Safety climate as an indicator for major accident risk: Can we use safety climate as an indicator on the plant level?

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Abstract:
Measuring safety climate is regarded a proactive approach to safety management. With increased focus on developing indicators for major accidents, there is a need to critically assess the effectiveness of current practices in providing early warning signals for organizations at risk. The main purpose of the present study is to investigate the ability of safety climate tools to assess the risk of major accidents on the plant level. Using data material from the Norwegian offshore oil and gas operations, we have tested whether three major close call incidents could be detected through using safety climate data from the period before the incidents. We examined the problem through testing (1) if the installations in question deviated from the industry average, and (2) if the trends for the installations could reveal that something was wrong. The results are inconclusive; only one of the installations deviates negatively from the industry average one year before the incident, and the trend variations are so small that it is questionable if they would have triggered actions from the management. The challenges when relying on safety climate as a means of managing risk of major accidents on individual installations are discussed.

Keywords: Major accident risk; Safety climate; Risk indicators; Human and Organizational factors

1. Introduction

Assessing, describing and improving safety climate is commonly regarded as a proactive approach to safety management [(1)]. Ideally, descriptions of safety climate should serve as a means to identify the latent conditions [(e.g.2, 3)] of major accidents, and consequently serve as opportunities to prevent organizational shortcomings from becoming the root causes of future accidents. Safety climate is hence argued to enable predictive safety condition monitoring [(4)] which implies that there is an assumption of a valid connection between safety climate and accidents.

The link between safety climate and major accident risk is, however, debated within the safety science community. One obvious reason for this is that major accidents are so rare that a link between organizational factors and major accident frequency is hard to establish statistically. As a consequence of this, the link between safety climate and safety performance is usually analyzed by using personal injuries and recently, major accident precursors as outcome variable [(e.g.5, 6-8)]. Safety climate scores has been found to be a leading indicator for major accident risk seen through the occurrence of major accident precursors such as gas leaks from the perspective of the Petroleum Safety Authority (PSA) [(7)] and a large oil and gas producing company on the

Norwegian continental shelf (NCS) [8]. These are both examples of studies conducted on large samples, where the frequency of the dependent variable (gas leaks) is high enough for statistical analysis. However, this does not answer the question whether safety climate scores can be used in a meaningful way to assess major accident risk on individual installations. If safety climate measurement is to serve as an indicator on the individual installation level, it should be able to identify organizations at risk. This can be done either by comparing the results of one organization to other similar organizations (e.g. comparison with an industry average), or by identifying negative development in the safety climate scores of a single organization. In short, a valid indicator should call attention to some difference or change that can indicate that intervention is needed.

The purpose of this study is to assess if there are variations in the safety climate scores that can provide us with information that can serve as a warning that there is a need to proactively implement changes on an individual installation level. We have developed the following hypothesis:

Hypothesis 1: Organizations that have experienced major accidents or incidents (close calls) has lower safety climate scores than comparable units in the industry in the time period before the incident.

This has been investigated by looking at three serious close call incidents on the NCS between 2001 and 2013. We are testing whether the safety climate scores on these installations could have been used as indicators of major accident risk.

Such cross sectional comparison is dependent on available scores from other companies or installations. However, the test of this hypothesis can serve as a demonstrator of the ability of safety climate measures to clearly identify installations at risk (demonstrate discriminant validity).

Trend monitoring can on the other hand be relevant for individual organizations, as tracking of the development is argued to be useful in determining if we are moving in the right direction or not. If safety climate can be used as a leading indicator on the installation level, we should be able to detect poorer scores on Safety Climate measures in the time period leading up to an accident, hence:

Hypothesis 2: Organizations that experience major incidents (close calls) experience a negative development in safety climate measures in the time period before the incident.

In the next sections, we will briefly describe safety climate as a concept and previous research on safety climate as an indicator for major accident risk. Next, the data material and methodology is presented and analyzed in Section 3. The results are presented in Section 4, and the discussion in Section 5 wraps up the results along with reflections on the usefulness of safety climate as an indicator for management of major accident risk on individual installations. We will also discuss how such tools can aid managers in the everyday operational management of human and organizational aspects impacting major accident risk. We conclude the paper with suggestions for further research.

2. Safety climate and major accidents

2.1 Background

Zohar launched the term safety climate as early as 1980, primarily as an area of research rather than as a specific concept [9]. In later years, the term safety climate is used to describe the practice of measuring a manifestation of safety culture; the elements of safety culture that lends themselves to study through questionnaires, aiming to assess perceptions of safety related conditions and experiences of the employees in an organization. Safety climate assessments are usually described as "snapshots" [10] of safety culture at a given point in time, however at a coarser level than the overall culture, which consist of more enduring and complex phenomena that require a more thorough approach in order to be fully described [11]. Despite the differences between safety climate and culture, the two are used interchangeably in the research literature. This is unfortunate, since the two concepts have their origins in two quite different theoretical and methodical traditions: Climate from a psychometric tradition, and culture from a sociological and anthropological tradition. There are several papers defining, studying and discussing safety climate. We will not go into further details on the theoretical underpinnings of the concept of safety climate here. The reader is referred to the valuable writings of Zohar [12], Guldenmund [13-15], Mearns [16] and Flin [10] for more in depth theory on safety climate.

2.2 Challenges

Safety climate questionnaires are described as providing insight into a temporary status of the manifestations of safety culture, valid for the particular moment of the survey [17]. Guldenmund [14] describes safety climate surveys as quick and dirty, with quick being a reference to the relatively effortless acquirement of large amounts of data, and dirty, because the results provide a broad perspective, even superficial [18]. Guldenmund [13] has questioned the practical usefulness of results from such surveys in designing interventions to improve safety and states that "Aggregated numbers, like frequencies or means, do not offer much insight into organizational culture, much less an understanding of it" [15 p. 1469].

2.3 Safety climate as a major accident risk indicator

There are several studies linking safety climate to various aspects of safety performance, such as compliance [19, 6] and safety participation [20, 6]. The relationship between safety climate and occupational accidents has also been investigated, where some studies has established a connection [21, 22]. However, the relationship between safety climate and major accidents are poorly investigated, and as far as we can see, the only direct study on the relationship between safety climate and major accidents is Antonsen`s [23] comparison of safety climate data for a specific installation that had a major accident and the inquiry after the accident. He made a case against the ability of safety climate tools to provide indication that the organization was prone to experiencing a major accident. He found that the pre-incident survey results indicated that the culture of the organization was "a culture of compliance and learning, sensitive of the risks involved and highly oriented towards safety" [23p.247]. The results of the inquiry after the incident are reported as virtually opposite. Table 1 below highlights the findings from Antonsen [23p. 249, direct transcript].

Safety culture survey before the incident (mid -2003)	Incident investigation and causal analysis (November, 2004)
Safety highly prioritized	Safety subordinate to a dominating cultural value of "meeting production targets"
Risk assessments carried out before and during work operations	Lack of risk assessments, poor understanding of risk assessment
High degree of compliance to rules and procedures, breaches sanctioned by management	Severe breaches of procedures, culture of non-compliance
Good climate for communicating safety relevant information	Weaknesses in communication climate
Incidents and near misses reported, measures taken to prevent recurrence	Not all incidents and near misses reported, limited use of the organization`s and other`s safety experience
Insufficient managerial involvement	Insufficient managerial involvement

Table 1. Comparison of safety climate results and findings from an accident investigation

These results can be considered a blow to the ability of surveys to capture the essence of a safety culture. The safety climate measures might not be comprehensive enough to reflect the safety culture. Further, there is no universal agreement to what one should include in such measures. Antonsen argues that the time factor is unlikely to have caused this transformation of the safety culture, as culture is a conservative phenomenon, where the context, tasks and risks would have to change significantly in order to impact the culture. However, Antonsen`s study design was based on only one case, a rather short survey in addition to basing the comparison on two fundamentally different data sources: accident investigation and safety climate scores. An accident investigation is conducted with the benefit of hindsight, and is logically constructed in accordance with a negative outcome. This information is compared to results from a survey conducted under normal conditions. While comparisons between pre-incident and post-incident descriptions are useful for shedding light on how safety climate can be related to major accident scenarios, the experience of a negative outcome influences how the conditions for safety are perceived in the light of hindsight. In the present study, we wish to avoid this bias by focusing our analysis on what could possibly be known in the time period before the incidents by using available data describing the conditions for safety under normal conditions.

2.4 Safety climate as a precursor indicator

Other studies of major accidents and Safety climate in the offshore industry are on precursor events, such as hydrocarbon (HC) leaks, which ultimately have the potential to develop into major accidents provided that unfortunate conditions are present at the time of the incident. Vinnem et al [7] have found that negative safety climate scores were associated with higher frequencies of HC-leaks in a study of root causes for major hazard precursors in the Norwegian offshore industry. Similarly, on another set of data with a different safety climate inventory, Kongsvik, Kjøs Johnsen, and Sklet, (2011) [8] found that more negative safety climate scores were associated with an increase in the number of gas leaks in the following 12 month period after the survey. They found that safety climate accounts for 17 % of the variance in HC leaks during the subsequent 12 months after the survey. Nonetheless, safety climate was found to explain more of the variance than technical indicators expected to impact leak frequency, such as installation weight, installation age, and the number of leak sources. The studies of Vinnem et al. [(7)] and Kongsvik et al. [(8)], demonstrate that precursor events to some degree can be explained by negative scores on safety climate.

These are important findings showing that safety climate should be taken seriously when considering the conditions for safety. However, the studies are based on a large number of facilities. There is still a need to critically assess whether and how safety climate assessments can serve as proactive indicators informing decision-making on the individual installation level.

3. Data and methods

3.1 Data

3.1.1 RNNP

The Trends in Risk level project (RNNP) was initiated by the Petroleum Safety Authority (PSA) Norway around 2000 and is aimed at monitoring trends in risk level in the Norwegian oil and gas industry. Annual reports are prepared and published on the PSA website. RNNP builds on statistical, engineering and social science methods to present a picture of the risk level, including major accident risks, risk perception and cultural factors [(24)]. As part of RNNP, a questionnaire study of safety climate, working environment and perception of risk has been conducted biannually since 2001.

3.1.2 The Norwegian offshore risk and safety climate inventory

Through the years, a range of climate questionnaire tools have been developed [(e.g.13)]. Commonly used tools for assessing safety climate contain a series of questions aiming to measure the respondents values, beliefs, attitudes and perceptions about various statements that are assumed to be relevant for safety [(22)]. The Norwegian Offshore risk and safety climate inventory (NORSCI) developed and used by the PSA of Norway is a typical tool in this context, although with more emphasis on safety related behaviors [(25)]. The PSA [(25)] (based on Cooper [(26)]) emphasizes an interaction perspective between the person, situation and behaviors which in combination determines an outcome. During the RNNP pilot project, key areas were identified and were to serve as a guide to form the content of the questionnaire tool. The Safety climate index built [(25)] on the theoretical basis presented in Cooper [(26)] covers:

- Demographics: relevant background information such as position, seniority, and type of company and shift rotation.
- Behavior: safety relevant behaviors, such as use of personal protective equipment, incident reporting, override of safety functions, backing up or correcting colleagues and stopping work when experiencing over-complex conditions.
- Person: employees premises for safe job execution, which includes skills and competence, understanding one’s own work in relation to simultaneous operations, risk seeking, safety attitudes and ability to maintain own emergency response task responsibilities.
- Situation: First, this includes conditions that affect safety related behaviors, such as formal routines to prepare non-routine work operations, use of safe job analyses,

managers demanding execution of work operations despite insufficient competence regarding the specific equipment and procedures, and colleagues expectations of efficient work execution. Second, the situation aspect is intended to cover surrounding reactions to safety related behaviors. How does a colleague or managers react to dangerous work execution? Do they encourage this type of behavior in order to get the job done, or do they neglect it? Does the environment encourage engaged discussions in safety meetings, or is silence preferred?

The data collected in the RNNP project is used as basis for the RNNP-report, where the biannual issues contain results from NORSCI. Researchers and consultants commonly get access to the data upon request and compliance with anonymization practices. Several studies have been published based on data from NORSCI (11, 27, 7, 28, 29).

The measures used in NORSCI is based on a review of previous research on safety climate followed by a questionnaire design process with pilot testing and feedback, which resulted in the inventory which was first launched in 2001 and is still administered biannually (see 11 for more information on the questionnaire design and basis). The questionnaire is scored on a 5 point scale. All items in factor 1 and 3 are negatively (reverse) phrased, meaning that 5 equals 1 compared to the remaining items in the inventory.

Tharaldsen et al. (11) published a longitudinal study of NORSCI where they among others examined the psychometric qualities of the questionnaire. Based on data from 2001 and 2003, the researchers (11) developed a safety climate structure by using both confirmatory and exploratory factor analysis techniques. The study resulted in a five-dimensional structure comprised of the following factors: 1. Safety prioritization, 2. Safety management and involvement, 3. Safety versus production, 4. Individual motivation and 5. System comprehension. The present study is based on the same safety climate structure.

3.1.3 Participants and sample

The total data material contains 51803 responses from employees in the Norwegian Oil and gas industry, with an average of 7400 responses on each biannual data collection. The respondents are mainly male (90,2 %), which is considered representative for the offshore industry in the time period (30).

To test whether installations involved in close call major accident scenarios deviate from the industry mean, we have selected offshore installations based on their primary functions. The sample contains installations with Production, Drilling and Quarters (PDQ) functions. We chose to include installations where the different functions are located on individual structures, but connected through bridges in the sample, as they will be facing a similar proximate environment to fully integrated PDQ installations. Based on these criteria, 23438 out of 51803 responses from 45 installations between 2001 and 2013 constitute the sample used in this study. All offshore personnel categories are included in the sample.

3.1.4 *The incidents*

There have not been any major accidents on the Norwegian continental shelf since the RNNP started, but we have experienced several near misses with the potential of developing into major accidents under marginally changed circumstances. In order to identify such incidents, the PSA investigation database has been searched, and incidents with a major accident potential has been identified based on the following criteria:

- Major accident potential
- Investigated incident with public investigation report
- Safety culture issues identified as underlying factors for the incident

Three incidents match the criteria for the relevant time period (2001 – 2013). These could have resulted in major accidents under slightly different circumstances (PSA). All incidents involve major uncontrolled release of hydrocarbons. For confidentiality reasons, the incidents will only be referred to as Incident A, B and C. They are described briefly below, with focus on the underlying human and organizational causes comparable to issues assessed in the safety climate questionnaire.

Incident A

Large, uncontrolled release of hydrocarbons. According to the PSA, the event did not escalate into a disaster mainly because of luck. The main findings from the accident investigation point towards lack of safety compliance, lack of risk assessments, lack of risk comprehension, and poor leadership involvement in operations. The findings are in particular related to the planning phase of the operations, where the executing personnel discipline was excluded from participating. The work that resulted in the accident was hastened due to earlier completion of preceding work, and this might have led to stress during the work operations. The deviations are described as systematic, spanning across the organization from onshore planning to offshore operations, contractors, leadership and executing personnel. A recent organizational change is believed to have contributed to more complexity and problems with responsibilities and use of procedures.

Incident B

Large, uncontrolled release of hydrocarbons. Under insignificantly changed circumstances, the incident might have developed into a major accident according to the PSA. Main findings are related to planning and poor utilization of resources including former experience with similar work operations. This includes a lack of risk assessments both during planning and execution phase of the operation, as well as insufficient involvement of relevant expertise. Opposing views on the operations were handled poorly, and a recent organizational change resulted in unclear responsibilities and a more complex safety management system. The complex system and contradictory procedures for the same operation hampered the ability for workers to comply with safety procedures.

Incident C

Large release of hydrocarbons that would have resulted in severe consequences, if ignited. The underlying causes of the incident relate to poor planning, and insufficient involvement of relevant personnel in the planning phase. The operator was for instance not involved in the pre job meeting before executing the work operation resulting in the release. The work operation was a time saving measure and risks were not addressed during planning. The work was based on assumptions rather than specific plans, and deficiencies in the design of the system were not considered.

3.2 Methods

The statistical analyses were conducted using SPSS 22 (2013). We used the same 5-dimensional factorial structure as presented in Tharaldsen et al. [11]. All items are scored on a Likert scale from 1 to 5. Factors 1 and 3 contain reverse phrase questions, which means that 1 equals the most negative response and 5 most positive. The scoring for these questions where kept. Factors 2 and 4 and 5 originally rated 1 as most positive, and 5 as most negative for the items in these factors. The scores for these factors were reversed to facilitate the reader's interpretation of the results. In the following, a higher score thus implies better rating of the safety climate factors. Before testing the hypothesis, a Principal component analysis (PCA) was conducted and we were able to replicate the 5-dimensional structure proposed by Tharaldsen et al. [11].

Independent samples T-tests were performed between the mean score for installations and fields with PDQ facilities and mean score for installations where incident A, B and C occurred. The analysis was performed as a pre and post measure, in order to test hypothesis 1 and 2. Levene`s test was used to determine if we could assume equal variance between the two samples [31].

4. Results

4.1 Descriptive statistics

Table 2 contains the descriptive statistics. Cronbach`s alpha was calculated. Commonly, alpha scores above 0.7 are considered to demonstrate acceptable reliability. Alpha scores between 0.60 and 0.70 can be considered borderline, but in general they are not considered poor [32]. Factors 1 to 3 has scores above 0.7 while factor 4, Individual motivation, and factor 5, System Comprehension, both were between 0.6 and 0.7. The scores are in line with previous findings [11], and the lower reliability scores are on factors with few items, and hence regarded to be within a tolerable limit.

Table 2
Descriptive statistics for factors, 2001 – 2013, PDQ offshore installations

Factors (No. of items)	N	Mean	SD	Cronbach`s alpha
F1 Safety prioritization (8)	23448	3.92	0.72	0.75
F2 Safety management and involvement (11)	23470	4.25	0.55	0.84
F3 Safety versus production (4)	23397	3.27	0.95	0.72
F4 Individual motivation (4)	23368	4.66	0.47	0.67
F5 System comprehension (4)	23400	3.86	0.77	0.69

4.2 Comparison with industry average

Hypothesis 1 was aimed at analyzing the difference between the organizations at risk and the other organizations in the industry:

H1: Organizations that have experienced major accidents or incidents (close calls) have a lower mean score on NORSCI than the comparable units in the industry in the time period before the incident.

The results for each installation are presented in the next sub sections.

4.2.1 *Installation A vs industry average*

The results of the t-test for the year before incident A are presented in Table 3. There are very small variations in the scores from the installation that experienced incident A and industry mean scores on NORSCI. None of the differences are significant (p> .05, two tailed).

Table 3
Difference between installation A and industry average, one year before incident

	Incident A		Industry		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.87	0.68	3.9	0.68	0.60
F2 Safety management and involvement	4.19	0.53	4.21	0.54	0.48
F3 Safety versus production	3.02	0.93	3.13	0.95	1.62
F4 Individual motivation	4.65	0.41	4.66	0.47	0.30
F5 System comprehension	3.72	0.79	3.72	0.85	-0.60

*p≤ .05. **p< .01. (Installation A, N=211. Industry, N=4380)

4.2.2 *Installation B vs industry average*

The results from the mean comparison on scores from the NORSCI reveals quite large significant differences between installation B and the industry mean (table 4). The installation at risk for incident B has a significantly lower (more negative) mean score compared to the industry average on all factors in the NORSCI.

Table 4
Difference between installation B and industry average, one year before incident

	Incident B		Industry		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.70	0.70	3.99	0.67	4.33**
F2 Safety management and involvement	3.98	0.62	4.27	0.56	4.81**
F3 Safety versus production	2.97	0.82	4.27	0.95	4.70**
F4 Individual motivation	4.59	0.49	4.69	0.46	2.06*
F5 System comprehension	3.48	0.79	3.84	0.79	4.73**

*p≤ .05. **p< .01. (Installation B, N=113. Industry, N=2665)

4.2.3 *Installation C vs industry average*

There are no significant differences between installation C and the industry average on safety climate scores the year before the accident (table 5).

Table 5
Difference between installation C and industry average, one year before incident

	Incident C		Industry		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.95	0.76	4.04	0.66	0.91
F2 Safety management and involvement	4.14	0.77	4.31	0.54	1.36
F3 Safety versus production	3.12	1.19	3.4	0.94	1.51
F4 Individual motivation	4.70	0.36	4.70	0.49	-0.06
F5 System comprehension	3.91	0.70	3.94	0.74	0.23

(Installation C, N=41. Industry, N=3360)

4.3 Trends in NORSCI scores

The second hypothesis is aimed at testing whether the organizations at risk showed a negative development in safety climate scores in the time before the incidents:

> H2: Organizations that experience major incidents (close calls) demonstrate a negative development on NORSCI in the time period before the incident.

To test the hypothesis, we performed independent t-tests between two survey years before the incidents. The results are presented in the next sections. The two survey years are labeled year -3 and year -1. The survey in year -3 is conducted three years before the incident, and the survey in year -1 is conducted one year before the incident.

4.3.1 Installation A

As we can see from table 6, there was a quite large significant increase in factor 1 between year -3 and year -1 for the installation experiencing incident A. Apart from these changes, we cannot observe significant changes on any of the other factors.

Table 6
Development in NORSCI for installation A

	Year -3		Year -1		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.03	1.01	3.87	0.68	-5.65**
F2 Safety management and involvement	4.05	0.56	4.19	0.53	-1.71
F3 Safety versus production	2.85	0.93	3.02	0.93	-1.21
F4 Individual motivation	4.57	0.57	4.65	0.41	-0.86
F5 System comprehension	3.70	0.76	3.72	0.79	-0.23

*$p \leq .05$. **$p < .01$ (N, year -3=51, N, year -1=211)

4.3.2 Installation B

As we can see from table 7, there was a significant decrease in the NORSCI factors 2 (safety management and involvement) and 5 (System comprehension) which indicates a negative development of the safety climate scores for the installation on these factors. Although the mean scores for factor 3 and 4 are higher in year -1 than year -3, the changes are not significant.

Table 7
Development in NORSCI for installation B

	Year -3		Year -1		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.86	0.65	3.70	0.7	1.935
F2 Safety management and involvement	4.21	0.48	3.98	0.62	3.25**
F3 Safety versus production	3.10	0.90	2.97	0.82	1.25
F4 Individual motivation	4.65	0.45	4.59	0.49	0.96
F5 System comprehension	3.70	0.85	3.48	0.79	2.15*

*$p \leq .05$. **$p < .01$ (N, year -3=168, N, year -1=113)

4.3.3 Installation C

From table 8, we can see that the development in NORSCI scores are relatively flat, with no significant changes from year -3 to year -1.

Table 8
Development in NORSCI for installation C

	Year -3		Year -1		
Factors	M	SD	M	SD	t
F1 Safety prioritization	3.94	0.67	3.95	0.76	-0.28
F2 Safety management and involvement	4.12	0.62	4.14	0.77	-0.21
F3 Safety versus production	3.05	0.84	3.12	1.19	-0.36
F4 Individual motivation	4.71	0.41	4.70	0.36	0.12
F5 System comprehension	3.67	0.79	3.91	0.70	-1.68

*p≤ .05. **p< .01 (N, year -3=87, N, year -1=41)

5. Discussion

5.1 H1: Installations with incidents vs industry average

The results from the analysis of installation A vs industry average does not provide us with any warning that a major incident will happen one year later. No differences between the industry average scores and installation A could be observed. This is contrary to the findings in the accident investigation, where unique conditions for the installation were described as contributing to the major accident risk.

The safety climate for the installation at risk of incident B is significantly more negative compared to the industry average on all NORSCI factors one year before the incident. Seen in the perspective of the accident investigation, these results are in line with expectations. Similar issues as for incident A has been highlighted, where reorganization, rearrangement of the structure of procedures and governing documents were reported as contributing to increased complexity. Installation B among others scores significantly lower (more negative) on factor 5, System comprehension. This is the factor related to perception of how easy it is to find the right governing document, knowing which person within the organization to report to and if the procedures are suitable for the work tasks. However, although a similar description was given in the investigation of incident A, these aspects were seemingly not caught by the safety climate measurement.

The results from the analysis installation C show that we cannot discriminate the installation from its peers. The number of respondents from installation C is relatively small, but the variations in the mean scores between the industry and the installation are nonetheless negligible.

To summarize, our hypothesis is confirmed in one case, but not in the other two. Overall, the results are thus inconclusive.

5.2 Trend monitoring of safety climate to identify changes in risk

One of the advantages of a questionnaire is that it is a reliable method compared to other methods commonly used in social sciences. Provided we have a valid and reliable measure, we can track development and implement measures if we see an unwanted development in the trend. The results from the analysis give a mixed picture of the development of the safety climate on the installations.

Installation A seems to be improving on the safety climate scores, where factor 1, Safety prioritization, is significantly more positive in year -1 than in year -3. The average scores are all rising, and if human and organizational factors are managed on basis of the safety climate assessment the result is a reassurance that the installations safety climate is on the right path.

Installation B demonstrates the opposite trend of installation A, where the scores on all factors are lower in year -1 than in year -3. However, only factor 2, safety management and involvement and factor 5, system comprehension demonstrates a statistically significant decline. Observation of the changes might have triggered management actions to improve the conditions, provided safety climate trends were included in the installations risk management system. We cannot know whether potential changes would have affected the risk level, although the underlying factors observed in the accident investigation to some degree corresponds with the safety climate assessment.

Installation C is in a flat to slightly increasing trend judging by the average scores alone. However, no statistically significant changes can be found, and hence there is no reason to conclude that the results in year -1 are different from year -3.

Although one should not exaggerate the value of comparing the safety climate scores with the incident reports, we can observe that the incident reports point towards many issues that could have been expected to impact the scores on typical items in the safety climate questionnaire. Installations A and B had been reorganized just months before the survey; a process which has been described as slow, and insufficiently consistent resulting in unclear responsibilities. Further, it was found that professional critical questions and objections were not sufficiently taken into consideration, which might have contributed to weakening of barriers. It was also found that the organizations had a lack of understanding and expertise in high risk operations. All installations had demonstrated deficiencies in risk management in the planning process of the operations leading up to the accidents. These are underlying factors that are more or less common for all major accidents, and a proactive indicator should be sensitive to these matters.

5.3 Can we use safety climate as an indicator on the plant level?

The analysis presents somewhat inconclusive results. The managers of installations A and C would not have received any signals of danger from the safety climate assessments. In fact, installation A could have concluded that they were actually in a positive development of the prioritization of safety. If we try to take the perspective of the decision-makers on the respective plants, an obvious conclusion is that positive safety climate scores should not be interpreted as indicating that the organizational conditions for safety are all OK and do not require further attention.

For installation B, the story is somewhat different. As the installation both differed from industry average and displayed a negative development, this could have been seen as a warning sign that the conditions for safety were deteriorating. Again taking the perspective of local decision-makers, the results from the safety climate assessment should be the source of concern and make managers worry about practical drift and eroding safety margins. The question is, however, how are these managers able to act on this information? How can general diagnoses of safety climate be translated into concrete measures? These questions point to the relationship between indicators and their direct safety relevance [(33)]. Safety climate is an attempt to measure organizational conditions with an indirect relationship to safety performance. This means that there is a high level of ambiguity in how the measurement is to be interpreted and which local actions that should be taken, which in turn means that measurements of safety climate do not meet common quality criteria for safety performance indicators [(34)]. Irrespective of this, the development in safety climate scores of installation B is clearly an indication of *something* that should catch the attention of decision-makers. What is the link between this "something" and improvement measures? The answer is "interpretation". All weak signals of danger need to be interpreted in order to be meaningful and this is also the case with diagnoses of safety climate. This interpretation requires some form of in-depth assessment into *why* the safety climate scores display a negative development. In the well-known iceberg model of organizational culture of Edgar Schein, safety climate constitutes espoused values. In order to understand these espoused values, the underlying structures of meaning must be understood.

It is important to underline that the findings of this study does not imply that organizational conditions for safety cannot be assessed or understood. On the contrary, given sufficient depth in the analysis, understanding of human and organizational factors is vital for avoiding major accidents. Our argument is that there is a need to separate between conditions and causes in the “anatomy” of major accidents: We have become so used to look for organizational causes in major accidents that we may tend to forget that it is always actions/inactions and/or events that are the direct causes of accidents, not organizational factors. Organizational factors may influence why people take certain actions, but a poor safety climate can never be a direct cause of an accident, only indirect. Safety climate is regarded as the distal antecedents of safety behavior, mediated by more proximal drivers of safety behavior, such as knowledge, skills and motivation [(35)]. The causal trajectories when dealing with more distant antecedents of behavior are more or less chaotic; perhaps too chaotic to serve under the indicator label. When designing indicators for major accident risk, it is therefore our view that it is important to focus on more proximal factors and maintain the link from the shop floor, and strive to follow a logic of causal specificity. Reducing the distance between the factors that constitute the indicators and the performance at the sharp end is likely to probe into aspects that more directly influence performance and risk. This implies a bottom-up approach, where an important prerequisite is a solid understanding of the work that takes place at the sharp end.

Thus, the argument ends at the not surprising conclusion that it will be very hard to understand the organizational conditions for safety without a deeper understanding of how safety-critical work is being performed, priorities are made and the conventions for action and interaction (e.g. [(36, 23, 37)]). This means that the struggle to reduce the concept of culture to a measurable phenomenon (safety climate) is not necessarily fruitful when dealing with the relationship between human and organizational factors and their explicit contribution to major accident risk; describing the phenomenon[(18)], and leaving it out of the indicator discussion will be a more fruitful approach. Safety climate assessments probe into conditions rather than causes; conditions that are present in all organizations to a greater or lesser degree. In an indicator perspective, we need to grasp the most direct influences on safety, which might differ considerably between industries, organizations and their maturity in dealing with human and organizational aspects. There is a need to realize that an indicator in a government perspective can be different from what we need on the individual installation level, where the same indicator might not meet the requirement for sufficient participants to average out random influences [14]. However, safety climate is still discussed under the "risk indicator" label, where safety climate is referred to as the most used leading indicator [3, 10]. The results from this study can be used as an argument to question the position of safety climate as an indicator, and draw attention to the pitfalls of relying on the measurement of perceptions of safety related conditions to manage risk on individual installations. Assessing human and organizational factors in a major accident perspective is in need of a different approach.

5.4 Limitations

The current study and the implications we have drawn from it demonstrate that safety climate is likely to be a poor indicator on the installation level to assess major accident risk. The study demonstrates that an installation manager will have trouble using the results to manage major accident risk in an operational setting. However, there are several methodological limitations that the reader should bear in mind when interpreting the results of this study. First, we are investigating only three cases. More cases are needed in order to fully understand the relationship between safety climate and installations at risk of major accidents. Second, we have tested one construct of safety climate in this paper. Other constructs might be better; a question that our study does not cover. Third; safety climate is considered a distal antecedent of safety behavior, mediated by the more proximal drivers of safety performance. On the basis of this, one could argue that we perhaps could have deduced that the concept was unfit for indicator purposes without testing the hypothesis. However, our study contributes to highlighting the importance of treating various indicators with caution, regarding the level of investigation we are considering. The scope of investigation into human and organizational factors needs to be sensitive to which level of the industry we want to design the indicators for. While regulatory bodies such as the PSA or large offshore operators can make use of safety climate surveys, smaller operators and individual installations will struggle, as we have demonstrated in this study.

6. Conclusion

The main point of the study is that it is by no means intuitive what an assessment of safety climate indicates about major accident risk in the organization. The strength of safety climate surveys as investigated in the current study lies in first and foremost as a method to gain quick surface information about safety related conditions. The practical use of safety climate assessments should hence not be as indicators for safety performance, but as an indication of where to focus the attention for further assessment of factors, drawing the attention to local conditions more directly linked to major accident risk. This implies that the method might be suited for regulators or larger operators to keep an overview of the status, and providing information about installations needing a more thorough investigation.

The mixed results of this study leaves us with several questions that could be interesting to investigate further: First, is the discrepancy between results of accident investigations and results from safety climate measurements a result of poor safety climate survey tools, or biases in the accident investigation reports (hindsight, outcome etc.)? Second, is there a better construct of safety climate that can serve as indicators on the installation level? Third, what level of investigation serves the purpose of indicators on the major accident related human and organizational conditions on the individual installation level?

7. References

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