Contribution of Production Support System to Reinforce Process Resilience in the Chemical Industry\textsuperscript{1}\textsuperscript{*}

Hajime Eguchi, Davaadorj Nyambayar, and Ichiro Koshijima

Abstract—The chemical industry can be defined as a typical type of plant industry. As it is impossible to see inside of a plant directly, a system; PSS (Production Support System) that enables to monitor a process status with sensors is applied. Since it costs to implement PSS, a company checks the reasonability of the amount of investment from the viewpoints of resource saving, energy saving and man-power saving by estimation of effects provided by PSS. The company tends to rely on the manpower saving out of these three kinds of saving though such man-power saving causes a decline of total skills in a production process plant. This situation brings a risk of occurrence of many issues in the process plant. Actually, in the industry, the resilience of production process is worthy of notice as a capacity to restrain a lot of disruptive signals. The process resilience is generated by 1) Production plant personnel, 2) PSS, and 3) Production unit. It is necessary to prevent accidents and some troubles to execute the production activity. Especially the level of skills and knowledge of the production plant personnel are mostly concerned with the process resilience. If margin time can be produced due to PSS, it will be devoted to educating and training the production plant personnel. As a result, the process resilience will be reinforced.

I. INTRODUCTION

The chemical industry can be defined as a typical type of plant industry. Since it is impossible to see directly inside of a process where products are produced from raw materials, many process data are monitored with field sensors. Production plant personnel consisting of technical staff members in a production team engages in daily routines and judges as to whether the situation of the production process is acceptable or not with the sensors by respective process values. The sensor-based process monitoring system (Production Support System, hereafter referred to as PSS) becomes more complicated and large-scale, and also becomes more sophisticated and expensive. Therefore, when a company requires a return from investment for PSS, three viewpoints are considered: 1) the resource saving, 2) the energy saving, and 3) the man-power saving. Before the implementation of PSS, the company estimates financial advantage to be obtained from the investment for PSS. However, as the return from the resource saving and the energy saving are also dependent on external economic environments, it is hard to obtain the advantage as expected. As the effect of man-power saving is thought to reduce the cost of labor, this factor is promoted actively. Naturally, the reduction of the production plant personnel brings the degradation of total skills and the level of skills and knowledge to operate the production process smoothly. Nevertheless, the production process has to maintain and improve the capability to restrain disruptive signals occurring in and out of the production process (Process resilience). And it is necessary to progress the level of skills and knowledge for reinforcement of the process resilience by education and training because the process resilience is strongly concerned with the level of skills and knowledge of the production plant personnel.

Moreover, PSS is effective to create the margin of time in the daily routines of the production plant personnel. Consequently, the production plant personnel will be able to improve the level of skills and knowledge.

II. SKILLS IN THE PRODUCTION PROCESS

The production process in the chemical industry is composed of 1) Production plant personnel, 2) PSS, and 3) Production unit. These components have their own process resilience respectively, and the authors have already shown the managerial components of the process resilience [1, 2], proposed the method to evaluate the process resilience quantitatively [3, 4, 5]. As the skills in the production process and the level of skills and knowledge play the important role, it is necessary to evaluate the total skills in the production process quantitatively.

A. Elements of skills and daily routine in the production process

A production team is composed of more than one person. The skills in the production process are classified into three categories. 1) Operational skills that mainly require physical work, 2) Memory skills that are based on the record of operation, 3) Communication skills that are required for the mutual understanding of group members [3]. Each one of the members executes own skills in the daily routines and has an own level of skills and knowledge to execute a smooth operation of a plant. The level of skills is composed of two factors: job position and effort in staff duty [6]. The examples of daily routines conducted by the production plant personnel can be listed as follows:

A) Monitoring the operation and changing the set point values of controllers;
B) Performing data entry of measured values in the operation report;

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H. Eguchi is with the Department of Social Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya-City, Japan (corresponding author to provide phone: 090-3143-9681; e-mail: h.e@triton.ocn.ne.jp). D. Nyambayar is with the Department of Social Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya-City, Japan. I. Koshijima is with the Department of Social Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya-City, Japan.
C) Editing the operation report;
D) Planning the production schedule;
E) Searching for the cause of process issues;
F) Checking of equipment and preparing for plant operation;
G) Participating in job team meeting.

Measuring the work hours allocated to each job is possible. Next, work hours devoted to skill, hereafter referred to as WHDS are estimated. Production plant personnel should decide the rate of distribution by self-judgment, i.e., the measured work hours are distributed to three types of skills. According to the position of staff members in a job team, the skills suitability is different, i.e., in the case of the supervisor, the operational skills are less suitable than the communication skills and the memory skills. Moreover, the memory skills are less suitable than the communication skills. It is possible to calculate the suitability between three categories of skills for each position with hierarchical analysis [7].

Besides, as the technical level of each member is different, another index, the level of skills and knowledge, is introduced. This index is a sum of the position of each staff and the effort in duty. It is improved by the education and training. Therefore, the effort in the duty of each member should be appreciated periodically in the company [6].

B. Quantitative estimation of skills

The skills of the production plant personnel (Q) (Value of skills, hereafter referred to as VOS) are calculated with WHDS (B), the skill's suitability about the position of the staff member (W1), and the level of skills and knowledge (V).

\[ T_k = B_k \cdot W^{1_k} \] (1)
\[ Q = T_k \cdot V \] (2)
\[ V = (\text{position of staff} + \text{effort in duty})^T \] (3)

Here, \( T_k \) is the weighted WHDS. The reason of this definition is as follows.

- VOS is different according to the skill’s suitability of staff members even if they engage in the same routine or for the same time duration. If the production plant personnel execute the routine suitable to the position, higher VOS is obtained during the same time duration of work [6, 7].
- The level of skills and knowledge depends not only on the position but also on the effort in duty. For the improvement of effort in duty, the company should offer the opportunity of the education and training to every production plant personnel according to the criterion in the company.

III. ROLE OF PRODUCTION SUPPORT SYSTEM

The targets of the implementation of PSS are the resource saving, the energy saving, and the man-power saving. The company tends to rely on the man-power saving out of these three kinds of saving. On the other hand, to attain man-power saving, the company can anticipate the reduction of labor cost. However, as a result of such personnel reduction, the skills in the production process will decline, and also some serious issues will occur. Therefore, the company should aim at the effect of man-power saving generated by PSS without personnel reduction. Precisely, in the case that margin time can be produced due to PSS, it will enable to educate and train the production plant personnel. The level of the skills and knowledge will improve gradually by the education and training. Three functions of PSS that create the margin time in the daily routines introduced in a real chemical process plants are shown in Section A, B and C. These plants are all batch-wise production plants. This type of plant has several features.

The batch-wise production plant has the following advantageous points compared with a continuous production plant:

- It has a simple mechanism. Consequently, the construction cost is lower than the continuous production plant of the same production scale.
- It is adaptable to a large variety of products. Therefore, it is possible to produce more kinds of products than the continuous production plant.
- The adjustment of the production quantity is simple with more than one plant.
- It is possible to replace wrong batch plant by another one of the same types.

However, the batch-wise production plant has the following disadvantageous points compared with the continuous production plant:

- The number of kinds of process parameters to be monitored such as temperature, pressure, flow rate, and so on are more than that of the continuous production process of the same production scale.
- The interval of transitional stage during a passage from the start to stop of a production is shorter than the continuous production plant, resulting in a high frequency of transitional operation i.e. the unsteady state is longer than the continuous production plant.

Therefore, PSS is necessary to advance the above advantageous points and compensate the above disadvantageous points.

A. Batch plant production scheduling system [8]

In this production process, there are six reactors with different sizes. To comply with variable orders from clients, a producer should use particular combinations of reactors for producing required products, considering about shipping times, with practical skills and knowledge. As to a suitable production schedule, empirical knowledge is also necessary, because there are various constraints to be satisfied by the producer for the suitable production schedule. This system is composed of several constraints and the estimation function. And the feasible solution is searched and found within a practical time using the combinatorial optimization method. Further, since the production schedule changes frequently, skillful staffs having the practical skills and knowledge have always been required. Here, if such skills and knowledge can be filled by
the function of PSS, the experienced staffs will be released from time-consuming routines because they can be replaced with less-experienced staffs.

B. Batch reactor temperature control system [9]

There are a lot of transitional operations in a batch reactor during a passage from start to stop of a reaction, and dynamics of controlled variables change largely. Therefore, it was difficult for a conventional controller to control in a stable manner the inner temperature of the batch reactor to improve the quality of final products. This production process includes two batch reactors in each of which, Model Predictive Control (hereafter referred to as MPC) is implemented to improve the controllability. In this case, two controllers are cascaded. The controlled variable of an upper loop is the internal temperature, while that of a lower loop is the inlet temperature of cooling water. As a result of the implementation of MPC, the deviation of internal temperature is reduced from 6°C to 2°C. Moreover, the feed flow change of raw material to reduce the deviation and the fluctuation of internal temperature and the set point change of internal temperature are made redundant by the implementation of MPC, which allows easy tuning of the parameter because of the reduced number of parameter to be adjusted. After that, the workload of the production plant personnel concerned with the batch reaction can be vastly reduced.

C. Batch plant operation management system [10]

In the case of the batch plant, many process variables are gathered with field sensors to monitor the state of operation continuously. As the number of data to be managed in the batch plant for smooth operation are usually larger than that of a continuous production plant of the same production scale, the data for the batch plant should be treated efficiently. As to batch plant, there are two types of data gathering interval. One is a batch-wise interval (The trigger of this type is the batch start and stop operation), and another is a continuous data gathering interval (The trigger of this type is the fixed time). Consequently, two types of data have different structures. Therefore, it was necessary to utilize some particular procedures which can be provided only by experienced production plant personnel. On the other hand, this system; BOMS (Batch plant Operation Management System) has a function to keep consistency between two types of data. Accordingly, using Relational Data Base provided by BOMS, these different types of data can be searched smoothly and rapidly. Moreover, these data can be accessed with a network system. As a result of the implementation of BOMS, the production plant personnel can reduce their workload for searching the requested data, i.e. margin time is born.

All examples of PSS mentioned above are implemented to improve the productivity of batch plant, but they apply to another type of plants, for example, the continuous plant, utility plant, etc. Therefore, PSS is always available for the production process in the chemical industry.

IV. RESILIENCE GENERATED IN THE PRODUCTION PROCESS

A production process is composed of three elements: 1) Production plant personnel, 2) PSS, and 3) Production unit and these elements have the capability to restrain disruptive signals occurred in and out of the production process (Process resilience). There are two types of signals:
1) The signal that occurs unexpectedly like accidents, troubles or natural disasters,
2) The signal that occurs inevitably accompanied with the production activity like start up/shut down operation, grade shifting or flow change of products, and purchase order etc.

As for the resilience in the industry, an analysis uses a resilience matrix (The raw indicates the size of a mass of human beings, i.e., individual, group and organization, and the column indicates the intensity of signals.) [11]. As to these three elements of the production process, managerial items are defined respectively using the intensity of the disruptive signals as the column, the managerial subjects or objects as raw [1, 2].

The process resilience generated in the production process is as follows.

a) The process resilience produced by the production plant personnel has been evaluated quantitatively based on the skills and the level of skills and knowledge. As the scale of the plant is different, the number of engaged production plant personnel is also different depending on respective production processes. Also, the duration of work hours and the contents of routine are different according to the production process, the averaged level of skills and knowledge by the weighted WHDS is used to evaluate the resilience produced by the production plant personnel [3]. Here, WHDS designates the degree of contribution of each production plant personnel.

Process resilience produced by the production plant personnel is as follows.

\[ R_{cc} = \sum \frac{\text{weighted WHDS}_i \times \text{level skills knowledge}_i}{\sum \text{weighted WHDS}_i} \]  (4)

b) In the case of PSS, the effect of man-power saving is produced by the replacement of skills by the function of PSS. Therefore, assuming that the level of skills and knowledge of production plant personnel is replaced and followed by the function of PSS, the resilience produced by PSS is calculated using the replaceable WHDS and the replaceable levels and knowledge [4].

Process resilience produced by PSS is as follows.

\[ R_{PSS} = \frac{\sum \text{replaceable WHDS}_i \times \text{replaceable level skills knowledge}_i}{\sum \text{replaceable WHDS}_i} \]  (5)

Figure 1 is the procedure to improve the process resilience with the function of PSS.
c) In the case of the production unit, the managerial subjects are related to the individual, group, and company, while the managerial objects are the detection of the accidents and troubles, the repair, and rebuild of units, risk assessments, etc. It is possible to evaluate the process resilience produced by the production unit based on the resilience produced by the production plant personnel and the result of risk assessments because both of them depend on the level of skills and knowledge of production plant personnel [5].

Process resilience produced by the production units is as follows.

\[ R_{PU} = R_{PPP} \times \text{Minimum value of IR} \]  
\[ \text{(see APPENDIX AIII. as to IR: Index of Resilience)} \]

V. EXAMPLE OF EVALUATION IN THE REAL PRODUCTION PROCESS

It is possible to show the example of the process resilience in the real production process quantitatively. This plant has two reactors to produce a plastic. In this plant, three production plant personnel (Supervisor, Deputy-supervisor, New-comer) engage in the daily routines. The daily routines are classified into seven categories as mentioned in Chapter II. This plant operates only daytime for 23 days per month, for 8 hours per day. Three categories of process resilience are as follows (see APPENDIX in detail).

\[ R_{PPP} = 0.993 \]  
\[ R_{PSS} = 0.173 \]  
\[ R_{PU} = 0.062 \]  

The process resilience produced by three elements in the production process depends on the level of skills and knowledge of the production plant personnel, so the certain execution of the education and training for the production plant personnel is the most important mission of the company to improve the process resilience.

VI. CONCLUSION

As mentioned above, the process resilience is most concerned with the level of skills and knowledge of the production plant personnel. If margin time in the daily routines of them are produced by PSS, the education and training to improve the process resilience will be possible. As a result of the appropriate education and training, the process resilience will be reinforced. There are two procedures to produce margin time as follows.

- To review job routine assignments in a team and to reallocate members between several teams so that appropriate routines can be carried out in the team.
- To replace the daily routines, which have been executed by the production plant personnel, with the functions of PSS. As the replaced routines implemented in PSS succeeds to the process resilience produced by the production plant personnel, and if the production plant personnel gains the new skills or knowledge, total process resilience will improve.

Consequently, roles that a company should perform are to clarify skills required to the production plant personnel and to improve the level of skills and knowledge by the education and training. Moreover, to accelerate this process, a company should promote the implementation of PSS. And, it is indispensable to establish the system of personnel appreciation to reflect the result of the education and training for the production plant personnel correctly and to dissolve the difference of process resilience between several sections.

APPENDIX

The contents of Appendix AII. to AIII. are the detailed calculation process of each process resilience.

AII. Calculation of process resilience generated by Production plant personnel [3]

At first, the weighted work hours devoted to skills \( T_k \) are calculated as follows \( k = 1: \text{supervisor}, k = 2: \text{deputy supervisor}, k = 3: \text{newcomer} \).

\[ T_1 = B_1 \cdot W_1 \]  
\[ = (22.96,10.58,3.85,13.08,4.91,27.56)^T \]  
\[ T_2 = B_2 \cdot W_2 \]  
\[ = (16.11,33.26,33.26,8.263,4.549,33.26,22.73)^T \]
\[ T_3 = B_3 \cdot W_{13} \]
\[ = (5, 30, 20, 0, 5, 60, 20)^T \]  (12)

The overall weighted work hours devoted to skills in the team \( T_{\text{total}} \) are as follows.

\[ T_{\text{total}} = T_1 + T_2 + T_3 \]
\[ = (44.07, 73.84, 57.11, 21.34, 14.46, 135.87, 70.29)^T \]  (13)

Here, the dimension of \( TV \) is “hour”.

\[ TV = \sum_{i=1}^{7} T_{\text{total}} \cdot i = 416.98 \]  (14)

Next, the concatenation of matrix \( T_1, T_2, T_3 \) multiplied by vector \( V \) indicates the overall value of skills for each activity of team \( Q \).

\[ V = (1.2, 1.0, 0.8)^T \]  (15)

\[ Q = (T_1 \cdot T_2 \cdot T_3) \cdot V \]
\[ = (47.66, 69.95, 53.88, 23.95, 14.44, 132.39, 71.81)^T \]  (16)

The summation of the component of vector \( Q \) that indicates the overall value of skills for all activities of team \( QV \) is as follows (here, the dimension of \( QV \) is also “hour”).

\[ QV = \sum_{i=1}^{7} Q_i = 414.08 \]  (17)

\[ R_{\text{pp}} = \frac{QV}{TV} = 0.993 \]  (18)

\section*{TABLE I Weight vector \( W_1 \)}

<table>
<thead>
<tr>
<th>Weight vector ( W_{1k} )</th>
<th>Supervisor</th>
<th>Deputy supervisor</th>
<th>Newcomer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 0.5740</td>
<td>1/0.8054</td>
<td>1/1.0</td>
<td></td>
</tr>
<tr>
<td>2) 0.9823</td>
<td>2/0.9098</td>
<td>2/1.0</td>
<td></td>
</tr>
<tr>
<td>3) 1.7785</td>
<td>3/1.3633</td>
<td>3/1.0</td>
<td></td>
</tr>
</tbody>
</table>

1) Operational skills, 2) Memory skills, 3) Communication skills

\section*{TABLE II Matrix of work hours devoted to each skill \( B_1, B_2, B_3 \)}

<table>
<thead>
<tr>
<th>Skill</th>
<th>Supervisor</th>
<th>Deputy supervisor</th>
<th>Newcomer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1) 2) 3) 1) 2) 3) 1) 2) 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A)</td>
<td>40 0 0 20 0 0 5 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B)</td>
<td>15 2 0 30 10 0 20 10 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C)</td>
<td>5 1 0 30 10 0 15 5 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D)</td>
<td>6 8 1 8 2 0 0 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E)</td>
<td>0 5 0 0 5 0 5 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F)</td>
<td>40 20 0 30 10 0 50 10 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G)</td>
<td>0 10 10 0 10 10 0 15 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\section*{All. Calculation of process resilience generated by PSS \[4\]}

To estimate \( R_{\text{pss}} \), it is necessary to use \( W_{1k}, B_k, BN_k \), and \( C_v^{abc} \). The components of \( BN_k \) (the normalized components of \( B_k \)) are as follows (see TABLE III).

\section*{TABLE III Matrix of normalized WHDS \( BN_1, BN_2, BN_3 \)}

| Work i | 1) 2) 3) 1) 2) 3) 1) 2) 3) |
|--------|-------------------|---------|
| A)     | 40/40             | 0/20/0  | 0/5/0  |
| B)     | 15/2/17           | 0/30/40 | 0/10/40| 0/20/30| 0/10/30|
| C)     | 5/6/16            | 0/30/40 | 0/10/40| 0/15/20| 5/20/0 |
| D)     | 6/15/8/15         | 1/15/80 | 2/10/0| 0/0/0  |
| E)     | 0/5/0             | 0/0/5   | 0/5/0  |
| F)     | 40/60/20/60       | 0/30/40| 0/10/40| 0/50/60| 10/60/0|
| G)     | 0/10/20           | 10/0/20| 0/10/20| 0/10/20| 0/15/20| 5/20/0 |

The replaceable hours by the implementation of the PSS \( (C_v^{abc}) \) are estimated through the measurement and analysis of work hours (or the assumption of work hours) (see TABLE IV).

In this case, the functions implemented into the PSS are as follows (These functions are explained in Chapter III.).

a) Advanced control system
b) Data-gathering and monitoring system
c) Production-scheduling system

The replaceable weighted WHDS by the PSS \( (\Delta T_k) \) is represented as follows. Here, \( BN_k \) is the normalized WHDS (see TABLE III).

\[ \Delta T_k = C_v^{abc}(BN_k \cdot W_{1i}) \]  (19)

\section*{TABLE IV Matrix of replaceable work hours by each function \( C_v^{abc}, C_v^{total}, C_v^{abc}, C_v^{total} \)}

<table>
<thead>
<tr>
<th>Work i</th>
<th>Alternative</th>
<th>A)</th>
<th>B)</th>
<th>C)</th>
<th>D)</th>
<th>E)</th>
<th>F)</th>
<th>G)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>1)</td>
<td>2)</td>
<td>3)</td>
<td>1)</td>
<td>2)</td>
<td>3)</td>
<td>1)</td>
</tr>
<tr>
<td>A)</td>
<td>0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B)</td>
<td>0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C)</td>
<td>5 5 5 5 5 5 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D)</td>
<td>0 0 0 0 0 0 0</td>
<td></td>
<td></td>
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<tr>
<td>E)</td>
<td>0 0 0 0 0 0 0</td>
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<td></td>
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<tr>
<td>F)</td>
<td>0 0 0 0 0 0 0</td>
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<td></td>
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<tr>
<td>G)</td>
<td>0 0 0 0 0 0 0</td>
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</tbody>
</table>

The total weighted WHDS \( (T\text{KD}) \) are as follows using (10), (11), (12).

\[ T1D = \sum_{i=1}^{T} T_{1i} = 125.54 \]  (20)

\[ T2D = \sum_{i=1}^{T} T_{2i} = 151.43 \]  (21)

\[ T3D = \sum_{i=1}^{T} T_{3i} = 140 \]  (22)

The total VOS of this team \( (QV) \) is as follows.

\[ V = (v_1, v_2, v_3)^T \]
\[ = (1.2, 1.0, 0.8)^T \]  (23)

\[ QV = (T1D, T2D, T3D) \cdot V \]
\[ = 414.08 \]  (24)

The replaceable weighted WHDS by the PSS \( (\Delta T_k) \) calculated by \( B_k, BN_k \), and \( C_v \): WHDS, \( BN_k \): normalized WHDS, \( C_v^{abc} \): replaceable work hours by the PSS, \( \Delta T_k \): replaceable weighted WHDS by the PSS) are as follows.

\[ \Delta T_1 = C_v^{abc}(BN_1 \cdot W_{1}) = (5.74, 7.85, 10.51)^T \]  (25)

\[ \Delta T_2 = C_v^{abc}(BN_2 \cdot W_{1}) = (4.03, 13.76, 2.48)^T \]  (26)

\[ \Delta T_3 = C_v^{abc}(BN_3 \cdot W_{1}) = (1.3, 0)^T \]  (27)
The total replaceable weighted WHDS by the PSS \((\Delta T_{kD})\) are as follows.

\[
\Delta T_{1D} = \sum_{i} \Delta T_{1i} = 24.10 \ (28)
\]

\[
\Delta T_{2D} = \sum_{i} \Delta T_{2i} = 20.27 \ (29)
\]

\[
\Delta T_{3D} = \sum_{i} \Delta T_{3i} = 4.0 \ (30)
\]

The replaceable levels of skills and knowledge \((\Delta v_1, \Delta v_2, \text{and} \Delta v_3)\) are as follows.

\[
\Delta v_1 = (\frac{\Delta v_{1D}}{T_{1D}}) \cdot v_1 = 0.230 \ (31)
\]

\[
\Delta v_2 = (\frac{\Delta v_{2D}}{T_{2D}}) \cdot v_2 = 0.134 \ (32)
\]

\[
\Delta v_3 = (\frac{\Delta v_{3D}}{T_{3D}}) \cdot v_3 = 0.023 \ (33)
\]

\[
\Delta V = (\Delta v_1, \Delta v_2, \Delta v_3)^T = (0.230, 0.134, 0.023)^T \ (34)
\]

The resilience generated by the PSS is deduced from the weighted average of the replaceable level of skills and knowledge by the PSS using the total replaceable WHDS.

\[
R_{PSS} = \frac{\Delta v_1 \cdot \Delta T_{1D} + \Delta v_2 \cdot \Delta T_{2D} + \Delta v_3 \cdot \Delta T_{3D}}{\Delta T_{1D} + \Delta T_{2D} + \Delta T_{3D}}
\]

\[
= 0.173 \ (35)
\]

### III. Calculation of process resilience generated by production unit [5]

The risk assessment is executed on every unit work, and at first, the frequency of work and the degree of harm concerning 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 V. The scale of the frequency, and the degree of harm will be defined as the company’s rule.

![TABLE V Matrix of potential risk](image)

In TABLE V, the component \((i,j)\) of the matrix equals to column \(i\) multiplied by row\(j\). According to the component of the matrix, the index of resilience (hereafter referred to as IR) is defined as the inverse of the potential risk, \(i.e. \text{IR} = 1 / \text{potential risk}\). 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 \(R_{PSS}\) 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.

\[
R_{PU} = R_{PSS} \times \text{Minimum value of IR} \ (36)
\]

Here, as \(R_{PP}\) equals 0.993, suppose that the maximum value of the potential risk in the works of this production process equals to 16 (Both of the frequency of work and the degree of harm equal to 4.), \(R_{PU}\) is as follows.

\[
R_{PU} = 0.933 \times \frac{1}{16} = 0.062 \ (37)
\]

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