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MANAGEMENT | RESEARCH ARTICLE

Modeling the impact of safety climate on process safety in a modern process industry: The case of the UAE's oil-refining industry

Mohamed Ali Al Mazrouei¹, Khalizani Khalid^{1*} and Ross Davidson¹

Abstract: This study examines the psychometric properties of process safety and models the relationships between top management commitment to safety (Model 1), top management safety practices (Model 2), and supervisory safety behavior (Model 3). It is hypothesized that these determinants are positively related to process safety. Data were provided by 180 workers in an oil refining company in the UAE. The results show high reliability in the overall process safety score and dimensions (employees' engagement in safety, employees' safety performance, and safe working environment). Confirmatory factor analyses indicate that 12 items can be combined into a higher-order process safety factor model. The findings from the controlled models demonstrate that top management commitment to safety, top management safety practices, and supervisory safety behavior are positively and significantly related to process safety and its dimensions. By contrast, in the freely estimated model, top management commitment to safety and top management safety practices are not significantly related to process safety. Overall, process safety has very good psychometric properties, suggesting that it can be used for safety research and future research related to psychological-behavioral safety.

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PUBLIC INTEREST STATEMENT

Human factor indicators for process safety can provide insight into safety levels in high-risk industries, such as oil refining. Studies assessing human factor indicators of process safety are globally limited. This is the first national study examining human factor indicators of process safety and their relationship with top management commitment to safety, top management safety practices, and supervisory safety behavior in the UAE, and in the Gulf region. This study contributes to safety research and safety management by developing and validating human factor indicators of process safety, which have received little attention in prior research. It identifies that top management commitment to safety, top management safety practices, and supervisory safety behavior are each positively related to process safety. There is an evident need for interventions in process industry environments.

Subjects: Ergonomics & Human Factors; Human Performance Modeling; Engineering Management; Human Resource Development; Energy Industries & Utilities

Keywords: UAE; oil refining industry; safety climate; process safety; structural equation modeling

1. Introduction

Process safety has received global attention since the beginning of the 21st century owing to its link to occupational accidents and injuries (Reniers, Ale, Dullaert, & Foubert, 2006). There is substantial interest among employers and occupational health and safety professionals in improving process safety, since ineffective process safety is associated with such incidents as explosions, fires, and toxic spills, which could inflict severe damage, including fatalities, injuries, property destruction, environmental degradation, and production loss (Mahan, Morawetz, Ruttenberg, & Workman, 2013), thereby placing a substantial and long-term financial burden on organizations. However, to improve process safety and mitigate occupational accidents and injuries, it is important to understand the factors that influence process safety. Existing research has largely focused on antecedents, such as safety culture, safety climate, and engineering and technical-related issues (Hendershot, Herber, & King, 2011; Keren, West, Rogers, Gupta, & Mannan, 2003; Mearns, 2017; Olive, O'Connor, & Mannan, 2006; Ostroff, Kinicki, & Muhammad, 2012). Mearns (2017) advocates integrating human factors and additional contextual factors likely to influence process safety.

Safety climate refers to shared perception of the policies, procedures, and practices related to workplace safety (Zohar, 1980). This notion also indicates the extent to which safety is a workplace priority, and thus warrants greater attention within the process safety context (Zohar & Luria, 2005). Furthermore, examining safety climate at the site level is crucial because, as Ostroff et al. (2012) suggest, safety climate is rooted in the perceptions of individual employees. Hunter and Wolf (2016) suggest that some safety climate factors (e.g., supervisor safety behavior) might be more crucial to process safety than others (e.g., top management commitment to safety and top management safety practices). Reniers et al. (2006) state that process plants are becoming difficult to control owing to a sudden increase in the scale and complexity of modern process industries. Consequently, effects on safety climate factors are inevitable (Kidam & Hurme, 2012). Based on various theories, the impact on safety climate could be problematic in terms of occupational accidents and injuries in general, and specifically on process safety (von Wehrden et al., 2012).

There is limited research on the relationship between safety climate factors and process safety, including its dimensions. There has been more research on system maintenance and technical issues, and less on human factors and management systems issues, in general. However, prior studies and meta-analyses have tended to conclude that the relationships between safety climate factors and process safety are unclear and that future research is still needed (Hendershot, 2012). Various reasons have been suggested for the mixed findings on the relationships between safety climate and process safety. However, other researchers have argued that safety climate factors might have different effects on particular dimensions of process safety (Mearns, Hope, Ford, & Tetrick, 2010; Pousette, Larsman, Eklöf, & Törner, 2017).

The United Arab Emirates (UAE) is a major player in the oil and gas industry, which has been the backbone of its economy since the late 1950s (Butt, 2001). With estimated oil and gas reserves of 81,135.9 MMb (million barrels), the UAE is the eighth largest oil producing country (Yin, Bai, Gao, & Xu, 2018). UAE Vision 2030 presents an agenda for diversifying from oil and gas to manufacturing, transportation, and hospitality and tourism (ADCED, 2008), but oil and gas will continue to play a major role in the country's future. Recent research on the UAE oil and gas industry suggests that human factors are controlled in relation to process safety to optimize human performance and reduce human failure using diverse safety management strategies (Harhara, Singh, & Hussain, 2015; Shqairat & Sundarakani, 2018). These studies elucidate that human factor was not given

attention in process safety management research human factor elements have received limited attention in most studies of organizational safety and health (OSH) and process safety management. Research contends that industry and the Organizational Safety and Health Act (OSHA) regulators should pay much more attention to human factors to manage hazards in the process industries (Theophilus, Nwankwo, Acquah-Andoh, Bassey, & Umoren, 2018). A unique feature of process safety in the process industries is that the framework for managing operating systems integrity and processes to handle hazardous petrochemical substances are affected by the human factors of workers' emotions, commitment, and cognitive biases, with potentially adverse consequences for the resilience of safety systems and procedures. In this context, human reliability determines agility in the process industry because it heavily depends on human factors, including workforce involvement, employee performance, and work environment.

This study adds to the existing process safety literature by adopting the recommendations of prior researchers (Khan et al., 2016; Swuste, Theunissen, Schmitz, Reniers, & Blokland, 2016) to investigate the specific safety climate factors in process safety.

This paper comprises four sections. First, the theoretical foundations leading to our hypotheses are presented. This is followed by description of the data collected from the UAE's oil and gas sector. The findings from the data are then presented in section 3. We conclude by discussing the research findings, including implications, limitations, and future research directions.

1.1. Process safety

It is important to focus on process safety in an attempt to improve workplace safety in modern process industries. However, progress in process safety research has been slow, owing to an inconsistent definition of "process safety." Hunter and Wolf (2016) describe process safety as preventing major accidents that involve hazardous chemical processes. This description is consistent with that of Hendershot (2012), who suggests that process safety concerns controlling the risk of failures and errors caused by humans. Earlier safety studies have distinguished the concepts of employees' safety engagement, employees' safety performance, and safe working environment for employees using individual variables (Aryee & Hsiung, 2016; Mearns et al., 2010). However, this study departs from earlier research by recognizing the concepts of employees' safety engagement, employees' safety performance, and safe working environment for employees as human factors that could affect process safety (Engemenn & Scott, *in press*; Hendershot, 2012; Huang et al., 2016; Prussia, Willis, & Rao, 2019; Wachter & Yorrio, 2014). Specifically, this study measures process safety as a higher-order construct comprising three dimensions: employees' safety engagement, employees' safety performance, and safe working environment for employees. Employees' safety engagement refers to employees expressing concern regarding health and safety hazards (e.g., provision of personal protective equipment, PPE, e.g., safety glasses and fall protection harnesses) (Cooper, 2015). Employees' safety performance refers to safety-related behavior at work (e.g., wearing PPE and encouraging co-workers to wear PPE) (Neal & Griffin, 2006). Safe working environment for employees refers to working conditions that do not harm employees and instead protect their wellbeing (e.g., routine health-care check-ups and PPE tests and inspections) (Sieberhagen, Rothmann, & Pienaar, 2009). Therefore, we regard employees' safety engagement, employees' safety performance, and safe working environment for employees as the three dimensions of process safety.

Hypothesis 1: Employees' safety engagement, employees' safety performance, and safe working environment for employees are the three dimensions of process safety.

1.2. Safety climate and process safety according to action theory

The current study adopts action theory as a framework to understand why safety climate and process safety are causally related. Action theory suggests that objective situational factors, such as management commitment to safety, management safety practices, and supervisory safety

behavior are social actions that must be considered within systems of action orientation at the organization level (Griffin & Neal, 2000). For example, if an employee thinks that top management is not committed to protect his or her wellbeing in the workplace, this could lead to process safety failures. According to this theory, safety climate is an emergent model because of complex reciprocal interactions and relationships about the priority of safety based on how safety climate factors influence action (Dekker, Cilliers, & Hofmeyr, 2011). While there is some research to support action theory's suggestion about the relationship between safety climate factors and process safety (Kiani & Khodabakhsh, 2013; Kouabenan, Ngueutsa, & Mbaye, 2015), there are inconsistent results (Flin, 2007, p. 91). These inconsistencies have led to growing recognition that the level of management's role in the safety climate context is not the same as that in the relationship with process safety (Oah, Na, & Moon, 2017). Other researchers have regarded different multilevel management roles as tending to have robust relationships with process safety. By contrast, a general management role is considered to offer ambiguous results with regard to safety climate and process safety relationship.

1.2.1. Top management commitment to safety

Top management commitment to safety refers to the degree to which the top management appears to highly prioritize safety issues and communicates and acts on such issues effectively (Neal & Griffin, 2006; Neal, Griffin, & Hart, 2000). Consistent with previous research on safety climate, process safety, and safety management (Hendershot, 2012; Hofmann, Michael, & Zohar, 2017; Olive et al., 2006; Ostroff et al., 2012; Vinodkumar & Bhasi, 2011), this study proposes that top management commitment to safety is positively related to process safety. According to action theory, top management commitment to safety is a cognitive resource that helps employees to shape their perceptions toward managing workplace safety (Norman, 1990, 1993). The theory suggests that top management commitment to safety should contribute to employees' favorable process safety (Dekker et al., 2011; Gravina, King, & Austin, 2019). Cooper (2015) suggests that commitment to safety should be derived by directly questioning top management and monitoring their commitment to safety. Doing so is important because top management commitment to safety manifests through their practices and behavior. Other researchers have explained that direct interactions of top management with lower-level employees (e.g., talking to employees about safe work practices) demonstrate commitment (Cooper, 2015; Hsu, Lee, Wu, & Takano, 2010; Tucker, Diekrager, Turner, & Kelloway, 2014). Specifically, some researchers have suggested that top management's communication about safety is a means of measuring top management commitment to safety. Ladewski and Al-Bayati (2019) argue that consultation and good communication by management promote a safety climate and result in enhanced safety, productivity, and employee morale in an organization. Consistently, Vinodkumar and Bhasi (2011) found that top management commitment to safety ranked among the top factors of safety climate to predict safety behavior in both OHSAS 18001- and ISO 9001-certified organizations. Therefore, we hypothesize as follows:

Hypothesis 2: Top management commitment to safety is positively related to process safety.

1.2.2. Top management safety practices

Top management safety practices refer to actual practices, roles, and functions related to safety (Vinodkumar & Bhasi, 2009). Researchers have found that top management practices play a significant role in predicting process safety (Gyekye & Salminen, 2007; Hofmann et al., 2017). Zohar and Luria (2010) state that top management safety practices reflect an organization's desire and commitment to prioritize safety. Hofmann et al. (2017) report that if employees perceive top management as concerned about and supportive of employees' safety and wellbeing, they often reciprocate by engaging in safe work behavior. Other researchers have found that top management practices encouraging employees to work safely include providing appropriate work equipment, informing employees about hazards, rewarding and applauding safety behaviors, and visiting workplaces to alert workers regarding unsafe work practices always; moreover, employees

are likely to behave safely in response to the top management safety practices implemented by an organization (Hofmann et al., 2017; Vinodkumar & Bhasi, 2009; Zohar & Luria, 2010). Regarding action Norman (1990, 1993) argues that management safety practices build the foundation of workplace safety norms and values for employees. Action theory posits that safety practices can be accumulated over time and can benefit from work experiences (Prussia et al., 2019; Yu, Cao, Xie, Qu, & Zhou, 2019). Drawing on these lines of research, we propose that management safety practices are positively related to process safety because they influence employees' workplace safety experiences, helping them to effectively prioritize safety and effectively process information about safety in the workplace environment. Therefore, we hypothesize as follows:

Hypothesis 3: Management safety practices are positively related to process safety.

1.2.3. *Supervisory safety behavior*

Supervisory safety behavior refers to employees' perceptions of the direct role played by their supervisors in practicing safety (Luria, Zohar, & Erev, 2008). This definition is consistent with researchers' suggestion that this behavior informs and establishes supervisor safety practices as a link to safety climate (Huang et al., 2014; Zohar & Luria, 2010). Consistent with previous research related to safety climate and safety management, we propose that supervisor safety behavior is positively related to process safety. According to action theory, supervisory safety practices provide social foundations of thought and action that guide employees' interaction and interrelationships, resulting in the capacity for discriminating safety details and safety action capability (Engemenn & Scott, *in press*; Norman, 1990, 1993). In turn, employees form complimentary, co-existing perceptions of workplace safety and safety priority because supervisory safety practices provide fundamental assumptions that define and guide employees' process safety (Zohar & Luria, 2005). These practices, in turn, shape employees' engagement, employees' safety performance, and safe working environment, as manifested in the actions of employees based on their perceptions of their supervisors' behavior. This pattern is related to the general pattern of priorities in supervisor practices over time (Nielsen, 2014). Therefore, the creation of consistent patterns in supervisory practices initiates process safety. This concept is consistent with the propositions of numerous researchers (Yorio, Willmer, & Moore, 2015; Zohar & Luria, 2010), who have emphasized the pivotal role of supervisors in modifying employees' safety behavior. While some researchers suggest that supervisory practices are linked to management commitment to safety (Rundmo, 2000), this study argues, consistently with Gao, Fan, Wang, Li, and Pei (2019), that the level of direct contact between top management and supervisory-level management determines the demonstration of safety behavior to employees. Therefore, we hypothesize as follows:

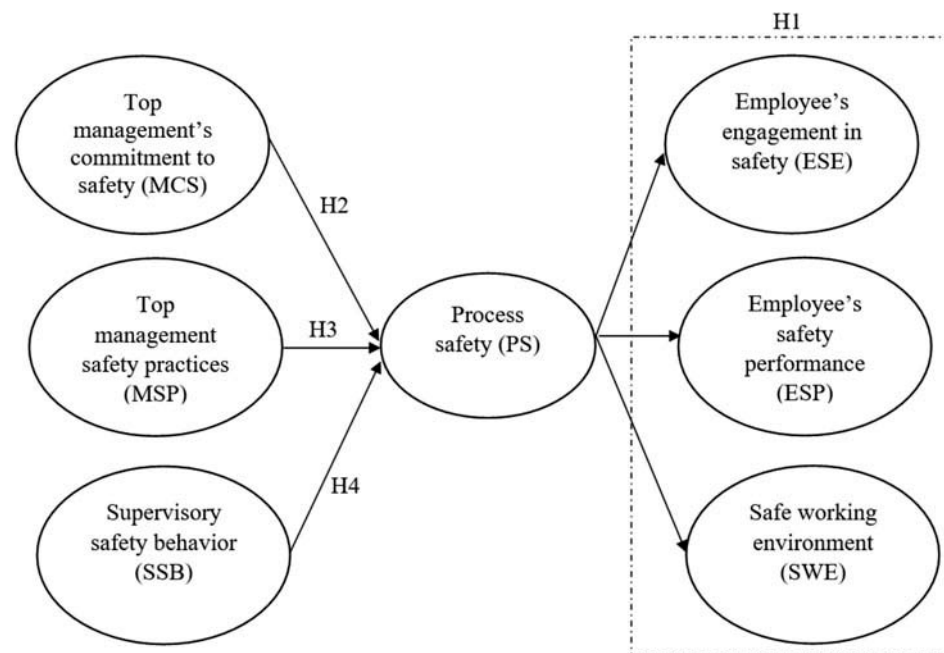
Hypothesis 4: Supervisory safety behavior is positively related to process safety.

The research model is depicted in Figure 1.

2. Method

This study's participants were 180 workers with various jobs at an oil refining company in Abu Dhabi, UAE. Of the participants, 131 (72.8%) were male, and 49 (27.2%) were female. The workers' ages ranged from 22 to 60 years, with a mean age of 38.8 years ($SD = 0.89$). In terms of the highest educational level attained, 53 participants (29.4%) held a high school diploma or technical certificate, 68 (37.8%) held an undergraduate university degree, and 59 (32.8%) held a graduate university degree. Job tenure ranged from 6 months to 30 years, with a mean job tenure of 12.3 years ($SD = 0.71$). Most participants were Emirati (79; 43.9%); 17 (9.4%) participants were from other Gulf Cooperation Council states, and 22 (12.2%) participants were from other Middle Eastern or North African nations. The remaining participants were North American (3; 1.7%), Asian (49; 27.2%), African (8; 4.4%), and others (2; 1.1%). In terms of job position, 55.6 percent worked at lower management level, and 44.4 percent worked at supervisory level.

Figure 1. The research model.



This study was approved by the Institute of Research Board Committee of Abu Dhabi University, and consent to participate in the study was obtained from the biggest oil refining company in Abu Dhabi, UAE. Subsequently, the participants were recruited for a cross-sectional online survey. To increase workers' participation in the survey, snowball sampling was used in this study. E-mail invitations were sent through the company's department heads, who were asked to encourage employees to complete the survey in their respective departments. The survey was distributed in February 2018; by the end of planned 3-month period of February–May 2018, the survey link had been clicked 259 times and 180 individuals had started the survey after reading the cover letter and providing their informed consent to participate. Of 562 workers in the oil refining company's database, 180 (32.0%) completed the survey and provided data on the study variables. This response rate met the threshold of 30 percent suggested by Frohlich (2002).

To develop a robust conceptual framework for understanding the determinants and dimensions of process safety, we conducted focus group interviews to develop the attributes based on the literature review. For the purpose of content analysis, two mini focus group interviews were conducted for this study. Each focus group comprised four different job workers from oil refining companies, and a professor. The group members were briefed and had the purpose of the focus group interview explained to them. They were encouraged to discuss and list factors that may influence process safety and to identify the human factor elements missing from process safety management in their workplaces. The outcomes of these discussions were then summarized, and conclusions were drawn to categorize their opinions. A final list of 15 safety climate attributes and twelve process safety attributes were identified as frequently mentioned by participants and similar to those identified in prior studies.

The survey questionnaire's face validity was tested by consulting experts. Although the constructs used in this study were validated by previous research, a draft questionnaire was reviewed by experts to ensure readability from the process industry worker's perspective. A pilot test was conducted with five process industry workers and two professors expert in the field of OSH. It was found that the questionnaire was generally simple, readable, and could be completed relatively quickly. However, minor changes were proposed and incorporated into the final edition of the questionnaire. In the final questionnaire, none of the items, scale answer options, or instructions

was translated into Arabic, because English is the primary language in the major oil refining plant in the UAE.

The three process safety dimensions of employees' engagement in safety, employees' safety performance, and safe working environment were measured with a 7-point Likert scale that ranged from 1 = totally disagree to 7 = totally agree. Employees' engagement in safety (dimension 1) was measured with a five-item scale adapted from the communication dimension of the Questionnaire of Safety Culture Values and Practices developed by Díaz-Cabrera et al. (2008). Example items are "I feel that the organization values my contributions to promoting process safety" and "I believe that it is possible to achieve zero process safety incidents at my organization." A three-item scale of employees' safety performance (dimension 2) was employed using items adapted from Vinodkumar and Bhasi (2009). Example items are "I use all the necessary safety equipment to do my job" and "I ensure the highest levels of safety when carrying out my job." A four-item scale for safe working environment was adapted from the company values dimension of the Questionnaire of Safety Culture Values and Practices (Díaz-Cabrera et al., 2008). Example items are "I feel that my organization wants to reduce process safety incidents" and "My organization ensures regular checks to ensure that process safety standards are maintained." The Cronbach's alpha for the overall scale was 0.830, and the alphas for the dimensions were 0.794 (employees' engagement in safety), 0.851 (employees' safety performance), and 0.780 (safe working environment).

Top management commitment to safety was measured with a five-item scale adapted from Vinodkumar and Bhasi (2011). This construct is highly reliable and is frequently used in safety research as an indicator of the success of an organization's safety programs (Amponsah-Tawiah & Mensah, 2016; Casey, Griffin, Flatau Harrison, & Neal, 2017). The measurement was initially developed with a sample of process industry employees similar to this study's sample. Example items are "Safety is given high priority by the management" and "The top management acts quickly to solve problems after near-miss accidents are reported." Participants responded to the items on a 7-point Likert-scale that ranged from 1 = totally disagree to 7 = totally agree. The alpha for the scale was 0.782.

Five questions regarding top management safety practices were measured with a 7-point Likert-scale that ranged from 1 = totally disagree to 7 = totally agree, which was adapted from Hayes, Perander, Smecko, and Trask (1998). Their study showed that safety management practices were among the best predictors of accidents, safety performance, and safety-related behavior. These findings are consistent with previous research supporting the importance of top management safety practices in predicting accident-related variables (Wachter & Yorio, 2014; Zohar & Luria, 2010). Moreover, the research showed that management safety practices positively correlated with employees' engagement and accident prevention in a sample of process industry employees. Example items are "Top management conducts frequent safety inspections" and "Management provides safe working conditions." The alpha for the scale was 0.867.

Supervisory safety behavior was measured with a five-item 7-point scale adapted by Hayes et al. (1998). Their results showed that supervisory safety behavior was among the most important factors in process safety incidents/accidents. Furthermore, researchers have recently examined the role of perceptions of workplace safety in understanding industrial accidents (Casey et al., 2017; Erdogan, Ozyilmaz, Bauer, & Emre, 2018). Example items are "My immediate supervisor involves workers in setting safety goals" and "My immediate supervisor enforces safety rules." The alpha for the scale was 0.871.

2.1. Statistical analyses

This study adopts the psychometric scale-development procedures advanced by safety and organization studies (Prussia et al., 2019; Vinodkumar & Bhasi, 2011). First, exploratory factor analyses (EFA) using principal component analysis extraction and the varimax rotation method were conducted for each dimension of process safety (i.e., employees' engagement in safety, employees' safety performance, and safe working environment) using SPSS Version 18.0 (SPSS Inc, 2009). Next,

comprehensive confirmatory factor analyses (CFA) were performed to examine the measurement model using SPSS AMOS (Arbuckle, 2014). Finally, to further evaluate the model, this study employed the following fit indices: chi-square (χ^2), comparative fit index (CFI), normed fit index (NFI), Tucker-Lewis Index (TLI), and root-mean-square error of approximation (RMSEA). The satisfactory cut-off values used in this study are CFI ≥ 0.90 , NFI ≥ 0.90 , TLI ≥ 0.90 , and RMSEA ≤ 0.08 ; the cut-off values for good fit indices are CFI ≥ 0.95 , NFI ≥ 0.95 , TLI ≥ 0.95 , and RMSEA ≤ 0.06 (Bentler, 1990; Byrne, 2010; Forza & Filippini, 1998; Hair, Black, Babin, & Anderson, 2010; Satorra & Bentler, 1994). CFA was also performed to verify the construct reliability and validity of the process safety scale. Finally, the conceptualization of process safety as a hierarchical multidimensional construct was tested based on the above discussions.

To confirm the proposed hierarchical structure of process safety, a series of CFAs was performed in two stages. Stage one comprised sequentially evaluating the 12 indicators of process safety, the three dimensions of process safety, and the overall second-order factor model of process safety. After the measurement model had been confirmed, stage two comprised regressing the constructs of safety climate (i.e., top management commitment to safety, top management safety practices, and supervisory safety behavior) on process safety using structural equation modeling in AMOS. The reliability estimates and collinearity diagnostics of the studied variables were also examined using SPSS Version 18.0 (SPSS Inc, 2009).

3. Results

3.1. Exploratory factor analyses (EFA)

Based on the eigenvalues and factor loadings from the EFA, all items were grouped under respective factors and are summarized in Table 1. The EFA revealed that the underlying dimensions of process safety (i.e., employees' engagement in safety, employees' safety performance, and safe working environment) were sufficient, and no issue of multicollinearity existed [χ^2 (66) = 1616.651, $p < 0.05$, KMO = 0.912]. The results were consistent with the cut-off values suggested by Hair et al. (2010). All factor loadings were greater than 0.50, KMO was greater than 0.50, Bartlett's significant value was greater than 0.05, and eigenvalues were greater than 1.0. Through the EFA procedures, this research aligns with both the theoretical view of process safety (i.e., literature-based approach) and the workers' perception of process safety (i.e., survey-based empirical assessment).

3.2. Confirmatory factor analyses (CFA)

Twelve items from the three dimensions of process safety were examined in the correlated model and were constrained to load onto their corresponding factors. The results of the CFA model indicate a good fit ($\chi^2 = 76.615$, $p < 0.01$, $df = 39$; CFI = 0.982; NFI = 0.954; TLI = 0.975; RMSEA = 0.058). The CFA loadings for all items had values between 0.80 and 0.98, were statistically significant, and loaded onto their respective factors, as summarized in Table 2. All Cronbach's alpha (α) and composite reliability values far exceed 0.70, which supports the construct reliability of the process safety dimensions (see Table 2). The results showed adequate convergent and discriminant validity: AVEs exceeded 0.50 (Kline, 2010) and the square roots of AVE values exceeded the construct correlation values (Fornell & Larcker, 1981). In addition, all factor loadings far exceeded 0.50, and the t -values were statistically significant ($p < 0.01$) (Hair et al., 2010).

Because the three process safety dimensions were highly and positively correlated ($0.82 \leq r \leq 0.88$, $p < 0.001$; see Table 2), the standardized regression coefficients may be associated with large standard errors due to potential multicollinearity (Winship & Western, 2016). Therefore, we examined the variance inflation factors (VIFs), which estimate the extent to which the standard error of a regression coefficient for a given predictor is inflated due to correlations among the predictors, compared to the situation of completely uncorrelated predictors. The rule-of-thumb range for VIFs to indicate severe multicollinearity among predictor variables is between 4 and 10 (Yoo et al., 2014). In Model 1, the VIFs for the three process safety dimensions were 1.35 for employees' engagement in safety, 3.35 for employees' safety performance, and 1.52 for safe working

Table 1. Summary of exploratory factor analysis

Dimension	Items	Mean	SD	Factor loadings	Eigenvalues	Total variance explained
Employees' safety engagement (ESE)	ESE1 My organization values my contribution to promoting process safety	5.63	1.07	0.86	6.952	57.933
	ESE2 My organization values employees' suggestions on improving safety	5.71	1.04	0.87		
	ESE3 My organization values employees' adherence to process safety procedures	5.64	1.09	0.82		
	ESE4 My organization regularly promotes process safety	5.71	1.05	0.80		
	ESE5 My organization can achieve zero process safety events/incidents	5.70	1.18	0.79		
Employees' safety performance (ESP)	ESP1 I use all of the necessary safety equipment when doing my job	5.72	1.06	0.79	4.615	31.897
	ESP2 I ensure the highest levels of safety when carrying out my job	5.71	1.12	0.76		
	ESP3 I know how to use safety equipment and understand standard work procedures	5.68	1.14	0.73		

(Continued)

Table 1. (Continued)

Dimension	Items	Mean	SD	Factor loadings	Eigenvalues	Total variance explained
Safe working environment (SWE)	SWE1 My organization wants to eliminate process safety incidents	5.71	1.32	0.73	3.427	22.892
	SWE2 The leadership at my organization reviews process safety procedures after an event/incident occurs	5.92	0.97	0.71		
	SWE3 My organization conducts regular checks to ensure that process safety standards are maintained	5.77	1.05	0.72		
	SWE4 I feel safe when working at my organization	5.71	1.18	0.67		

Note: N = 180; all loadings are significant at $p < 0.01$.

Table 2. Summary of confirmatory factor analyses for dimensions of process safety

Construct		1—ESE	2—ESP	3—SWE
1.	Employee's engagement in safety (ESE)	0.85		
2.	Employees' safety performance (ESP)	0.83**	0.90	
3.	Safe working environment (SWE)	0.82**	0.88**	0.91
	Average variance extracted (AVE)	0.72	0.80	0.83
	Cronbach's α	0.85	0.89	0.89
	Composite reliability	0.96	0.92	0.94
	Factor loadings	0.80–0.91	0.88–0.91	0.84–0.98

Note: N = 180; all are significant at ** $p < 0.01$, values on the diagonal are the square-root of the AVE for each construct.

environment. These values suggest that although there was some multicollinearity due to inflated standard errors, it was not a serious problem.

Overall, the results were consistent with previous research, thus supporting the hypothesized factor structure of process safety (Hypothesis 1; Erdogan et al., 2018; Hofmann et al., 2017; Raines, 2011). The results indicate that all three dimensions of process safety were well qualified. Therefore, the comprehensive validation procedures have established that the three dimensions and 12 items constitute a good instrument for measuring process safety.

3.3. Test of proposed factor structure of process safety

Based on the above discussions, this study suggests that process safety is a hierarchical, multi-dimensional construct. Process safety can be conceptualized as second-order factor model. Consistent with Prussia et al. (2019), this study examined this model in three stages. The first step was to test the 12 indicators of process safety. As shown in Table 3 (see also Figure 2), the model indicates a satisfactory fit ($\chi^2 = 82.898$, $df = 39$; CFI = 0.972; NFI = 0.950; TLI = 0.953; RMSEA = 0.079). These results suggest that the 12 indicators are adequate to measure process safety. The second step was to test the three dimensions of process safety (see Figure 3). As shown in Table 3, the model suggests a good fit ($\chi^2 = 62.697$, $p < 0.01$, $df = 39$; CFI = 0.985; NFI = 0.962; TLI = 0.975; RMSEA = 0.058). The final step was to assess the three dimensions of process safety, to which, this study models process safety as the overall second-order factor model (see Figure 4). All three dimensions have between three and five items. As shown in Table 3, this proposed model indicates a good fit ($\chi^2 = 63.168$, $df = 39$; CFI = 0.985; NFI = 0.962; TLI = 0.976; RMSEA = 0.057). These results suggest that the three dimensions are suitable for and capable of measuring process safety in a process industry context. All three stages of the proposed hierarchical structure of process safety are well supported, thus demonstrating the validity of the full model of process safety. In this context, process industry workers not only evaluate process safety on the three dimensions but also observe process safety as a higher-order factor corresponding to the 12 indicators.

Table 3. Summary of fit indices for the proposed factor structure of process safety

Model assessments	χ^2	df	CFI	NFI	TLI	RMSEA
Model 1: test of process safety indicators	82.898	39	0.972	0.950	0.953	0.079
Model 2: test of process safety dimensions	62.697	39	0.985	0.962	0.975	0.058
Model 3: test of the second-order factor	63.168	39	0.985	0.962	0.976	0.057

Note: N = 180.

Figure 2. Indicators of process safety.

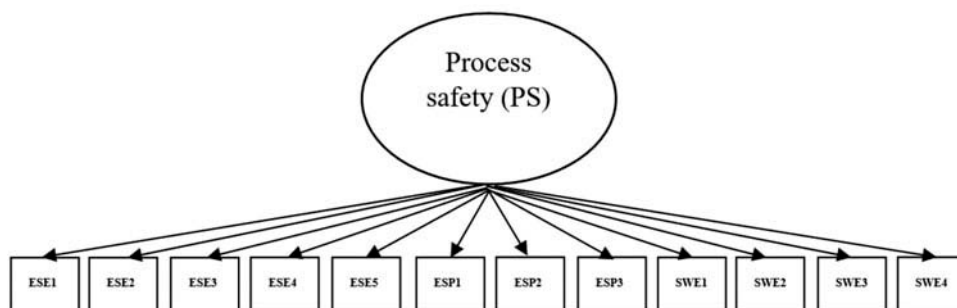


Figure 3. Dimensions of process safety.

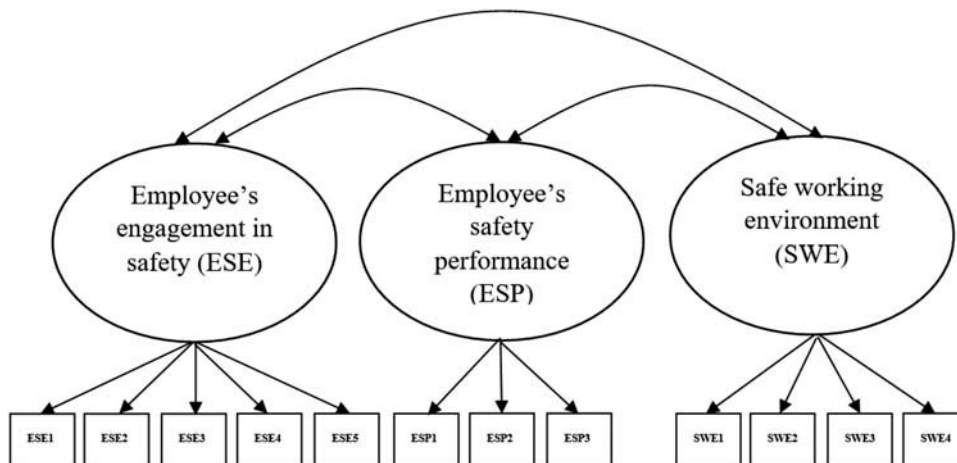
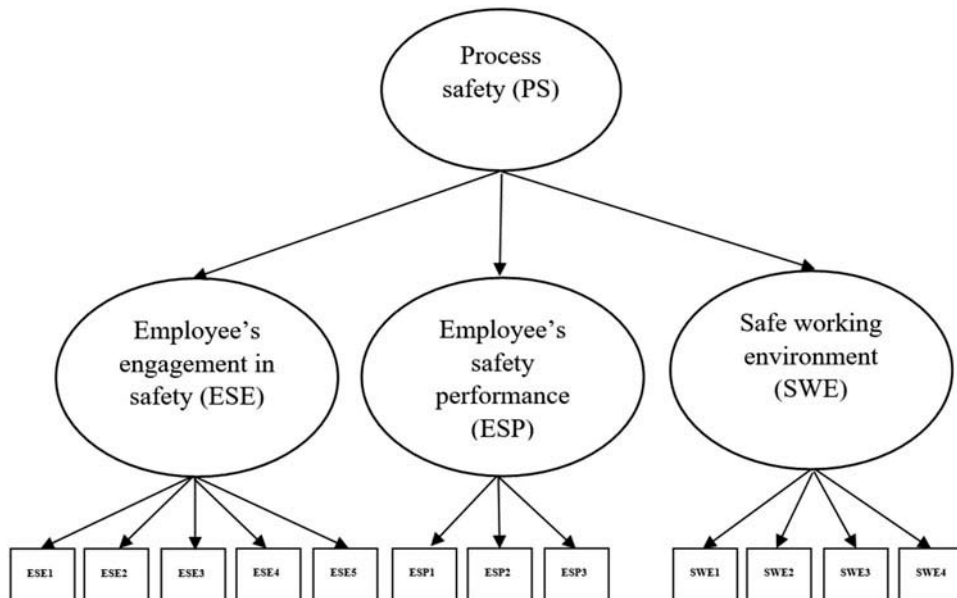


Figure 4. Second-order factor model of process safety.



3.4. Hypotheses tests

According to Hypothesis 1, employees' engagement in safety, employees' safety performance, and safe working environment are the three dimensions of process safety. This is confirmed in Table 1 to 3: the second-order factor model of process safety was found to be valid and reliable,

and the results show its suitability and capability for measuring process safety in a modern process industry context. Thus, Hypothesis 1 is supported.

After thus confirming the measurement model of process safety, structural equation modeling was performed using AMOS to examine nomological validity by testing the relationships between theoretically related constructs of safety climate (i.e., top management commitment to safety, top management safety practices, and supervisory safety behavior) and process safety. Before regressing the safety climate constructs on process safety, we conducted correlation analysis to explore the association between the studied variables. Because the process safety scale is conceptualized as a second-order factor model, we first computed the scores of the three dimensions of process safety by averaging the items under each dimension. As reported in Table 4, all studied variables were positive and significantly correlated, with values between $r = 0.647$, $p < 0.01$ (supervisory safety behavior and top management commitment to safety) and $r = 0.825$, $p < 0.01$ (top management safety practices and top management commitment to safety). Top management commitment to safety ($r = 0.768$, $p < 0.01$), top management safety practices ($r = 0.789$, $p < 0.01$), and supervisory safety behavior ($r = 0.747$, $p < 0.01$) were all also positively and significantly associated with process safety. The reliability values of the studied variables support construct reliability. Moreover, the results in Table 4 show adequate convergent and discriminant validity because AVEs exceeded 0.50 (Kline, 2010), the square roots of AVE values exceeded the construct correlation values (Fornell & Larcker, 1981), and all factor loadings far exceeded 0.50 with statistically significant t -values ($p < 0.01$) (Hair et al., 2010). In addition, the results indicated satisfactory model fit ($\chi^2 = 252.387$, $df = 121$; CFI = 0.958; NFI = 0.924; TLI = 0.947; RMSEA = 0.078). Since the safety climate factors of top management safety practices and top management commitment to safety were highly and positively correlated ($r = 0.83$, $p < 0.01$; see Table 4), we examined the VIFs to assess multicollinearity. The VIFs of the studied variables were between 2.00 and 4.19, suggesting that although there was some multicollinearity due to inflated standard errors, it was not a serious problem (Yoo et al., 2014). These findings provide preliminary support for Hypotheses 2, 3, and 4.

Table 5 shows the results of four regression analyses of process safety predictors. First, we controlled for top management safety practices and supervisory safety behavior while regressing top management commitment to safety on process safety (Model 1; Hypothesis 2). Second, we controlled for top management commitment to safety and supervisory safety behavior while regressing top management safety practices on process safety (Model 2; Hypothesis 3). Third, we controlled for top management commitment to safety and top management safety practices while regressing supervisory safety behavior on process safety (Model 3; Hypothesis 4). The rationale for this evaluation strategy was three-fold: (1) when workers are less perceived that their top management

Table 4. Correlations, reliability values, average variances extracted, and factor loadings of the studied variables

Dimension/Variable		1—PS	2—TMCS	3—TMSP	4—SSB
1.	Process safety (PS)	0.88			
2.	Top management commitment to safety (MCS)	0.77**	0.85		
3.	Top management safety practices (MSP)	0.79**	0.83**	0.86	
4.	Supervisory safety behavior (SSB)	0.75**	0.65**	0.70**	0.88
	Average variance extracted (AVE)	0.77	0.73	0.75	0.77
	Cronbach's α	0.88	0.85	0.86	0.88
	Composite reliability	0.91	0.93	0.94	0.94
	Factor loadings	0.81–0.94	0.83–0.89	0.83–0.91	0.82–0.94

Note: N = 180; all are significant at ** $p < 0.01$; values on the diagonal are the square-root of the AVE for each construct.

Table 5. Results of the causality analyses of process safety predictors

Hypotheses	H2	H3	H4	Final Model
Model assessments	Model 1	Model 2	Model 3	Model 4
Top management commitment to safety	0.692** ^a	0.770** ^b	0.384** ^b	0.135
Top management safety practices	0.738** ^b	0.484** ^a	0.601** ^b	0.148
Supervisory safety behavior	0.932** ^b	0.706** ^b	0.108 ^a	0.307**
Employee's engagement in safety	0.982**	0.987**	0.989**	0.900**
Employees' safety performance	0.614**	0.612**	0.628**	0.607**
Safe working environment	0.979**	0.977**	0.988**	0.998**
R ²	0.61	0.64	0.58	0.81
F	91.73	104.13	159.65	144.94
Fit indices				
χ^2	623.010	613.432	670.700	404.164
df	288	288	288	264
CFI	0.927	0.929	0.917	0.970
NFI	0.874	0.876	0.864	0.918
TLI	0.911	0.914	0.899	0.959
RMSEA	0.076	0.079	0.086	0.054

Note: N = 180; ^a uncontrolled variable; ^b controlled variable.

Standardized regression coefficients (β) are shown.

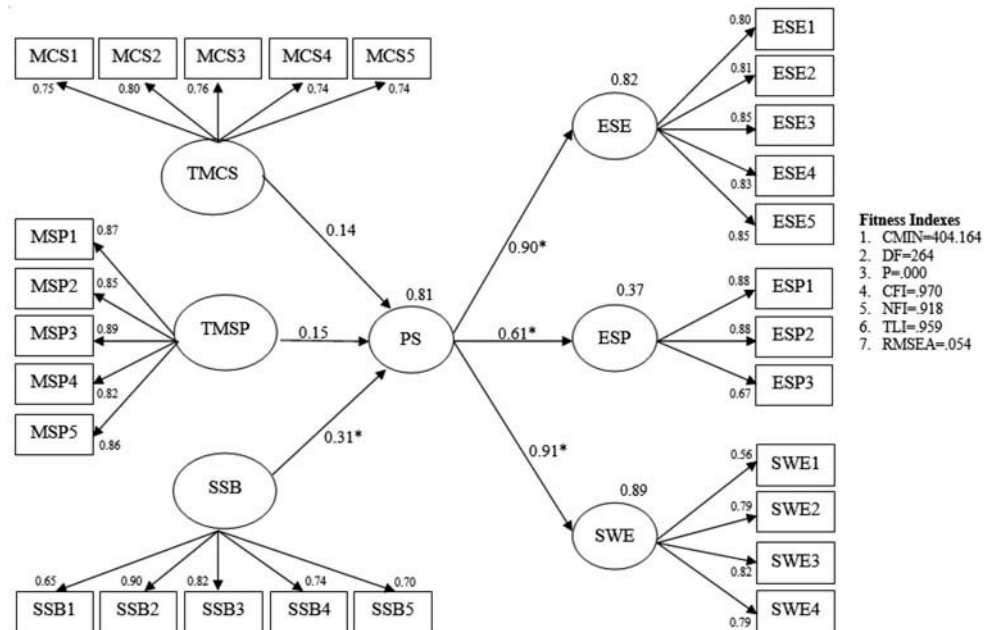
** $p < 0.01$.

committed to safety, they may be more likely to mimic top management practices and adopt the safety behaviors of their supervisor; (2) workers may believe that poor safety practices among top management do not indicate that top management have low safety commitment and may believe that it influenced safety behavior of their supervisor; and (3) workers may perceive that supervisors' safety misbehavior is not linked to either the safety commitment or safety practices of top management (Gao et al., 2019; Ladewski & Al-Bayati, 2019; Yu et al., 2019).

As shown in Model 1 (Table 5), when top management safety practices and supervisory safety behavior were controlled, top management commitment to safety ($\beta = 0.692$; $p < 0.01$), top management safety practices ($\beta = 0.738$; $p < 0.01$), and supervisory safety behavior ($\beta = 0.932$; $p < 0.01$) significantly predicted process safety (employees' engagement in safety, $\beta = 0.982$; $p < 0.01$; employees' safety performance, $\beta = 0.614$; $p < 0.01$; safe working environment, $\beta = 0.979$; $p < 0.01$). Therefore, Hypothesis 2 is supported. In addition, the causal structure showed satisfactory fit ($\chi^2 = 623.010$, $df = 288$; CFI = 0.927; NFI = 0.874; TLI = 0.911; RMSEA = 0.076). Overall, top management commitment to safety in Model 1 explained 61% of the variance in process safety.

Hypothesis 3 predicts that top management safety practices are positively related to process safety ($\beta = 0.484$, $p < 0.01$) when top management commitment to safety ($\beta = 0.770$, $p < 0.01$) and supervisory safety behavior ($\beta = 0.706$, $p < 0.01$) are controlled. As shown in Model 2 (Table 5), the dimensions of process safety were also found to be significantly related, with employees' engagement in safety most affected ($\beta = 0.987$; $p < 0.01$), followed by safe working environment ($\beta = 0.977$; $p < 0.01$) and employees' safety performance ($\beta = 0.612$; $p < 0.01$). Therefore, Hypothesis 3 is

Figure 5. The final model.



supported. The causal structure was also sufficient ($\chi^2 = 613.432$; $df = 288$; $CFI = 0.929$; $NFI = 0.876$; $TLI = 0.914$; $RMSEA = 0.079$). Model 2 explained 64% of the variance in process safety.

Interestingly, as shown in Model 3 (Table 5), supervisory safety behavior insignificantly predicted process safety ($\beta = 0.108$, $p > 0.05$) when top management commitment to safety and top management safety practices were controlled. The controlled variables were found to be significantly related to process safety (top management commitment to safety: $\beta = 0.384$, $p < 0.01$; top management safety practices: $\beta = 0.601$, $p < 0.01$). The reflective dimensions of process safety were also found to be significantly related, with employees' engagement in safety most affected ($\beta = 0.989$; $p < 0.01$), followed by safe working environment ($\beta = 0.988$; $p < 0.01$) and employees' safety performance ($\beta = 0.628$; $p < 0.01$). The causal structure had an adequate fit ($\chi^2 = 670.700$, $df = 288$; $CFI = 0.917$; $NFI = 0.864$; $TLI = 0.899$; $RMSEA = 0.086$). Model 3 explained 58% of the variance in process safety. Therefore, Hypothesis 4 is not supported.

Finally, we combined top management commitment to safety, top management safety practices, and supervisory safety behavior in Model 4—a freely estimated model—to measure their relationships with process safety. Only supervisory safety practices were found to positively predict process safety ($\beta = 0.307$, $p < 0.01$; see Table 5, Model 4); neither top management commitment to safety ($\beta = 0.135$, $p > 0.05$) nor top management safety practices ($\beta = 0.148$, $p > 0.05$) significantly predicted process safety. The model generated a good fit index ($\chi^2 = 404.164$, $df = 264$; $CFI = 0.970$; $NFI = 0.918$; $TLI = 0.959$; $RMSEA = 0.054$). Overall, Model 4 explained 81% of the variance in process safety in which all three dimensions of process safety are significantly related (safe working environment: $\beta = 0.998$, $p < 0.01$; employees' engagement in safety: $\beta = 0.900$, $p < 0.01$; employees' safety performance: $\beta = 0.607$, $p < 0.01$; see Figure 5).

4. Discussion

This study examined the psychometric properties of process safety and its constructs to establish the criterion-related validity of the safety climate factors of top management commitment to safety, top management safety practices, and supervisory safety behavior. Overall, the findings showed that the process safety construct has very good psychometric properties and can be used to measure safety outcomes. Thus, the scale can be used for future health and safety-related

research. The following discussion summarizes and interprets our key findings in the context of relevant theories and previous empirical research.

First, we were able to demonstrate that the process safety model assesses the three distinct dimensions of safety outcomes in a highly reliable way, and that when these dimensions are combined, they form a higher-order factor. The three dimensions included in the initial questionnaire were chosen based on previous studies (Díaz-Cabrera et al., 2008; Vinodkumar & Bhasi, 2009) conducted in various industries and with different populations to cover all possible areas. Employees' engagement in safety and a safe working environment emerged as factors in the study of Varmazyar, Mortazavi, Arghami, and Hajizadeh (2016), which was conducted in a public transportation system environment. Boughaba, Hassane, and Roukia (2014) report safety performance as one of the factors in their study in the petrochemical industry. Despite using different questionnaire items, earlier studies have often reported the factors of employees' engagement in safety, safe working environment (Díaz-Cabrera et al., 2008), and employees safety performance (Vinodkumar & Bhasi, 2009). In this study, the items related to these dimensions were loaded onto a single factor named "process safety."

Importantly, this study confirmed the reliability and construct validity of the process safety scale. All of the factors were positively correlated, which aligns with the findings of earlier research (Hendershot, 2012; Kidam & Hurme, 2012; Wachter & Yorio, 2014). Hendershot (2012) and Wurst and Cornelisen (2013) report that process safety is not a technical issue but, rather, one aspect of safety culture. It is an issue involving human factors (behavior), management systems, and communication.

Second, consistent with Hypotheses 2 and 3, we found that top management commitment to safety ($\beta = 0.692$, $p < 0.01$) and top management safety practices ($\beta = 0.484$, $p < 0.05$) predicted process safety when controlling for other factors. These findings are consistent with previous safety research finding positive relationships between top management commitment to safety and process safety (Cooper, 2015; Tucker et al., 2014) and between top management safety practices and process safety (Gyekye & Salminen, 2007; Hofmann et al., 2017). We further found that Hypothesis 4 was not supported by the findings of Model 3 ($\beta = 0.108$, $p > 0.05$). This result is interesting given that supervisory safety behavior has positive bivariate correlation with process safety. Earlier studies have also found that workers tend to violate process safety procedures and behave unsafely due to work pressure from supervisors and managers, rather than a lack of awareness of the risks involved (e.g., Choudhry & Fang, 2008; Kiani & Khodabakhsh, 2013; Luria et al., 2008). To avoid negative consequences and to satisfy their bosses, workers may take shortcuts in work processes. Therefore, production pressure tends to cause unsafe processes via lowering workers' safety motivation. Moreover, production pressure may cause managers and supervisors to temporarily prioritize production over safety and, thus, ignore some process safety indicators to stay on schedule. Consequently, supervisory safety behavior can negatively affect workers' safety processes. Wachter and Yorio (2014) indicate that process safety management systems and practices depend on the levels of safety focus and the cognitive and emotional states of workers. Workers' perceptions may affect an organization's process safety even within an environment of highly structured safety management systems. These findings support the suggestions from earlier research that process safety should go beyond engineering and technical elements (Hendershot, 2012; Hofmann et al., 2017; Wurst & Cornelisen, 2013) by also aiming to influence the psyches and personalities of employees (Cooper, 2003).

Contrary to our expectation, Model 4 showed no significant relationship between process safety and either top management commitment to safety ($\beta = 0.135$, $p > 0.05$) or top management safety practices ($\beta = 0.148$, $p > 0.05$) when no control elements were added to the safety climate factors. Model 4 does, though, support Hypothesis 4's prediction that supervisory safety behavior significantly predicts process safety ($\beta = 0.307$, $p < 0.01$). The importance of social support in the process safety of the process industry has long been recognized. This result is also consistent with recent studies arguing that supervisory safety behavior creates a positive level of safety behavior among workers, whereas neither top management commitment to safety nor top management safety

practices have much influence on workers' process safety in the workplace (Gao et al., 2019; Ladewski & Al-Bayati, 2019; Yu et al., 2019). Previous research has indicated that frontline supervisors significantly influence the safety behavior of their employees, which directly affects process safety (Hsu et al., 2010; Luria et al., 2008). Lingard, Cooke, and Blismas (2010) indicate that social support has taken on such an important role because frontline workers are more likely to be influenced by their daily interactions with supervisors and co-workers. Compared to top management safety commitment (Flin, Mearns, O'Connor, & Bryden, 2000) and top management safety practices, social support has a distinct role in the workplace and is perceived differently by different workers (Amponsah-Tawiah & Mensah, 2016). Social support is understood as a factor that shapes behavior at the group level, while top management safety commitment and safety practices mainly influence the upper-level management of an organization (Huang, Lee, McFadden, Rineer, & Robertson, 2017). Past studies have proved that the social support of supervisory safety behavior facilitates process safety and, thus, is vital to improving the safety climate (Bosak, Coetsee, & Cullinane, 2013; Hsu et al., 2010; Kouabenan et al., 2015).

4.1. Practical implications

Because process safety is a core construct in safety research and action theory, our findings have implications for safety research. First, companies in UAE process industries can use our reliable and validated, non-technical and non-engineering construct to measure process safety. This measure is important in assessing workers' receptivity to safety rules and regulations, because they can understand the processes, hazards, and their consequences better than other workers can. Second, the complexity of the psychological-behavioral safety relationship can be further understood, recognized, and valued as an integral part of process safety efforts (Geller, 1997). Our findings are consistent with the suggestion by earlier studies that cognitive psychological factors are vital in safety research, because they have multiple causal effects on safety governance, thoughts, and actions (Johari, Alam, & Said, 2018; Masudin, Wastono, & Zulfikarjah, 2018; Weibert & Plunkett, 2006). Third, our findings have implications for the motivation of individual workers to expend efforts endorsing process safety-related behavior. Thus, many questions are raised concerning the role of human psychological factors in modifying and altering the dysfunctional condition between safety climate factors and psychological factors, which are observed to be mutually exclusive. Although human error is regarded as an essential component in action theory, the causative effect of human psychology on process safety failure is critically important in predicting reinforced attitudes and behavior modification toward reducing safety-related accidents.

5. Conclusion, limitations, and future research

Previous researchers have argued that no universal set of process safety factors exists and that the complexity of modern process industries influences safety climate. In addition, it is possible that the factors that influence safety climate within one industry might not be valid in another industry, because organizations differ in multilevel management styles and safety regulations, resulting in different safety perceptions, which are then reflected in different factor structures. The main dimensions and items included in this study's questionnaire influence the process safety factor structure. This study showed that the process safety construct has good psychometric properties and can be used to measure important safety outcomes. Specifically, the measure is highly reliable and enables distinction between the three process safety dimensions, which can, in turn, be combined into a higher-order process safety factor. Moreover, this study demonstrated the criterion-related validity of the scale, such that supervisory safety behavior positively predicted process safety, although supervisory safety behavior did not significantly predict process safety when top management commitment to safety and top management safety practices were controlled. Overall, the findings showed that this instrument can be used to evaluate the state of process safety in the process industry and to conduct future research on safety culture.

First, this study was designed sectionally, in a multicultural organization context, and without differentiating workers' educational and positional backgrounds. Thus, cross-sectional causality

conclusions cannot be drawn. For instance, the relationships among process safety and its indicators among different levels of management remain unknown. Future longitudinal and experimental research is needed to explore the multigroup relationships between top management commitment to safety, top management safety practices, supervisory safety behavior, and process safety. Second, our sample focused on highly educated and skilled workers in a process industry, the vast majority of whom had graduate degrees. Thus, future research is needed to demonstrate the generalizability of our findings to less well-educated groups of workers. Third, we modified all the variable measures taken from previous studies to better fit the context of our study, which might have influenced their reliability and validity. However, the positive relationships between these measures and their positive associations provide some evidence of their construct validity. Finally, future research is needed on the mediating and moderating factors that can explain and further elucidate the links between top management commitment to safety, top management safety practices, supervisory safety behavior, and process safety outcomes. For instance, researchers could examine the mediating and moderating roles of safety motivation and safety knowledge and study the link between safety training and enhanced safety-related outcomes.

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Conflict of interests

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