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Interdisciplinary collaborations facilitate safety climate research

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ABSTRACT

The Mary Kay O'Connor Process Safety Center has collaborated with and supported faculty and doctoral students in their research in the Department of Psychological and Brain Sciences at Texas A&M University for more than a decade. This collaboration is the result of the recognition that organizational scientists have knowledge and skills that can address the human side of workplace and process safety. This paper reviews some of the research that has grown out of this long and fruitful collaboration and provides specific practical recommendations about building a state-of-the-science process safety climate assessment program. Based on a series of studies resulting from this collaboration, some important conclusions include: ensuring safety climate measures are neither contaminated nor deficient and assessing safety climate more than once a year. This paper demonstrates how academic-corporate partnerships and engineering-social science partnerships can create useful and important information to support environment, safety, and health (EHS) practice.

1. Introduction

It is clear that workplace safety and unsafe incidents are multiply determined by various causes including: engineering, processes, human-machine interactions, human resources, and organizational systems. Process safety engineers are concerned about reducing risks in the workplace. According to the Center for Chemical Process Safety, the first element in guidelines for risk based process safety is a process safety culture or “a positive environment where employees at all levels are committed to process safety” (CCPS, 2007). Within the context of risk assessment and mitigation, it is important to gather information directly from workers. One way to do this is to conduct a “safety culture assessment” (Pasman et al., 2017). How employees perceive their work environment and what behaviors and risks are tolerated can be just as informative and useful as other risk assessment tools. Organizational scientists are experts in human behavior in organizational contexts and are able to assess employee experiences, attitudes, beliefs, cognitions, and behaviors. Thus, collaborations between process safety engineers and organizational scientists create a perfect synergy of expertise for conducting a safety climate[1] assessment to ultimately support environment, safety, and health (EHS) practices.

In recognition of this, the Mary Kay O'Connor Process Safety Center (MKOPSC) at Texas A&M University has collaborated with faculty and graduate students in the Department of Psychological and Brain Sciences (PBSI) at Texas A&M University who specialize in industrial-organizational (IO) psychology over the past decade to create a program of research on safety climate. In this paper, we review some of the strides made in safety climate research through that partnership. The goals of this retrospective are (a) to illustrate the value of an investment in social science research using the MKOPSC-PBSI collaboration as an exemplar and (b) to encourage continued collaboration between social scientists and engineers to extend safety climate science/research and improve workplace safety.

2. Organizational scientists

IO psychology[2] is the scientific study of how people behave in the workplace, how they create workplace processes and products, and how workplace experiences affect people's well-being. IO psychologists attempt to address workplace problems in order to improve employee's well-being and organizational success. Both of these outcomes are important to IO psychologists as these are intertwined and mutually reinforcing—a successful organization can employ more people and give them positive workplace experiences; workers whose well-being is respected and supported by organizations can help organizations be more successful. IO psychologists contribute to the science and practice of employee selection/staffing, training, motivation, leadership, and occupational health, among other topics.

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[1] Organizational scientists, including IO psychologists, make a distinction between organizational culture and organizational climate. The concept of safety culture in the EHS literature (CCPS, 2007; Pasman et al., 2017) aligns with the organizational science concept of climate (Ostroff et al., 2012; Zohar, 2003, 2010). Thus, to be consistent with the organizational science literature, we use the phrase “safety climate.” We describe this distinction further in section 2.

[2] For more information about IO psychology, please visit the website of the professional society for IO psychology in the US, the Society for Industrial and Organizational Psychology (www.siop.org), Division 14 of the American Psychological Association.

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Human Factors[3] (HF, sometimes called Applied Experimental and Engineering Psychology) is related to but distinct from IO psychology. Human factors psychologists combine cognitive psychology (i.e., the study of sensation and perception, memory, and decision making) with design and implementation principles. They strive for safer, more effective, and more reliable systems both within and outside the workplace through an improved understanding of the user's requirements, human-machine interactions, and human and machine limitations.

Process engineers are likely to benefit from partnerships with both IO psychologists and HF psychologists, albeit for different information and different goals. As an example, process engineers might work with HF psychologists to design a new system for delivering and recording process or change management information to operators or skilled maintenance workers; process engineers would then work with IO psychologists to determine what employee factors facilitate or inhibit the adoption of the new systems in the field (e.g., time and production pressures, team communication). Correspondingly, MKOPSC engineering faculty have forged alliances with both types of psychologists. In this paper, we focus on research collaborations with IO psychologists and a program of research focusing on the measurement of safety climate and its relationships with important workplace personal and process safety outcomes (e.g., injuries, incidents).

3. Overview of safety climate concepts

Before reviewing research that has been supported by MKOPSC, we first review foundational safety climate concepts.

3.1. What is safety climate?

Organizational scientists distinguish between organizational culture and climate. Ostroff et al. (2012) defined organizational climate as employee perceptions of the organizational expectations about workplace behaviors, norms, and attitudes, whereas organizational culture is the shared motives, identities, and values that arise from employees' common experiences. When discussing the differences between climate and culture, Ostroff et al. noted, “Whereas climate is about experiential descriptions of perceptions of *what happens*, culture helps define *why these things happen*” (p. 566, emphasis added). Typically, when safety personnel use the term “safety culture,” they are encompassing both culture and climate from organizational science. Here, we use the term “climate” to be consistent with organizational science definitions and because the methods we use in our research align with methods used to assess organizational climate.

Organizational climate refers to the employees' shared perceptions of organizational policies, procedures, and practices about some component of organizational life (Ostroff et al., 2003, 2012; Reichers and Schneider, 1990; Schneider and Reichers, 1983). Climate guides employees about which behaviors are rewarded, supported, and expected in the workplace (O'Reilly and Chatman, 1996; Schneider and Reichers, 1983). Organizational scientists usually examine climate for specific aspects of organizations because these different domains in organizations have different policies, procedures, and practices. That is, there is not a monolithic organizational climate, but rather a series of “climates for” different parts of the organization (e.g., safety, diversity, service, etc.; Schneider and Reichers, 1983). Safety climate is one of the most studied organizational climates (Schneider et al., 2013).

Building on the definition of organizational climate, safety climate is employees' shared perceptions of policies, procedures, and practices regarding workplace safety (Zohar, 2003). Many researchers consider safety climate to be multidimensional, but there is no consensus on its underlying factors (Guldenmund, 2000). What is clear, however, is that management commitment to safety is a key (and possibly superordinate) element of safety climate (Beus et al., 2018; Flin et al., 2000; Zohar, 2003). For example, our research showed that management's commitment to safety is manifested in organizations in several ways, including: safety communication, coworker safety practices, safety training, employee involvement in safety, safety rewards, and safety equipment and housekeeping (Beus et al., 2018).

Although we usually focus on the *shared* perceptions from employees to represent climate, individual employees' responses are also useful and important information. An individual's safety climate score (i.e., the average score of the survey items that measure safety climate) has been referred to as psychological climate (James and Jones, 1974); in contrast, “organizational climate” refers to aggregated climate perceptions within some relevant grouping (e.g., workgroup, plant, division, worksite, organization). Psychological climate has significant utility as it predicts both workplace safety behavior and injuries (Beus et al., 2010; Nahrgang et al., 2011) and thus it should not be discounted as an important part of a safety climate assessment program.

3.2. Key features of safety climate

When describing safety climate, two features are key: level and strength. Level is the “goodness” or “badness” of safety climate for a group. It is calculated as the average of the individual employee psychological safety climate scores for all the individuals within a meaningful group, such as all employees who report to a particular supervisor or all employees in a unit within the organization (Chan, 1998; Schneider et al., 2002). Groups can be compared on level of safety climate; for example, Manager Imani's workgroup has a better safety climate, as indicated by a higher safety climate score, than does Manager Mateo's workgroup.

Strength represents the extent to which a workgroup agrees about the level of safety climate. Climate strength is calculated through some measure of within-group variation or deviation; usually, it is the standard deviation of the responses of the employees within a group to a safety climate measure (Schneider et al., 2002). When there is lower within-group variability, there is greater sharedness of perceptions or agreement among the employees within the group; thus, the climate is stronger (Schneider et al., 2002).

These two features—level and strength—are important to understanding safety climate and its ability to predict organizational outcomes, employee behavior, and unsafe events. Safety climate level, unsurprisingly, is linked with a variety of outcomes, such that higher (better) safety climates are linked to better outcomes (Bergman et al., 2014; Beus et al., 2010; Christian et al., 2009; Nahrgang et al., 2011). On the other hand, safety climate strength is conceptualized as a moderator of the safety climate level → outcomes relationship. This is because safety climate strength, as a measure of agreement, shows the extent to which a group's score is relevant to each member of the group; higher agreement means that the group's average score is more representative of each member. When agreement is high, the members of the group are on the same page regarding safety climate level. Further, when agreement is high, there is greater normative pressure for people to act similarly (O'Reilly and Chatman, 1996; Schneider et al., 2002). Research supports these contentions, demonstrating that the effect of climate level on organizational outcomes is stronger when climate strength is high than when climate strength is low (Schneider et al., 2002).

3.3. Common safety climate assessment practices

Like other types of organizational climate, safety climate is usually measured with employee surveys. The surveys are conducted with individual employees because even though safety climate is *shared* perceptions, climate arises from the *individual employee* perceptions that

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[3] For more information about this discipline, please visit the website for Division 21 of the American Psychological Association (http://www.apa.org/about/division/div21.aspx).

are held in common within a group. Then, these individual responses are used to calculate safety climate level and strength for each group.

There are many safety climate measures in the safety literature (e.g., Beus et al., 2018; Zohar and Luria, 2005), as well as a vast number that are proprietary and homegrown in organizations worldwide. As noted above, safety climate is considered to be multidimensional, but management commitment to safety is an essential component. Most safety climate measures reflect this, measuring some aspects of management commitment to safety as well as (usually) some additional aspects (Beus et al., 2013). Safety climate measures do not have to be long to be useful, as demonstrated by studies with instruments composed of about ten items (Bergman et al., 2014; Hofmann and Stetzer, 1996; Zohar, 2002). Finally, most safety climate measures are conducted using a five-point Likert-type scale, whereby respondents read a series of statements and reply to each with one of five response options that ranging from “strongly disagree” to “strongly agree”.

4. Safety climate assessment: some lessons learned from the MKOPSC-PBSI collaboration

The above review captures many of the common practices that are found in the science and practice of safety climate assessment and which are considered good practices. In the next section of this paper, we review several key studies conducted at Texas A&M University in collaboration with MKOPSC. This review focuses in particular on factors that influence safety climate assessment. This review focuses on some of the most critical and foundational questions in safety climate measurement. This includes the creation of a good survey instrument and the criteria for “good” in this context, the frequency of measurement, and whether industry-specific or general measures are more useful.

4.1. Construct clarity is essential to a good measurement system

Many surveys that are aimed at measuring safety climate also include other topics (or as they are called in psychological research, *constructs*[4]) beyond safety climate, whether related to safety climate (e.g., safety attitudes, risk tolerance, recent unsafe experiences) or beyond (e.g., satisfaction with health care options). Deploying surveys that capture numerous constructs and achieve multiple organizational goals is an acceptable and common practice because it (a) allows for contemporaneous correlations between safety climate and its possible drivers and (b) reduces the number of survey requests of employees. However, our research shows that when developing a survey and reporting its results, it is important to use previously validated measures of psychological constructs published in peer-reviewed empirical literature and to carefully separate the different constructs into distinct survey scores (i.e., totals or averages).

Via meta-analysis,[5] we examined the effect of construct contamination and construct deficiency on the safety climate-injury relationship (Beus et al., 2010). Contamination is the inclusion of extraneous, systematic variance in the measure (Messick, 1980, 1995); in practice, this often occurs through the inclusion of questions about something else, even if it is somewhat related (e.g., perceived risk with a measure of safety climate). Deficiency is the exclusion of relevant systematic variance in the measure (Messick, 1980, 1995); in practice, this often occurs by overlooking important topics when constructing the measure. Aggregating across nearly 30 studies from researchers around the world, our analyses showed that contamination of the safety climate measures (e.g., the inclusion of perceived risk) overstated the safety climate-injury relationship (i.e., had inappropriately higher correlations), whereas deficiency (e.g., failing to capture management commitment to safety) of the safety climate measure reduced this relationship (i.e., had inappropriately lower correlations).

At first blush, it might seem advisable to create contaminated measures because they have larger correlations with injuries, which means that they explain more variance in injuries than do uncontaminated measures. However, this is a bad strategy because it makes it difficult to know what the drivers really are for unsafe incidents. Instead, the constructs should be separated and then individually related to the outcome of interest; this separation is essential so the results demonstrate what factors really are linked to safety in the workplace. Thus, distinguishing between assessments (even within the same survey) of multiple safety-related variables can help organizational leadership make good data-driven decisions on where to prioritize investments and deploy new resources.

4.2. Safety climate should be measured frequently

Our meta-analysis also demonstrated that as the time over which injuries were aggregated lengthened, the correlation between safety climate and injuries were reduced (Beus et al., 2010). This effect—-where there is a low relationship between safety climate and key outcomes when those outcomes are aggregated across large time period—is not an uncommon finding (e.g., Neal and Griffin, 2006). Aggregation of key outcome data over large time periods is relatively common in safety climate assessment for two reasons. First, it is difficult to model rare data; serious deviations from process integrity and serious injuries or property damage are relatively rare events at most organizations in industries that demand high reliability (Perrow, 1984; Roberts, 1990). Thus, to capture sufficient variability across sites (e.g., workgroups, plants) and avoid floor effects, these event data are aggregated over long time periods. Second, safety climate assessments appear to be deployed relatively rarely compared to other safety measures. Instead of being treated like key leading process indicators, safety climate assessments are almost exclusively treated by organizations like other human resources oriented assessments (e.g., performance evaluations, employee satisfaction surveys). These human resources assessments are often conducted on time periods of biannually, annually, or biennially. Consequently, the outcomes are aggregated across the intervening time period (6 months, a year, two years).

The results of our meta-analysis led us to wonder about the “shelf life” of a safety climate assessment. We wanted to know when the relationship between a safety climate assessment and unsafe incidents expires (Bergman et al., 2014). That is, when does an assessment of safety climate go past its useful date? When are the data no longer “fresh” and new data are needed? Fortunately, due to our relationship with MKOPSC, we were given access to a database of personal and process incidents over a nearly 4-year time period from all of the sites of a global chemical processing company. We were also contracted to conduct a safety climate assessment in the middle of that time period. We sorted the incidents by type (e.g., fires, first-aid injury, etc.) and then into monthly periods. We used these monthly periods to create graduated aggregates of incidents (i.e., the first month following the safety climate assessment, then the two months following the safety climate assessment, then the three months, and so on), so that we could test how successively longer time periods influence the relationship between safety climate and incidents. We also constructed the same kind of graduated aggregate from the incident data in the time prior to the safety climate assessment. Thus, we were able to examine the shelf-life relationship in two ways: with unsafe incidents as the predictor

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[4] Construct is a technical label for experiences that exist but cannot be *directly* observed (unlike height, weight, age, or blood pressure). Evidence of constructs is gathered by asking people about their experiences with the concept. Beyond the constructs listed here, other constructs include: love, conscientiousness, extraversion, and job satisfaction.

[5] A meta-analysis is a quantitative summary of a set of studies (Aguinis et al., 2011; Schmidt, 2008). This summary finds the average relationships across the studies. It is useful because the set of studies together can overcome the limitations of any single study (e.g., small sample size, cultural effects of a single country study).

(i.e., unsafe incidents that occurred up to two years prior to the safety climate assessment) and with unsafe incidents as the criterion (i.e., unsafe incidents occurring up to two years following the safety climate assessment). Thus, both the leading and lagging relationships were examined which we had previous speculated about (Payne et al., 2009) and demonstrated empirical support for (Beus et al., 2010).

Our analyses showed that as a leading indicator, safety climate predicted incidents of different severity levels (e.g., damage less than $10000 or first aid; damage more than $10000 or severe injuries), but safety climate predicted the most severe incidents over the shortest aggregated period of time. Similarly, when incidents predicted safety climate, the more severe incidents had the shortest predictive period. For the most critical relationship (climate predicting more severe incidents), the predictive power is strongest in the first month after the assessment and drops off quickly, such that the ability of a safety climate assessment to predict incidents expires after only 3 months.

Thus, our results demonstrated that usual practices such as aggregating incidents over 6-, 12-, or 24-month periods underestimate the safety climate-incident relationship and, for the most severe events, make it appear that safety climate assessments have no predictive effect, possibly resulting in a broader conclusion that safety climate in unimportant. However, our results clearly demonstrated that safety climate is a predictor of severe incidents and should be used to identify areas of concern within an organization.

Practically, our results indicate organizations should assess safety climate at least once a quarter, but it may be a better practice to assess monthly (if not more often) which is much more frequently that what appears to be industry standard of less than once a year (Payne and He, 2017). Further, organizations need to attend to the aggregation period they use in reporting and analyzing incident rates. Yearly counts of incidents, for example, would make it seem like safety climate cannot predict severe incidents and thus would make safety climate assessment programs seem like a poor investment. Shorter aggregation periods (monthly or quarterly) reveal very different effects and show the utility of safety climate assessment programs and how they can be used to identify organizational hot spots that need just-in-time attention. Treating safety climate assessments more like a key process indicator, rather than like human resources surveys, allow organizations to more efficiently deploy resources and maintain and improve safety climate—and, by extension, workplace safety.

A reviewer raised a concern about over-surveying or surveying too frequently. Certainly survey fatigue, when respondents feel over-surveyed or become tired, bored, and/or uninterested in responding, can be a serious concern which can reduce response rates. This can be combatted by administering very short surveys (i.e., less than 10 items) at a time or by seeking a representative sample in which individual employees are asked to respond to every other or every third or fourth survey, depending on the size of the organization. Organizations can track response rates over time in order to maximize responding and representativeness. Finally, developing a climate of assessment would encourage employees to participate frequently. A good climate of assessment would have hallmarks such as employees believing that their survey responses are critical to organizational safety and success and management demonstrating this by being responsive to survey responses and linking survey responses to organizational efforts.

4.3. Are industry-specific measures of safety climate necessary?

While conducting our meta-analytic review of the literature (Beus et al., 2010), we identified 61 unique safety climate measures that had been used in research. In a follow-up review of over 1500 items within these measures (Beus et al., 2011), 33 of the 61 measures included at least one industry-specific item (e.g., "Policies regarding not recapping used needles are posted; " Day, 1999, p. 88), whereas 28 measures consisted of only general items (e.g., "A busy situation does not prevent supervisors from intervening if someone acts against safety rules; " Varonen and Mattila, 2000, p. 765). Although other safety climate researchers have advocated for the development of industry-specific safety climate measures (Zohar, 2010), our next goal was to empirically determine whether industry-specific measures were useful to understanding and predicting safety-critical psychological states (e.g., knowledge, motivation), safety-related behavior, and injuries.

To answer this empirical question, Keiser and Payne (2018) examined safety climate in five different kinds of university laboratories: animal biological, biological, chemical, human subjects/computer, and mechanical/electrical. Akin to industry differences, each type of laboratory served has unique hazards, risks, and corresponding policies and procedures. Over 700 laboratory personnel were surveyed, with each person completing a general measure of safety climate (i.e., no lab-specific cues) and a corresponding measure that had laboratory-specific cues for the type of laboratory the person worked in. The general safety climate measure and the lab-specific safety climate measure were each correlated with a variety of self-reported safety-related outcomes (knowledge, motivation, behavior, and injuries). Results indicated that the inclusion of context-specific information in the safety climate measure did not usually improve the ability to predict safety-relevant behaviors and psychological states beyond what the general measure could do; in fact, contrary to expectation, the context-specific cues were most helpful for contexts where safety was objectively less critical (e.g., in human subjects/computer labs rather than chemical labs; Keiser and Payne, 2018). Thus, this well-designed study suggests that it is not necessary to use an industry-specific measure of safety climate when predicting self-reported safety-related outcomes.

That said, much of our research has taken place with the oil and gas and chemical processing industry. Within this industry (as well as others), there is a strong concern about process safety which could be simply described as keeping the process safe. In other words, ensuring that chemicals and hazards remain contained and are combined in ways that are consistent with regulations. Violations of process safety include leaks, spills, and releases of toxic substances (Hopkins, 2009), as well as fires and explosions. Building on the safety climate research, process safety experts propose a process safety climate which can be defined as employees' perceptions of the policies, procedures, and practices concerning process safety. Some indicators of a weak process safety climate include a lack of operating discipline, toleration of serious deviations from safe operating practices, and complacency toward serious process safety risks (BP Baker Report, 2007). In our research, we have found that a short (12 item) process safety climate measure relates significantly to process safety incidents including environmental impact, fire/explosions, and property damage (Payne et al., 2010). Some of the most useful process safety climate items concerned preventing large backlogs, conducting routine housekeeping, and promptly correcting health and safety concerns. However, unlike Keiser and Payne (2018), Payne et al. (2010) did not compare industry-specific to general safety climate measures; it may be the case that a general measure of safety climate would have predicted these process safety incidents just as well as the industry-specific measure did. In fact, a recent meta-analysis revealed that general safety climate measures predicted adverse events better than industry-specific measures (Jiang et al., 2018); however, additional research is warranted.

4.4. Summary of key findings about good safety climate measurement

This brief review points to several important concerns when developing a safety climate assessment program. First, the safety climate measure should be well designed, with no extraneous content (i.e., contamination) and covering all critical domains (i.e., not deficient). Although other constructs might be assessed on the same survey, it is essential that survey analysis correctly parse the different constructs in order to identify drivers of safety climate and unsafe events so organizations can correctly deploy corrective action.

Second, safety climate assessment should be frequent. Safety climate assessments should be part of the process safety and assessment plan and not treated as a human resources function. The predictive power of safety climate assessments is strong, but short-lived. To capitalize on the utility of safety climate assessment, the assessment must occur at least quarterly and would be better at a monthly or even weekly basis. Fortunately, very short assessments (on the order of five to ten items) can be used to do this and they can be deployed via mobile devices to quickly reach a large number of employees.

Finally, the jury is still out regarding whether industry-specific items are necessary in a good safety climate assessment program. Based on the basic delineation of climate (Schneider and Reichers, 1983), it is clear that process safety and personal safety should be differentiated, as the objects being protected and the policies, practices, and procedures therein are different. However, what is not yet clear is whether the process and personal safety climate assessments need industry-specific cues (e.g., “needles” in nursing vs. “lockout/tagout” and “permit to work” in chemical processing) or whether general terms (e.g., “personal protective equipment” in any industry) suffice. In Keiser and Payne's (2018) carefully designed and elegant study, there was little to suggest that the investments required to develop industry-specific items paid off; however, their study did not have objective process safety data to calibrate their two measures with. Thus, it is too soon to know whether this is a valuable practice.

5. Conclusion

Our program of research on safety climate has revealed that construct clarity is essential to a good measurement system. Brief measures of safety climate can be sufficient, but it is important to ensure that they are not contaminated or deficient. Safety climate should be measured frequently and much more frequently than what appears to be the norm in practice. Finally, it does not appear necessary to use industry-specific measures of safety climate when predicting general safety outcomes.

Over the last decade, MKOPSC and the Department of Psychological and Brain Sciences at Texas A&M University have created a fruitful and influential program of research on safety climate. This work can only be accomplished via collaboration between safety practitioners and organizational scientists, using real organizational data as a key part of evaluating the role of safety climate in the workplace. As part of this retrospective, we must thank MKOPSC and its membership for their support and interest in our work. We hope that this review spurs additional collaborations between organizational scientists and safety practitioners, answering questions essential to the human side of safety practice and ultimately making workplaces safer resulting in all employees going home healthy every day.

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