SAFETY METRICS OF PERFORMANCE FOR SMALL AND MEDIUM-SIZED ENTERPRISES – CASE STUDY

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To systematically reduce workplace safety risks and improve business performance, the principle of continuous improvement is usually used. It is based on the selection of objectives and subsequent monitoring of their fulfilment using key performance indicators in the given area, in the field of safety this means safety metrics. These, therefore, serve to constantly monitor the state of the organisation's safety management system, i.e. to obtain information about the level of strategies, processes and activities used by the organisation to manage health and safety risks. Although the safety metrics applicable in a large organisation are already well described in the literature, thereis a problem with the use of these metrics in small or medium-sized enterprises. Here, the suggested metrics often appear to be ineffective, they cannot properly monitor the state of safety.
This article aims to introduce a procedure for defining key performance indicators in the field of safety applicable in a small or medium-sized enterprise and to present this procedure in a case study.

KEYWORDS

safety metrics, performance of processes, risk management, process safety management, safety indicator

1 INTRODUCTION

Process safety metrics are important process indicators for assessing theperformance of processes from the perspective of their safety. Merely measuring the number of safety incidents over a given period is inadequate in a small or medium-sized enterprise (as well as e.g. the criterion of damage to property or the environment) with regard to the low frequency of occurrence of such events. It is necessary to first know the system of activities and then set suitable metrics formonitoringthe performance of the safety management system of the risk process. In general, a comprehensive processsafety management system should contain a number of different metrics that track the different system dimensions and performance of all critical elements. Metrics provide data from which performance information is generated in a given area, predicting future performance and further supporting the expected behaviour of the managed system.

In small and medium-sized enterprises, risks are often underestimated. [European commission 1995] Occupational injuries:

- Are 20% more common in companies with fewer than 50 employees than in companies with 100 to 1000 employees;
- Are 40% more common in companies with 50 employees than in companies with over 1000 employees.

2 TYPES OF METRICS

2.1 Severity metrics

Process safety metrics can be categorised by severity (Concept of Severity) into the following groups:

- Lagging Metrics –process safety incidents that meet the gravity threshold and should be reported as part of process safety metrics;
- Near-Miss Incidents –incidents that were not defined by safety metrics before their occurrence;
- Other Near Misses –system failures that could lead to an incident or accident;
- Leading Metrics –measurements ensuring that the level of safety and operational discipline are maintained, including the measurement of dangerous behaviour or insufficient operational discipline when selecting equipment, construction designs and specifying the frequency and methodsof controls.

2.2 Proactive and reactive metrics

Another possible aspect of safety metrics is whether the metric tracks performance over time or whether it provides information about the subject's quality or the overall performance of the system.

- Activity metrics –are proactive control metrics that measure how the system's requirements are met. For example, these metrics are: Number of completed system risk assessments; Percentage of verifications of planned operational procedures; Number of completed planned emergency exercises etc. Generally, these metrics provide the management of organisations with a tool of control that is implemented regularly, systematically, such that it provides information as to whether the system is fulfilling the intended purpose and how it is being further improved on the basis of the learning process, by setting and implementing measures. These metrics thus enable us to know for what reasons (why) something has been achieved.
- Outcome metrics – are result metrics that assess whether activities (measures) related to safety (policies, procedures and practices) achieve the desired results and whether measures lead to a reduced likelihood of accidents or less serious consequences of accidents. Generally, these metrics are viewed as measuring performance, effectivity and changes in safety performance. Specifically, for example, they might record the number of fires in relation to the number of inspections etc. Output indicators provide information about what results are being achieved or whether requirements are being met, but unlike Activity metrics they do not tell us why the results have or have not been achieved.

It is clear that both these types of metrics are necessary for an overall assessment and understanding of the system. Therefore, the quality of the overall process safety system can be evaluated using result metrics.

2.3 Stakeholder metrics

Metrics can be further categorised according to stakeholders. Information may be passed on to internal groups, in particular senior staff, then to organisational units, for example to facility management or external groups such as business associations, regulating bodies or the public. For clarification, it should be noted that any metric that must be listed in order to comply with the law is an external metric according to this categorisation.

- Internal metrics – are internal metrics that are applied in an organisation for its management. These metrics should be primarily available within the organisation and it is the management's decision which of them will be presented externally. Internal metrics should include Leading Metrics, Lagging Metrics, Near-Miss Incidents and Other Near Misses,as well as Activity Metrics and Outcome Metrics. For example, these metrics may concern the level of understanding of employee briefings, the degree of compliance, or how employee incentives are used. Internal metrics can be used to set external metrics, but they can also help provide additionalinformation to external parties.
- External metrics – are generally reported within the organisation and, in particular, outsideit. For example, governmental organisations are provided with information on injuries and ill persons, emissions into the environment etc. In the European area, the major accident reporting system (MARS) openly provides information on major accidents in accordance with the Seveso III Directive.

2.4 Evaluation metrics

Metrics can be categorised from an evaluation perspective according to whether they represent values in absolute terms or as ratios that provide context and allow for more effective comparisons over time and within the organisation as whole. This categorisation is very important for the overall expression of meaningfulness and usefulness for recipients of information at various hierarchical organisational levels.

- Absolute Metrics –these are scales in which the number of reported events is recorded in a simple form. Absolute metrics do not necessarily provide information about the quality of activities, changes or trends over time. They can also lead to more difficult comparisons within the organisation. However, regulatory authorities and the public may have considerable interest in being informed about some of the results of absolute metrics. Such information might concern, for example, the number of leakages, the quantities involved in leakages, the number of extraordinary events per year etc.
- Normalised Metrics – are ratios that provide a better context for comparisons across different process technologies, locations, companies or industrial segments. For this reason, they are easily usable as metrics for benchmarking. Examples of these metrics include: the number of hours worked over a certain period, the total volume of output produced over a certain period, the percentage of controls for mechanical strength over a certain period etc. Establishing normalised metrics is recommended when at least 200,000 hours have been worked by approx. 100 workers per year within an organisation. Here, the role played by the probability of incidents is already insignificant. It is also necessary to pay due attention to these indicators owing to the potential distortion of details and knowledge from individual events.

To be verifiable and to provide the necessary information, metrics must be reviewed with regard totheir properties, i.e. their ability to serve their purpose, namely, their quality. Process characteristics can be further divided by the acquisition of information:

- Direct characteristics – these are attributes that can be measured directly. These are, for example, physical quantities, such as temperature, pressure and volume etc.;
- Indirectcharacteristics – these can be measured only using indirect methods. These are, for example, corporate culture, employee identification with the running of the company etc.

3 REQUIREMENTS FOR METRICS

Useful, informative and trustworthy metrics (high quality) can be identified by the following specific rules:

- Objectivity and impartiality – they inform specifically about the actual state of a process; [Cierna 2016]
- Reproducibility – different identically trained workers must, in similar conditions, measure similar results, i.e. it should not matter whether measurements are carried out by worker A or worker B;
- Consistency – definitions and units of metrics are consistent within the company. This is an essential precondition for implementing benchmarking;
- Relevance – metrics should match the relevance of the process behaviour. Metrics must therefore be meaningful and must have informative value (data analysis and evaluation) about whether a process isin line with the objectives or within the limits of a regulation. Consequently, this entails that, based on the acquired knowledge, the managed system will need to be further developed (learning process), including the applied metrics. The authors[Johansen and Rausand 2010]develop this thinking, arguingthat some of the criteria, such as validity and acceptability, can only be evaluated in light of a particular analytic-deliberative process, whereas others, for example, transparency, rationality and communicability, can be evaluated on a more generic basis;
- Comparability – metrics can be compared with others that are similar. For example, comparability can be given within a specific time period, according to certain processes, devices, branches or among companies at a national or international level. So-called Consensual Metrics, which are defined by stakeholders, such as professional associations, intergovernmental groups etc., are generally recognised;[Hnilica 2013]
- Integrity of legislation – legislative requirements (relevant) define certain tests and mandatory metrics. Companies have appropriately set and implemented regulatory metrics as part of their internal processes/systems to avoid excessive submission of reports and so make the whole reporting more efficient. They also have specific metrics that are used to evaluate the system overall (review) against requirements;
- Representative sample – metrics provide a sufficient quantity of data for objective process/system status detection. Data is collected at appropriate times and

is accurate. Information is provided at a suitable time to the managed system;

- Customeraccess – metrics information has its customers. They are, for example, the management of the company and process operators. The first group will be more interested in regular, aggregated information (especially about the achievement of goals, trends etc.), while the latter group will be more concerned with a wider range of information, a greater degree of detail and more frequent information about the process;
- Frequency of measurements – timely re-measurement is essential for process management, so it is essential to determine the interval at which processes are evaluated when performing setting. Here is another link to the recipient of information, because in the context of frequency setting the speed of information gathering for decision-making is also a very important factor in the safety of process implementation. Here we can distinguish so-called short-term and long-term metrics. Short-term metrics are characterised by the fact that processes require immediate information needs in terms of their management. Long-term metrics measure more progressive changes in process performance, generally overall performance;
- Comprehensibility – metrics must be easy to use, i.e. comprehensible. If they are less easy to grasp, problems will arise with obtaining information for management (reliability, accuracy, unwanted behaviour etc.), which is unacceptable in terms of process safety;
- Reviewing – metrics must be periodically reviewed to ensure that they meet all the needs and expectations of stakeholders. This is a system review that takes into account, in particular, context, integrity, documentary value and undoubtedly the degree to whichstakeholder needs and expectations about the process/system are met.

Metrics can also be viewed through risk assessments. According to [Johansen and Rausand 2012], there are 17 generally applicable metrics that define metrics for society, individuals and groups associated with major accident hazards. These are as follows: Individual Risk Per Annum (IRPA), Localised Individual Risk (LIRA), Individual Risk of Dangerous Dose (IRHSE), Potential Loss of Life (PLL), Fatal Accident Rate (FAR), FN-Diagram, Weighted Risk Integral (RICOMAH), Scaled Risk Integral (SRI), Total Risk (TR), Potential Equivalent Fatality (PEF), Potential Environmental Risk (PER), Recovery Time (RT), FE-Diagram, Expected Economic Loss (EL), Frequency of Intermediate Events (e.g.Core Damage Frequency (CDF) and Loss of Main Safety Function (LSF)), Conditional Expected Damage (CED) and Monetary Collective Risk (MCR).

In the course ofa company's operation, it is useful to have metrics not only for so-called hard indicators (direct characteristics) but also for measuring, for example, the already mentioned employee behaviour and attitudes.[Wiley 2010]Only by applying these metrics can we obtain the necessary safety guarantees for the company's system of operation in the long run. Quality metrics are generally characterised by the following features:

- They guarantee accurate and detailed comparison;
- They lead to corrective and preventive measures;
- They do not lead to misinterpretations;
- They are comprehensible and understandable;
- Information acquired from them has a clear statistical basis.

The authors[Johansen and Rausand 2012]proposed 11 criteria that could be used to evaluate the quality of metrics: validity, reliability, transparency, unambiguity, contextuality, communicability, consistency, comparability, specificity, rationality and acceptability. Another author[Norzok 2001]adds the following recommendation in the form of 5 criteria: suitability for decision support, adaptability to communication, unambiguity, concept independence and uncertainty.
According to [Leveson 2015], high quality metrics (Leading Indicators Process) meet the following seven attributes:

- Complete – all the critical assumptions leading to the accident are defined. From this group of assumptions, the metrics for system management are set;
- Consistent – all inconsistencies in metrics are identified and solved. This is essential for designing process safety;
- Effective – metrics should adequately address underlying assumptions, uncertainties and vulnerabilities, and be able to accurately indicate risks;
- Traceable – each leading indicator and the action attached to it should be identified as a response to one or more assumptions;
- Minimal – there should be no extraneous assumptions, checks or actions that are not necessary to prevent accidents;
- Continually improving – metrics are continually updated over time based on feedback from their performance evaluation (review);
- Unbiased – metrics should minimise prejudice in the area of risk assessment and risk management.

Another approach to assessing the quality of metrics is based on SMART logic. While preserving the number of key elements at 5, it is possible to assess the effectiveness of metrics**:** [Doran 1981], [Taaffe, Allen and Grigg 2014]

- Relevance –metrics must be relevant to company performance goals and standards. This information must be relevant to what the company is trying to achieve;
- Validity –it is important that the information provided through metrics assesses the currentstate and confirms that goals are realistic;
- Clarity –the given data must be presented in a way that is easily understood by stakeholders;
- Timeliness – it is important to take action based on metrics information within a suitable timeframe;
- Cost –it is important to assess the cost of metrics. Costs for metrics generally include items spent on data collection, data evaluation and manipulation, and maintaining metrics, including data archiving.

4 CASESTUDY – DETERMINATION OF SAFETY METRICS IN A MEDIUM-SIZED ENTREPRISE

This case study was drawn up in a company which is a major manufacturer and supplier of shock absorbers for the chassis of all kinds of rolling stock. Before the study was carried out, only the number of occupational injuries was used as a safety indicator, which proved to be insufficient.In 2017 there was a significant increase in the number of occupational injuries, and for this reason the company decided to systematically increase the level of safety using safety metrics.

Information analysis from this company has served to establish effective performance indicators in the field of safety (the last 5 years is the analysed period).
Currently, this company has approximately 190 workers, of whom 45 work in the technical-economic professions. However, in the last five years, the number of employees changed. An overview of the evolution in the number of employees over the past 5 years is given in Table 1.
No major crash, accident, environmental impact event or fire has occurred in this company. These major events, which can be used to assess the state of safety in a large company, are inapplicable as metrics in this case.
There are several occupational injuries in the company every year. These are listed in Table 1.

Year	Number of employees	Number of occupational injuries
2012	164	6
2013	168	4
2014	182	5
2015	177	3
2016	186	3
2017	190	10

Table 1. Comparison between the values of basic indicators

The direct indicator, i.e. the number of occupational injuries, is difficult to apply to small enterprises, as it is less sensitive to slight changes in the safety situation. It is also altered by the change in the number of employees in the company.
Given that no fatal accidents have occurred in the organisation, it is not possible to use baseline indicators set for large companies such as the OSHA fatality index, Fatal Accident Rate (FAR) or the Fatality Rate.
For this reason, a standardised number of occupational injuries is determined according to the number of workers. The data is contained in the following table.

Year	Standardised number of occupational injuries per employee	Standardised number of days lost due to an occupational injury
2012	0.037	0.585
2013	0.024	0.250
2014	0.027	0.258
2015	0.017	0.316
2016	0.016	0.505
2017	0.053	

Table 2. Standardised number of occupational injuries per employee

Both standardised indicators should be in a relative ratio, so the correlation coefficient was calculated. It came to 0.32. This value shows only a slight positive correlation with a low level of confidence. This means that both values are not a reliable indicator.
For this reason, the use of alternative indirect safety metrics may be considered. The first to be considered is the fluctuation coefficient. This can be used as an indicator of the level of employee satisfaction in the company. The second metric is the sickness figure, which can be used to judge changes in the safety culture of the company given the large fluctuations in the number of ill persons. The third metric is the number of running projects. This has been selected because the company is currently undergoing significant innovation which could be the source of injuries (employees are not able to adapt to changes so fast,leading toa lower level of compliance with the rules).

Year	Fluctuation coefficient	Sickness figure	Number of projects
2012	19.48	0.035	5
2013	10.14	0.041	5
2014	10.98	0.042	5
2015	19.72	0.037	4
2016	13.44	0.056	2

Table 3. Fluctuation coefficient, sickness figure and number of projects

Based on changes in these indicators, it should be possible to judge the decline in the level of safety culture or decline in employee satisfaction. However, this assumption cannot be confirmed from the evaluated course of time. Also, the correlation coefficient between these indicators and the increase in occupational injuries does not show asignificant positive correlation with any high level of confidence. Norcan these indicators be considered a reliable safety metric.
The third indirect indicator (number of running projects) should, therefore, be correlated with the standardised number of occupational injuries. The correlation coefficient is 0.72. This value indicates a high degree of confidence. It can, therefore, be said that a high number of innovative projects has a negative impact on safety.

5 RESULTS DISCUSSION

The presented analyses in the case study show that direct metrics are not quality indicators that can be used to plan changes within the safety system and health protection in the workplace.
Indirect indicators do not have sufficient information capacity. The only indicator that is related to direct indicators of context is the number of running projects, so it would be beneficial to consider reducing the burden on employees caused by new projects.
The limit values for safety matrics are expressed in terms of risk or simillar variable that is associated with the risk.

6 CONCLUSIONS

Safety metrics are a very effective safety management tool in a large organisation. However, their use often appears ineffective in small enterprises, where they are unable to keep track of the state of safety. This article introduces an approach to establishing key performance indicators in the field of safety applicable to small or medium-sized enterprises, and this is presented in a case study.
In the case study it is shown that the use of direct and standardised metrics is inconclusive and, therefore, management of the safety system on their basis would be ineffective. Of the indirect metrics, only the correct management of innovation activities is practically usable.
The monitoring of half-injuries seems effective since it would increase sensitivity (10-30 half-injuries per occupational injury).
The use of the so-called internal metrics (e.g. level of understanding of employee briefings, compliance rate and efficiency of employee feedback) is very effective. [Kotek 2014]
The continuation of this article can be seen in the wider application of the proposed approach in other companies of the same size and a longer-term verification of the effectiveness of this approach.

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REFERENCES
[Cierna 2016] Cierna, H. and Sujova, E. 2016, Application of modern QMS – Kaizen management system. MM Science Journal, 2016, no. NOVEMBER, 1456-1464.
DOI:10.17973/MMSJ.2016_11_2016162
[Doran 1981] Doran, G. T. There's a S.M.A.R.T. way to write management's goals and objectives. Management Review, 1981, Vol. 70, No. 11, pp. 35-36.
[European commission 1995] European commission, 1995. Self-audit Handbook for SMEs: Safety and Health at Work: Office for Official Publications of the European Communities. ISBN 92-826-9366-X.
[Hnilica 2013] Hnilica, R., Jankovsky, M., Dado, M. and Messingerova, V. Experimental evaluation of combined effects of risk factors in work environment, Engineering for Rural Development, 2013, pp. 577-583.
[Johansen and Rausand 2010] Inger Lise Johansen, Marvin Rausand, Foundations and choice of risk metrics, Safety Science, Vol. 62, February 2014, pp. 386-399, ISSN 0925-7535.
[Johansen and Rausand 2012] Johansen, I.L., Rausand, M., 2012. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Hong Kong (China). pp. 10–13, 2012. Hong Kong, Chapter – Risk metrics: Interpretation and choice.
[Kotek 2014] Kotek, L., and Mukhametzianova L. Experience with using Self-Audit Handbook for SMEs in Process and Power Industry. Chemical Engineering Transactions, 2014, Vol. 36, pp. 73-78, ISSN 2283-9216.
[Leveson 2015] Nancy Leveson, A systems approach to risk management through leading safety indicators, Reliability Engineering & System Safety, Vol. 136,2015, pp. 17-34, ISSN 0951-8320.
[Norzok 2001] NORSOK Z-013, 2001. Risk and emergency preparedness analysis (English version). Standard Norge, Oslo.
[Taaffe, Allen and Grigg 2014] Taaffe, K., M., Allen, R. W. Grigg, L. (2014) "Performance metrics analysis for aircraft maintenance process control", Journal of Quality in Maintenance Engineering, Vol. 20, No. 2, pp.122-134.
[Wiley 2010] CCPS (Center for Chemical and Process Safety). 2010. Guidelines for Process Safety Metrics. Hoboken, N.J: John Wiley & Sons, Inc. ISBN 978-0-470-57212-2.

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