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An Innovative Single Trend Lagging Indicator for Performance of Process Safety

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A single trend lagging indicator of process safety performance has been developed based on previous work done by the CCPS and API institutions. This indicator provides significant advantages in creating a comprehensive performance measure and predictor irrespective of the size of the operating unit.

1. Introduction

Performance metrics are an essential part of any organisation as "you don't improve what you don't measure" (CCPS, 2008). Historically, effective tracking of process safety lagging indicators was difficult. As modern petrochemical facilities become increasingly more complex, so do the risks involved with the management thereof (Turk and Mishra, 2013). Following the disastrous BP Texas City incident, the Baker Panel recommended that a composite lagging indicator measuring process safety incidents, consisting of the numbers of fires, explosions, loss-of containment incidents and process-related injuries should be adopted (Baker et al., 2007). Conceptually the intent is that a trend of fewer and/or less severe process safety incidents would indicate improved performance. The goal of an effective process safety management system should be early detection of failures. An encompassing indicator of performance would enable companies to avoid catastrophic incidents (Turk and Mishra, 2013).

2. Current process safety indicators and developments

Various industrial organisations and companies have proposed process safety metrics. The Centre for Chemical Process Safety (CCPS) and the American Petroleum Institute (API) developed both leading and lagging metrics, but to date no common method has been established.

The CCPS introduced two important concepts (CCPS, 2008):

- Assigning a volume threshold for each chemical above which a release would be reportable. This concept recognises the inherent differences in the hazardous nature of chemicals.
- Developing the concept of a process safety incident severity level which is assigned based on four consequence criteria, e.g. injury, damage etc. However, the application was limited to serious incidents.

The API, proposed Tier 1 and 2 process safety events, based on event consequences, as lagging indicators of performance (API, 2010).
Companies often track the number of significant or serious process safety incidents. However, these incidents don’t occur often and for smaller operating units sufficient incidents to achieve statistical significance and provide a meaningful indicator of performance are not reported (Hopkins, 2007). This observation is confirmed by a recent study stating that even if consistent reporting is applied, meaningful information arising from tracking Tier 1 and 2 indicators, as promoted by API RP754, will generally be limited to large facilities or groupings (Mendeloff et al., 2013).

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The Chemical Safety Board (CSB) is concerned that current process safety metrics do not adequately focus the attention on process safety risks (Mendeloff et al., 2013). This clearly provides motivation for more innovative indicators to be developed, independent of the size of the operation.

2.1 Chemical release threshold quantities for incident classification

CCPS developed a volume threshold for all common chemicals above which a release would be classified as a serious incident, termed a "Process Safety Incident" (CCPS, 2008). This approach recognises the fact that a release of a small amount of a highly hazardous chemical could be more severe than a large release of a less hazardous chemical.
The CCPS threshold quantities are based on the UN Dangerous Goods classification. It has three packing group classes for flammable chemicals (as seen in Table 1) and four packing group classes for toxic chemicals (Table 2). In addition to the above, CCPS also assigned threshold quantities to other hazardous chemicals such as pyrophoric chemicals, acids, alkalis, etc. (CCPS, 2008).
The API adopted the CCPS threshold quantities and added a second tier threshold quantity in order to differentiate between their Tier 1 and 2 incident classes (API, 2010).

Table 1: Packing groups for flammable chemicals

UN DG criteria	Equivalent NFPA criteria	Flash point (cc)	Initial boiling point	Tier 1(kg)	Tier 2(kg)
Packing Group I	Flammable vapor or gas	-	$B_p \leq 35\ ℃$	500	50
Packing Group II	Flammable liquid	$F_p < 23\ ℃$	$B_p > 35\ ℃$	1000	100
Packing Group III	Combustible liquid	$23\ ℃ \leq F_p \leq 60\ ℃$	$B_p > 35\ ℃$	2000	1000

Table 2: Packing groups for toxic chemicals

Toxic Inhalation Hazard Zone Group	Inhalation Toxicity	Tier 1(kg)	Tier 2(kg)
TIH Zone A	$LC_{50} \leq 200ppm$	5	0.5
TIH Zone B	$200ppm < LC_{50} \leq 1{,}000ppm$	25	2.5
TIH Zone C	$1{,}000ppm < LC_{50} \leq 3{,}000ppm$	100	10
TIH Zone D	$3{,}000ppm < LC_{50} \leq 5{,}000ppm$	200	20

3. The Sasol Incident Severity Index

Sasol Limited developed a lagging indicator of performance called the Process Safety Severity Index (SI). The intent was to have a single indicator suitable for measuring performance of smaller operating units of the company where there are too few serious process safety incidents to achieve statistical significance. This metric includes small incidents, which are often a predictor for larger incidents. The methodology develops more useful variants of lagging indicators of performance in order to better measure and analyse the health of process safety at plant and business level. It is a build on the work previously done by the CCPS and API institutions, as discussed in section 2.
For each incident reported that meets the definition of a process safety incident, no matter how small, an SI is calculated. This is done by considering a number of criteria, based on the actual consequences of the incident as well as failure of specific controls. An Excel tool enables the process. The resulting index is used to classify the incident into Minor, Moderate, Significant or Major categories. A monthly Severity Rate (SR) for a unit or grouping is calculated and trended as explained below.

3.1 Criteria for calculating the Severity Index (SI)

The criteria used to calculate the SI of an incident is listed below in Table 3 alongside its relative weighting, or maximum score. For each incident, a score is assigned to each criterion.

Table 3: Severity criteria and weightings for SI calculation

Criteria	Weighting
Quantity and hazardous nature of the chemical released	150
Actual consequences:	
Actual injuries	100
Direct financial loss ($)	100
Environmental impact, community impact and bad publicity	100
Time taken to stabilise the emergency	50
Control failures:	
Mechanical integrity strategy or execution failures	50
Preventive control failures	50
Management control failures	50
Mitigating feature failure	50

$$SI_{incident} = \frac{\sum individual\ weighted\ criteria}{7.0} \tag{1}$$

The weightings add up to 700, so dividing the sum of the weighted criteria by 7 gives an SI score out of 100. A more severe incident will therefore have a higher SI score.
It should be noted that the last four criteria relate to the failure of specific controls and were included after much deliberation. Control failures account for up to 28% of the total SI score. The inclusion thereof is motivated from the perspective that failures of specific control measures should be viewed in a serious light. It serves further in reiterating the importance of maintaining process safety controls.

3.2 Severity Rate (SR)

In order to enable comparative scores across plants of varying age, scale and risk profiles, a Severity Rate (SR) is calculated by normalising the total severity of all incidents that occurred within a single month in relation with the hours worked. The SR is calculated as follows:

$$SI_{month} = \sum SI\ for\ all\ incidents\ that\ occurred\ in\ the\ month \tag{2}$$

$$SR = \frac{SI_{month} \times 200\ 000}{Employee\ hours\ worked\ for\ the\ month} \tag{3}$$

Here the 200 000 is a constant included as a scaling factor. The SR is then used as the single trend lagging indicator of performance. Note that the hours worked is a measure of the size of the operation and does not reflect exposure as in the case of personal safety. (CCPS and API also use hours worked to normalize their severity rate.)

3.3 Development of a wider scale of release threshold values for use in the Severity Index

As discussed in section 2.1, API developed two release threshold quantities for each chemical related to their Tier 1 and 2 incidents. In order to cover a wider range of process safety incidents, additional thresholds were incorporated into the SI development.
As an example, Table 4 below shows the range of release thresholds that were developed for Packing Group II chemicals. It includes additional points between and around the API Tier 1 and Tier 2 thresholds. Depending on the size of the release a severity score could now be determined for use in the SI calculation.

Table 4: Release thresholds and severity score for a Packing Group II release

Classification	Quantity (kg)	API 754 Tier thresholds	Severity score
Packing Group II	> 5,000		150
	1,000 - 5,000	1,000 (Tier 1 release threshold)	100
	200 - 1,000		50
	100 - 200	100 (Tier 2 release threshold)	10
	20 - 100		5
	0 - 20		0

3.4 Criteria scoring tables

Tables were developed for all criteria used in the SI methodology to allow a selection from predetermined scenarios. To demonstrate an example, the table below shows the options used for injury quantification:

Table 5: Actual injuries scoring criteria

Actual injuries	Severity score
On-site fatality	100
Multiple hospitalisations	100
Off-site injury	100
Multiple on-site recordable injuries	80
Lost workday case on-site	40
Medical treatment case or restricted Work	10
First aid case	5
No injury	0

3.5 Enablement

The use of this methodology in the operational environment is enabled through an Excel-based tool. The Excel tool allows detailed information to be entered easily through VBA (Visual Basic for Applications) based user forms for each criterion. Automatic calculation and subsequent classification into four classes of incidents are done based on the SI score. The tool allows creation of an incident database. A chemical database with the CCPS classification for approximately 3000 chemicals is built into the tool.

Monthly, the Severity Rate (SR) is calculated using Eq(2) and Eq(3) as well as the 12 month moving average (12MMA) of the monthly SR. This allows effective trending for this lagging indicator of process safety performance.

Analysis of the incident severity distribution is enabled through graphical representation in several formats. Additionally, the Excel tool is used as a database and allows a number of root causes to be assigned to a specific incident within the database once the incident investigation has been completed. This allows effective analysis of incident causality to be performed in conjunction with the detailed severity classification.

4. Additional topics

4.1 Definition of a process safety incident

In order to establish clear boundaries for reporting, a definition of a process safety incident is required. All incidents that conform to this definition are reported and the SI calculated:

An incident that resulted in: a fire; an explosion; or an episodic, unintended release of a hazardous chemical from primary containment; or an excursion of pressure energy that causes harm; and in all cases where chemicals and a chemical process was involved.

4.2 Potential severity

Process safety incidents often have the potential to escalate if circumstances were different. An LPG release may blow away on one day with no serious consequences. However, on another day it may encounter an ignition source and cause a vapour cloud explosion. It is therefore essential to recognise potential for escalation of an incident and then escalate the investigation level. The Excel-based enabling tool determines the potential severity as Low, Medium or High based on the potential chemical release and potential subsequent injuries.

4.3 Classification of incidents for benchmarking purposes according to API RP754

In addition to the Sasol incident classification, the Excel enabling tool also classifies incidents according to API RP754 into Tier 1 and Tier 2 incidents. Alignment with these criteria enables international benchmarking.

5. Performance data

Sasol has been applying this methodology since 2009. Figure 1 below shows the trend of the SR for Sasol as a whole over a number of years. A decline in the SR implies that the number of incidents and/or severity of incidents, or both, declined.

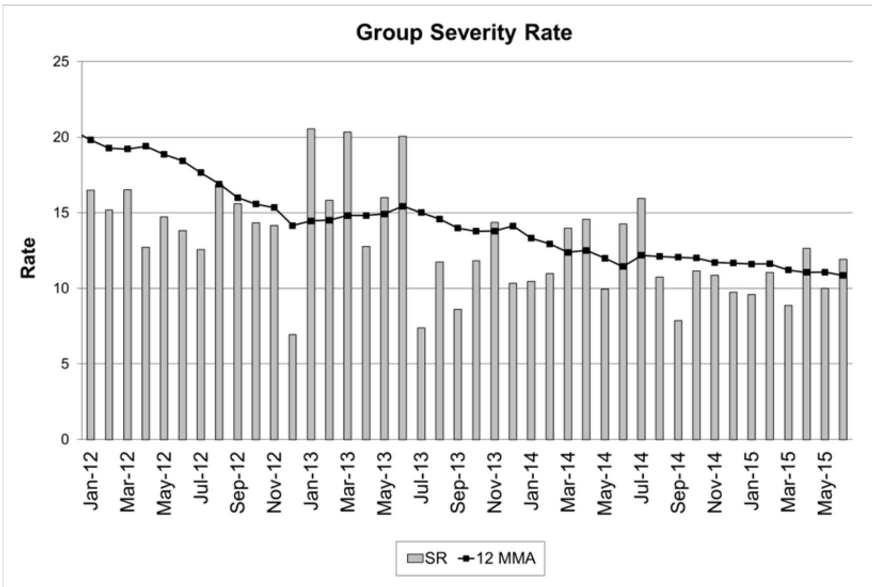

Figure 1: Sasol Group Severity Rate

5.1 Case study

This case study, as seen in Figure 2, covers the data on all incidents of differing severities that occurred within a Sasol operating entity over an 18 month period. The 12 MMA of the SR for this entity had been increasing steadily and eventually during April 2015, a Significant (Tier 1) process safety incident occurred.
As shown by the familiar accident pyramid introduced by H.W. Heinrich (Heinrich, 1931), one can expected to experience a larger number of lower consequence incidents (Minor classifications) in relation to the high consequence incidents. From Figure 2 it can be seen that the Significant incident was preceded by a steady increase in the SR across the target threshold. This is indicative of the predictive power of this metric.

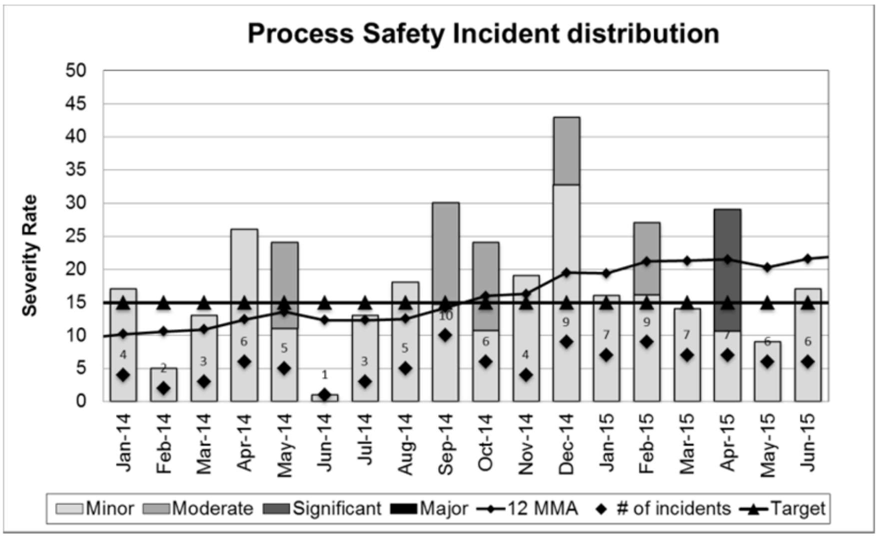

Figure 2: Process safety incident distribution

An increase in the SR gives an indication of a decrease in the health of the process safety systems at a given operating entity. It can be observed that the total SR per month has a direct dependence on the number of incidents experienced and the severity of those incidents.

An increasing trend in the 12 MMA of the SR over this period implies that the likelihood of a more serious incident occurring increased. By recognising the significance of this predictor, timeous management interventions could possibly prevent the escalation of small incidents into a catastrophic incident.

6. Conclusions

This work further highlights the importance of performance metrics and especially lagging indicators in the successful management of process safety risks. The application of the SI methodology as a single trend lagging indicator of performance introduces useful developments on the earlier work of CCPS and API. The major advantage is that it includes all incidents no matter how small, and allows performance of smaller operating units to be measured. Sasol successfully applied this methodology for a number of years to trend performance. It has also proven to be an effective indicator of the likelihood of the plant to experience a serious incident.

References

ANSI/API, 2010, Recommended Practice 754: Process Safety Performance Indicators for the Refining and Petrochemical Industries, First ed.

Baker J.A., Leveson N., Bowman F.L., Priest S., Erwin G., Rosenthal I., Gorton S., Tebo P.V., Wilson L.D., 2007, The Report of the BP U.S. Refineries Independent Safety Review Panel. www.absa.ca/IBIndex/TheBakerPanelReport.pdf accessed 19.08.2015

Center for Chemical Process Safety, 2008, Process Safety Leading and Lagging Metrics. American Institute of Chemical Engineers, New York, NY.

Heinrich H.W., 1931, Industrial Accident Prevention, McGraw-Hill, New York, NY.

Hopkins A., 2007, Thinking About Process Safety Indicators, Working Paper 53 Prepared for the Oil and Gas Industry Conference, Manchester, UK.

Mendeloff J., Han B., Fleishman-Mayer L.A., Vesely J.V., 2013, Evaluation of process safety indicators collected in conformance with ANSI/API Recommended Practice 754. Journal of Loss Prevention in the Process Industries, 26, 1008-1014.

Turk M.A., Mishra A., 2013, Process safety management: Going beyond functional safety. Hydrocarbon processing, Houston, TX.