Quantitative Estimation of Risks for Production Unit Based on OSHMS and Process Resilience

D Nyambayar¹, I Koshijima¹ and H Eguchi¹
¹Nagoya Institute of Technology, Gokiso-Cho, Showa-Ku, Nagoya-shi 466-8555, Japan
E-mail: nyamaa0727@gmail.com

Abstract. Three principal elements in the production field of chemical/petrochemical industry are (i) Production Units, (ii) Production Plant Personnel and (iii) Production Support System (computer system introduced for improving productivity). Each principal element has production process resilience, i.e. a capability to restrain disruptive signals occurred in and out of the production field. In each principal element, risk assessment is indispensable for the production field. In a production facility, the occupational safety and health management system (Hereafter, referred to as OSHMS) has been introduced to reduce a risk of accidents and troubles that may occur during production. In OSHMS, a risk assessment is specified to reduce a potential risk in the production facility such as a factory, and PDCA activities are required for a continual improvement of safety production environments. However, there is no clear statement to adopt the OSHMS standard into the production field. This study introduces a metric to estimate the resilience of the production field by using the resilience generated by the production plant personnel and the result of the risk assessment in the production field. A method for evaluating how OSHMS functions are systematically installed in the production field is also discussed based on the resilience of the three principal elements.

1. Introduction
Three principal elements of a production process are: (i) Production Units, (ii) Production Plant Personnel and (iii) Production Support System hereafter, referred to as PSS (a computer system introduced for improving productivity). Each principal element has production process resilience [1] that is a capability to restrain disruptive signals occurred in and out of the production process. These signals affect various production activities. There are already several reports explaining the relations between the managerial subjects, the managerial objects, the managerial components and the scale of disruptive signals [2, 3, 4]. In each principal element, risk assessment is indispensable for the production field.

In a production facility of a common-law jurisdiction, employers have a common law duty to take reasonable care of their production plant persons for their general safety. Here, occupational safety and health management system hereafter, referred to as OSHMS [5], is introduced to reduce accidents and troubles in the facility [6, 7]. OSHMS can also be applied to occupational safety and health or workplace safety and health area concerned with the safety, health, and welfare of people engaged in work or employment. In this paper first half, analyzed of the OSHMS and find out for a method for evaluating how OSHMS functions are systematically installed in the production field. The latter half introduces a metric to estimate the resilience of the production field by using the resilience generated by the production plant personnel and the result of the risk assessment in the production field.
The production plant personnel is related to all production activities in the production process by quantitatively using the level of skills and knowledge [9]. The author of that paper [9] estimated the resilience generated by the production plant personnel, hereafter referred to as RPPP.

Moreover, PSS is a computer system implemented in the production process to improve the productivity, and formalized skills of the production plant personnel are introduced in a computer system as an application software. Therefore, the resilience generated by PSS, hereafter, referred to as RPSS, is estimated quantitatively by the level of skills and knowledge transferred to PSS by the technique.

As to the production facility, the risk assessment is one of the managerial objects to keep higher resilience. And all of the production activities are the objectives of a risk assessment in the production process. Therefore, the degree of potential risk is estimated in works performed by the production plant personnel. Consequently, it is possible to estimate resilience of plant units, hereafter, referred to as RPU, using RPPP and the result of the risk assessment on the production process.

2. Risk assessment on the production process

In the production facility, OSHMS (Occupational Safety and Health Management System) is introduced to reduce the accidents and troubles in the production field. OSHMS contains the risk assessment requirements to reduce the degree of potential risks in all works in the facility [7, 9, 10].

In OSHMS, PDCA (Plan, Do, Check, Act) activities are requested for continual improvement of the safety production environment. However, there is no clear statement to adopt the OSHMS standard into the production field.

2.1. Analysis of OSHMS specification

OSHMS is a standard that defines management statements of potential risks and countermeasures related to occupational health and safety concerns in a working environment, clarifies the responsibility of the production plant personnel, and requests for implementation of its program at all production field. However, while OSHMS is adopted in the actual production company, OSHMS does not specify production plant personnel who ought to perform certain actions under particular company’s environment.

This paper discusses and analyses Chapter 4 of 2007[5] edition of OSHMS, which contains directives on activities relating to health and safety. In Table 1, the following items are extracted from each sentence in the chapter.

- Sentences location.
- Sentence.
- Subjects, object, and verbs within a sentence.
- Knowledge, skill, the rule for understanding subject and object, and for taking actions specified by verbs.

The results show that the entity in charge of safety is primarily the “organization” and there is no mention in the standard that ‘who’ should actually “act.” Furthermore, when the object was extracted during the analysis, hardly any details were mentioned, and it was hence not clear what action should be taken within the organization. Table 1 shows only top a few lines as an example of the analysis of the standard clauses.

Basically, OSHMS standard was written as a rule-base. There are many rules in the standard, though knowledge and skills are necessary for applying the rules as showing Rasmussen’s behavior model [11].

Skill-based behavior: This represents patterned and highly automated activities with little conscious attention.
Rule-based behavior: This represents activities that are modularized and selected on the condition specified in advance.
Knowledge-based behavior: This represents improvisation of activities in an environment where the available rules do not exist.
### Table 1. An example of analyzed clauses of the OSHMS standard (Section 4.2 of OHSAS18001:2007).

| Location | Sentence | Subject | Verb | Object | Knowledge, rule, skill |
|----------|----------|---------|------|--------|------------------------|
| 29-32 row from the top, page 90 | 1. Hazard identification, risk assessment and determining controls The organization shall establish, implement and maintain a procedure(s) for the ongoing hazard identification, risk assessment, and determination of necessary controls. | organization | planning | risk assessment | rule |
| 22 row from the top, page 92-16 row from the top, page 93 | The procedure(s) for hazard identification and risk assessment shall take into account: a) routine and non-routine activities; b) activities of all persons having access to the workplace | organization | shall take into account | hazard risk assessment | rule |
| 21-26 row from the top, page 95 | The organization’s methodology for hazard identification and risk assessment shall: a) be defined with respect to its scope, nature and timing to ensure it is proactive rather than reactive; and b) Provide for the identification, prioritization and documentation of risks | organization | risk assessment | organization’s methodology for hazard identification | rule |
| 24-27 row from the top, page 97 | For the management of change, the organization shall identify the OH&S hazards and OH&S risks associated with changes in the organization, the OH&S management system, or its activities, prior to the introduction of such changes. | organization | change | OH&S management system | knowledge, Rule |
| 1-2 row from the top, page 98 | The organization shall ensure that the results of these assessments are considered when determining controls. | organization | shall ensure | determining control | rule |

#### 2.2. Clarification of activities in OSHMS clauses

When a company implements OSHMS, it follows the relevant clauses in OSHMS standard. The standard uses PDCA cycle, which includes OH&S policy, goals, health and safety planning, its implementation and operation, daily inspections and improvements, system audits, and regular review of the system itself. This management cycle is adopted by company for continual improvement.

In Figure 4 that shows a tree diagram from factory to work, for example, certain information is needed to go PDCA cycling well. Table 1 reveals that the following three indispensable information are unclear for implementing and operating OSHMS:
• The input and output of a given activity.
• The main subject of a person who carries out the activity.
• The conditions on the limitations and resources that must be taken into account in executing the activity.

To identify these elements in each clause of OSHMS standard, IDEF0, a function modeling methodology, is used. Activities in IDEF0 can be identified as verbs in the clauses. Concomitantly, in IDEF0 drawing, feeds to execute an activity are expressed as inputs, and results of the activity can be expressed as outputs. The controls manage the activity, and mechanisms are required resources to execute the activity.

Figure 1 shows activities specified in the subsection 4.3.1 in the OSHMS standard. Existing activities in Figure 1 are the determination of the source of hazard, the risk assessment, and the establishment of steps to determine how to manage, implement, maintain, and disseminate those steps. Four steps “establishment of steps” “implementation of steps” “maintaining steps” and “dissemination of steps” form the basic structure of activities in all the OSHMS clauses.

2.3. Operational steps of resilience matrix

Figure 2 shows the Resilience Matrix (RM) used by Bracco [1]. In this matrix, Rasmussen’s SRK (Skill, Rule, and Knowledge) model and organizational (Individual, Group, and Organization) levels are combined in the three-by-three chart. The steps in the RM are as follows:

Step 1: It is easy to handle signals, which are to be responded to, within normal business operations through skill-based responses.

Step 2: Although a response may occur in a reaction to unpredictable signals, a certain set of operational procedures can nonetheless be followed. Thus, it is possible to respond to certain set rules even in such cases.

Step 3: Even if the signals become harder to predict and handle, the response shifts from rule-based response to knowledge-based response.

Step 4: To respond the signals, individuals must have the superior capability to recognize difficult-to-detect signals. Therefore, it is necessary to share information with other members for the responses in such cases.

Step 5: The response in Central Step should be demonstrated as a new operational procedure in day-to-day training and work towards dropping the signal to a point where it is sufficiently easy to handle with a skill-based response.

Step 6: When the group fails to deliver an adequate knowledge-based response in Step 4, and when the signal can only be managed at a higher level, the relevant information must be reported to the organization for it to respond.

Step 7: New and difficult-to-handle signals flow in from groups in Step 5. In the case of too many incoming signals, the organization should create an operation procedure and respond by changing or updating the operational manual and the regulations.

Step 8: When operational procedures are strengthened to handle weaker signals, the new operational procedure is adopted.

Central Step: If the signals being responded to can be handled through group-level operational procedures, the response should be formed by applying business operations, regulations, and precedents

By the end of this resilience cycle, a new signal is incorporated into regulations, procedures, and precedents, thus becoming standardized. It is subsequently part of the routine business of frontline operators.
2.4. Resilience matrix based OSHMS-PDCA cycle

In the factory, every unit work estimates for hazard detection. The RM can be applied to show each of unit work PDCA cycle in OSHMS standard. The risk assessment group and individual. The RM can be defined as a cycle to develop new operational procedures, for individuals to implement it, and provide feedback regarding its ease of use as a group to maintain and increase organizational resilience. Furthermore, it covers activities that occur during establishment, implementation, and maintenance. Accordingly, it seems to be appropriate to place the IDEF0 model (See Figure 1) of the OSHMS standard into the RM to specify the structure of the organizational activity cycle and identify inherent activities.

When an activity to disseminate informational output does not link up with the next activity, the production plant personnel of the organization cannot determine how to use the disseminated information based on the OSHMS clauses. Therefore, each official of the organization uses his/her
discretion in using the disseminated information. Based on these issues it can be assumed that a resilient organizational model should look like that shown in Figure 3.

PDCA cycles are shown in Figure 3 that help disseminate the OSHMS standard throughout the chemical industry. It is necessary to establish section-based PDCA cycles within the individual, group, and corporate level to run the company-wide PDCA cycles (shown in dotted line) continually without failure.

Each section goes through the implementation - maintenance - improvement stages. Subsequently, the improvement must be checked and tested. If it passes the check, one can move on to the next stage. If the improvement fails the check, one goes back to an improvement section, provides safety instructions, and returns to the cycle.

If the cycle does not work, Off-JT or OJT has to be organized as follows;
Off-JT: Education of the OHSMS standard applied to departments from the organization and to individuals from their department.
OJT: Education of own safety experience in each response provider

3. Risk assessment
Figure 6 showed a degree of potential risk. The resilience is estimated using the frequency and the degree of harm. The scale of the frequency and the degree of harm will be defined as the company’s rule. The minimum potential risk is one, the maximum potential risk is 25, and higher the potential risk, the lower the resilience. We think about the education on the Rule-based, Skill-based, Knowledge bases on Table 2.

Rule-bases: Work frequency “small” and degree of harm “small.”
Skill-based: Work frequency “middle” and degree of harm “middle.”
Knowledge-bases: Work frequency “large” and degree of harm “large.”

3.1. Identification of the work in the production process
Before the risk assessment of works in the production process, all of the works are identified to prevent the oversight. The whole structure in the factory is described as the tree diagram from the factory as the start point to the unit work in Figure 4 [12].

Figure 4 shows a typical structure of works in a factory. For developing RM, a factory in Figure 4 is an equivalent to an organization in RM. Section and unit process is reflexed as a group. Work is specified as an individual activity.
3.2. Unit work and unit operation to estimate the potential risk
All works are described according to the operation procedure of the following example [12]. In the example of the strainer to remove the foreign objects in the flow (See Figure 5), the unit work is described as the sequence of the unit operation from (1) to (7).

(1) Check and close the valve <7> on purge drain line of bypass line.
   Hazard: If it opens, spout the liquid (Harm: Soaking up the liquid).
(2) Open outlet valve <6> and inlet valve <5> sequentially, and start feeding to the bypass line.
   No hazard
(3) Close inlet valve <2> and outlet valve <3> sequentially, and stop feeding to the current line.
   Hazard: Error of sequence causes the spout of liquid (Harm: Soaking up the liquid).
(4) Open the valve <4> slowly on purge drain line of former line, and reduce the residual pressure.
   Receive the residual using a bucket.
   Hazard: If the bucket is too small, the liquid overflows (Harm: Soaking up the liquid).
(5) After the completion of the purge, detach the flange of the strainer, and change the strainer in the former line.
   Hazard: If the size of the wrench is wrong, the slip of wrench occurs (Harm: Fall to the ground).
(6) Attach the flange to the former line.
   Hazard: If the size of the wrench is wrong, the slip of wrench occurs (Harm: Fall to the ground).
(7) Close the valve <4> on purge drain line of former line.
   No hazard

In this example, the potential hazard in work is identified in each unit operation (1), (3), (4), (5) and (6).

4. Estimation of resilience using the result of risk assessment
The risk assessment is executed on every unit work, and at first, the frequency of work and the degree of harm about the potential hazard are estimated. The resilience is estimated using the frequency and the degree of harm. Higher frequency of work or higher degree of harm brings to lower $R_{PU}$.

The degree of potential risk is shown as the component of Table 2. The scale of the frequency and the degree of harm will be defined as the company’s rule. In Table 2, the minimum potential risk is 1; the maximum potential risk is 25, Component of the matrix $(i, j)$ equals $(i \times j)$. According to the component of Figure 6, the index of resilience, hereafter referred to as IR, is defined as the inverse of the potential risk, (i.e. $IR=1/\text{potential risk}$).

|   | 5 | 10 | 15 | 20 | 25 |
|---|---|----|----|----|----|
| 5 | 4 | 8  | 12 | 16 | 20 |
| 4 | 3 | 6  | 9  | 12 | 15 |
| 3 | 2 | 4  | 6  | 8  | 10 |
| 2 | 1 | 2  | 3  | 4  | 5  |

Table 2. The matrix of potential risk.
In the production process, the work of the production plant personnel reaches to all production activities concerning the production units. Therefore, the combination of IR calculated by the result of risk assessment and \( R_{PPP} \) gives \( R_{PU} \). One production process contains several hundred or thousands of unit works, and it is possible to decide the degree of the potential risk to each unit operation. Consequently, the highest degree of the potential risk is the representative one of the whole production process. Therefore, \( R_{PU} \) is as follows.

\[
R_{PU} = R_{PPP} \times \text{Minimum Value of IR} \quad (1)
\]

If the degree of potential risk in the works is intolerable, the measure of risk reduction is practiced. Therefore, as the degree of risk decreases gradually, IR of the production units becomes higher by degrees. In the example (See Table 2), IR is from 0.04 to one, and \( R_{PU} \) is not greater than that of the production plant personnel. If all unit works have the minimum risk, \( R_{PU} \) equals to that of the production plant personnel (\( R_{PPP} \)). Here, in the case that \( R_{PPP} \) is 0.993 [6], suppose that the maximum value of the potential risk in work equals to 16 (Both of the frequency of work and the degree of harm equal to 4,), \( R_{PU} \) is as follows.

\[
R_{PU} = 0.993 \times \frac{1}{16} = 0.062 \quad (2)
\]

4.1. Total resilience on the production process

Three components of the production process, (i) Production Units, (ii) Production Plant Personnel, (iii) PSS, have own resilience respectively. Moreover, it is possible to estimate them quantitatively. The most important resilience is \( R_{PPP} \). This resilience is calculated using the work hours devoted to skills (work hours engaged in the daily routine), hereafter referred to as WHDS, and the level of skills and knowledge concerning the production plant personnel [7]. The skills are classified as the three types of factors: operational skills that play an important role for the use of mainly hands and legs, memory skills that take a significant part for the use of the memory for achieving smooth operation and communication skills that have a considerable place for the attainment of effective mutual communication.

WHDS are these three factors as the duration of daily work of each production plant personnel, and the work hour is measured, and the proportion of each skill is analyzed in the daily routine. As the production plant personnel has an appropriate job according to the position in the workgroup (suitability of skill), WHDS should be weighted. The level of the skills and knowledge contains a factor of position and a factor of effort in staff duty.

Weighted WHDS=WHDS ×suitability of skill about the position of staff member \( \quad (3) \)

Level of skills and knowledge=Position of the staff member+Effort in the staff duty \( \quad (4) \)

Each production process has a different number of staff members, and each production plant personnel has different WHDS. Therefore the resilience is estimated by the level of skills and knowledge weighted by WHDS, i.e. \( R_{PPP} \) is the weighted-average of the level of skills and knowledge of the production plant personnel.

Each production plant personnel has own work hours in the daily routine and own WHDS; therefore, a weighted-average of the level of skills and knowledge is used to indicate \( R_{PPP} \).

\[
R_{PPP} = \frac{\sum \text{(Weighted WHDS×Level of skills and knowledge)}}{\sum \text{(Weighted WHDS)}} \quad (5)
\]

\( R_{PPP} \) is available to estimate the resilience regardless of the number of production plant personnel. Because a high level of skills and knowledge causes high \( R_{PPP} \), it is indispensable to provide the education and training to improve the capability of the production plant personnel. Moreover, if the production plant personnel involves in an appropriate job for the position in the workgroup, the total work hours in the work group will be optimal. Also, the margin of work hours to devote to the education and training will be created [6, 7].
In PSS, several techniques that are the formalized skills of the production plant personnel are implemented. According to the proportion of a job replacement by PSS, PSS can take over the level of skills and knowledge [8]. $R_{PP}$ is the weighted-average of the level of skills and knowledge of the production plant personnel using the weighted WHDS. Therefore, $R_{PSS}$ is deduced by the weighted-average of the replaceable level of skills and knowledge by PSS using the replaceable WHDS. $R_{PSS}$ is as follows:

$$R_{PSS} = \frac{\sum \text{(Replaceable WHDS)} \times \text{(Replaceable Level of skills and knowledge)}}{\sum \text{(Replaceable WHDS)}}$$  

(6)

4.2. Result total resilience on the production process

Therefore, if all skills in the production process are replaced by the function of PSS, i.e. all skills of the production plant personnel are transferred to PSS, and if the production plant personnel obtain the margin of time to master the new skills, $R_{PP}$ will become higher. Moreover, equation (1) shows that $R_{PU}$ is calculated by $R_{PP}$ and the result of risk assessment. The higher the harm of potential risk, the lower $R_{PU}$. Consequently, to keep higher resilience on the production process, following measures are effective.

- The periodical and continuous education and training for the production plant personnel is effective to improve $R_{PP}$.
- It is possible to reduce the total work hours in the work group by the practice of an appropriate job routine for the position. Therefore, the job reallocation should be considered periodically.
- It is necessary to implement the formalized skills as the technique in PSS to reduce the work hours of the production plant personnel.
- It is possible to use the margin of work hours to master the new skills and to practice a higher level of works.

After the estimation of potential risk in the production process, the reduction of risk to improve $R_{PU}$ is necessary.

5. Conclusions

In the production process, the resilience that restrains the disruptive signal to prevent the accident and trouble. Analysis of the OSHMS, for a method for evaluating how OSHMS functions are systematically installed in the production field. In addition to $R_{PP}$ and $R_{PSS}$, a metric to estimate $R_{PU}$ is proposed in this paper. The new and original contribution of this paper is that the result of the risk assessment is usable in the evaluation of the resilience of the production unit.

The measures based on the quantitative estimation that enables to improve the total resilience on the production process i.e. to increase the capacity to restrain the disruptive signal will progress the total productivity gradually of the production process.

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