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Safety compliance and safety climate: A repeated cross-sectional study in the oil and gas industry



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Introduction: Violations of safety rules and procedures are commonly identified as a causal factor in accidents in the oil and gas industry. Extensive knowledge on effective management practices related to improved compli-ance with safety procedures is therefore needed. Previous studies of the causal relationship between safety climate and safety compliance demonstrate that the propensity to act in accordance with prevailing rules and procedures is influenced to a large degree by workers' safety climate. Commonly, the climate measures employed differ from one study to another and identical measures of safety climate are seldom tested repeatedly over extended periods of time. This research gap is addressed in the present study. Method: The study is based on a survey conducted four times among sharp-end workers of the Norwegian oil and gas industry (N = 31,350). This is done by performing multiple tests (regression analysis) over a period of 7 years of the causal relationship between safety climate and safety compliance. The safety climate measure employed is identical across the 7-year period. Conclusions: Taking all periods together, the employed safety climate model explained roughly 27% of the variance in safety compliance. The causal relationship was found to be stable across the period, thereby increasing the reliability and the predictive validity of the factor structure. The safety climate factor that had the most powerful effect on safety compliance was work pressure. Practical applications: The factor structure employed shows high predictive validity and should therefore be relevant to organizations seeking to improve safety in the petroleum sector. The findings should also be relevant to other high-hazard industries where safety rules and procedures constitute a central part of the approach to managing safety.

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1. Introduction

The oil and gas industry, onshore as well as offshore, contains a characteristic convergence of several hazardous elements that have the potential for both occupational accidents and major disasters. Hydrocarbon leakages, falling objects, fires, explosions, blowouts and hydrogen sulfide emissions are all examples of such elements. Thus, ever since the initial phase of the petroleum activity, consideration has been given to accident prevention ([Sutton, 2012](#page9)).

Within the Norwegian oil and gas industry, to which the present study gives its attention, the sum of such preventive measures has reduced the risk level substantially ([Ryggvik, 2003](#page9)). As a result of this, the number of high potential events, serious personal injuries, and lives lost due to accidents has decreased considerably during the last two to three decades ([PSA, 2012a](#page9)).1 However, events with catastrophic potential still happen. These are seldom or never caused by one single causal factor. Rather, a multitude of organizational, behavioral and

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technical factors contribute to such incidents. However, some causal factors occur more frequently than others. According to annual analyses of incident data performed by the International Association of Oil & Gas Producers (OGP), one of the most common causal factors of fatal incidents and high potential events in the oil and gas industry is viola-tions of safety procedures ([OGP, 2011, 2012, 2013, 2014; Walker,](#page9) [Poore, & Eales, 2012](#page9)).

The fact that violations of safety procedures are a frequently occur-ring causal factor is not a new finding. Analyses and investigations of high-profile oil and gas accidents, such as the Piper Alpha disaster in 1988 ([Paté-Cornell, 1993](#page9)), the Texas City refinery explosion in 2005 ([Hopkins, 2008](#page8)) and the Montara blowout in 2010 ([Hayes, 2012a](#page8)), all identify a lack of compliance with rules and procedures as a contributing cause in accident scenarios. This is also the case within the Norwegian oil and gas industry, where investigations of both occupational accidents and high potential events repeatedly identify violations of safety proce-dures as a causal factor (e.g. [Austnes-Underhaug et al., 2011; PSA,](#page8) [2013, 2015a, 2015b; Schiefloe et al., 2005](#page8)).

The significance of safety violations as an important causal factor in accidents is not only valid within the oil and gas industry, but is a frequent finding in accident investigations and analyses across different

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industries (e.g. [Hopkins, 2011; Lenné, Salmon, Liu, & Trotter, 2012](#page8)). This has led to a considerable amount of research aimed at identifying the reasons for non-compliant acts. In recent years, however, and similarly to this paper, researchers have been more focused on identifying condi-tions that promote safety compliance rather than on simply identifying violation-provoking conditions. The factor that has probably gained most research attention is that of safety climate (e.g., [Agnew, Flin, &](#page8) [Mearns, 2013; Barbaranelli, Petitta, & Probst, 2015; Cavazza & Serpe,](#page8) [2009; DeJoy, Schaffer, Wilson, Vandenberg, & Butts, 2004; Liu et al.,](#page8) [2015; Sinclair, Martin, & Sears, 2010](#page8)). Safety climate can be defined as a set of perceptions that employees share regarding the priority of safety in their organization, and it is the preferred term when psychometric questionnaire surveys are employed to uncover such perceptions ([Flin, Mearns, O'Connor, & Bryden, 2000; Zohar, 1980, 2010](#page8)). In spite of some variation regarding the strength of the causal relationships, safety climate studies indicate that a positive safety climate promotes safety-compliant behavior (for review studies see, for example, [Alper](#page8)

* [Karsh, 2009; Clarke, 2006](#page8)). This finding is important, because it dem-onstrates that compliance with safety procedures is not a result of mere chance and individual differences, but rather that it is highly influenced by manageable contextual factors. A challenge with these studies, however, is that identical measures of safety climate are seldom tested repeatedly over extended periods of time. Hence, the stability of the identified causal relationships between safety climate and safety com-pliance has not been subject to testing ([Yule & Flin, 2007](#page9)).

Safety within the oil and gas industry is highly regulated, and virtu-ally all work operations are governed by rules and procedures. Thus, a high level of safety presupposes a high level of compliance ([Bryden,](#page8) [2002](#page8)). Extensive knowledge on effective management practices related to improved compliance with safety procedures is therefore needed. However, studies of the causal relationship between safety climate and safety compliance within the oil and gas industry have the same challenges as those within other industries ([Mearns, Whitaker, & Flin,](#page8) [2003](#page8)). Hence, the stability of the causal relationship is not properly confirmed, and there is no agreement regarding which safety climate factors are most important in influencing workers' compliance with safety procedures.

Based on a repeated cross-sectional survey, administered four times within a period of 7 years, among front-line workers within the Norwegian oil and gas industry, the aim of the present study is to perform multiple tests of the causal relationship between safety climate and safety compliance. This allows for repeated testing of a theoretical model that is held constant over a prolonged time span, thereby increasing the reliability and the predictive validity of the factor structure. This is believed to be important for at least two reasons. Firstly, it can contribute to the theoretical development of safety climate and safety compliance research, where repeated tests of causal relationships are lacking. Secondly, improved empirically based knowledge on the antecedents of safety-compliant behavior should be particularly relevant to the oil and gas industry and other industries where formal procedures constitute a vital part of the system of safety barriers.

2. Theoretical background

According to [Griffin and Neal's (2000)](#page8) safety performance frame-work, the term ‘safety compliance’ constitutes one of two aspects of the more overarching term ‘safety behavior.’ The other aspect is safety participation. Safety participation refers to the type of voluntary behav-ior that employees engage in to improve safety, such as helping colleagues, raising safety concerns and making suggestions to improve safety. Safety compliance, on the other hand, refers to core safety tasks that have to be carried out by individuals to maintain safety at work. Hence, safety compliance is often defined, in line with [Neal et al.](#page8) [(2000](#page8): 101), as behavior that ‘involves adhering to safety procedures and carrying out work in a safe manner.’ In the present paper, however,

safety compliance is understood as being narrower and consistent with [Masia and Pienaar (2011)](#page8), who define the term as ‘the extent to which employees adhere to safety standards, procedures, legal obligations and requirements.’

As regards possible antecedents of safety compliant behavior within the oil and gas industry, several organizational factors have been studied. These include leadership involvement ([Dahl & Olsen, 2013](#page8)), workload ([Rundmo, Hestad, & Ulleberg, 1998](#page9)), employee involvement ([Antonsen, Almklov, & Fenstad, 2008](#page8)), pressure for production ([Mearns, Flin, Gordon, & Fleming, 2001](#page8)), and rule clarity and compre-hensibility ([Dahl, Fenstad, & Kongsvik, 2013](#page8)). A similarity between most of these studies and studies that focus on safety climate as a possi-ble precursor of compliance is that the explanatory factors are con-structed on the basis of workers' perceptions of the subject. Another similarity is that these perceptions are uncovered by psychometric questionnaire studies.

As already described, safety climate can be defined as a set of percep-tions that employees share regarding the priority of safety in their orga-nization ([Zohar, 1980](#page9)). Hence, safety climate measures are multifaceted and cover a broad range of employee perceptions of the priority of safety within the organization. Basically, safety climate occurs as individual perceptions, but in aggregated form they represent the generalized group perceptions of the organization's priority of safety ([Payne, Bergman, Rodríguez, Beus, & Henning, 2010](#page9)). According to [Zohar (2010)](#page9), it is these perceptions that form the frame of reference for employees about what sort of behavior is expected, supported, and rewarded. Thus, employee behavior will tend to align with these per-ceived expectations.

Numerous safety climate structures exist within the safety research literature. The factor structure employed in this study is based on the most common features of the safety climate construct, as identified by [Flin et al. (2000)](#page8). In their review study, Flin et al. examined the thematic basis of 18 questionnaire scales used to assess safety climate and 50% of the scales were from studies in the energy/petrochemical sector. This makes Flin et al.’s study particularly relevant as a starting point for the present study. The most common features measured in safety climate surveys were found to be (a) safety competence, (b) safety systems,

1. management/supervision, (d) work pressure, and (e) risk. As regards risk, some researchers have chosen to include this dimension as a part of the safety climate construct (e.g., [Cooper & Phillips, 2004](#page8)), while others use risk as an outcome variable where risk is operational-ized as risk-related behavior (e.g., [Rundmo et al., 1998](#page9)). In the present study, the risk dimension is used as an outcome variable, represented by safety compliance, whereas the four other features of the safety climate construct are treated as independent variables. The assumed relationship between these four features of the safety climate con-struct and safety compliance will be presented in more detail in the following.

2.1. Safety competence

According to [Flin et al. (2000)](#page8), competence appeared in one-third of the reviewed safety climate scales. The essence of competence was found to be the perceived general level of qualifications, skills, and knowledge, along with associated aspects such as training, selection and competence standards and assessment. Previous research that has focused on safety knowledge and safety training, as aspects of the competence concept, indicates that there is a positive causal relation-ship between safety competence and safety compliance. For example, in a study of the manufacturing industry, [Kwon and Kim (2013)](#page8) found that the level of safety knowledge was significantly related to safety compliance. Similar findings were obtained among retail employees by [Sinclair et al. (2010)](#page9). Studies have also demonstrated a positive rela-tionship between safety training and safety compliance, for example in the passenger ferry industry ([Lu & Yang, 2011](#page8)), the chemical industry ([Vinodkumar & Bhasi, 2010](#page9)) and in container terminal operations

|  |  |
| --- | --- |
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([Lu & Yang, 2010](#page8)). In line with this research, the following hypothesis was formulated:

Hypothesis 1. Safety competence will positively predict safety compliance.

2.2. Safety system

Safety system appeared in two-thirds of the studies of safety climate reviewed by [Flin et al. (2000)](#page8). The features of this dimension included a range of aspects related to the organization's safety management systems, from safety officials and safety committees to safety policies and permit-to-work systems. Previous studies of the relationship between safety system and safety compliance indicate a positive causal relationship. For example, a study within the mining industry found that there is a positive link between rule clarity, comprehensibility, and compliance. Similar findings have been obtained within the off-shore service vessel industry where perceived procedure vagueness was found to be negatively related to safety compliance ([Dahl et al.,](#page8) [2013](#page8)). Furthermore, [Antonsen et al. (2008)](#page8) found that simplicity of procedures as well as the user-friendliness of the system in which they are organized are significant success criteria for high compliance. The face validity of the relationship between safety system and compli-ance is also strong; knowing the content and having access to the proce-dures can be seen as a basic minimum prerequisite for compliance. Based on these findings, the following hypothesis was formulated:

Hypothesis 2. Safety system will positively predict safety compliance.

2.3. Safety supervision

According to [Flin et al. (2000)](#page8), the management/supervision dimen-sion was explicitly or implicitly represented in all of the reviewed safety climate scales. Supervision is commonly measured by assessing the ‘respondents’ satisfaction with supervision or their perceptions of the supervisors' attitudes and behaviors with respect to safety’ ([Flin et al.,](#page8) [2000](#page8): 185). According to [Zohar (2010)](#page9), the safety climate is comprised of factors that contribute to the employees' perception of the types of behavior that are expected, supported, and rewarded. In this perspec-tive, the role of the supervisor is central in communicating and setting the standard for safety behavior, an assumption that has been support-ed in previous research. For example, [Lu and Yang (2010)](#page8) found that leaders positively affect the level of safety compliance among their subordinates by expressing concern for safety, by emphasizing safety policies clearly, and by rewarding safe behavior. Furthermore, leaders have been found to affect safety compliance positively by standing out as positive and safe behaving role models for their staff, by challenging workers to develop improved practices and by inspiring their staff to achieve exceptional safety standards ([Inness, Turner, Barling, & Stride,](#page8) [2010; Kapp, 2012; Mullen & Kelloway, 2009](#page8)). The impact of leadership is also found to be more positive when leaders are involved in daily work operations at the sharp end ([Dahl & Olsen, 2013](#page8)). In line with the existing leadership literature (for a review study, see [Pilbeam,](#page9) [Doherty, Davidson, & Denyer, 2016](#page9)), the following hypothesis was formulated:

Hypothesis 3. Safety supervision will positively predict safety compliance.

2.4. Work pressure

The last central feature that emerged in [Flin et al.'s (2000)](#page8) analysis of safety climate was related to workload and work pace. This factor was labeled ‘work pressure.’ Work pressure is frequently studied in relation to occupational health issues through the jobs demands-resources

model (JD-R) ([Karasek & Theorell, 1992](#page8)). The model has, in the last few years, been used in studies of safety behavior such as compliance (e.g., [Bronkhorst, 2015](#page8)). [Nahrgang, Morgeson, and Hofmann (2011)](#page8) conducted a meta-analysis of the relationship between the JD-R model and burnout, engagement and safety behavior. The researchers found that high job demands and low job resources were negatively related to safety compliance. Similarly, a study conducted in the energy sector by [Hansez and Chmiel (2010)](#page8) found support for a positive relationship between job demands, through job strain, and routine violations, and a negative relationship between job resources, through engagement, and routine violations. However, [Turner, Stride, Carter, McCaughey, and](#page9) [Carroll (2012)](#page9) only found support for a relationship between positive job resources and safety compliance, whereas they found no significant relationship between demands and safety compliance in a study of staff in the health-care industry. Similarly, [Li, Jiang, Yao, and Li (2013)](#page8) conducted a study of workers in the petroleum industry, and found a significant positive relationship between job resources and safety compliance, but also an unexpected positive relationship between job demands and safety compliance. Hence, there are mixed findings about the role of respectively pressure and positive resources in predicting safety compliance. However, the balance between safety and production is a recurring theme within safety research, and is thought to play a fundamental role in accidents ([Dekker, 2011;](#page8) [Rasmussen, 1997; Reason, 1997](#page8)) and also in the formation of workers' safety attitudes, such as attitudes toward reporting incidents ([Probst &](#page9) [Graso, 2013](#page9)). The balance between safety and pressure for production is also a vital part of safety climate ([Zohar, 2010](#page9)). Despite some mixed research findings on the role of demands and resources on safety com-pliance, the following hypothesis was formulated:

Hypothesis 4. Work pressure will negatively predict safety compliance.

3. Method

3.1. Survey and respondents

This study was based on a cross-sectional survey among sharp-end workers within the Norwegian oil and gas industry. Sharp end workers are the personnel involved in safety critical tasks, in direct contact with the hazardous working environment. In the oil and gas industry, the sharp end typically consists of occupations such as drillers, crane opera-tors, derrick men, roughnecks and maintenance personnel. The survey was administered every second year within a period of 7 years by the Petroleum Safety Authority Norway (PSA) to monitor a wide range of health and safety issues within this particular industry. The four samples consisted of respondents from operating, contracting and subcontracting companies and included a total of 464 different enterprises spread over fixed offshore installations, floating offshore installations and onshore petroleum terminals. All of the offshore installations included in the samples operate on the Norwegian Continental Shelf (NCS) and all of the onshore terminals are located along the Norwegian coast.

The response rates (see [Table 1](#page3)) among the offshore workers varied between 27% (period 4) and 32% (period 3). Among the onshore

Table 1

Response rates, demographics (%) and N for all response periods.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Period 1 | Period 2 | Period 3 | Period 4 |
|  |  |  |  |  |
| Response rate offshore | 30.0 | 30.0 | 32.0 | 27.0 |
| Response rate onshore | 58.0 | 32.0 | 37.0 | 29.0 |
| Gender (% male) | 93.5 | 93.8 | 93.7 | 93.2 |
| Leader | 31.9 | 34.7 | 36.0 | 35.3 |
| Fixed installation | 53.4 | 54.0 | 54.7 | 54.5 |
| Floating installation | 14.2 | 22.8 | 25.3 | 27.5 |
| Onshore terminal | 32.4 | 23.2 | 19.9 | 18.0 |
| N | 8193 | 7425 | 8086 | 7646 |
|  |  |  |  |  |

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workers, the response rates varied between 29% (period 4) and 58% (period 1). This resulted in a total sample size of 31,350 respondents.2 The gender distribution shows that roughly 90% of the respondents in all measurement periods were men. This is representative of the NCS as a whole where roughly 10% of sharp-end workers are women ([PSA,](#page9) [2012b](#page9)). Furthermore, between 32% (period 1) and 36% (period 3) of the respondents reported that they had leadership responsibilities.

3.2. Measures and data analysis

3.2.1. Independent variables and factor analysis

In the survey, the respondents were asked roughly 150 questions related to health, safety and working environment conditions and 25 questions concerning background information (e.g., demographics and conditions of employment).

Fifteen of the 150 items were used to measure safety climate (see [Table 2](#page4)). These items were selected on the basis of safety climate literature ([Flin et al., 2000](#page8)). All of the items were formulated as statements that the respondents were asked to assess their agreement with, such as I have received sufficient safety training and I have easy access to procedures and instructions related to my work. The level of agreement was assessed on a five-point Likert scale. The scale ranged from totally disagree (1), via the middle option neither agree nor dis-agree (3), to totally agree (5). A not relevant option was not included. Hence, the respondents were forced to assess their level of agreement.

In order to reduce the number of items to a manageable size and in order to uncover the underlying safety climate factor structure, explor-atory factor analysis (EFA) was conducted in the total sample. The EFA method applied was principal component analysis (PCA) with varimax rotation. The number of factors to retain was based on a combination of

1. inspecting the scree plot for a bend point and (b) the factor solution that produced the cleanest factor structure (i.e., with no or few item cross-loadings, as recommended by [Costello & Osborne, 2005](#page8)). For factor loadings equal to or above .40 it was considered appropriate to include an item in the corresponding factor ([Meyers, Gamst, & Guarino,](#page8) [2006](#page8)). Reliability and internal consistency were assessed by Cronbach's alpha ([Field, 2009](#page8)).

3.2.2. Dependent variables and regression analysis

The dependent variable safety compliance was measured by one single item regarding compliance with procedures ([Table 2](#page4)). Similarly to the safety climate items, the safety compliance item was also formu-lated as a statement that the respondents were asked to assess their agreement with by using the same five-point Likert scale. In contrast to the safety climate variables, which were all related to the respondents' perceptions of the safety-specific aspects of their working environment, the safety compliance item was related to the respondents' own behavior. The item was presented as Sometimes I break safety rules to get the job done quickly. However, the values for this item were reversed so that a high score indicates high compliance, whereas a low score indicates low compliance.

Separate hierarchical multiple regression analysis (ordinary least squares, OLS) was conducted for each measurement period to test the hypothesized relationship between safety climate and safety compli-ance (e.g., [Meyers et al., 2006](#page8)). The hierarchical procedure means that each safety climate factor was entered into the model in separate steps. In this way, each hypothesis was tested in each separate step. In addition to one step for each of the four hypotheses, a model including control variables (the two dichotomous variables male and leader) was entered into the first model (model 1). Thus, five models (model 1 to model 5) were tested in each measurement period.

1. Respondents within the following areas of work were excluded from the analyses: catering, administration and security. In addition, respondents who answered “other” on the work area item were excluded.

Table 2

Descriptive statistics for items.

|  |  |  |  |
| --- | --- | --- | --- |
| Items | | Mean | SD |
|  |  |  |  |
| Q1 | I have received sufficient work environment training | 4.15 | 0.99 |
| Q2 | I have received sufficient safety training | 4.42 | 0.78 |
| Q3 | I know the HSE procedures well | 4.47 | 0.73 |
| Q4 | I think it's easy to find the right steering documentation | 3.18 | 1.24 |
| Q5 I have easy access to procedures and instructions related to my work | | 4.20 | 0.99 |
| Q6 | The HSE procedures are suitable for my work tasks | 4.19 | 0.90 |
| Q7 | I always know which person within the organization to report to | 4.11 | 1.09 |
| Q8 | I prefer not to discuss HSE conditions with my leader (reversed) | 4.44 | 0.93 |
| Q9 | My leader appreciates that I raise topics related to HSE | 4.45 | 0.87 |
| Q10 My leader is committed to working with HSE on the installation | | 4.40 | 0.85 |
| Q11 The safety deputies' suggestions are taken seriously by the leaders | | 4.11 | 0.97 |
| Q12 Sometimes I am forced to work in a way that threatens safety | | 1.68 | 1.08 |
| Q13 In practice the concern for production precede the concern for HSE | | 2.40 | 1.31 |
| Q14 I experience group pressure which jeopardizes HSE-evaluations | | 1.89 | 1.10 |
| Q15 There are often parallel work operations proceeding that leads to | | 2.32 | 1.18 |
| dangerous situations | |  |  |
| Q16 Sometimes I break safety rules to get the job done quickly (reversed) | | 4.18 | 1.13 |
|  |  |  |  |

In order to test the hypotheses, the direction and the p-values of the regression coefficients (B) were assessed. The alpha level was set to .05. This implies that if the regression analysis yielded p-values below .05 this indicated that the hypothesis was supported by the data. P-values greater than .05 indicated that the hypothesis was not supported by the data. In addition to the p-value of each regression coefficient, the model as a whole was evaluated by explained variance (R2) and the change in explained variance between each model (ΔR2). The relative effect of each safety climate factor was evaluated by the standardized regression coefficient, beta (β).

4. Analysis and findings

4.1. Exploratory factor analysis

The initial considerations of the sample verified that the data and the included items were appropriate for factor analysis. Bartlett's test of sphericity and Kaiser–Meyer–Olkin's measure of sampling adequacy showed satisfactory results (see [Table 3](#page5)).

By inspecting the scree plot a bend was identified at factor 3, indicat-ing a three-factor solution where items Q7–Q15 were grouped together. However, this solution resulted in several cross-loadings above .40. A four-factor solution was tested and this showed satisfactory results (i.e., a simple factor structure with no cross-loadings above .40). Hence, the four-factor solution was selected. This solution accounted for 59% of the total variance. The results of the factor analysis, presented in [Table 3](#page5), show that all of the included variables have sufficient factor loadings (above .40) on a factor to be included in the final four-factor solution (factor loadings below .40 are suppressed in [Table 3](#page5)). The four factors were labeled as follows:

1. Safety system. This factor consists of four items (Q4–Q7) concerning the respondents' perceptions of the degree to which procedures, instructions and steering documentation are suitable, and easy to find and get access to, and furthermore, the degree to which they know who to report to. After varimax rotation, this factor accounted for 16.6% of the variance. The factor loadings varied from .641 to .792.
2. Safety supervision. This factor consists of four items (Q8–Q11) concerning the respondents' perceptions of the degree to which their leader is committed to working with HSE, appreci-ates that HSE topics are raised and can discuss them. After varimax rotation, this factor accounted for 14.7% of the variance. The factor loadings varied from .507 to .719.
3. Work pressure. This factor consists of four items (Q12–Q15) concerning the respondents' perceptions of the degree to which

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
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| Table 3 | | |  |  |  |  |  |  |  |
| Exploratory factor analysis: PCA, Varimax with Kaiser normalization (all periods). | | |  |  |  |  |  |  |  |
|  | | |  |  | |  |  |  |  |
| Items | | |  | Factor loadings | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  | 1 | | 2 | 3 | 4 | Communalities | |
|  |  | |  |  |  |  |  |  |  |
| Q1 | I have received sufficient work environment training | |  |  |  |  | .845 | .806 |  |
| Q2 | I have received sufficient safety training | |  |  |  |  | .845 | .812 |  |
| Q3 | I know the HSE procedures well | |  |  |  |  | .451 | .413 |  |
| Q4 | I think it's easy to find the right steering documentation | | .792 | |  |  |  | .661 |  |
| Q5 | I have easy access to procedures and instructions related to my work | | .729 | |  |  |  | .633 |  |
| Q6 | The HSE procedures are suitable for my work tasks | | .641 | |  |  |  | .582 |  |
| Q7 | I always know which person within the organization to report to | | .668 | |  |  |  | .523 |  |
| Q8 | I prefer not to discuss HSE conditions with my leader (reversed) | |  |  | .678 |  |  | .527 |  |
| Q9 | My leader appreciates that I raise topics related to HSE | |  |  | .719 |  |  | .650 |  |
| Q10 | | My leader is committed to working with HSE on the installation |  |  | .695 |  |  | .612 |  |
| Q11 | | The safety deputies' suggestions are taken seriously by the leaders |  |  | .507 |  |  | .458 |  |
| Q12 | | Sometimes I am forced to work in a way that threatens safety |  |  |  | .683 |  | .547 |  |
| Q13 | | In practice the concern for production precede the concern for HSE |  |  |  | .622 |  | .523 |  |
| Q14 | | I experience group pressure which jeopardizes HSE-evaluations |  |  |  | .643 |  | .528 |  |
| Q15 | | There are often parallel work operations proceeding that leads to dangerous situations |  |  |  | .739 |  | .579 |  |
|  |  |  |  |  |  |  |  |  |  |

Bartlett's test of sphericity (approx. Chi-square) = 139,452 (p b .001). Kaiser-Meyer-Olkin measure of sampling adequacy = .91. Factor loadings below .40 are suppressed.

pressure of various types (by force, group pressure and produc-tion pressure) threatens safety. After varimax rotation, this factor accounted for 14.3% of the variance. The factor loadings varied from .622 to .739.

1. Safety competence. This factor consists of three items (Q1–Q3) concerning the respondents' perceptions of the degree to which they have received sufficient training regarding work environ-ment and safety and the degree to which they know the HSE (health, safety and environment) procedures. After varimax rotation, this factor accounted for 13.4% of the variance. The factor loadings varied from .451 to .845.

4.2. Discriminant validity, internal consistency and reliability

In [Table 4](#page5) correlations between the four factors and Cronbach's alphas within the factors are presented. According to [Netemeyer,](#page9) [Bearden, and Sharma (2003)](#page9), factors that correlate too highly with factors from which they are supposed to differ are an indication of low discriminant validity. Low or moderate correlations are an indication of high discriminant validity, i.e. that the constructs measure different underlying factors. In [Table 4](#page5) all correlations are moderate. Thus, dis-criminant validity can be considered acceptable.

According to [Nunnally (1978)](#page9), Cronbach's alphas above .70 are indi-cations of adequate internal consistency and reliability. In [Table 4](#page5), all alpha scores are equal to or above .70, with values ranging between

.700 and .766 as shown in the diagonal in the table. Thus, the internal consistency and reliability of the factors were considered adequate.

4.3. Hierarchical regression analysis

The results from the hierarchical regression analysis are presented in [Table 5](#page6). As shown in the table, the analysis was conducted in five steps (model 1 to model 5) for each measurement period. In model 1, the two dichotomous control variables male and leader were entered into the

Table 4

Pearson correlation between measurement constructs, with Cronbach's alpha in diagonal (all periods).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Construct | | Number of items | 1 | 2 | 3 | 4 |
|  |  |  |  |  |  |  |
| 1. | Safety system | 4 | (.766) |  |  |  |
| 2. | Safety supervision | 4 | .473 | (.723) |  |  |
| 3. | Work pressure | 4 | −.461 | −.532 | (.700) |  |
| 4. | Safety competence | 3 | .529 | .489 | −.391 | (.740) |

All correlations are significant at the p b .01 level.

regression analysis. In model 2 the first safety climate factor, safety competence, was entered and in model 3 the second safety climate factor, safety system, was entered. In models 4 and 5 respectively the two remaining safety climate factors, safety supervision and work pressure, were entered into the regression analysis.

As shown in model 1, the two control variables male and leader are significantly related to safety compliance in all four measurement periods. Male is negatively related to safety compliance, whereas leader is positively related to safety compliance. This means that men, on average, score significantly lower than women on the safety compliance variable whereas leaders, on average, score significantly higher than their subordinates do. Furthermore, the standardized regression coeffi-cient (β) shows that the effect of being a leader is more influential than the effect of gender. However, the total effect of the two control variables is very low. The explained variance varies between 1.1% (period 1) and 2.1% (period 2). Hence, the two control variables do not contribute much to explaining the variation in safety compliance.

The explained variance increases significantly (ΔR2) in all measure-ment periods when safety competence is entered into the regression analysis in model 2. The explained variance (R2) in model 2 varies between 8.5% (period 1) and 11.5% (period 2). As shown in the table, safety competence is positively and significantly related to safety compliance in all measurement periods. Thus, the analysis gives support to [Hypothesis 1](#page3), which postulated that safety competence will posi-tively predict safety compliance. This is supported in all measure-ment periods. For example, in period 1 a one-unit increase in the safety competence factor results in an increase in the safety compli-ance variable of .468 units. Furthermore, in the same measurement period the standardized regression coefficient (β) shows that the effect of safety competence (.272) is far more powerful than the effect of the two control variables.

As shown in model 3, the introduction of safety system leads to a significant increase (ΔR2) in the explained variance in all measurement periods. The explained variance (R2) in model 3 varies between 11.8% (period 1) and 15.2% (period 2). As shown in the table, safety system is positively and significantly related to safety compliance in all mea-surement periods. Thus, the analysis gives support to [Hypothesis 2](#page3), which postulated that safety system will positively predict safety compliance. This is supported in all measurement periods. For example, in period 2 a one-unit increase in the safety system factor results in an increase in the safety compliance variable of .319 units. Furthermore, in the same measurement period the standardized regression coeffi-cient (β) shows that the effect of safety system (.235) is far more powerful than the effect of the two control variables. Entering safety system into the regression analysis also reduces the effect of safety com-petence in all measurement periods, and the standardized regression

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Table 5

Linear regression: safety compliance with unstandardized (B) and standardized (β) regression coefficients.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Model 1 |  |  | Model 2 |  | Model 3 | |  |  | Model 4 |  | Model 5 | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | B | | β | B | | β | B | | β |  | B | β |  | B | β |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Period 1 | Constant |  | 4.179 |  |  | 2.238 |  |  | 1.913 |  |  | .986 |  |  | 3.743 |  |  |
|  | Male |  | −.181 | −.037 |  | −.222 | −.046 | −.275 | | −.057 | −.212 | | −.044 | −.186 | | −.039 |  |
|  | Leader | .258 | | .103 | .207 | | .082 | .146 | | .058 | .093 | | .037 | .092 | | .037 |  |
|  | Safety competence |  |  |  | .468 | | .272 | .279 | | .162 | .144 | | .084 | .091 | | .053 |  |
|  | Safety system |  |  |  |  |  |  | .312 | | .217 | .205 | | .143 | .090 | | .063 |  |
|  | Safety supervision |  |  |  |  |  |  |  |  |  | .428 | | .255 | .198 | | .118 |  |
|  | Work pressure |  |  |  |  |  |  |  |  |  |  |  |  | −.506 | | −.369 |  |
|  | F-value | 43.69 | |  | 616.15 | |  | 294.46 | |  | 423.93 | |  | 965.32 | |  |  |
|  | R2 | .011 | |  | .085 | |  | .118 | |  | .164 | |  | .257 | |  |  |
|  | Δ R2 |  | .011 |  |  | .073 |  | .034 | |  |  | .046 |  | .093 | |  |  |
| Period 2 | Constant |  | 4.205 |  |  | 1.982 |  | 1.779 | |  |  | .971 |  | 3.859 | |  |  |
|  | Male | −.236 | | −.048 | −.254 | | −.051 | −.318 | | −.065 | −.273 | | −.055 | −.252 | | −.051 |  |
|  | Leader | .345 | | .143 | .249 | | .103 | .182 | | .075 | .150 | | .062 | .134 | | .056 |  |
|  | Safety competence |  |  |  | .527 | | .309 | .310 | | .182 | .174 | | .102 | .112 | | .066 |  |
|  | Safety system |  |  |  |  |  |  | .319 | | .235 | .232 | | .172 | .105 | | .078 |  |
|  | Safety supervision |  |  |  |  |  |  |  |  |  | .383 | | .229 | .149 | | .089 |  |
|  | Work pressure |  |  |  |  |  |  |  |  |  |  |  |  | −.528 | | −.387 |  |
|  | F-value | 72.96 | |  | 709.38 | |  | 294.41 | |  | 291.94 | |  | 918.25 | |  |  |
|  | R2 | .021 | |  | .115 | |  | .152 | |  | .187 | |  | .285 | |  |  |
|  | Δ R2 |  | .021 |  |  | .094 |  | .037 | |  |  | .035 |  | .098 | |  |  |
| Period 3 | Constant |  | 4.192 |  |  | 1.841 |  | 1.612 | |  |  | .809 |  | 3.554 | |  |  |
|  | Male | −.136 | | −.028 | −.162 | | −.033 | −.237 | | −.049 | −.179 | | −,037 | −.181 | | −.037 |  |
|  | Leader | .289 | | .123 | .222 | | .094 | .161 | | .068 | .121 | | .051 | .108 | | .046 |  |
|  | Safety competence |  |  |  | .548 | | .305 | .318 | | .177 | .158 | | .088 | .107 | | .060 |  |
|  | Safety system |  |  |  |  |  |  | .340 | | .246 | .241 | | .174 | .112 | | .081 |  |
|  | Safety supervision |  |  |  |  |  |  |  |  |  | .418 | | .252 | .190 | | .115 |  |
|  | Work pressure |  |  |  |  |  |  |  |  |  |  |  |  | −.489 | | −.365 |  |
|  | F-value | 88.81 | |  | 743.03 | |  | 356.32 | |  | 382.98 | |  | 843.58 | |  |  |
|  | R2 | .015 | |  | .108 | |  | .150 | |  | .193 | |  | .278 | |  |  |
|  | Δ R2 |  | .015 |  |  | .092 |  | .042 | |  |  | .043 |  | .085 | |  |  |
| Period 4 | Constant |  | 4.247 |  |  | 2.131 |  | 1.744 | |  |  | 1.031 |  | 3.863 | |  |  |
|  | Male | −.170 | | −.036 | −.206 | | −.044 | −.269 | | −.058 | −.222 | | −.048 | −.223 | | −.048 |  |
|  | Leader | .272 | | .116 | .212 | | .090 | .134 | | .057 | .106 | | .045 | .077 | | .033 |  |
|  | Safety competence |  |  |  | .496 | | .287 | .247 | | .143 | .126 | | .073 | .082 | | .047 |  |
|  | Safety system |  |  |  |  |  |  | .396 | | .282 | .303 | | .216 | .173 | | .123 |  |
|  | Safety supervision |  |  |  |  |  |  |  |  |  | .353 | | .217 | .109 | | .067 |  |
|  | Work pressure |  |  |  |  |  |  |  |  |  |  |  |  | −.504 | | −.379 |  |
|  | F-value | 48.36 | |  | 616.42 | |  | 454.64 | |  | 271.02 | |  | 861.84 | |  |  |
|  | R2 | .014 | |  | .095 | |  | .151 | |  | .184 | |  | .275 | |  |  |
|  | Δ R2 |  | .014 |  |  | .082 |  | .056 | |  |  | .032 |  | .091 | |  |  |

p b .001. p b .020.

coefficient shows that the effect of safety system is more powerful than the effect of safety competence. However, safety competence still makes a significant contribution to explaining the variation in safety compli-ance. Hence, [Hypothesis 1](#page3) is still supported when the effect of safety system is controlled for.

The explained variance increases significantly (ΔR2) in all measure-ment periods when safety supervision is entered into the regression analysis in model 4. The explained variance (R2) in model 4 varies between 16.4% (period 1) and 19.3% (period 3). As shown in the table, safety supervision is positively and significantly related to safety compliance in all measurement periods. Thus, the analysis gives support to [Hypothesis 3](#page3), which postulated that safety supervision will positively predict safety compliance. This is supported in all measurement periods. For example, in period 3 a one-unit increase in the safety supervision factor results in an increase in the safety compliance variable of

.418 units. Furthermore, in the same measurement period the standard-ized regression coefficient (β) shows that the effect of safety supervision (.252) is far more powerful than the effect of the two control variables. The standardized regression coefficient also shows that the effect of safety supervision is more powerful than the effect of safety competence and safety system. Entering safety supervision into the regression anal-ysis also reduces the effect of safety competence and safety system. However, both still make a significant contribution to explaining the variation in safety compliance. [Hypotheses 1 and 2](#page3) are therefore still supported when the effect of safety supervision is controlled for.

In the fifth and last model, work pressure is entered into the regres-sion analysis. This results in a substantial and significant increase (ΔR2) in the explained variance in all measurement periods. The explained variance (R2) in model 5 varies between 25.7% (period 1) and 28.5% (period 2). As shown in the table, work pressure is negatively and sig-nificantly related to safety compliance in all measurement periods. Thus, the analysis gives support to [Hypothesis 4](#page3), which postulated that work pressure will negatively predict safety compliance. This is supported in all measurement periods. For example, in period 4 a one-unit increase in the work pressure factor results in a decrease in the safety compliance variable of .504 units. Furthermore, in the same mea-surement period the standardized regression coefficient (β) shows that the effect of work pressure (−.379) is far more powerful than the effect of the two control variables. The standardized regression coefficient also shows that the effect of work pressure is far more powerful than the effect of safety competence, safety system, and safety supervision. Entering work pressure into the regression analysis also leads to a sub-stantial reduction in the effect of safety competence, safety system, and safety supervision. However, all three still make a significant contribu-tion to explaining the variation in safety compliance. [Hypotheses 1, 2,](#page3) [and 3](#page3) are therefore still supported when the effect of work pressure is controlled for. Nevertheless, among the safety climate factors, work pressure is the factor that contributes the most to explaining the varia-tion in safety compliance. For example, while the standardized regres-sion coefficient (β) of work pressure in model 5 in measurement

|  |  |
| --- | --- |
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period 1 is −.369, the β of safety competence is .053, the β of safety system is .063 and the β of safety supervision is .118.

In sum, then, the hierarchical regression analysis gives support to all four hypotheses in all four measurement periods. Hence, the theoretical model displays high and stable predictive validity. This means that the analysis, with repeated testing, confirms that the three safety climate factors safety competence, safety system and safety supervision posi-tively predict safety compliance and that the last safety climate factor, work pressure, negatively predicts safety compliance.

5. Discussion

5.1. Key findings

The aim of the present study was to perform multiple tests of the causal relationship between safety climate and safety compliance. Such multiple testing allows for repeated testing of a theoretical model that is held constant over a prolonged time span. A repeated cross-sectional study design was used to test the stability of the causal relationship between safety climate and safety compliance, and to ex-plore which safety climate factors are most important in influencing workers' compliance with safety procedures.

We built on the common features of safety climate identified by [Flin et al. (2000)](#page8) to extract questions from an existing survey database. The results from the factor analysis yielded a sound factor structure comprised of four factors: safety competence, safety system, safety supervision, and work pressure. The four factors were hypothesized to predict the level of safety compliance over a 7-year period, in four separate surveys. The two control variables gender and leader were ex-amined in the hierarchical regression analysis. Workers with leadership responsibilities were found to be more compliant than subordinates, and male workers were found to be less compliant than their female colleagues. The effects of the control variables on compliance were found to be statistically significant, but small.

The hypothesized positive relationship between safety competence and compliance was supported across all four time periods. On average, safety competence adds about 8% explained variance in safety compli-ance during the four measurement periods when it is added to the regression model. This implies that efforts to ensure knowledge of HSE procedures and to focus on proper training in safety and working envi-ronment is important in enhancing compliant work practices. These findings are in line with research from the passenger ferry context where a positive relationship between competence enhancement and compliance has been identified ([Lu & Yang, 2011](#page8)).

The safety system was hypothesized to contribute positively to compliance, and support was found for the hypothesis across all four measurement periods. Procedures and guidelines are basic constituents of a safety system, and are to be used by workers before and during the execution of work tasks in all high-hazard industries. We found that a well-organized safety system where procedures are easy to access, and where the relevant procedures are readily available, facilitates safety compliance. This is in line with research on offshore supply bases ([Antonsen et al., 2008](#page8)) and offshore service vessels ([Dahl et al.,](#page8) [2013](#page8)). Safety system adds roughly 4% explained variance in safety com-pliance on average during the four periods when it is entered into the regression model.

Support was also found for the third hypothesis, assuming a positive effect of safety supervision on safety compliance. Adding safety supervi-sion to the regression model yielded roughly an additional 4% explained variance on average across the four measurement periods. The signifi-cant positive contribution of supervisors to enhancing safety compli-ance is rooted in their ability to include workers in safety-related discussions and value workers' input in safety-related matters. This is in line with previous research ([Dahl, 2013; Lu & Yang, 2010](#page8)) and the assumption that workers gravitate toward behaviors that are expected, rewarded, and supported in the organization ([Zohar, 2010](#page9)).

Our findings also support the role of the involvement of supervisors on safety compliance in daily safety work, in line with previous findings from the offshore petroleum industry ([O'Dea & Flin, 2001](#page9)).

Finally, we found significant support for the hypothesized negative relationship between work pressure and safety compliance. Adding work pressure to the regression model increased the explained variance by roughly 9% on average across the four time periods. Based on the standardized regression coefficients, work pressure was the most important contributor to safety compliance in our model. Balancing safety and production is a recurring theme within the safety sciences (e.g. [Dekker, 2011; Hayes, 2012b; Rasmussen, 1997; Reason, 1997;](#page8) [Zohar, 2010](#page8)), and our findings demonstrate that imbalanced priorities between production and safety have a negative impact on safety com-pliance. This finding further demonstrates the validity of [Zohar's](#page9) [(2010)](#page9) claim that workers tend to gravitate to behaviors that are expected, supported, and rewarded, and thus that climates favoring production over safety will have a negative impact on safety behavior.

5.2. Theoretical and practical implications

As described in the introductory section, identical measures of safety climate are seldom tested repeatedly over extended periods of time. This means that the stability of identified causal relationships between safety climate and safety compliance has not been subject to testing. A significant theoretical contribution of the present study is that a repeated set of tests of a theoretical model that is held constant over a prolonged time span is conducted. Furthermore, the theoretical model explains a significant proportion of the variation in safety compli-ance. The stability of the model over time demonstrates that the common features of safety climate, as identified by [Flin et al. (2000)](#page8) and as operationalized in the present study, show high predictive valid-ity in relation to safety compliance.

The most important practical implication of the findings is that we have highlighted some significant factors that are highly manageable for companies seeking to enhance the level of safety compliance. The findings indicate that safety compliance can effectively be enhanced by focusing on appropriate leadership practices, the usability of the safety system and the safety competence of employees. This means that companies seeking to enhance safety compliance should focus on leadership practices that show a clear commitment to safety concerns, on improved accessibility and clarity of safety procedures, and on train-ing that emphasizes increased knowledge of safety issues and safety procedures. Furthermore, our findings demonstrate that work pressure is the most important contributor to safety compliance. This means that the organization should focus on the enacted priorities when faced with safety issues that might conflict with production targets. There is little use in stating that safety is a top priority if workers are implicitly or explicitly pressured into prioritizing production over safety in practical situations (see [Dekker, 2011; Zohar, 2010](#page8)). This finding is particularly relevant for industries facing extreme austerity measures, such as the petroleum industry where the data for this paper stems from.

5.3. Limitations and further research

When interpreting the results of this study, the reader should bear some methodological limitations in mind. First, the data consists of self-report measures, with some known potential limitations such as social desirable responses and modal responses. Furthermore, the dependent and independent variables are drawn from the same source, making the analysis prone to common method bias. Future studies of the employed factor structure should therefore seek to investigate the dependent variable with the use of other data sources, such as observa-tions of actual work and behavioral observation measures. Second, although the repeated cross-sectional design of the current study is a strength, it cannot fully account for the causal relationship between safety climate and compliance. Future research should aim to verify

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the sequential relationship between safety climate and safety compli-ance in a longitudinal study design in order to validate further the assumed cause and effect relationship. Third, the analysis we conducted in this paper can be strengthened through implementing mediating factors between safety climate and safety compliance: knowledge, skills and motivation, the so-called proximal drivers of behavior ([Neal &](#page8) [Griffin, 2004](#page8)). Including these proximal drivers of safety behavior leads to a more complete picture of how safety climate affects safety compliance. Future research can shed light on how the distal anteced-ents of safety compliance are mediated through the proximal drivers of behavior, and contribute to a more comprehensive understanding of the drivers of safety compliance. A better understanding of the causal chain will improve our ability to design suitable, cost-efficient measures to enhance safety compliance further in the future.

Despite the above-stated limitations, the results of the current study and the implications we can draw from them are believed to be relevant to the development of safety climate and safety compliance research and to organizations seeking to improve safety in the petroleum sector. The findings should also be relevant to other high-hazard industries where safety rules and procedures constitute a central part of the approach to managing safety.

6. Conclusion

Based on a review of the common features of safety climate ([Flin](#page8) [et al., 2000](#page8)), we extracted questions from an existing survey database, and conducted a factor analysis, which yielded a sound factor structure comprised of four factors: safety competence, safety system, safety supervision and work pressure. The four factors were found to predict the level of safety compliance over a 7-year period, in four separate surveys, thereby increasing the reliability and the predictive validity of the factor structure. Taking all periods together, the total model explained roughly 27% of the variance in safety compliance. The most important safety climate factor in explaining the variance in safety compliance was work pressure. This implies that when designing mea-sures to improve compliance, the most effective means are related to training and ensuring a sound balance between safety and production. Due to the fact that safety violations are a common causal factor in accidents in the petroleum industry, these findings are important when designing measures to reduce the risk of future incidents. The findings are relevant for all high-hazard industries that rely on proce-dures in controlling risk.

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Selected publications:

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