System Resilience construction Model of Human-automation Manufacturing Process

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Abstract. Despite increasing automation levels and digital solutions, manufacturing process safety still very much rely on the inescapable contribution of the human factor. The changing relationship between man and automation system together with the increased complexity result in high risks for process safety. From time perspective, the resilience of a manufacturing system shows a curve divided into dimensions: adaptability, recovery and innovation. Perceptual stance, contextual integration and decision making and doing are made up of system resilience elements. As a socio-technical system, a human-automation manufacturing system may strengthen resilience by considering both technical and organizational sides. It is an effective approach to construct manufacturing system resilience by assigning the functions according to the task, the operator, and the situation considering the system dynamics.

1. Introduction
The current manufacturing environment has never been more uncertain. Change and turbulence are the signs of this era. Risks and crises abound in the manufacturing environment. Natural disasters, terrorist attacks, rapid development of industry 4.0 technology, the global spread of the COVID-19 pandemic is now challenging global manufacturing system, Sino US trade war, trade disputes between Japan and South Korea, trade disputes between the United States and Europe and other emergencies all lead to increased uncertainty in global supply chains, and even endanger the existence of manufacturing enterprises. Faced with risks and high uncertainty, how can a manufacturer deal with impact and achieve sustainable production? According to the theory of resilience, an organization with resilience has ability of absorbing unwanted and unforeseen disturbances, which proposes a way forward by considering resilience of a socio-technical manufacturing system from both technical and organizational sides.

This paper proposes a methodology based on the concept of resilience and integrate resilience into human-automation system and put forward a new framework to construct system resilience.

2. The concept of resilience
The original meaning of resilience is "rebound" and "bounce back". In the early days, physicists used the word "resilience" to describe compressive capacity of materials, resilience is regarded as the ability of an object to recover from an external impact or the attribute that the material can adapt to the external force to restore its original state[1]. Psychology introduces the concept of resilience to
describe the behavior pattern of individual's positive adaptation in major crisis, and emphasizes the
process of individual's positive adaptation in the face of adversity. Later, the concept of resilience was
introduced into the fields of ecosystem, sociology, economics and management fields, breaking the
previously clear boundaries of disciplines, and becoming an important concept in interdisciplinary
research[2]. In management field, resilience is widely used to study the robustness, tenacity and
recovery of both employee and organization[3]. Although different professional fields have different
interpretations of the concept of resilience, the essence is the same. All of the definitions emphasize
adaptability, adjustment and innovation of the system facing external shocks and disturbances[4].
Therefore, resilience can be divided into three dimensions: (1) the adaptability that a system uses
resources and energy to maintain the status quo; (2) ability of recovery by which a system make timely
minor technical adjustments according to external changes or shocks to restore to the original state; (3)
innovation ability by which a system reshape structure and surpass the original state.

3. human-automation manufacturing system resilience model

3.1. components of human-automation manufacturing system resilience

According to social-technical system theory, a human-automation manufacturing system is composed
of technical and social system[5]. As shown in figure1, technical system is the system of production
tools, equipment, technology and automation level, etc. The social system consists of people at work,
including individual employees, teams, organizations, rules, culture, etc. There are complex interaction
relations between the elements of technical system and social system[6]. The system essential factors
and their coupling are dominant supporting elements of a human-automation manufacturing system.
The resilience of technological system consists of the material and technical resilience, while the
resilience of social system provides psychosocial support. Operators and work teams are important
resources to generate resilience. The psychological characteristics, cognitive ability, experience and
organizational ability of Operators and work teams could determine the efficiency of technical system
resilience. Besides, the care and support provided by the social system also promote the generation of
system resilience[7]. Management system in social system is an important pillar to cultivate and
promote system resilience by way of promoting the coordination of various elements.

The internal subsystems are open system and have interaction with the external environment by
way of material flow, energy flow and information flow[8]. A human-automation manufacturing
system could obtain resilient structure and ability through cooperative effect of system elements and
develop from low-level resilience to high-level. It should be pointed out that when the impact of
disturbs exceeds the system resilience threshold, a human-automation manufacturing system can no
longer be restored to the original state, but into another state, forming a new balance.

![Fig. 1 Components of human-automation manufacturing system resilience](image-url)
3.2. Human-automation manufacturing system resilience model

From a resource-based viewpoint, the generation and development of resilience of human-automation manufacturing systems depend on the existence and distribution of various resources in crisis situations[9]. System resilience is a function of three variables, including perceptual stance, contextual integration and decision making and doing. All of the variables make up system resilience elements.

\[ R = f(P, I, D) \]  

Where \( R \) is resilience of human-automation manufacturing system, \( P \) is perceptual stance, \( I \) is contextual integration and \( D \) is decision making and doing. Perception stance is the self-perception and judgment of the system in certain circumstances. When the manufacturing system faces uncertainty impact or in crisis situations, it will first scan internal and external environment, aware, perceive and judge possible results of disturbance, which is the basis of the subsequent critical vulnerability management of the system. Contextual integration emphasizes the comprehensive utilization of both social-technical system and environmental resources, mobilizing internal and external resources to effectively deal with disturbances, improving system adaptability to enhance the effective response to risk situations. Decision making and doing refers to specific implementation of plans proposed by operators and work teams. Employees and teams are important resources to generate resilience[10]. The psychological quality, cognitive ability and organizational ability of employees and teams are important criteria for the generation of system organizational resilience[11]. At the same time, the care and support provided by the social system provide guarantees for the generation of system resilience, which are conducive to the system to cope with the uncertainty of the external environment and promote the generation of system resilience.

An effective approach to constructing human-automation manufacturing system resilience should assign the functions according to the task, the operator, and the situation considering the system dynamics[12]. Figure 2 shows system resilience model of a human-automation system. The model focus is not only on the optimization of technology systems such as tools and procedures, but also includes mental models of both operators, work teams and management as a full-fledged part of the whole manufacturing process. In traditional ways, the control system only refers to technical control systems. However, in a human-automation manufacturing, the control system should be extended to social control systems including human and organization dimensions which must be integrated into the management of the control loop to couple automation’s efficiency with the flexible human mindset. The operators and work team act as decision makers who work in synergy with the control system at a decisional level, and the actions of both operators and work teams also participate in the controlled production process where complex interactions are played. To improve manufacturing resilience, each system element and interaction requires careful management taking into account its specificity. The sensors and control system could constantly monitor and detect any deviations in real time.
As shown in figure 2, system resilience depends on the effective interfaces between social system and technology system based on sensors and control system. The operator and work team could gain awareness about the status of system by means of multiple sensory cues. If the technology system adopts human-machine cooperation working technology such as cooperation robot, which means networks of operators interacting with complex systems in a tightly coupled manner, then system resilience depends heavily on complex interaction between social and technology systems. Automation technology system is adaptable, and has ability of quickly change the automation level in a timely manner taking into account unpredictable operators’ responses. And the operator can also be allowed to decide the level of production pace according to the situation including the operator’s state, performance and the system status.

Especially, building system resilience should be guided by the above model to promote harmonization of the fragments’ behaviour by changing its role according to the degree of control. The manufacturing system could provide flexible fragments that cope with the inherent variability of changes and disturbs coming from human and organizational factors, process changes and productivity needs. And system resilience enables the manufacturing system to reduce the risk of negative gaps by two basic ways: one is improve capacity of perceptual stance of operator and work team, the other is to obtain high contexture integration and decision making and doing on the basis of establishing social system resilience.

4. Conclusions
Widespread unexpected events such as natural and human-made disasters all lead to increased uncertainty in the manufacturing environment, a manufacturer with high resilience ability can deal with impact quickly, survive and obtain sustainable development. A human-automation manufacturing system is a socio-technical system consisted of social system and technical system. As a socio-technical system, a manufacturing system may strengthen resilience by considering both technical and organizational sides.

(1) From time perspective, the resilience of a manufacturing system shows a curve divided into dimensions: adaptability, recovery and innovation. System resilience could be quantified according to time in which the system adapt, recover and innovate.

(2) perceptual stance, contextual integration and decision making and doing are made up of system resilience elements. A human-automation manufacturing system resilience model is built from resource arrangement perspective. As an automation technology system is adaptable, the resilience of a system depends heavily on complex interaction between social and technology systems, and an effective approach of constructing human-automation manufacturing system resilience should assign

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**Fig.2 System resilience model of a human-automation system based on social-technical system**

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the functions according to the task, the operator, and the situation considering the system dynamics.

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