

Development of a Resilience Enhancement Model based on the Pandemic Experience in Industrial Contexts

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After the COVID19 pandemic, the industrial process industry and the manufacturing sector experienced that the pandemic impact needs to be included among the unforeseen threats and the management, technology and internal policy must be developed through a resilience lens into mitigation, adaptation, and preventative measures. This paper examines the lessons learned from Covid-19 based on pilot case studies in Italy, Serbia and Czech Republic, focusing on the claim “building back better” by developing resilient responses in process industries.

1. Introduction

The emergency triggered by COVID-19 revealed that both the industrial processes and the manufacturing sector must include, among the unforeseen threats and external environmental stressors, the pandemic impact (Fabiano et al., 2024). The effectiveness of the World Health Organization recommendations to mitigate the negative effect of COVID-19 on the operational, logistical, health and safety performance of workers was evaluated by statistical surveys in multinational industries (Oliveira Neto et al., 2022). The COVID-19 crisis offered many learning opportunities to improve engineering risk management practices relying on some of the techniques used in process safety analysis and risk mitigation in the pandemic risk management (Alauddin et al., 2022). The objective of this work is to describe how the risk assessment techniques can be applied, and adapted, to pandemic risk management. Following the reasoning of Duchek (2020), Organizational Resilience (OR) is the ability of an organization to anticipate, prepare for, respond, and adapt to incremental changes and sudden disruptions to survive and prosper. OR can be obtained by properly balancing preventative control, mindful action, performance optimisation and adaptive innovation, as well as managing the tensions inherent to these distinct perspectives (Bragatto et al., 2021). The research focuses on developing a conceptual model for the organizational resilience evaluation for different industrial sectors covering manufacturing and the process industry and relying on the experience gained during the first and second waves of the pandemic emergency. In this regard, as an overall safety umbrella, the organizational resilience assessment and setting up resilience indicators can support business continuity and help deal with unexpected events, absorbing the disruptive potential. The methodology adopted within the research was based on the identification of industrial sectors and activities liable to be impacted by pandemic, on the development of the OR checklist and the design and elaboration of tailored questionnaires. By using selected case-studies covering both the manufacturing and the process sector in three countries (Italy, Serbia and the Czech Republic), a Systemic Resilience Model (SRM) has been developed by a data-driven approach identifying the significant precursors of an accident, or near miss under pandemic condition. The SAFERA project RESilience enhancement MODEL along with related studies, aims to analyse organizational causality and optimize resilience in dynamic business environments

(UniGe, 2024). In an era of increasing uncertainty and rapid change, organizational resilience has become a critical factor for long-term success and sustainability. This paper presents an overview of the project's methodology, key findings, and implications for organizational decision-making, incorporating insights from multiple related studies, evidencing among other issues, that digitization, AI and system approach will be of help, but human thinking remains "conditio sine qua non" (Pasman et al., 2024).

2. Methods

The overall project focuses on three main aspects:

1. The four perspectives on OR strategy, as described in Bragatto et al. (2021), i.e.: Performance Optimization; Adaptive Innovation; Preventative Control and Mindful Action.
2. The four resilience objectives (Hollnagel et al., 2006), i.e., Monitor, Learn, Anticipate and React.
3. The OR components previously anticipated and validated by Markowski et al., (2021), i.e., Leadership and Safety Culture, Risk Awareness, Communication - Information Flow, Skill and Competencies, Action, Decision-making Process, External / Internal Circumstances.

These main aspects form the foundation for developing strategies to enhance organizational resilience and performance (Markowski et al., 2021). By implementing a combination of proactive measures, continuous learning initiatives, and adaptive innovation practices, organizations can effectively navigate uncertainty and capitalize on emerging opportunities. The aspects listed above were, grouped according to the resilience objective they pursue, and the organisational perspective they adopt, as shown in Table 1.

Table 1: Organizational Resilience components, strategies and objectives

<i>Organizational Resilience Component</i>	<i>How to achieve</i>	<i>Resilience Objective</i>
Leadership and Safety Culture (LSC)	Mindful Action / Performance optimization	Anticipate / React
Risk Awareness (RA)	Preventative Control / Mindful Action	Monitor / Anticipate
Communication - Information Flow (CI)	Adaptive innovation / Performance optimization	Learn / React
Skill and Competencies (SC)	Preventative Control / Performance optimization	Monitor / React
Action, Decision-making Process (A)	Preventative Control / Adaptive innovation	Monitor / Learn
External / Internal Circumstances (C)	Mindful Action / Adaptive innovation	Anticipate / Learn

Tailored surveys were designed to rate the current state and importance of different organizational factors, as below detailed. Subsequently, the different aspects of organizational resilience have been modelled by the Analytic Hierarchy Process (AHP) method. The weight coefficients obtained with the AHP model were used to calculate the resilience index. Additionally, the project employed Bayesian network modelling techniques to explore the interdependencies among various organizational factors and their impacts on key outcomes such as business impact and suspension incidents. This approach allows for a comprehensive understanding of the complex relationships within organizational systems and provides valuable insights for decision-makers.

2.1 Data Collection and Pre-processing

The project utilized datasets comprising organizational attributes and performance metrics from multiple companies across different countries. Data was collected through specific questionnaires, covering various aspects of organizational resilience, including company size, industry sector, employee training, procedural adherence, and incidents of suspension. An "ad hoc" questionnaire was developed to gather information on a series of control variables related to workers' personal characteristics and to assess the pandemic impact on business continuity and safety levels of an Italian industrial port related to different activities including HazMat handling. It was possible to obtain 226 questionnaires completed, each covering 22 questions, grouped according to the defined OR components. To assess organizational resilience at different organizational levels in Serbia transport and mining companies, the questionnaire was properly tailored according to the same OR components and submitted to transport and mining companies, obtaining 148 respondents. Different job qualifications and organizational levels were surveyed (Strategic Manager Level, Middle Manager Level, First Line Managers, Transport and Mining Machine Operators and Other Workers) asking to rate the current state and importance of the item in the questionnaire on the 5-point Likert scale. According to a tested approach addressing safety climate (Spasojević-Brkić et al., 2022), descriptive statistics and statistical tests Kolomogorov and U* Mann Whitney (Mann & Whitney, 1947) are used to test the differences between organizational levels (operative, tactical and strategic). With a peculiar focus on on resiliency and emergency response, and an ad-

hoc designed questionnaire was submitted to members of the Czech volunteer fire brigade units (JSDH) and JSDH commanders, obtaining 505 responses providing an interesting and clear picture of the resiliency of firemen volunteers units, JSDH's activities during the Covid-19 crisis. Globally, these surveys provided valuable insights into organizational practices, safety culture, and resilience factors across different industrial contexts. All raw data underwent pre-processing steps to ensure consistency and reliability with the main focus on handling missing values, encoding categorical variables and performing necessary data transformations.

2.2 Causal Discovery Algorithm

The project employed the Peter and Clark algorithm for causal discovery (Spirtes et al., 1993). This constraint-based approach is here developed for learning the structure of Bayesian networks from observational data, aiming at discovering the causal relationships between variables by identifying conditional independence relationships among them. The algorithm-based approach was designed according to the following steps:

1. *Initialization*: Begin with a fully connected undirected graph.
2. *Conditional Independence Tests*: Perform tests between pairs of variables to determine direct causal relationships.
3. *Eliminate Spurious Relationships*: Remove edges between conditionally independent variables.
4. *Orient Edges*: Establish the directionality of causal relationships.
5. *Refine the Structure*: Apply additional tests and heuristics to improve accuracy.

Bayesian network modelling techniques were used to analyze causal relationships within the complex organizational context. The designed approach allows for the representation of complex dependencies between variables and provides a probabilistic framework for reasoning about organizational factors and their impacts.

2.3 Multilevel Flow Modelling (MFM)

In addition to Bayesian network modelling, the research project incorporated Multilevel Flow Modelling (MFM) techniques (Morten, 2013). MFM is a functional modelling methodology used to represent complex systems and their interdependence. This approach provides a complementary perspective on organizational resilience by capturing the flow of resources, information, and processes within the system.

3. Results and discussion

3.1 Learned Network Structure

The causal discovery process resulted in a learned network structure that reveals key insights into organizational causality. We argue that the more knowledge is available about the structure, the more the Covid 19 epistemic uncertainty can be reduced. The network structure depicted in Figure 1 illustrates the complex relationships between various organizational resilience actors.

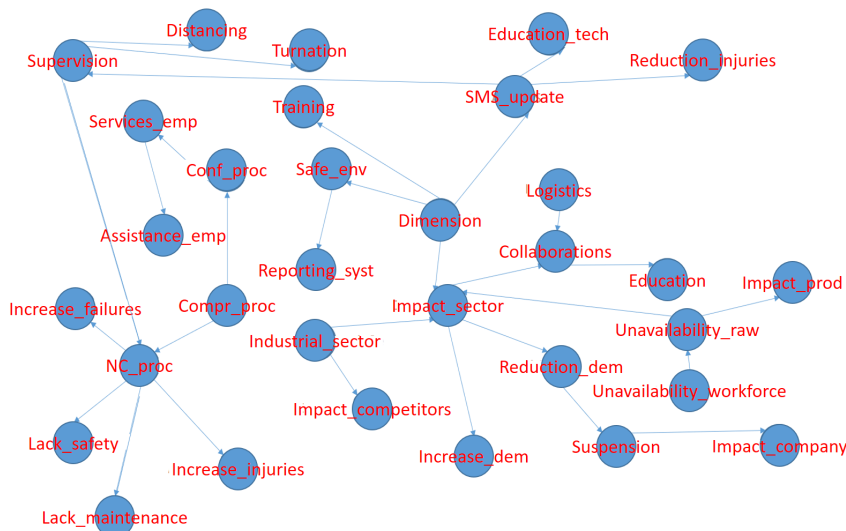


Figure 1: Learned Causal Structure.

3.2 Key Insights on Causality

Analysis of the learned network structure yielded several important insights, summarized in the following.

- *Direct Impact on Organizational Resilience:* Employee training and procedural adherence were found to have a direct impact on firm organizational resilience. This is evidenced by their strong connections to business impact and suspension incidents.
- *Indirect Causal Paths:* Complex organizational dynamics were observed through indirect causal paths between factors such as company size, industry sector, and organizational resilience.
- *Safety Management System (SMS) Importance:* The learned causal network structure underlines the crucial role of the SMS in ensuring the safety and well-being of personnel, assets, and the environment, by posing emphasis on anticipation of unwanted events and proactive management.

3.3 Organizational Optimization Strategies

Based on the analysis, the project identified several organizational optimization strategies aligned with the above mentioned four objectives of organizational resilience. These strategies provide a comprehensive framework for enhancing organizational resilience and performance. The analysis highlighted the importance of adhering to and updating the main SMS pillars, including risk management, safety culture, and compliance with regulations. The need for innovation within the SMS framework resulted strongly emphasized, especially in the face of unexpected events such as pandemics. Key areas for innovation include real-time monitoring and reporting, continuous improvement, and integration of safety and innovation. The incorporation of survey data from different Countries allowed for cross-country comparisons of organizational resilience practices. These comparisons revealed both commonalities and differences in approaches to safety management, risk perception, and organizational culture across different industrial contexts. The application of Multilevel Flow Modelling (MFM) provided additional insights into the functional aspects of organizational resilience. MFM allowed for the representation of complex system interdependencies and helped identify critical flows and bottlenecks within organizational processes. This analysis complemented the Bayesian network approach by offering a different perspective on system dynamics and potential points of failure or improvement.

Figure 2 depicts the relative importance of organizational resilience goals for the assessment of safety and security at work by workplace, as defined by the investigation performed in the transport and mining companies.

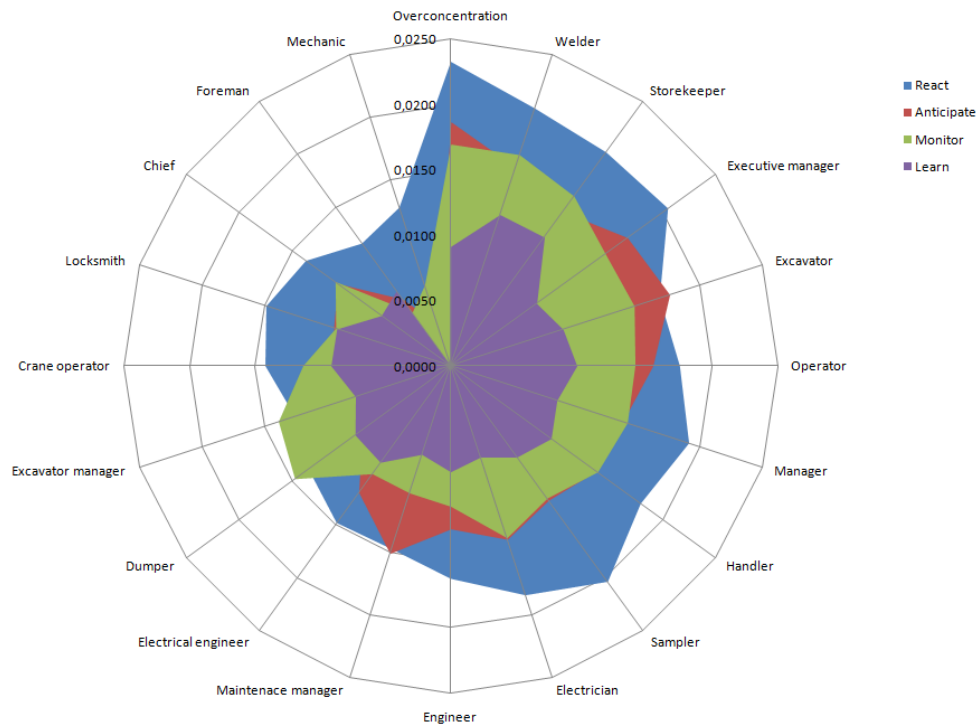


Figure 2: Radar diagram of organizational resilience for the assessment of safety and security at work by workplace.

Table 2 summarizes the quantitative results referred to the 4 resilience objectives. The Reaction and Anticipation aspects have good resilience index values. Middle level managers, first line managers, transport and mining machine operators and other workers have a very high resilience index in terms of the Reaction angle (11.92, 10.14, 11.44 and 11.24 respectively), while strategic level managers have a twice

lower value of resilience index. The prediction index values at all organizational levels are good, between 3.79 and 5.66. The values of the Monitoring aspect are good at the middle level of managers and operators, and somewhat lower, but adequate at other organizational levels. However, employees at all organizational levels have low values of coefficients of OR in terms of the Learning aspect (ranging from 0.81 to 2.13), which indicates that employees do not use experiences from previous periods. Deep epistemic uncertainties on pandemics, i.e. lack of knowledge, information ambiguity and poor controllability resulted critical elements to be considered in developing emergency planning and response. Transport and mining machine operators have the highest aggregate resilience index value, while strategic level managers rank the lowest one. It is also noticeable that the Monitoring aspect, depending on the organizational level, has alternately good and adequate values, which points out that organizational restructuring could improve this aspect. Finally, the high values of the coefficients regarding the aspect of Reaction at all organizational levels indicate the readiness to organizationally adapt to changes with corrective activities, rather than planned and preventive measures.

Table 2: Resilience cornerstone indexes and total resilience in transport and mining companies.

Resilience Cornerstone	Strategic Manager	Middle Manager	First Line Managers	Transport and Mining Machine Operators	Other Workers
IR _A	5.29	3.79	4.56	5.66	5.27
IR _L	2.13	0.81	1.71	1.85	2.13
IR _M	2.95	3.51	2.95	3.73	3.09
IR _R	5.85	11.92	10.14	11.44	11.24
IR _{Total}	16.22	20.03	19.36	22.68	21.73

The analysis of past incidents and near-misses allows for highlighting the importance of learning from experience and incorporating lessons learned into organizational practices (Fabiano et al., 2024). This retrospective analysis contributed to the development of more robust resilience strategies and improved risk management approaches. From the investigation performed in the manufacturing setting, it emerges that the Reaction and Anticipation aspects have good resilience index values. The prediction index values at all organizational levels are good, and the values of the Monitoring aspect are good at the middle level of managers and operators, and somewhat lower, but adequate at other organizational levels. It is also noticeable that the Monitoring aspect, depending on the organizational level, has alternately good and adequate values, which points to the fact that organizational restructuring could improve this aspect. Finally, the high values of the coefficients regarding the aspect of Reaction at all organizational levels indicate the readiness to adapt to changes with corrective activities, rather than planned and preventive measures. The determining role of the cornerstone "Reaction" emerges from the results obtained in volunteer fire brigade units and JSDH commanders' investigation. In this context, the role of emergency responders was analysed to quantitatively assess its contribution to the overall resilience improvement and the main findings in strengthening the process can be summarized as follows.

Critical communication issues to be addressed include: one-directional process; not enough from "above"; chaotic and contradictory information flows; power-play attitude instead of leadership.

Other critical remarks include the perception by local unit felt being abandoned by headquarter and government and the enforcement of resilience attitude much more at local level than at central level.

Summarizing, the main findings of the whole project emphasized the critical role of human factors and organizational culture in shaping resilience. Factors such as leadership commitment, employee engagement, and effective communication were identified as key drivers of organizational resilience. The study highlighted the need for an evidence-based holistic approach that integrates technical, organizational, and human aspects of safety and resilience. Based on the analysis, the project identified six organizational resilience components optimization, each aligned with the pertinent Strategies and Objectives of resilience:

1. *Mindful Action / Performance Optimization (Anticipate, React)*: This strategy involves proactively anticipating potential issues or opportunities and reacting swiftly to optimize organizational performance.
2. *Preventative Control / Mindful Action (Monitor, Anticipate)*: This approach combines proactive monitoring and anticipatory actions to prevent potential risks or disruptions before they occur.
3. *Adaptive Innovation / Performance Optimization (Learn, React)*: This strategy focuses on continuous learning and adaptive innovation to optimize organizational performance.
4. *Preventative Control / Performance Optimization (Monitor, React)*: This approach involves proactive monitoring of key performance metrics and rapid response to deviations from expected norms.
5. *Preventative Control / Adaptive Innovation (Monitor, Learn)*: This strategy integrates proactive risk management with continuous learning and innovation efforts.

6. *Mindful Action / Adaptive Innovation (Anticipate, Learn)*: This approach combines proactive anticipation of future trends and challenges with a focus on continuous learning and innovation.

4. Conclusions

The international research project provided valuable insights into organizational resilience and optimization strategies. By employing advanced causal discovery techniques, Bayesian network modelling, and complementary methodologies such as Multilevel Flow Modelling, the research has revealed complex relationships between various organizational factors and their impacts on key outcomes. The findings highlight the importance of employee training, procedural adherence, and a robust Safety Management System in enhancing organizational resilience. The identified optimization strategies, aligned with the four OR cornerstones offer a comprehensive framework for organizations to improve their adaptive capacity and performance in dynamic environments. Additionally, the project underscores the need for continuous innovation within the SMS framework, emphasizing the integration of advanced technologies, data analytics, and a culture of continuous improvement. The cross-country comparisons and diverse methodological approaches provide a rich tapestry of insights that can be applied across different industrial and cultural contexts. In conclusion, this study can contribute significantly to our understanding of organizational resilience and provide practical strategies for optimization. As organizations face increasingly complex and uncertain environments, the insights and recommendations from empirical findings may offer valuable guidance for decision-makers seeking to enhance their organizational resilience and long-term sustainability.

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