ORGANIZATIONAL STRUCTURE ON THE RESILIENCE OF PRODUCTION PROCESSES BASED ON HUMAN FACTORS IN THE CHEMICAL INDUSTRY

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Abstract

In the chemical industry, a production process must possess a high resilience against the influence of disruption to maintain a high productivity. Resilience is provided by the skills and knowledge (human factors), by the production unit and by the production support system (artificial factors). Therefore, a well-managed production process possesses an inherent resilience. Such a process must be supervised by a managerial structure that provide the ability to respond to all categories of disruptive signals. Three categories of disruptive signals exist: large scale (e.g., fire, explosion and disaster), medium scale (e.g., emergency stop, the start-up and shut-down) and small scale (e.g., manual operation, set point change). An organizational structure that responds to such disruptive signals should consist of: individual, group and company (the managerial subjects). In order to maintain the high resilience, it is important to invest in the education and training to advance the level of skills and knowledge. Moreover, formal channels of communication between the managerial subjects have to be established and exercised on a continual basis. This paper discusses the categories of disruptive signals, and the corresponding managerial components responsible for their control based on human factors. Furthermore, several traits to improve the resilience are examined.

Keywords: Resilience, Chemical industry, Production process, Human factors, Skills and knowledge, Disruptive signals.

1. Introduction

In a production system, the purpose of a production unit is to transform raw materials into a product, in an efficient and predictable manner. There are two broad categories of production systems: material production and assembly. The chemical
industry is a typical example of the former, and its production units are threatened by various disruptions (hereafter referred to as disruptive signals) that may lead to production problems. In previous studies, the concepts of resilience and Resilience Engineering in a chemical plant were proposed, in order to estimate the ability of a production unit to resist the influence of such disruptive signals [1]. The concept of resilience markers was introduced, to reduce the vulnerabilities caused by organizational size [2, 3]. Moreover, a resilience matrix was defined to classify the responses in the organization according to the scale of disruptive signals [4].

There are various disruptive signals that may impact on the production process, by changing its operational state. For example, a small-scale disruptive signal represents a change in operation conditions, such as a set point change. An emergency stop and the start-up and shut-down operations of a process unit are examples of medium-scale disruptive signals, while a fire, an explosion or a natural disaster are considered large-scale disruptive signals.

The production process is composed of the production plant personnel, the production units and the production support system (PSS, the computer system that assists the production). The first component belongs to the category of human factors, while the last two are classified as artificial factors, and they all contribute to the improvement of the resilience.

The operation of the production process is tailored in accordance with the demands of the client. Therefore, in order to improve productivity, it is necessary to restrain the influences of disruptive signals, by increasing the resilience of the production process. In this framework, the stakeholders in charge of responding to a disruptive signal are the individual (production plant personnel), the group (teams of individuals that operate the production process) and the company (i.e., the managerial subjects that manage the managerial components), each playing a role in the improvement of the production process’s resilience.

Section 2 discusses the sources of resilience, Section 3 introduces the optimal managerial structure of the organization, based on human factors, necessary to maintain the resilience, Section 4 describes the specific approaches, and Section 5 concludes with some remarks regarding the application of the resilience matrix to the chemical industry.

2. The Source of Resilience in the Production Process

2.1. Review of related works

A model of organizational resilience, proposed in [4], is shown in Fig. 1. This 3×3 resilience matrix has “signal variability” in the vertical axis and “actors that should provide a response” in the horizontal one. Each element of the matrix represents an indispensable response that should be taken into account by a specific actor. Moreover, the resilience matrix shows the nine steps to follow in order to enhance operational safety.

Previous works [1, 5-13] categorized resilience, as it relates to plant operations, into nine key concepts, illustrated in Fig. 1 [4]. The methods applied in previous studies to confirm these key concepts are illustrated respectively in each sector of the resilience matrix in Fig. 2. Some papers addressed steps 3, 4
and 6, based on a social science approach; while other papers regarded steps 1 and 7. However, no paper was found about steps 5 and 8.

Bracco et al. stated in [4]: “At this point (Step 4) the group should decide the right path. If the signal variability is concerning work-group procedures and habits, it is possible to adapt tasks, rules and practices to the new information (Central step) and move to the implementation of the new procedures in the everyday practices (Step 8), going back to Skill-based management of now tractable signals” [4]. This means that the lack of a deep analysis concerning Step 4, the Central step and Step 8, may prevent effective and immediate involvement of actors that are able to “eventually provide strong responses to weak signals” [4]. Therefore, studying the “group” contribution has an emergent priority for the production process research community.

2.2. Resilience in the production process

The following paragraphs present the sources of resilience in the production process.

i) The skills and knowledge of the production plant personnel that operate the production process (human factors).

The skills and knowledge of the production plant personnel are indispensable to the operation of the production process, and their level dictates productivity [14]. The quantitative estimation of the value of skills, weighted by the level of skills and knowledge, permits to evaluate the scale and trend of resilience. In this approach, the value of skills of the production plant personnel is calculated based on the working hours, measured by the analysis of the daily work [15]. The level of skills and knowledge \( V \) is composed of two components as shown in Eq. (1) [16]:

![Fig. 1. Resilience matrix [4] (Two arrows are added on the original figure in [4] to show clearly the relationship between Figs. 1 and 2).](image_url)
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Fig. 2. Resilience matrix for key concepts.
\[ V = \text{position of the staff member} + \text{effort in staff duty} \]  

The position of staff member component indicates the personal cost, experience and current level of skill, e.g., supervisor, deputy-supervisor; while the effort in staff duty represents the level of personal effort, e.g., a record of learning and training in the company for their duties. The skills and knowledge is a source of resilience based on human factors.

**ii) The production units and the PSS (artificial factors).**

The production unit and the PSS also contribute to the improvement of the resilience of the production process. The production units are designed to immediately counteract the disruptive signal present in the production process (e.g., emergency stop function) or to provide an extra endurance (e.g., pressure or temperature). The PSS is designed to improve productivity by saving resources, energy and man power. The automatic operation of the process, performed by the PSS, as opposed to the manual intervention of the production plant personnel, ensures the ability to cope with small disruptive signals, and this represents a source of resilience based on artificial factors.

The relationship between the three elements that comprise the source of resilience is shown in Fig. 3, where the arrows indicate the flow of information from sender to receiver. It is necessary to establish the flow of information in order to maintain resilience.

**3. Managerial Components Required to Maintain Resilience**

The managerial components required to maintain the resilience of the production process, in function of signal scale and organizational structure (the managerial subjects), are presented in the resilience matrix in Fig. 4. The concept of resilience matrix is now proposed for the industry [4]. In this matrix, the horizontal entries correspond to the categories that manage the disruptive signals, i.e., the individual, the group and the company (the managerial subjects). The disruptive signal scale, from small scale to large, constitutes the vertical entries. The matrix elements are the managerial components that maintain and improve
plant resilience. In this framework, knowledge, rule (or procedure) and skills deal with the large, medium and small-scale disruptive signals, respectively.

In the case of a small organization, the ultimate goal of management is to achieve a reliable practice. However, in a large organization, more emphasis is placed on the regular implementation of the company’s managerial plan. In the case of a small disruptive signal, training and development of technique is the key to maintaining productivity; while for a large-scale disruptive signal, quick and accurate communication, information sharing and education in the company are of most importance. The numbering added to the items in Fig. 4 represents the actions demonstrated in Fig. 3.

There are two categories of disruptive signals: the first category consists of signals that have already occurred, and the degree of their influences is known. The second category is composed of those signals that have not yet occurred, and the degree of their influences is not yet known. The best way to deal with the former category is to absorb the negative effects principally through the resilience of artificial factors. In the case of the latter, the best approach is to make an assumption about their degree of negative effects and guard against such disruptive signals through human factors.
The following paragraphs introduce the steps that represent the responsibilities of each managerial subject, with respect to the level of disruptive signal (see Fig. 4).

**Step 1** lists the resource of resilience against the small-scale disruptive signals that appear on the production process, due to manual intervention (e.g., a filter change in a pipeline) or a change in operating conditions (e.g., set point change, grade shifting operation of products), and are the responsibilities of the individual in order to improve the resilience.

**Step 2** details the resource of resilience against the medium-scale disruptive signals to which the individual responds in order to improve the resilience. These are the unexpected or infrequent operations that result from issues with the process (e.g., the emergency stop of the unit, product quality does not follow the specifications), and the production plant personnel should follow the operation procedure provided for the unit (e.g., start-up / shut-down procedures).

**Step 3** applies to the resource of resilience against the large-scale disruptive signals for which the individual is responsible in order to improve the resilience. One important role of the individual is to recognize and identify the symptoms of a large-scale disruption, such as a natural disaster. Therefore, the production plant personnel has to acquire sufficient knowledge for dealing with production issues or natural disasters. Moreover, the individual must be notified on the current status of any production issues, or any damage resulting from a disaster, which has been shared with the other group members (see Fig. 5).

**Step 4** notes the resource of resilience against the large-scale disruptive signal. The responsibilities of the group are meant to improve the resilience. Specifically, its role is to share the information quickly with other groups in the company (see Fig. 5). Other important responsibilities are to cope, initially, with a production issue or disaster, to notify the appropriate authorities (fire, police, etc.) and evacuate all personnel to the designated safety areas. For efficient execution, each member of the group must learn and practice the necessary procedures on a continual basis.

**Step 5** documents the resource of resilience against the large-scale disruptive signals for which the companies are responsible, in order to improve the resilience. The role of the company is to formulate the preventive measures for large-scale disruptive signals (e.g., fire, explosion), and ensure that adequate resources have been provided to deal with natural disasters, such as a typhoon, earthquake or tsunami. Experts from outside the company should oversee the implementation of these measures and provide education and training at the individual and group levels.

**Step 6** enumerates the resource of resilience against the medium-scale disruptive signals for which the company is responsible, in order to improve the resilience. The company ensures that the daily operational procedures for production are standardized and consistent. The company also provides the education and training facilities to improve the skills of production plant personnel, and to put best practice into operation. Since unexpected or infrequent operation, due to a production plant personnel error, is a rare event, it is all the more important to establish appropriate operational procedures and provide on-going training, if the effects of such events are to be prevented or kept to a minimum.

**Step 7** details the resource of resilience against the small-scale disruptive signals, to which the company responds in order to improve the resilience. The role of the company is to maximize production while using the minimum amount
of resources, energy and manpower to ensure the safe and efficient operation of the production units. The company also strives to improve productivity by transferring proven best-practice to other production units [17].

**Step 8** lists the resource of resilience against the small-scale disruptive signals, to which the group responds in order to improve the resilience. When a PSS is initially implemented to improve productivity, it is the role of the group to transform the skills of the production plant personnel into techniques, i.e., the transformation of skills into formalized knowledge, in order to develop the new functions of PSS. This transformation is achieved through the continual practice of workplace skills and the provision of education and training for group members.

**Step 9** details the resource of resilience against the medium-scale disruptive signals, to which the group responds in order to improve the resilience (Central step in Fig. 1). As an unexpected or infrequent operation, the role of the group is to establish the correct operation procedures of each production process, in order to operate without any trouble, and to provide the necessary education and training support for the production plant personnel.

### 4. Specific Approaches and Remarks

As shown in Fig. 4, the organization of the managerial infrastructure is based on human factors and is used to improve resilience. The matrix is arranged according to managerial subjects, i.e., the individual, the group and the company. The following paragraphs present the specific approaches for each managerial subject, along with several remarks.

**i) The individual (production plant personnel)**

During daily operation, the most important task of the individual is to monitor and adjust any fluctuations in the production process, and to immediately share this information with other members of the group (see Fig. 5). However, once the group has been informed of the issue in question, the collective wisdom of the group should supersede the judgment of the individual.

![Fig. 5. Information flow in the company.](image-url)

Additionally, the individual has to make an effort to improve his/her skills, and acquire the knowledge to recognize and identify any production issues that may arise, and lead to a disaster. The criteria by which the company evaluates the skills and knowledge level of the individual must be unambiguous, and the
evaluation results should be presented in a manner that is relevant to the individual, and be reflected in his/her personnel record.

**ii) The group.**

The group is a team, composed by individuals of the production plant personnel, which operates the production process. It has to cope appropriately with a disruptive signal, based on information supplied by an individual and shared with other group members. When appropriate, the information should be shared with other relevant groups in the company (see Fig. 5).

Moreover, the group should constantly reinforce the correct operation procedures for dealing with disruptive signals, through education and training sessions that every member is supposed to attend. In addition, individual achievements of team members should be recognized and acknowledged by the group.

In order to facilitate the automatic operation of the production process by the PSS, the group must transform skills into techniques (i.e., formalized knowledge), in order to generate allowance for the production plant personnel’s daily work. The technique should be implemented on the PSS as its embedded function [17]. Furthermore, the members of the group should devote their allowance to improving existing skills and acquiring new skills according to the plan of group.

**iii) The company.**

In the case of a large-scale disruptive signal, the company must take appropriate preventive and security measures. Contingency planning is required to minimize the damage arising from production issues or disasters. Moreover, the role of the external specialist is critical in supplying an independent and impartial opinion.

Standardized and consistent operation procedures are necessary to prevent production plant personnel errors. Such procedures also lead to a reduced workload for production plant personnel. The time saved may be used to facilitate the realization of a multi-functional and flexible workforce, leading to a subsequent increase in productivity.

To transfer the operation of a production unit from manual to automatic control, using the embedded function of the PSS, the company has to accelerate the development of techniques (i.e., formalized knowledge), based on skills. In such case, the technique, which impacts more on the investment, has to be implemented in the PSS [17].

The company must investigate the operating status of the production unit after a disruptive signal has occurred. The findings should be accurately and honestly presented, regardless of how effective the response of the individual, or group, was for the disruption in question.

The resilience provided by the initial implementation of the production unit may gradually decrease. In particular, a recent trend in companies has been to transfer their factories abroad, while maintaining their domestic facilities as the “mother plant”. Consequently, the resilience of many domestic production processes has reduced due to the aging of the production units and the PSS. Indeed, estimating the effects of artificial factors on the resilience of the production process will form the basis of the authors’ future work.
5. Conclusions

In the chemical industry disruptive signals are ever-present. Therefore, it is necessary to restrain the influences of these signals in order to maintain productivity. The ability of the production process, and managerial structures, to restrain the influences of the disruptive signals is referred to as the resilience of the production process. The managerial components required to maintain resilience may be classified according to the scale of the disruptive signal and the structure of the organization (i.e., the managerial subjects).

Two categories of resilience exist: the first one is represented by the skills and knowledge of the production plant personnel (human factors), while the second one comprises the production unit and the PSS (artificial factors). In this study, the improvement of resilience by means of human factors was discussed. Specifically, it is suggested that the skills and knowledge level of the production plant personnel should be improved through education and training. The on-going education and regular training of the production plant personnel, organized by the company, is indispensable in maintaining resilience at a high level. The results of this investigation should be used as a guide to ensure the resilience of the production process.

The next step in this work is to study the effects of artificial factors of production process on the resilience [18], and to develop a metric that quantitatively estimates the resilience based on human factors and artificial factors.

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References


