\sum_{i=1}^{NCAT} \sum_{j=1}^{NMEM} (1.0 + Rate_{i,j})$$

The rating score are obtained from the appropriate set of category tables. For example, if the category is "Vessel Type" and the category member was "Storage Tank" then a Rate of 0.7 would be entered for this category. The more categories that are involved in the incident (Table 1) the higher will be the Rating score.

The numerical data of the incident, that is the reaction heat, T_{onset}, etc are initially incorporated into temperature penalty scores, $T_{penaltyi}$. These penalty scores are used as an additional indication of the actual severity of the incident. For example, linking the process temperature with the adiabatic temperature rise of the process and the onset temperature of the undesired reaction(s) provides a quantitative indication of the extent to which the events of the accident led to an unrecoverable situation. A similar process is adopted to assess the effects of pressure excursions. In this instance, the pressure data, P process' the pressure rating of the vessel, ~rate' the set pressure of the relief device, ~set' etc., a used to provide a similar set of pressure penalty scores, including a severe penalty for exceeding the value of 1.25 * MAWP.

It is necessary to distinguish, in a general manner, between three main types of exothermic runaways, based on the duration of the incident. The three types are the 'normal' exotherm, lasting at least 15 minutes; a fast reaction lasting no more than 15 minutes; an explosion (deflagration or detonation) lasting no more than 3 minutes hours. Energy_Release_Factor and Mass_Release_Factor are set, depending on the value of $t_{P\_excursion}$ or $t_{T\_excursion}$

If the incident duration is less than 15 minutes then all temperature related penalties are set to zero. If the incident is complete in 10 minutes, or less, then the pressure related penalties are modified.

Since T and P penalties are of different magnitudes; a scaling algorithm was employed to reduce both sets of penalties to the same order of magnitude.

The mass and energy release factors are also used in conjunction with the total energy content to provide Score_Mass and Score_Energy.

At this point all incident data inputs have been massaged to reflect their disparate numerical ranges. The values of the equation elements are combined together using the final equation:

$$\begin{aligned} \text{Graded\_Score} = \; & f\,[(1 + T_{penalty1}); (1 + T_{penalty2}); (1 + T_{penalty3}); \\ & (1 + P_{penalty1}); (1 + P_{penalty2}); (1 + P_{penalty3}); (1 + P_{penalty4}); \\ & (1 + P_{time\_P1}); (1 + P_{time\_P2}); (1 + P_{time\_P3}); \\ & (1 + \text{Score\_Energy}); (1 + \text{Score\_Mass})] \end{aligned}$$