Evaluation of Risk Management Maturity: Measurable Proactive Indicators Suitable for Chinese Small and Medium-Sized Chemical Enterprises

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Abstract. Implementing risk management in chemical industry may bring a number of benefits. Risk management maturity reflects risk management capability of an enterprise from various aspects. The aim of this article is to determine a group of measurable proactive indicators suitable for Chinese small and medium-sized chemical enterprises to evaluate risk management maturity. The article describes the development process of the measurable proactive indicators. Appropriate proactive indicators are extracted from literature and divided into four families based on their characteristics, named operation based indicators, management based indicators, individual based indicator, resources and technology based indicators. Typical measurement examples of proactive indicators are proposed according to risk characters of chemical enterprises. Sixteen small and middle-sized chemical enterprises from China provide risk management records on fourteen indicators. The analysis result show the proposed measurable proactive indicators are available for Chinese small and middle-sized chemical enterprises and could reflect the risk management maturity of an enterprise.

1. Introduction
Risk management for chemical enterprises with numerous hazardous materials are of particular importance [1]. There are nearly 300,000 chemical enterprises in China, of which over 80% are small and medium-sized enterprises (SMEs) with poor risk management capability. Governments at all levels require to strengthen risk identification and management.

Enterprises can use proper measurable indicators to evaluate their current level of risk management maturity, to understand their strengths and weaknesses and to take suitable measures to improve their risk management performance [2]. During the past decade, several technological tools have been developed for construction and aviation industries to measure risk management maturity [3]. Almost all of the maturity measurement technological tools are based on the use of measurable indicators [4-6]. It has been proved that measurable indicators play an important role in the process of improving risk management performance [7].

In China, it is urgent demand to implement overall risk management among chemical enterprises. Main goal of this article is to determine measurable indicators suitable for Chinese small and middle-sized chemical enterprises to evaluate risk management maturity. The article is organized as follows: to begin with, proactive indicators are selected from literature. Definition or description of selected indicators are stated. Second, selected proactive indicators are divided into four families according to their characterizes and measurement examples are proposed. Third, sixteen Chinese small and middle-
sized chemical enterprises are invited to provide their risk management records on measurable proactive indicators. Finally, applying results of measurable proactive indicators for evaluation of risk management maturity are discussed.

2. Material and Method

2.1. Types of Measurable Indicators
Reactive indicators and proactive indicators display risk management maturity from different perspective. The focus of most reactive indicators is accident frequency, severity and cost, whereas proactive indicators can be a useful tool to help organizations to track, measure and adjust their risk management activities so they can effectively avoid harm. Proactive indicators could provide advanced warning of potential problems and therefore implementing preventive measures before accidents occur. The link between the proactive indicator and the corresponding target can be confirmed if the reactive indicator trends downward [8, 9]. Therefore, proactive indicators are adopted for evaluation of risk management maturity in present article.

2.2. Selection of Measurable Proactive Indicators
The literature regarding indicators of risk management maturity are surveyed. In Table 1, the principal proactive indicators mentioned in the literature are listed. The meanings of indicators are defined or described.

Table 1. The principal measurable proactive indicators regarding risk management maturity mentioned in the literature

| No. | Aspects                  | Proactive Indicator          | Definition or Description                                                                 | literature       |
|-----|--------------------------|------------------------------|------------------------------------------------------------------------------------------|------------------|
| 1   | Risk management operation| Identification of hazards    | Identify hazards or predict accident consequence with certain tools or means               | [2, 10, 11]      |
| 2   | Risk estimation and evaluation | Risks are quantified or described qualitatively                | [2, 11, 12]                                                        |
| 3   | Risk management operation| Preventive and corrective actions | Take measures to mitigate or avoid risk                                          | [12]             |
| 4   | Risk characterization    | Risk characterization        | Reflect threats, consequences and probability of risks by use methods                    | [2]              |
| 5   | Monitoring and review    | Monitoring and review        | Constant process aimed at verifying or recording the improvement of a risk management operation | [13]             |
| 6   | Managerial function      | Communication of OHS risks  | Exchange or share of OHS information among stakeholders                                | [9, 14-19]       |
| 7   | Disciplinary policy      | Disciplinary policy          | Formulate and execute disciplinary policy of risk control                               | [17, 20, 21]     |
| 8   | OHS training             | OHS training                 | Ensure employees acquire OHS awareness, knowledge and skills                           | [2, 15, 18, 22]  |
| 9   | OHS-related behavior     | OHS-related behavior         | Worker behaviors accord with OHS guidelines or regulations                              | [2, 15, 22]      |
| 10  | Compliance with OHS guidelines or regulations | Compliance with OHS guidelines or regulations | Worker behaviors accord with OHS guidelines or regulations | [15, 23-25]      |
Above fifteen proactive indicators basically show four aspects of risk management maturity in industry, named as risk management operation, managerial function, individual quality, resources and technology respectively [4]. The next major task is to extend number of indicators and raise measurement examples according to risk characteristics of chemical enterprises.

2.3. Proposition of Measurement Examples
First, measurement examples of operation based indicators are proposed in Table 2. “Operation based indicators” refers to quantification of risk management activities, including identification and evaluation of risks, preventive and corrective actions, risk characterization by category or level, and monitoring and review. These indicators provide an overseeing of risk management activities and application of risk-reducing approaches.

Table 2. Measurement examples of operation-based indicators

| Code | Indicator | Examples of Measurement |
|------|-----------|-------------------------|
| O1   | Identification of risk | Number of hazards identified |
|      |           | Number of special inspection on the safety of chemicals. |
|      |           | Number of special inspection on the work related risks |
|      |           | Number of persons trained in hazard identification |
| O2   | Risk estimation and evaluation | Number of estimations o revaluations carried out |
|      |           | Risks identified per level or per category |
| O3   | Preventive and corrective actions | Number of preventive and corrective measures recommended |
|      |           | Number of preventive and corrective measures found effective |
|      |           | Number of preventive measures per type of hazard (e.g., closed spaces, etc.) |
|      |           | New number of hazards reported after implementation of preventive and corrective measures |
| O4   | Risk characterization | Correlation between proactive and reactive indicators |
|      |           | Number of potential hazards classified by severity |
|      |           | Number of hazards per specific category (e.g., closed spaces, heights, etc.) |
| O5   | Monitoring and review | Number of new evaluations of risks |
|      |           | Effectiveness and efficiencies of corrective actions implemented |
“Management based indicators” refers to quantification of the role of management at risk control. They particularly focus on deployment of risk management at all levels of the business, including the communication of risks, OHS training for workers, disciplinary policy, organizational and process changes, evaluation of proactive indicators, OHS inspection, compliance with OHS regulations, etc. Measurement examples of management based indicators are proposed in Table 3.

**Table 3. Measurement examples of management-based indicators**

| Code | Indicator | Examples of Measurement |
|------|-----------|-------------------------|
| M1   | Contribution of management | Number of suggestions implemented by managers | Number of positive risk evaluations carried out by managers | Number of managers participating in OHS meetings |
| M2   | Communication of risks | Number and frequency of risk management meetings | Number of OHS information posters |
| M3   | Leadership and disciplinary policy | Number of OHS-related disciplinary actions | Number of recognitions of safe behaviours |
| M4   | Organizational or process changes | Number of new OHS organizational practices implemented | Frequency of OHS audits |
| M5   | OHS training | Hours of training/hours of work ratio | Number of training sessions | Number of emergency exercise |
| M6   | Evaluation of proactive indicators | Number of evaluations correlating predictive measures with OHS results. | Number of preventive actions for reaching OHS objectives |
| M7   | OHS inspection | Number of workplace inspections | Number of in-house regulatory inspections |
| M8   | OHS compliance | Percent compliance (and/or non-compliance) with applicable regulations and standards | Number of compliance inspections carried out by external evaluators |

“Individuals based indicators” (Table 4) refers to quantification of individual efforts and abilities at risk management. Including information on work related risks, perception of work related risks, worker involvement and participation with regard to risk management, safe behavior and education years, etc. Measurement examples of individual based indicators are proposed in Table 4.

**Table 4. Measurement examples of individuals based indicators**

| Code | Indicator | Examples of Measurement |
|------|-----------|-------------------------|
| I1   | Information on work related risks or hazards | Number of lessons focused on property or protection of chemicals | Number of consultations of individual regarding to work related risks or hazards |
| I2   | Perception of work related risks | Number, frequency and results of surveys or questionnaires on the perception of OHS in the organization |
| I3   | Worker commitment and participation | Number of workers involved in risk management activities or emergency exercises |
Number of stuff who work full-time on safety management

I4  Safe behavior
Number of observations of behavior indicating mindfulness of OHS
Observed ratio of high-risk to low-risk behaviors

I5  Education years
Percentage of workers who have bachelor degree (or above)

“Resource and technology based indicators” refers to the input of resource and technology at risk management. Including work environment, workload, technology application, preventive maintenance, fund, etc. Measurement examples of resources and technology based indicators are proposed in Table 5.

Table 5. Measurement examples of resources and technology based indicators.

| Code | Indicator               | Examples of Measurement                                                                 |
|------|-------------------------|----------------------------------------------------------------------------------------|
| T1   | Work environment        | Number of evaluations of written procedures relating to OHS risks                       |
|      |                         | Number of managers trained regarding specific tasks                                     |
| T2   | Workload                | Frequency of measurement of workload                                                    |
|      |                         | Number of workers who work less than 10 hours                                           |
| T3   | Technology              | Level of integration of risk management technology                                       |
|      |                         | Level of automation that is being applied in manufacturing                              |
| T4   | Preventive maintenance  | Percentage of worker designated as maintenance time                                     |
| T5   | Fund                    | Investment on labor protection products                                                 |
|      |                         | Ratio of OHS allotment to overall budget                                                |

3. Discussion

3.1. Evaluation of Measurable Proactive Indicators
In order to evaluate availability of proposed four families of measurable proactive indicators. Sixteen oil process-related chemical enterprises with employee number varying from 120 to 180 are invited into investigation. They are located in Heze city (Shandong province, China) where gathers a large number of oil refiners and processors though it is an underdeveloped area in China. These chemical enterprises are relatively uniform in production mode and major process units. These chemical enterprises are ranked according to records of OHS related accidents in the previous 24 months. Top eight enterprises are composed group A, while the rest composed group B. The applying results of measurable proactive indicators for evaluation of risk management maturity between group A and group B are displayed in Table 6.

Table 6 Applying results of measurable proactive indicators for evaluation of risk management maturity between group A and group B

| Code | Indicator               | Examples of Measurement                                                                 | Group A | Group B | Gap |
|------|-------------------------|----------------------------------------------------------------------------------------|---------|---------|-----|
| O1   | Identification of risks | Number of special inspection on the work related risks per month                        | 3.8     | 3.6     | 0.2 |
Managerial staffs of sixteen chemical enterprises provide risk management records on 14 indicators. Average value of measurable indicators were computed and compared between two groups. From Table 8, it can be found there is a gap of average value between group A and group B. Generally, group A acquired higher average value than Group B on each code, which are consistent with local government statistics regarding OHS-related injuries. This phenomenon confirmed conclusion that enterprises better that carried out proactive risk management activities resulted in less accident records [2]. This result shows selection of proactive indicators and examples of measurement are appropriate. These measurable proactive indicators could reflect risk management maturity of Chinese small and medium-sized chemical enterprise.

After carefully observation, in addition, it can be found invited chemical enterprises obtain similar average value at operation based indicators (O1, O2, O3, O5). Carrying out risk management operations are compulsive requirement by local government, so all respondents have good recodes. Gag appears on other indicators because Group B made less efforts at management, individual, technology and resources. For example, there are obvious gap appear on indicators (M2 、I1 、I3 、T2) between Group A and Group B.

4. Application of measurable proactive Indicators
Enterprise management department may use these indicators to get a basic understanding of their risk management maturity. Through using these measurable proactive indicators, managers can know what their peer have done and how they are performing relative to others in their industry. For example,

| Indicator | Description | Group A | Group B | Group C |
|-----------|-------------|---------|---------|---------|
| O2 | Risk estimation and evaluation | Number of risk evaluations carried out and validated per month | 3.5 | 3.4 | 0.1 |
| O3 | Preventive and corrective actions | New number of hazards reported after implementation of preventive and corrective measures per month | 1.1 | 1.1 | 0 |
| O5 | Monitoring and review | Number of new evaluations of risks per month | 1.2 | 1.1 | 0.1 |
| M1 | Contribution of management | Percentage of positive risk evaluations carried out by managers | 65% | 45% | 25% |
| M2 | Communication of risks | Number of risk management meetings per month | 2.4 | 1.0 | 1.4 |
| M3 | Leadership and disciplinary policy | Number of OHS-related disciplinary actions per month | 6 | 3.2 | 2.8 |
| M5 | OHS training | Hours of training/hours of work ratio | 0.08 | 0.04 | 0.04 |
| M8 | OHS compliance | Number of compliance inspections carried out by external evaluators per year | 3.5 | 2.2 | 1.3 |
| I1 | Information on work related risks or hazards | Number of lessons focused on property or protection of chemicals in last year | 4.5 | 2.0 | 2.5 |
| I3 | Worker commitment and participation | Percentage of workers involved in various risk management activities in last year | 85% | 37% | 48% |
| I5 | Education years | Percentage of workers who have bachelor degree (or above) | 18.2% | 13.3% | 4.9% |
| T2 | Workload | Percentage of workers who work less than 10 hours per day. | 95% | 70% | 25% |
| T5 | Fund | Investment on labor protection products per person in the last year (Yuan) | 220 | 115 | 105 |
Figure 1 described comparison results of measurements of proactive indicators between two enterprises from different groups.

![Figure 1](image)

Figure 1 Comparison results of measurements of proactive indicators between two enterprises

For Chinese SEMs in chemical industry, measurable proactive indicators are a new addition to risk management, two or three proactive indicators are a good place to start. It would be better to focus on a few key indicators that reflect the performance of risk management. Proper measurable proactive indicators could help Chinese SEMs to get quantification for risk reduction.

First, measurement examples of operation based indicators are proposed in Table 2. “Operation based indicators” refers to quantification of risk management activities, including identification and evaluation of risks, preventive and corrective actions, risk characterization by category or level, and monitoring and review. These indicators provide an overview of risk management activities and application of risk-reducing approaches.

5. Conclusion
Four families of measurable proactive indicators which could reflect various aspects of risk management maturity are selected from literature. They are named as “operation based indicators”, “management based indicators”, “individuals based indicators”, “resource and technology based indicators”. Typical measurement examples are proposed for these indicators. Sixteen oil process-related chemical enterprises are invited to access availability of proposed indicators for evaluation of risk management maturity. Results show that selection of indicators and proposition of measurement examples are appropriate. Enterprises with lower work related accident records obtain higher values on each proactive indicator. Chinese SEMs would adopt such measurable proactive indicators to understand their basic risk management maturity.

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References
[1] S. Wuellner and P. Phipps (2018). Employer Knowledge of Federal Requirements for Recording Work-Related Injuries and Illnesses: Implications for Occupational Injury Surveillance Data. AMERICAN JOURNAL OF INDUSTRIAL MEDICINE, 61(5), 422-435.
[2] G. Jia, X. Ni and Z. Chen (2013). Measuring the Maturity of Risk Management in Large-Scale Construction Projects. AUTOMATION IN CONSTRUCTION, 34(S1), 56-66.

[3] R. Wendler (2012). The Maturity of Maturity Model Research: A Systematic Mapping Study. INFORMATION AND SOFTWARE TECHNOLOGY, 54(12), 1317-1339.

[4] J. P. Moriarty and C. Smallman (2009). En Route to a Theory of Benchmarking. BENCHMARKING-AN INTERNATIONAL JOURNAL, 16(4), 484-503.

[5] T. S. Karseka and Y. L. Yanev (2013). Knowledge Management as an Approach to Strengthen Safety Culture in Nuclear Organizations.

[6] ATW-INTERNATIONAL JOURNAL FOR NUCLEAR POWER, 58(4), 221.

[7] K. F. Tee (2015). Identifying Critical Performance Indicators and Suitable Partners Using a Benchmarking Template. INTERNATIONAL JOURNAL OF PRODUCTIVITY AND PERFORMANCE MANAGEMENT, 64(3), 434-450.

[8] T. Kongsvik, S. A. K. Johnsen and S. Sklet (2011). Safety Climate and Hydrocarbon Leaks: An Empirical Contribution to the Leading-Lagging Indicator Discussion. JOURNAL OF LOSS PREVENTION IN THE PROCESS INDUSTRIES, 24(4), 405-411.

[9] B. Kneetgering and H. J. Pasman (2009). Safety of the Process Industries in the 21St Century—a Changing Need of Process Safety Management for a Changing Industry. JOURNAL OF LOSS PREVENTION IN THE PROCESS INDUSTRIES, 22(2), 162-168.

[10] A. Tremblay and A. Badri (2018). Assessment of Occupational Health and Safety Performance Evaluation Tools: State of the Art and Challenges for Small and Medium-Sized Enterprises. SAFETY SCIENCE, 101, 260-267.

[11] W. Zuo and J. Wei (2018). The Properties of Global Risk Networks and Corresponding Risk Management Strategies. HUMAN AND ECOLOGICAL RISK ASSESSMENT, 24(1), 159-173.

[12] K. T. Yeo and Y. Ren (2009). Risk Management Capability Maturity Model for Complex Product Systems (Cops) Projects. SYSTEMS ENGINEERING, 12(4), 275-294.

[13] K. Reinhold, M. Jaervis and P. Tint (2015). Practical Tool and Procedure for Workplace Risk Assessment: Evidence From Smes in Estonia. SAFETY SCIENCE, 71, 282-291.

[14] S. N. Luko (2013). Risk Management — Principles and Guidelines. QUALITY ENGINEERING, 25(4), 451-454.

[15] S. J. Legg, K. B. Olsen and I. S. Laird (2015). Managing Safety in Small and Medium Enterprises. SAFETY SCIENCE, 71, 189-196.

[16] A. P. Goncalves Filho, J. C. Silveira Andrade and M. M. de Oliveira Marinho (2010). A Safety Culture Maturity Model for Petrochemical Companies in Brazil. SAFETY SCIENCE, 48(5).

[17] A. P. Goncalves Filho and P. Waterson (2018). Maturity Models and Safety Culture: A Critical Review. SAFETY SCIENCE, 105, 192-211.

[18] X. Wu, Q. Liu and L. Zhang (2015). Prospective Safety Performance Evaluation On Construction Sites. ACCIDENT ANALYSIS AND PREVENTION, 78, 58-72.

[19] H. Nordlof, B. Wiitavaara and U. Winblad (2015). Safety Culture and Reasons for Risk-Taking at a Large Steel-Manufacturing Company: Investigating the Worker Perspective. SAFETY SCIENCE, 73, 126-135.

[20] J. E. Skogdalen and J. E. Vinnem (2012). Combining Precursor Incidents Investigations and Qra in Oil and Gas Industry. RELIABILITY ENGINEERING & SYSTEM SAFETY, 101, 45-58.
[27] N. Paltrinieri, K. Oien and V. Cozzani (2012). Assessment and Comparison of Two Early Warning Indicator Methods in the Perspective of Prevention of Atypical Accident Scenarios. RELIABILITY ENGINEERING & SYSTEM SAFETY, 108, 12-31.
[28] G. I. J. M. Zwetsloot, M. Aaltonen and J. Wybo (2013). the Case for Research Into the Zero Accident Vision. SAFETY SCIENCE, 58, 41-48.
[29] S. Unnikrishnan, R. Iqbal and A. Singh (2015). Safety Management Practices in Small and Medium Enterprises in India, 6(1).
[30] D. Masi and E. Cagno (2015). Barriers to Ohs Interventions in Small and Medium-Sized Enterprises. SAFETY SCIENCE, 71, 226-241.
[31] D. Fang, X. Huang and J. Hinze (2004). Benchmarking Studies On Construction Safety Management in China. JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT-ASCE, 130(3), 424-432.
[32] S. Antonsen, K. Skarholt and A. J. Ringstad (2010). the Role of Standardization in Safety Management - A Case Study of a Major Oil & Gas Company.
[34] D. Podgorski (2015). Measuring Operational Performance of OHS Management System—a Demonstration of Ahp-Based Selection of Leading Key Performance Indicators, 73, 146-166.
[35] J. Edworthy, S. Reid and K. Peel (2018). The Impact of Workload On the Ability to Localize Audible Alarms. Applied ergonomics, 72, 88-93