




## SPECIAL ISSUE ARTICLE

# Learning from accidents: Nontechnical skills deficiency in the European process industry

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### Abstract

Safety-critical industries have long been subjected to extensive research and development to enhance operator performance to improve their efficiency. From a human factors perspective, much of the work in process industries is related to either enhancing technical training of operators or related to improving the physical ergonomics of hazardous workplaces. The importance of Nontechnical Skills (NTS) in the process industries have traditionally been less emphasized, while other domains (e.g., aviation, healthcare) have led the development of investigating and improving NTS for the sharp-end operators. This study aims to investigate the association of NTS deficiencies to the major accidents from the past 5 years in the process industries within the European Union by analyzing the accident reports from The Major Accident Reporting System (MARS) database. The accident analysis results reveal potential NTS deficiencies in 27% (17 out of 64) of the cases involving the lack of situational awareness, decision making, problem-solving, communication, leadership, and time management issues. Based on the results of the analysis, a few implications, as well as future research directions, are proposed, which could facilitate the stakeholders in addressing NTS deficiencies of European process industry operators.

### KEYWORDS

accident analysis, complex systems, MARS database, nontechnical skills, safety, training

## 1 | INTRODUCTION

Process industries are complex sociotechnical systems that are engaged in the extraction, transportation, and processing of raw materials to manufacture semi-finished or high-quality end products by means of physical, mechanical, and/or chemical processes.<sup>1</sup> The evolution of the process industry throughout the last century has brought about transformational changes in technology usage, in the role of human operators, and the nature of their coexistence in complex sociotechnical workplaces.<sup>2</sup> As the role of humans changed towards more supervisory positions with increasingly

automated processes and systems, the underlying organization and the human-machine interaction in those work environments also changed.<sup>3</sup> The appropriate competency along with adaptive capabilities of human operators are highlighted in the literature as necessary factors for efficient operations in complex industrial environments.<sup>4</sup> Therefore, the lack of appropriate skills coupled with the increasing technological complexity in process industries can result in failures leading to accidents.<sup>5</sup> In addition, issues ranging from technical deficiencies to organizational management and human factors items are reportedly found to have links with industrial accidents.<sup>6</sup>

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The importance of Nontechnical Skills (NTS) in addition to the technical skills for safe and efficient operations have been emphasized in different domains (e.g., aviation, energy, maritime, and healthcare).<sup>7-10</sup> Consequently, the scope and requirements for ensuring safety in “process industries” have evolved further, taking into account differing issues related to NTS in complex socio-technical systems.<sup>2,11,12</sup> Earlier studies highlighted the lack of appropriate skills of the operators involved, such as communication, leadership, situational awareness, and decision-making skills, as contributing factors that could lead to differing failures in an industrial context. Therefore, different types of existing, as well as emerging NTS deficiencies that are prevalent in contemporary accidents, could be highlighted by analyzing recent accident reports from the European process industry.

Risk mitigation by analyzing failure events, for example, accidents, is a common practice in all domains and has taken numerous methodic approaches in the literature. Demings circle (1950), Reason's (1990) *swiss cheese model* and Kjellén's (2000) *safety information model* are some of the most prominently used models in industrial contexts.<sup>13-15</sup> Lessons learned from these events help understand the underlying contributing factors while mitigating future risks if addressed and acted upon. European process industries are no different from this type of risk mitigation approach. The “Seveso Directive – Technological Disaster Risk Reduction” administered by the European Commission mandates easy access to accident data for taking precautions both in legislative and industrial practices.<sup>16</sup> The European database of the Major Accident Reporting System (MARS) serves as one of the repositories where industrial incidents and accidents that have occurred within the European Union (EU) are reported. This database aims to serve as a transparent and objective source of lessons learned information and a detailed account of the reported accidents.<sup>17</sup>

The aim of this study is to investigate the contemporary major accidents occurring in the European process industry as reported in

the MARS database and elicit their potential linkage to NTS deficiencies from the accident reports. Based on the findings of this study, general implications related to training, strategy, industrial practice, and objective reporting are proposed, which could potentially enhance nontechnical skills (NTS) of the operators, as well as industrial safety in general.

## 2 | NTS IN PROCESS INDUSTRY

The cognitive and social skills required for efficient and safe operations are termed as NTS in academic literature.<sup>12</sup> Originating from the aviation industry in the late 1970s, the term nontechnical skills (NTS) has been promulgated in other domains (e.g., healthcare, maritime, process, and nuclear industries) over the years. Consequently, the NTS training method, that is, Crew Resource Management (CRM) training, initially formalized for aviation pilots, has been adopted in other domains as well; for example, BRM (Bridge Resource Management) and ERM (Engine Room Resource Management) in maritime domain; TeamSTEPPS (Team Strategies and Tools to Enhance Performance and Patient Safety) in the healthcare domain, and so forth.<sup>18</sup> However, the necessity for appropriate NTS training methodologies suited for process industries has been underlined in recent literature.<sup>19,20</sup>

The crucial NTS required for process engineers to ensure efficient operations in both traditional (i.e., where work methods and processes are individualized) and in team-based work environments are highlighted by Downing.<sup>21</sup> He suggested that NTS, such as listening, decision making, verbal communication, problem-solving, and leadership were required for a team-based work environment, whereas listening, decision making, problem-solving, time management, and verbal communication were crucial for a traditional work environment.<sup>21</sup> A study by Crichton and Flin highlighted the necessity of situational awareness, teamwork, leadership, and stress management for

**TABLE 1** Definition of different nontechnical skills (NTS) categories<sup>26</sup>

NTS	Definition
Situational Awareness	<b>Forecast and find solutions:</b> situational awareness refers to being aware of the surroundings, and involves the capability of evaluating critical environmental cues, processing vital safety information, forecasting near-future occurrences, and finding a way out from the emerging risks <sup>27</sup>
Decision Making	<b>Considering options</b> – generating alternative possibilities or courses of action. Assessing hazards and weighing up threats and benefits of potential actions <sup>26</sup>
Problem Solving	<b>Seeking appropriate answers</b> –the ability to integrate information from several different sources in order to improve organizational performance through the integration of multiple platforms, functions, and technologies <sup>28</sup>
Communication	<b>Establishing a shared understanding and ensuring</b> – ensuring that the team has the necessary information to carry out the resolution, understand it, and that an acceptable shared “big picture” of the case is held by team members <sup>26</sup>
Leadership	<b>Coping with pressure</b> – retaining a calm demeanor when under pressure and demonstrating to the team that the situation is under control. Adopting a suitably forceful manner, if appropriate, without undermining the role of other team members <sup>26</sup>
Time management	<b>Monitoring and controlling time</b> – self-management with regard to the performance of multiple tasks within a certain time period <sup>29</sup>
Fatigue management	<b>Monitoring and controlling habit</b> – management of a complex biological phenomenon that occurs as a function of active working time, time-of-day, workload, health condition, and off-duty lifestyle <sup>30</sup>

nuclear emergency response teams in addition to the NTS identified by Downing.<sup>22</sup> Marco et al. proposed a four-factor model comprising situational awareness, decision-making, communication, and fatigue that are identified as the most important NTS for ensuring safety in chemical industries.<sup>23</sup> The variability of NTS requirements based on differing contexts is observed in previous studies.<sup>24,25</sup> The relevant NTS fit for the process industry context for day-to-day operations is compiled here based on the findings of previous studies as situational awareness, decision making, problem-solving, communication, leadership, time management, and fatigue. The most appropriate definitions of the above-identified NTS are consolidated in Table 1.

### 3 | METHODS

The accidents reported in the MARS database from all process industry types within the EU are stratified into three categories: “major accident,” “near miss” and “other event.” However, only the recent accidents resulting in human injury or damage to the property and the environment, that is, the major accidents, were taken into account for this analysis since this study is directed to understand the existing, as well as emerging NTS deficiencies related to those accidents. Therefore, the latest dataset from the past 5 years (January 2017 to August 2021) was extracted from and filtered based on their availability of full accident reports in the database. Only the MARS database is used as a source of the accident reports since it is mandated by the European Commission for all European process industries to report their incidents in the database under the Seveso directive 2012/18/EU.<sup>16</sup> The reports are made online, and therefore, it is also referred to as eMARS database.

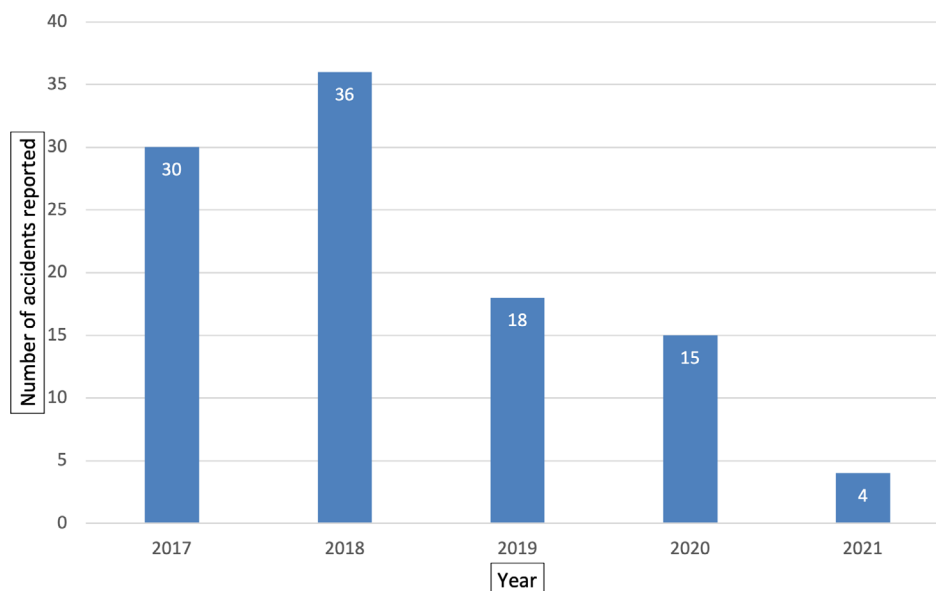
The information outlined in full accident reports includes the date and time of the occurrence, industry type, reporting reason, accident description, site and installation information, substances involved, causes, consequences, emergency response, as well as lessons

learned. A qualitative *content analysis* was performed to elicit any trace of NTS deficiencies linked to each of those accidents. A framework of categories, including NTS in the process industry, was first set based on the theoretical fundamentals of Rhona Flinn’s<sup>12,26,31</sup> work, as well as from other process industry related literature,<sup>21,23</sup> whereas the analysis of the accident reports was done within that framework. Two focused-group workshops with two human factor experts were operationalized to analyze the accident reports where the generated codes were noted on paper. A combination of inductive and deductive approaches was taken in order to confirm the association of NTS deficiencies with the reported accidents. The content analysis followed the framework as proposed by White and Marsh using purposive sampling latent depth of analysis in the inductive phase.<sup>32</sup> A third person who is a practitioner with a process industry background and an engineering degree screened the process to ensure the inter-rater reliability of the analysis.

NTS such as *situational awareness, decision making, problem-solving, communication, leadership, time management, and fatigue management* required for process industry engineers derived from scientific literature were used as the framework to guide the inductive process of content analysis.

**TABLE 2** Nontechnical skills (NTS) links to the reported accidents

NTS	Instances reported in accidents	Percentage of total accidents (approx.)
Decision making	10	16%
Problem solving	6	9%
Situational awareness	6	9%
Time management	4	6%
Leadership	2	3%
Communication	2	3%



**FIGURE 1** Major accidents from EU countries from 2017 to 2021<sup>17</sup>

## 4 | RESULTS

The initial screening of accidents extracted from the MARS database, which occurred in the process industries in Europe over the past 5 years, elicited 103 events in total (see Figure 1).

Although there are 103 accidents reported from the past 5 years, only 64 had written accident reports available (full or partial). Based on the established criteria for analysis, it was revealed that 17 of those accidents (27% of total 64 written reports) had links to NTS deficiency of operators. The analysis also highlighted that each NTS deficiency has an association with multiple accidents (see Table 2). Situational awareness, decision making, problem-solving, communication, leadership, and time management all had potential links to at least two incidents, whereas fatigue management had no association with any of the analyzed accidents. Therefore, the findings largely conform with the literature as identified in the NTS categorization stage. The identified industries involved in those accidents range from petrochemical, chemical installations, power generation, waste management, explosive material handling, along with a variety of other hazardous elements processing establishments. The ranking of NTS deficiencies based on their frequency of occurrence in all 64 of those accidents are described in Table 2.

## 5 | DISCUSSION

Differing NTS deficiencies regarding decision making, problem-solving, situational awareness, time management, leadership, and communication in the European process industry context were elicited in this study. This study reveals that ignoring alarms and failure to take critical decisions in time-pressure situations were some of the “decision making” deficiencies on account of human operators that contributed to major accidents. “Situational awareness” deficiencies stemmed from instances where the operators failed to assess the hazard of the situation, as well as the consequences of their actions. Failures related to the deficiency of “communication” skills (both verbal communication and listening) prevalently occurred during reporting and acknowledgment events. Both instances where either the operators failed to understand the information conveyed by other operators in a team environment or the nonverbal cues were misunderstood. Accidents related to “time management” mostly occurred due to late reporting or failure to take critical decisions within a stipulated amount of time. There were few instances where operators closed the wrong valve in a time pressure situation although they had formal competence and certification.

Since the reporting system on the MARS database is not specifically focused on operators' NTS deficiency, earlier studies related to accident investigation lacked this feature. For instance, Jacobsson et al. analyzed a total of 653 accidents from the MARS database based on a mid-2007 dataset where they underlined supervision, organizational attitude, training, process analysis, operator error, design, and procedures as prevalent causes of accidents.<sup>14</sup> This study is an effort toward highlighting the importance of reporting NTS deficiency related to the reported accidents in the database.

The findings of this study also point towards the necessity of appropriate measures in order to mitigate NTS-related accidents in the European process industry. For example, decision-making skills for process operators were reported to have increased in simulator training<sup>33</sup>; therefore, other types of identified skill deficiencies could also be alleviated by adopting appropriate strategies. The implications on account of the industry, as well as the future research direction section, include a few of the potential directions that can be adopted in this regard.

This study also identifies the need for an effective reporting system with an explicit focus on NTS deficiencies that may result in accidents. The caveats of accident reports include often being one-dimensional and superficial in nature,<sup>34</sup> and the MARS database is no exception. If this database is to serve as an objective source of lessons learned from accidents, the reporting elements should also include a detailed breakdown of events, especially containing NTS descriptors. These descriptors could facilitate discussions about mitigating the associated deficiencies as identified. Furthermore, many reported accidents restricted the full accident reports from publishing, which makes it impossible for others to learn from those events, a stark contrast to what the MARS database stands for. An open and trust-based reporting system would encourage all organizations to share accident investigation outcomes, lessons learned, and pathways for making improvements.

### 5.1 | Limitations

The accident reports from the MARS database provide a systemic description of the incidents in general. The main limitation is that some of the reports lack in-depth description and the availability of only the abstract of reports in some instances, either due to ongoing investigations or due to internal policies. Moreover, reporting the lack of NTS was not the sole purpose of those reports. As a result, the potential for bias during content analysis cannot be ruled out. Only the contemporary accidents from the past 5 years are taken into account in this study, which could be increased to as much as 41 years starting from 1979 in the MARS database. Larger sample sizes could have increased the robustness of the study. Another limitation is that not all accident reports from the last 3 years (2019, 2020, and 2021) are fully updated in the database. It could be interesting to see if an extended analysis of all reports beyond the 5-year range exhibits the lack of any particular type of NTS in the process industry operators.

## 6 | IMPLICATIONS AND FUTURE DIRECTIONS

Since human operators continue to be an important element for safe and efficient operations in the process industries, it is necessary to understand different dimensions of human involvement in those settings to improve their safety performance.<sup>12,33</sup> Addressing the human operators' NTS deficiencies is one dimension that could enhance workplace safety; hence, few potential implications and future research directions are outlined in this regard based on the findings of this study:

## 6.1 | Implications for the process industry

The findings of this study provide a baseline of understanding about the NTS deficiencies in the European process industry and their potential repercussions. Since training plays a crucial role in enhancing safety and mitigating the knowledge or skill gap in any industry, this study could help in the design and delivery of training systems especially suited for the NTS deficiencies as depicted in the European process industry. Stakeholders may utilize such results for training needs analysis and training strategies to be employed in the process industry, taking into account different cognitive and organizational aspects of the industry.<sup>35</sup> Different industrial stakeholders are seen employing innovative in-house training practices comprising a variety of hi-tech and lo-tech exercises and training solutions, especially focusing on NTS training,<sup>19</sup> which would increase in the near future considering the dynamic nature of the process industry as a whole.

Differing innovative training methods and practices from other domains, as well as different parts of the same industry, could also be employed in the formulation of suitable training strategies for the affected process industry segments. For example, a combination of cooperative learning and case study was found to be a better alternative to the traditional methods to increase students' perception of decision-making and problem-solving skills in the healthcare domain.<sup>36</sup> Plant simulators used with heightened decision-making practices are found to have a positive impact on team performance, which could eventually improve operators' individual team skills and NTS in complex environments.<sup>20,33</sup> Similarly, including a social perspective in learning, that is, creating a community of practice where different groups (e.g., experienced and novice operators) share an activity and learn from each other potentially improves NTS training outcomes in the process domain.<sup>37</sup> Therefore, European process industries could adopt the practice of organizing NTS-focused workshops, creating space for different experience groups where the operators could share formal and informal knowledge in a communal platform.

## 6.2 | Direction for future research

NTS deficiencies such as situational awareness, decision-making, leadership, teamwork, and the management of work-related stress and fatigue, some of which are identified in this study, are generally addressed in CRM training.<sup>38</sup> However, efforts directed to alleviate NTS deficiencies of industrial operators have been limited to adapted versions of CRM.<sup>20</sup> This approach of adopting similar aspects of CRM for all domains turned out to have mixed output in terms of knowledge acquisition and behavior of trainees.<sup>39</sup> Future research could chart out objective methods to address the lack of appropriate NTS training methodologies especially suited for process industry operators taking into account the state-of-the-art technologies to be used in industrial practices, as well as in training.

## 7 | CONCLUSION

The training paradigm for industrial operators traditionally focusing on improving their technical knowledge calls for strategic re-evaluation amidst increasing technological complexities in the process industry and subsequent alteration of human role. The content analysis of accident reports from the process industry in the European context, as presented in this study, supports the notion. The nature of the analyzed accidents indicates both a technical and nontechnical skills gap of human operators, in addition to the other process and design-related faults. This study specifically seeks to explore concurrent NTS deficiencies in the process domain and their repercussions from a recent dataset. The results indicate that the NTS deficiencies, such as situational awareness, decision making, problem-solving, communication, leadership, and time management, indeed played a crucial part in the culmination of major accidents in European process industries.

The implications outlined in this study and well-grounded potential development in the future are expected to be beneficial for industrial stakeholders and regulatory authorities for charting out directions in order to increase workplace safety. Future studies based on an extended analysis of evidence from a larger dataset could potentially benefit process industries around the globe.

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### AUTHOR CONTRIBUTIONS

**Hasan Mahbub Tusher:** Conceptualization (equal); formal analysis (equal); investigation (lead); methodology (equal); project administration (supporting); validation (equal); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Steven Mallam:** Conceptualization (equal); formal analysis (equal); funding acquisition (supporting); investigation (equal); methodology (equal); project administration (supporting); supervision (equal); validation (equal); writing – original draft (supporting); writing – review and editing (equal). **Risza Rusli:** Formal analysis (supporting); funding acquisition (supporting); investigation (supporting); methodology (supporting); project administration (supporting); supervision (supporting); validation (supporting); writing – review and editing (supporting). **Anne Kari Botnmark:** Funding acquisition (supporting); investigation (supporting); methodology (supporting); validation (supporting); writing – original draft (supporting); writing – review and editing (supporting).

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in The Major Accident Reporting System (MARS) of Europe at <https://emars.jrc.ec.europa.eu/en/emars/content>



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