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Assessing the statistical properties and underlying model structure of fifteen safety constructs

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ABSTRACT

Background: Organisations spend a considerable amount of time and effort on diagnosing and analysing risks within their organisation. In the area of occupational and process safety, a myriad of employee survey instruments is available. Many studies show that operational processes play an important role in an organisations overall safety. Yet, so far safety surveys mainly focus on safety measures or operational *safety* processes. A flexible instrument was developed with which a wide variety of constructs, from different disciplines, can be measured in a consistent and practical way. The resulting survey distinguishes itself from existing safety surveys by extending the scope with the operational processes which are also referred to as the 'Core Business'.
Study: This study reports on the development of a catalogue of constructs which were derived from scientific literature and practice. Each of these constructs has been developed with a view towards measurability in an employee survey. The reliability and validity for fifteen of these constructs was assessed. Five separate projects have been conducted within a range of organisations operating as high risk industries.
Results: Construct validity and the dimensional structure of the instrument have been established through exploratory factor analysis and confirmed through confirmatory factor analysis. Diverse aspects derived from motivational and ergonomic approaches to safety proved to be distinguishable in this analysis.
Conclusion: The described instrument allows the mapping and quantification of various aspects of the operational process that are, based on existing knowledge, related to the occurrence of incidents.
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1. Introduction

Over the past decades front-running organisations and industries have been successful in reducing the frequency of occupational accidents within their organisation. The combined oil and gas producing organisations for example have managed to reduce the frequency of personal harm year on year since 2004 (OGP, 2013). Although on a broader societal scale accidents and incidents still cause considerable personal harm (Takala et al., 2014) or, in the case of major high impact events, have consequences for business, people and environment (Baker et al., 2007; Onderzoeksraad voor Veiligheid, 2013; GPO, 2011; Powell, 2006a, 2006b, 2006c). The ability to map factors that may contribute to accident causation is therefore of great importance. Safety surveys are a common tool for this purpose. Here we will first provide a short review of existing safety surveys where we focus on two dominant approaches related to 'motivational aspects of safety' (e.g. Zohar, 2010) and 'workplace conditions and systems' (e.g. Reason, 1990). First, we focus on safety climate research, thereafter we describe surveys related to workplace conditions. Subsequently, we will present a new approach which intends to span domains and enable a more flexible approach to safety surveys. The overall goal of this paper is to introduce a newly developed catalogue of constructs. The resulting survey distinguishes itself from existing safety surveys by extending the scope with the operational processes which are also referred to as the 'Core Business'. Since safety is an integral part of successful business operations (Zwetsloot et al., 2017), this instrument can be starting point for organisations to enhance their operational safety through integral system management. The first findings concerning the reliability and validity of these constructs are provided.

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1.1. Safety climate

Understanding the complex array of factors that may contribute to accident causation is no easy task. One way to gain proactive insight is the study of organisational (safety) culture and safety climate (Guldenmund, 2007; Parker et al., 2006; Zohar, 2010). The concepts of safety culture and safety climate are closely related (see Guldenmund, 2007 for a discussion), generally organisational safety culture is seen as a more generic, overarching concept whereas safety climate refers to attitudinal and more overt manifestations of culture within an organisation. For recent literature reviews concerning safety climate we refer to Griffin and Curcuruto (2016) and Schwatka et al. (2016). In this area the use of questionnaires has been the most popular approach as a 'quick and dirty' method to gain insight into momentary safety attitudes, more accurately referred to as the organisation's safety climate (Guldenmund, 2007). Measuring safety perceptions or safety culture is not only popular in academia but is also used extensively within the wider industry, over 60% of organisations measured safety perceptions or safety culture within their organisation in one survey of Dutch safety professionals (van Kampen et al., 2014).

Extensive research has been conducted on the measurement of safety climate through questionnaires (see for example: Christian et al., 2009; Clarke, 2006; Guldenmund, 2000, 2007; Kines et al., 2011; Zohar, 2010). As a result, a large number of different questionnaires has been designed to measure safety climate, with each questionnaire using (slightly) different operationalisations of the concept, although with a similar goal. In order to use safety climate scores as a valid indicator for safety within organisations it is important to know the extent to which these scores are predictive of safety outcomes. Only a subset of safety climate studies takes the step to correlate the concept with safety outcomes, these have been summarised in several literature reviews and meta-analyses. Clarke (2006) analysed 28 studies which contained measures of safety climate combined with a measure of actual incidents or injuries (occupational accidents). She found that the relationship between safety climate and accident involvement was small and moderated by research design. Nahrgang et al. (2007) also found a small yet significant correlation between safety climate and accidents or injuries based on their meta-analysis of 24 studies. Christian et al. (2009) most recently conducted a systematic review looking not only at relationships between safety climate constructs and outcomes but more broadly at safety knowledge, motivation, performance (compliance and participation), personality and safety climate. Again, they found a modest relationship between safety climate and safety outcomes and identified a broad variety of concepts which were included in safety climate studies and were correlated with some proxy-outcome measure of safety (e.g. safety compliance and participation).

On the basis of these and other studies Zohar concluded in 2010 that recent meta-analytic studies revealed that safety climate offers robust prediction of objective and subjective safety criteria across industries and countries. Zohar, however, also concludes that much work is needed in exploring the relationship between safety climate and its antecedents and mediators. This is also apparent from the meta-analysis from Christian et al. (2009). They show the primary focus of current safety climate literature through a meta-analytic path analysis (Fig. 1) which was by necessity limited to only the factors which were found most consistently in the literature.

As can be seen from Fig. 1 the safety climate literature is currently focused on Safety compliance – the extent to which employees report adherence to obligatory safety behaviours – and Safety participation – the extent to which employees self-report additional positive safety behaviours which are not 'obligatory'. These behaviours are the main hypothetical mediators used in some form within most of the studies and they are grouped by Christian et al. (2009) as 'safety performance'. These factors are observed to relate negatively to (self-reported) accident and injury involvement and seen to be positively shaped by 'safety knowledge' and 'safety motivation' and in turn by 'safety climate'. The model shows the person-oriented (behavioural) focus of safety climate research in current practice with main pathways through individual motivation, individual knowledge and rule following behaviour.

1.2. Workplace conditions and systems orientation

Whilst intentional behaviour is evidently relevant for safety, other studies suggest that behaviours which can be influenced by knowledge and motivation are only a subset of those which are relevant. Aspects of the situation in which the work is conducted are seen to be at least, as if not more, relevant (Wagenaar and Groeneweg, 1987). Winsemius for example in 1965 writes that: *It is too easily forgotten that a 'human factor' as a direct causal element in the genesis of an accident can only mean some form of human behaviour which is not only determined by the individual's personal traits, but also by the situation the individual has to cope with (p. 151)*. It therefore seems to be especially useful to expand on the role of human error probability and latent conditions in relation to safety climate (Dekker, 2014, 2015). In his influential book 'Human Error' Reason (1990) identified particular types of cognitive error and combined it with earlier work on levels of cognitive processing (Rasmussen, 1980). Groeneweg (2002) reported on the development of basic risk factors or 'general failure types' and their assessment using a questionnaire instrument called TRIPOD Delta. The importance of systemic and organisational performance shaping conditions has been clearly established (e.g., Groeneweg, 2002; Hollnagel, 1998; Reason, 1990, 1997).

The findings of the investigation into the explosion of Piper Alpha (Cullen, 1990) lead to increased attention for organisational factors and the development of safety management systems. Organisational factors which are thought to influence worker conditions have been classified in many ways. The concept of basic risk factors (Groeneweg, 2002; Wagenaar et al., 1994) was developed by starting from the latent failure 'Swiss cheese' model of accident causation (Reason, 1990). At a similar point in time Hollnagel (1998) identified nine 'common performance conditions'. Guldenmund et al. (2006) identified nine elements of so-called management delivery systems which are primary safety management processes. Zacharatos et al. (2005) looked at High-Performance work systems and management practices in relation to occupational safety outcomes. Ale et al. (2008) used seven delivery systems or 'components of working safely'. Finally, Sklet et al. (2010) identified seven risk influencing factors. An overview of the themes these authors identified is included in Table 1.

As can be seen from Table 1 some similar concepts are included in most of these approaches though with different labels and level of detail. A questionnaire was central to the development of the 'basic risk factors'. The TRIPOD Delta checklist which was developed in the nineties uses a questionnaire-based approach to measure performance on these aspects (Hudson et al., 1991, 1998; Groeneweg, 2002). The instrument consists of a broad database of binary questions on observable characteristics of latent failures grouped into the factors. The instrument was used extensively in practice and was shown to provide additional insight into the performance of safety management systems over a purely audit based approach (Cambon et al., 2006) and was adapted to a healthcare setting (van Schoten et al., 2014). For the other taxonomies, quantification of organisational contributions to 'human error' has instead been focused on methods such as systematic interviews (Vinnem et al., 2012) and expert judgement (Ale et al., 2008;

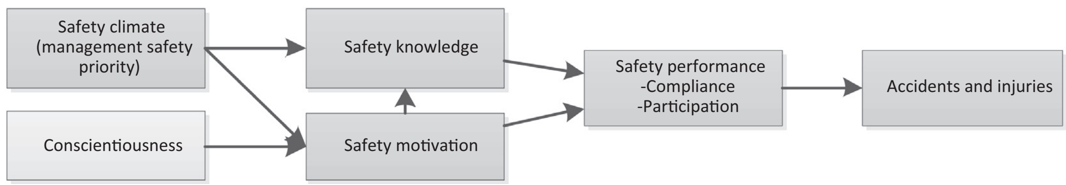

Fig. 1. Model of safety climate (adapted from Christian et al., 2009). The dark grey aspects have most support from Christian's meta-analysis. Christian added conscientiousness as well but the estimates were partly on generic rather than safety specific data (see Christian et al., 2009, p. 11).

Table 1
Risk factors and delivery systems.

Basic risk factors (Reason, 1990; Groeneweg, 2002; Wagenaar et al., 1994)	Common performance conditions (Hollnagel, 1998)	Delivery systems (Guldenmund et al., 2006; Duijm and Goossens, 2006)	Risk influencing factors (Sklet et al., 2010; Vinnem et al., 2012)	Delivery systems (Ale et al., 2008)	Zacharatos et al. (2005)
– Design	– Adequacy of man-machine interface and operational support	– Design specification, purchase, construction, installation, interface design/layout and spares	–	– Interface	–
– Hardware – Maintenance management	–	– Inspection, testing, performance monitoring, maintenance and repair	–	– Technology	–
– Housekeeping	–	–	–	–	–
– Error enforcing conditions	– Working conditions – Time of day (circadian rhythm) – Available time	–	– Workload and physical working environment – Work practice	–	–
– Procedures	– Availability of procedures/plans	– Procedures, plans, rules and goals	– Procedures and documentation	– Procedures	–
– Training	– Adequacy of training and expertise	– Competence, suitability	– Competence	– Competence	– Employment security – Selective hiring – Training
– Communication	–	– Coordination, communication	– Communication	– Communication	– Information sharing
– Incompatible goals	– Number of simultaneous goals	– Commitment, conflict resolution	–	– Motivation	– Contingent compensation – Transformational leadership
– Organisation	– Adequacy of organisation – Crew collaboration quality	– Availability, manpower planning	– Management – Management of change	– Availability	– Teams and decentralized decision making
– Defences	–	– Risk (scenario) identification, barrier selection and specification	–	–	–
–	–	– Monitoring, feedback, learning and change management	–	–	– Measurement
–	–	–	–	–	– Reduced status distinctions
–	–	–	–	–	– Job quality

Note: The aspects in this table have been sorted in such a way that broadly similar concepts are aligned in the same rows. A more precise matching of concepts is beyond the scope of this article.

Hollnagel, 1998). Finally, these factors have been identified as causal factors in a variety of incident investigations. For example in relation to the 'Storybuilder database' of accidents (Bellamy et al., 2007) and in a comparison between TRIPOD Delta and TRIPOD Beta (Groeneweg, 2002).

1.3. Challenges for further development

From our review of currently available safety questionnaires, challenges for further development were identified. Few, if any, questionnaires combine both motivational and behavioural aspects with workplace conditions and systems. More importantly, many studies show that operational processes play an important role in a organisations overall safety (e.g., Groeneweg, 2002; Hollnagel, 1998; Reason, 1990, 1997; Sklet et al., 2010). Yet, so far safety surveys mainly focus on safety measures or operational *safety* processes. For example, rather than looking at communication in general, safety surveys address communication of safety relevant information only (Sklet et al., 2010). This, however, misses out on a significant and recognized proportion of operational processes that can contribute to incidents.

In this paper, an instrument is introduced which promotes integral system management. The constructs included in the instrument aims not only at exposing direct safety weaknesses, but also shortcomings in the 'core business'. This based on the premise that if operational processes play a role in incidents, managing these operational process effectively and efficiently should result in fewer incidents. The goal of the instrument therefore is to measure and map the operational processes to give the organisation the necessary insights in which tools are most effective and in which parts of the organisation they should be employed.

2. Research goal

Given these challenges we set out to develop an instrument with which a wide variety of constructs, including safety and operational process themes from different disciplines, can be measured in a consistent and practical way.

2.1. Goals of the instrument developed

The new instrument should make large scale application in industry practical. This requires the design of a flexible instrument which makes it possible for users to select the topics of interest which are relevant for a particular project from a catalogue of separate constructs. Different combinations of constructs should still be easy to answer without forcing a cognitive burden on respondents through jarring changes. Constructs should therefore use a consistent writing style and the same or similar answer categories when possible. This last goal complicated an indiscriminate inclusion of existing instruments.

2.2. Goals of the present validation study

Goal of the present validation study is to briefly describe the constructs used in the instrument and to report on the tested reliability and construct validity for the developed constructs. This latter goal is achieved through reliability analysis, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The long-term goal of the project is to expand data-gathering using this instrument and to test criterion validity at the analysis level of an organisation. This study means to validate the first fifteen constructs both addressing motivational as well as workplace condition aspects of safety. Analysis is based on the application of the instrument amongst five organisations in the period 2013–2015.

3. Instrument development

The instrument was developed through the following phases:

- Identifying relevant themes.
- Defining and operationalising constructs.
- Preliminary use in eight projects.
- First analysis of statistical properties followed by first revision.

To start with, relevant themes were identified with a team of seven safety and human factors researchers. The constructs were subsequently operationalised using three to ten concrete items based on existing literature. Iterative scale and item generating sessions were held by one researcher whereas another researcher focused on identifying and refining items that could be used to measure the constructs. Subsequently two versions were reviewed by the other five researchers for conceptual clarity. This resulted in an item pool of approximately 300 items covering 38 constructs. These constructs include both direct safety measure (i.e., Priority for safety), but also various operational processes (i.e., Procedures). Table 2 provides an overview of the construct definitions and relevant references of the 15 constructs included in the analysis for this paper. In the remainder of this paper we will focus only on these 15 constructs. Table 6 also shows all individual questions included in the instrument for the 15 analysed constructs.

The first version of the questionnaire was tested across eight projects within organisations. Data were separately analysed using reliability analysis for each of these projects. A review was conducted based on these projects in which the following important considerations were made:

- Focus on the day-to-day (real-world) experiences of the employees;
- Concrete and clear questions, with minimal abstract language. The questions should be understandable for shop floor employees;
- Elimination of so-called 'double barreled' questions;
- Relevant, with a clear explanation of how each aspect is related to safety outcomes.

It was decided to change the response format from an agree-disagree format towards an item-specific format to reduce agreement/acquiescence bias (Saris et al., 2010; Podsakoff et al., 2003). Response formats were changed to 'frequency of occurrence' or on 'extent of occurrence'. In addition, a do-not-know answer option was added in an attempt to limit 'averaging tendencies' which may occur when respondents feel unable to answer a specific question. Questions were grouped thematically in order to facilitate responding through coherent groupings. This is known to enhance scale reliability compared to random groupings, although effects on scale validity are yet to established (Lam et al., 2002). These changes required rephrasing a sizable part of the questions.

An example of one construct as used is shown in Table 3. All constructs make use of this five-point answering format. Most constructs use the same answer categories, while for some constructs the answer categories vary due to the formulation of the questions (e.g., Not at all; To a limited extent; To some extent; To a great extent To a very great extent). The answering format was kept as similar as possible for all questions to allow comparison between constructs.

4. Validation

The measurement tool was further validated across multiple projects with organisations within different sectors (e.g. energy network organisations; drilling rigs; offshore installation; high tech food industry; chemical industry). The projects were conducted in the Dutch language in the Netherlands (four projects) and in the German language in Germany (one project). The instrument was used in one large project and replicated in four separate projects. The participating organisations were organisations who had approached TNO for gaining insight in the state of their safety. As such, we made use of a convenience sample that was self-selected. Nevertheless, the sample also represents the type of target organisation for which the current measurement tool is being developed.

As a result of differences in the exact assignment of each organisation (i.e., what aspects of safety climate was relevant for their particular case), there is variation in the constructs included for each individual project. This is due to the flexible nature of the instrument which allows some customization based on specific and individual cases. This analysis focuses on the main overlapping constructs. An overview of the projects and organisations is given in Table 4.

All projects were part of safety assessments conducted within the participating organisations. The projects were intended to gain insight into and propose improvements to factors that shape safety performance. All the organisations were engaged in relatively high risk activities such as chemical processing and the management of energy transport networks. Project 1 and 3 were business units of the same parent organisation. Four of the projects were conducted in organisations with operations partly subject to the European SEVESO-directive. Projects were part of organisation initiatives in which all, or a very large fraction, of the employees was approached.

4.1. Data analysis and preparation

Data analysis was conducted using IBM SPSS version 22 and R version 3.0.2 with the CFA package Lavaan (Rosseel, 2012).

Table 2
Overview of safety relevant constructs included.

Theoretical constructs	Description	Examples of earlier uses
Priority for safety	The extent to which (senior) management is committed to and prioritizes safety	Rundmo and Hale (2003), O'Dea and Flin (2003), Watson et al. (2005), Hansez and Chmiel (2010), Lekka and Healey (2012), Clarke (2013)
Leader consistency	The extent to which leader priority and commitment is perceived as consistent	–
Leading by example	Management encourages safe working by setting a good example	Fleming (2001), Wu et al. (2016)
Just culture	Balancing learning from failure with appropriate accountability; i.e. not blaming individuals for 'honest errors', but hold them accountable for wilful violations and gross negligence	Hudson (2007), Reason (1997), Dekker (2007, 2008), Dekker and Breakey (2016), Cromie and Bott (2016)
Staffing resources	The quality of the support and resources provided by the organisation for the task or work being performed	Hollnagel (1998), Zwetsloot et al. (2007), Reniers (2010)
Tasks roles and responsibilities	Clarifying roles and responsibilities so that all levels of management and employees are clear about which performance is expected	Hidden (1989), Hollnagel (1998), Health and Safety Executive (2002, 2003), Baker et al. (2007), Lekka and Healey (2012)
Procedures	The existence of adequate procedures with proper usability to deal with (safety) critical situations and operations to prevent violation and/or poor enforcement	Hollnagel (1998), Bell and Healey (2006), Deepwater Horizon investigation report (2010), Lindhout et al. (2010)
Management of organisational change	The extent to which changes (i.e. to working methods, organizational structure or staffing resources) are carried out by taking into consideration any potential consequences	Gupta (2002), Atherton and Gil (2008), Chief Counsel (2011), Guidelines for Managing Process Safety Risks During Organisational Change (2013)
Effective communication	Efficiency of communication between various sites, departments or employees both in terms of timeliness and adequacy	Hollnagel (1998), Groeneweg (2002), Newman et al. (2016)
Craftsmanship	The skillfulness and expertise of employees	Mascini and Bacharias (2012), Mascini et al. (2007)
Work planning	The quality of planning and coordination for various sites, departments or employees	Varonen and Mattila (2000), Rodrigues et al. (2015)
Training	The level and quality of training, together with operational experience	Meshkati (1991), Bell and Healey (2006)
Personal anticipation	The extent to which individual workers anticipate potentially risky conditions/events that may occur at work	Waugh et al. (2008), Probst et al. (2013)
Technical state	The extent to which the equipment and facilities of the organisation are of high quality	Hollnagel (1998), Groeneweg (2002)
Safety participation	Behaviours such as participating in voluntary safety activities or attending safety meetings	Griffin and Neal (2000), Neal and Griffin (2004), Curcuruto et al. (2015, 2016)

Table 3
Example construct items and answering format.

In my department	Never	Sometimes	Regularly	Often	Always	Do not know
there are sufficient colleagues to carry out the work	☐	☐	☐	☐	☐	☐
it is possible to arrange a replacement if someone is ill	☐	☐	☐	☐	☐	☐
it is necessary to put in a lot of overtime	☐	☐	☐	☐	☐	☐
the right people are available	☐	☐	☐	☐	☐	☐

Table 4
Organisations and projects.

	Year	Organisation business activity	Approximate organisation size	Dataset size before and after cleaning up	Response rate as percentage of administered	Method and language
Project 1	2014	Energy transport	2250–2500	N = 1553/1269	65%	Digital, Dutch
Project 2	2014	Chemical processing	250–500	N = 187/166	73%	Digital, Dutch
Project 3	2014	Energy transport	250–500	N = 258/235	84%	Digital, German
Project 4	2015	Specialty chemicals	1000–1250	N = 833/706	73%	Digital, Dutch
Project 5	2015	Equipment maintenance	150–200	N = 119/92	69%	Digital, Dutch

Respondents in all studies were free to interrupt and continue the questionnaire at will and could also skip questions or choose the 'do not know' response option. Missing data were expected and individual cases were deleted when the respondents had skipped a proportion of the questions when this was considered to be too large (20–30%). After these deletions, the remaining incidental blanks were substituted with the item mean.

The resulting dataset for Project 1 was randomly split in half. Cases were assigned to one of two groups of approximately equal size: Group 1 (n = 657) and Group 2 (n = 612). The datasets from Project 1 were used for the exploratory factor analysis step. The resulting datasets for the Projects 2 through 5 were used in confirmatory factor analyses. The data from Project 5 (n = 92) and Project 3 (n = 235) were combined to achieve a sufficiently large dataset (n = 327).

4.2. Reliability analysis

The Cronbach's alpha reliability statistics for the included constructs were computed; coefficients alpha above 0.70 are rated as (sufficiently) good and below 0.60 as inadequate (Joint American Educational Research Association, 1999). As reliability analysis is limited to correlation within a particular group of items more elaborate factor analyses were needed also.

4.3. Factor analysis

There is considerable discussion about the benefits of factor analysis and choosing between exploratory (EFA) techniques and confirmatory (CFA/SEM) techniques (e.g. Fabrigar et al., 1999; Russell, 2002; Matsunaga, 2015; Schmitt, 2011). The items in our instrument were grouped into hypothesized constructs based on their content during instrument development. However, the items were newly operationalized and had not yet been validated in this exact form. Therefore, we decided to use both EFA and CFA. The EFA we used to explore an underlying dimensional structure of respondents' answers. Replication with CFA was then used to confirm whether this structure was also apparent in data gathered during subsequent measurements. For the EFA the dataset derived from Project 1 was used with replications using CFA. In the CFA a second-order model in which individual constructs were grouped under overarching latent variables was tested additionally.

4.3.1. Exploratory factor analysis for Project 1

Extraction techniques used in EFA fit solutions to best describe a specific dataset. As a result poor replication of the underlying structure to a new dataset can occur and which has been noted (Guldenmund, 2007). In addition to replication using CFA we partly remedied this phenomenon by dividing our EFA data into two random halves (Project 1, first half, n = 657; Project 1, second half, n = 612).

The available literature additionally stresses the difficulty of choosing the right number of factors to extract (e.g. Fabrigar et al., 1999). An EFA can give different conceptual results depending on the number of factors extracted. There is a tendency to 'over-extract' factors when using common criteria such as the 'Kaiser criterion' (eigenvalues larger than one) and the so called 'bend in the scree plot' criterion (e.g. Hayton et al., 2004; Fabrigar et al., 1999). The recommended approach of a 'parallel analysis' was used to determine the number of factors to extract. In this approach, factor eigenvalues are compared to eigenvalues of a similar extraction from a completely random dataset (of the same size).

Finally, a decision had to be made on extraction and rotation techniques. Overall principal axis factoring (PAF) with oblique rotation is most appropriate for our instrument as intercorrelation between constructs is expected (Russell, 2002). A factor analysis with an oblique rotation can be used to identify factors even if they are not orthogonal. In the analysis PAF extraction and the oblique promax rotation were chosen.

EFA communalities were evaluated for both halves of the data from Project 1. For most items both halves gave a similar score for item communality. To decide on retaining items for the CFA step two cut-off values for the individual items were used at 0.6 and 0.5. All items with a loading value below 0.5 in both halves of the data were viewed as poorly contributing and were not included in the CRA analysis. If an item loaded poorly in one half of the data but more strongly (>0.6) in the other half of the data it was included into the CFA.

4.3.2. Confirmatory factor analysis for all data

Confirmatory factor analysis was conducted on the available datasets. Model fit was assessed using three fit indices: CFI, RMSEA and SRMR. Threshold values defined by Hair et al. (2006) were used which recognize that fit index thresholds are dependent on sample size and number of items. The CFA analyses in this project concern a relatively large number of items which requires a large sample size; as a rule-of-thumb the amount of subjects should exceed five times the amount of variables. To enable this, data from Project 3 and Project 5 have been combined and analysed jointly.

With each replication the 'simple factor structure' as indicated by the EFA analysis was tested first. For each replication this model was compared to a single factor model. In addition, a second-order factor model was tested along theoretically expected groupings. Latent variables were allowed to correlate in all cases, which is comparable to the choice for an oblique rotation in the EFA. Not all constructs were available in each dataset. In these cases, only the available constructs were used within the CFA model.

5. Results

5.1. Reliability analysis

Reliability coefficient alpha scores were computed for all the included constructs and datasets based on the original grouping of items. The coefficients ranged from 0.76 to 0.94, which is sufficient for group level analysis and offers the first step in the assessment.

5.2. Exploratory factor analysis

The first random half of the data consisted of n = 657 cases and 81 questionnaire items. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (0.94) indicated a highly sufficient number of cases.[1] Bartlett's test of sphericity was highly significant, χ^2(3240, N = 657) = 33,275, $p < 0.001$, indicating that items were correlated with other items. The second random half of the data which consisted of n = 612 cases was similarly suitable for the application of EFA.

The rotated component matrix was assessed in order to identify which items to keep and which to drop. Items were assessed on size of loading using the method described above using cut-off values of both 0.6 and 0.5. From the original 81 items, 13 items were dropped due to cross-loading or the lack of a distinct factor loading, leaving 68 items. In Table 6 the items that are dropped have been marked. Factor communalities for both halves of the data are shown below in conjunction with the CFA parameters in Table 5.

Fifteen constructs were hypothesized. The exploratory analysis suggested a twelve factor solution with three leadership aspects merged into one construct. In addition, two aspects of planning (work planning and personnel availability) emerged as a single construct in one of the two EFA halves.

6. Confirmatory factor analysis

Confirmatory factor analysis was conducted subsequently on the available datasets. Each dataset was analysed three times:

– <u>Model A</u>: a reference 'single factor model' in which all items were assumed to be related to only a single 'common factor'.
– <u>Model B</u>: a model as suggested by the EFA analysis using Horn's parallel criterion and using up to 12 constructs.
– <u>Model C</u>: a combined model in which 'leadership' and 'planning' were modelled as second order aspects.

If model A would exhibit the best fit to the data, this would be indicative of a single underlying factor for all items such as: 'a positive or negative assessment of safety'. Fit of model B would be indicative of the 12 factors from the EFA providing the best fit. Through model C it is hypothesized that the involved latent factors are themselves again grouped at a second order level. In Table 5 fit indices and tests are shown for the different models as applied to the data for the projects which were included.

For all models (A, B and C) a significant χ^2 is expected, given the size of the datasets, and this is also found. Model B provides a better fit than the simple single factor model in all cases. The second-order model (model C) outperforms the simpler 'model B' and leads to a modest increase in fit indices. Final models show a CFI value greater than 0.90 and a RMSEA value below 0.07.

Finally, the parameter estimates for each item in the questionnaire were assessed. When assessing the parameter estimates we

[1] Values should be higher than 0.50 in order to continue with the factor analysis.

Table 5
Fit indices for different factor models.

	Project 1	Projects 3 & 5	Project 2	Project 4
N	1269	327	166	706
Model A: Single factor				
CFI	0.40	0.49	0.59	0.48
χ^2	34,992	9288	1427	8868
DF	2210	1890	350	300
Model B: Up to twelve factors				
CFI	0.87	0.86	0.93	0.95
χ^2	9245	3790	520	679
DF	2144	1824	335	265
Final model: Including second-order factors				
CFI	0.92	0.90	0.95	[a]
χ^2	6400	3244	459	[a]
DF	2210	1819	333	[a]
p-value (χ^2)	0	0	0	0
RMSEA and 90% C.I.	0.040 (0.039–0.041)	0.049 (0.046–0.052)	0.048 (0.037–0.058)	0.047 (0.043–0.051)
RMSEA p-value (probability RMSEA < 0.05)	1	0,74	0,63	0,863
SRMR	0.052	0.056	0.051	0.034
Difference tests				
– Test of difference (A vs B)	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
– Test of difference (B vs C)	$p < 0.001$	$p < 0.001$	$p < 0.001$	–

[a] A second order factor model could not be tested with the data available from project 4.

observed the rule of thumb suggested by Hair et al. (2006) that a parameter estimate, i.e. the loading of an item onto a factor, greater than 0.5 was needed although it should preferably be above 0.7. In our final decision we weighed the items' performance in the available data. The combined table reproduced shows all items and their parameter estimates (Table 6). Based on the replications it was decided to drop three additional items for a total of 16 items dropped. One item was related to the construct 'just culture'. As a result, the construct is now only defined by two indicator items. It will be revised/expanded in later versions of the instrument.

7. Conclusion

This study reports on the development of a catalogue of constructs which were derived from scientific literature and practice and which are thought to be relevant for safety within organisations. The catalogue includes relevant constructs which are related to different scientific approaches – i.e. the safety climate approach and the workplace conditions and systems approach. Each of the constructs in the catalogue has been developed with a view towards measurability in an employee survey. A common problem in the development of safety surveys is that answering formats and themes are widely divergent. The constructs were developed to be similar in their wording and to use a consistent rating method. The harmonisation of question types and integration into a single format has the additional benefit that differences in the factor loadings of items are less likely to be the result of the method or form in which questions were posed.

Fifteen out of 38 constructs in the catalogue – which were considered to be the best developed and most widely used – were evaluated. The analysis was conducted on data derived from four projects within different organisations which are all active in high risk industries. The projects included a total of 2468 respondents. Internal consistency and discriminant validity was assessed using a combination of Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). Both approaches were combined and multiple datasets were used to limit the risk of overfitting within a particular dataset. EFA was conducted on two randomly split halves of the data from the largest project (P1) and presented an exploratory factor solution which substantially matched the design expectation and was similar across both random halves. Confirmatory factor analysis presented acceptable fit measures across the datasets from the different projects. Finally, a model in which three elements of safety leadership and two aspects of planning were organised using a second-order factor structure showed the optimal fit to the data.

Components focused on workplace conditions and systems were clearly distinguishable in the factor analyses from components focused on personal motivation. This shows that respondents – with the use of this survey – are able to provide a multi-component insight into elements of safety. The aggregated results can provide diagnostic information which can help organisations to find effective and efficient ways to improve their safety performance.

In conclusion, this instrument allows the mapping and quantification of various aspects of the operational process that are, based on existing knowledge (e.g., Groeneweg, 2002; Hollnagel, 1998; Reason, 1990, 1997; Sklet et al., 2010), related to the occurrence of incidents. This allows organisations to identify weak points in their operational process which if remedied contribute to a more effective, more efficient and therefore safer 'core business'.

8. Discussion

This study forms the first step in the goal to investigate and validate the developed constructs across datasets. Further expansion will allow for evaluation of the factor structure of new constructs where the same overall approach can be used. It will be critically important to continue to evaluate the uniqueness of each new construct with respect to existing measures. For example: considerable interest has been put towards the idea of a 'zero accident vision'. A new measure for the presence/absence of this type of vision in an organisation could be compared to existing constructs.

Several limitations should be noted with regard to the current study. Based upon current literature there is a presumed relation between the factors included in the measurement and safety outcomes. However, this relationship has not been tested in the present study. Safety outcomes in this case should be evaluated at the level of existing groups, for example, by correlating survey scores with organisation or business unit performance. To conduct an analysis with sufficient statistical power therefore requires a substantial number of participating organisations to acquire sufficient data.

Table 6
All items and their parameter estimates.

Variable		EFA communalities		CFA parameter estimates				Decision
	Procedures, guidelines and regulations in our company	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
procedures_01	are clearly written and expressed	0.64	0.62	0.63	0.73	0.64	0.77	Retained
procedures_02	are conflicting	<0.5	<0.5					Removed
procedures_03	are drafted by colleagues who are competent	0.54	<0.5					Removed
procedures_04	are easily accessible	0.78	0.72	0.69	0.71	0.62	0.67	Retained
procedures_05	are updated regularly and correctly	0.70	0.66	0.65	0.71	**0.58**	0.70	Retained
procedures_06	are known to the employees in the workplace	0.75	0.79	0.75	0.72	0.73	0.77	Retained
procedures_07	are easy to understand	0.85	0.74	0.73	0.72	0.78	0.78	Retained
procedures_08	really help in daily work	0.58	0.64	**0.57**	0.67	0.72	0.74	Retained
procedures_09	are changed without good reasons	<0.5	<0.5					Removed
procedures_10	are changed without communicating	<0.5	<0.5					Removed
	Our company ensures	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
training_02	that employees can practice their skills	,73	,85	0.70	0.70	0.80		Retained
training_03	that everyone is trained in major changes (such as new equipment or procedures)	,82	,88	0.83	0.79	0.78		Retained
training_05	that good training is available	0.88	0.87	0.84	0.76	0.85		Retained
training_06	that new employees will receive introductory training	0.58	0.58	**0.57**	0.72	0.67		Retained
	In our company	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
tvb_01	It is clear who does what and when	<0.5	<0.5					Removed
tvb_02	it is clear who has important knowledge and skills	<0.5	0.64	0.66	0.58	0.77		Retained
tvb_03	colleagues with important knowledge and skills are available when needed	<0.5	0.79	0.82	0.90	0.86		Retained
tvb_04	colleagues who are formally responsible are available when needed	<0.5	0.75	0.84	0.85	0.85		Retained
tvb_05	colleagues have sufficient authority for the execution of their tasks	<0.5	0.65	0.70	0.69	0.63		Retained
	Changes in the way of working or organisation	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
orgChange_01	are well prepared	0.67	<0.5	0.78	0.86			Retained
orgChange_02	are well thought out and planned	0.69	<0.5	0.80	0.92			Retained
orgChange_03	are implemented with care for safety	<0.5	<0.5					Removed
orgChange_04	follow one another too quickly	<0.5	<0.5					Removed
orgChange_05	are well directed/controlled	0.72	<0.5	0.92	0.84			Retained
orgChange_06	are guided well	0.66	<0.5	0.93				Retained
	In my department	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
persAvailable_01	there are sufficient colleagues to perform the work	0.75	0.68	0.72	0.66	0.67		Retained
persAvailable_02	it is possible to arrange a replacement if someone is ill	0.73	0.62	0.61	0.63	**0.56**		Retained
persAvailable_03	it is necessary to put in a lot of overtime	0.50	0.57	**0.27**				Removed
persAvailable_04	the right people are available	0.71	0.58	0.87	0.86	0.69		Retained
persAvailable_05	colleagues are available at the right time	0.68	0.64	0.85	0.86			Retained
	If employees make a mistake or commit an error	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
just_01	they are comfortable reporting this	<0.5	<0.5					
just_02	they are treated justly	0.57	0.53	**0.56**				Removed
just_03	they get unfairly blamed by the manager(s)	0.87	0.76	0.81	0.76		0.72	Retained
just_04	unjust sanctions are imposed	0.81	0.80	0.76	**0.57**		0.76	Retained
just_05	colleagues resent them for their error or mistake	0.63	0.64	**0.40**	**0.35**		**0.43**	Removed
Just_06	they are comfortable asking others for help	<0.5	<0.5					Removed
	In our department	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
plan_01	good working arrangements are made	<0.5	<0.5					
plan_02	activities are planned thoroughly in advance	0.72	0.75	0.86	0.84	0.82		Retained
plan_03	the right resources are available for carrying out the work	0.74	0.83	0.90		0.74		Retained
plan_04	activities are well coordinated	0.57	0.66	0.69	0.88	0.92		Retained
plan_05	the deployment of staff is planned well	0.57	0.76	0.82	0.85			Retained
	My managers	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
priority_01	are committed to safe and healthy working	0.85	0.70	0.74	0.71			Retained
priority_02	give safety a high priority	0.86	0.72	0.73	0.78			Retained
priority_03	take safety seriously	0.88	0.73	0.74	0.74			Retained
priority_04	overlook violations when it is very busy	<0.5	<0.5					Removed
priority_05	take safety into account when making investment decisions	<0.5	0.51					Removed
consistency_01	are predictable in their behaviour	<0.5	0.57					Removed
consistency_02	have a credible safety message	0.76	0.87	0.82	0.82			Retained
consistency_03	are consistent	0.67	0.83	0.79	0.78			Retained
consistency_04	Retained their promises	0.60	0.78	0.76	0.68			Retained

(*continued on next page*)

Table 6 (*continued*)

Variable		EFA communalities		CFA parameter estimates				Decision
	Procedures, guidelines and regulations in our company	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
rolemodel_01	set a good example	0.79	0.87	0.83	0.88			Retained
rolemodel_02	inspire employees to behave in a safe manner	0.74	0.77	0.83	0.85			Retained
rolemodel_03	do themselves what they ask of others	0.80	0.84	0.84	0.87			Retained
	The employees in my department	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
participate_01	voluntarily take on extra tasks to improve safety	0.73	0.70	0.64	0.67		**0.59**	Retained
participate_02	help each other to work safely	0.85	0.76	0.82	0.86		0.85	Retained
participate_03	discuss how the work can be done safely	0.90	0.89	0.85	0.87		0.87	Retained
participate_04	check whether a task can be done safely	0.93	0.89	0.88			0.82	Retained
participate_05	do everything to improve unsafe situations	0.77	0.83	0.82	0.86		0.78	Retained
participate_06	inform the manager(s) about unsafe situations	0.69	0.71	0.73	0.73		0.72	Retained
	The employees in my department	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
open_01	know how to give and receive criticism amongst each other	0.64	0.71	0.69	0.72	0.88	0.74	Retained
open_02	know how to conduct difficult conversations	0.74	0.83	0.67	0.79	0.81	0.68	Retained
open_03	address each other about behaviour	0.75	0.82	0.71	0.76	0.78	0.75	Retained
open_04	communicate openly and honestly with each other	0.85	0.82	0.87	0.83	0.91	0.86	Retained
open_05	communicate easily with each other	0.79	0.77	0.82	0.77	0.91	0.81	Retained
open_06	communicate openly and honestly with their supervisor	0.70	0.74	0.81	0.74			Retained
	The employees in my department	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
skilled_01	are professionally competent	0.87	0.83	0.85	0.83			Retained
skilled_02	know what is important when working	0.86	0.81	0.84	0.88			Retained
skilled_03	have experience doing the work	0.90	0.87	0.86	0.81			Retained
skilled_04	are knowledgeable about the work	0.92	0.90	0.88	0.89			Retained
skilled_05	do a good job	0.82	0.82	0.82	0.82			Retained
	_	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
anticipate_01	I anticipate potentially risky conditions/events which could occur during my work	0.74	0.87	0.78	0.85		0.81	Retained
anticipate_02	Whilst working I keep a close eye out for threats or dangers	0.80	0.88	0.87	0.87		0.83	Retained
anticipate_03	During work, I am attentive to signals which indicate a (possible) risk	0.81	0.88	0.87	0.89		0.79	Retained
anticipate_04	I have prepared for errors which may occur during work	0.83	0.74	0.65	0.72		0.62	Retained
anticipate_05	I investigate errors or deviations at work	0.75	0.74	0.61	0.67		**0.55**	Retained
	The equipment and facilities in our company	P1(h1)	P1(h2)	P1 (h1&h2)	P3 & P5	P2	P4	
techstate.pl_01	are of good quality	0.88	0.83	0.85	0.81	0.73		Retained
techstate.pl_02	are in a good technical condition	0.85	0.85	0.88	0.89	0.85		Retained
techstate.pl_03	are reliable and available	0.86	0.82	0.84	0.90	0.72		Retained
techstate.pl_04	are expertly maintained	0.71	0.76	0.65	0.82			Retained
techstate.pl_05	are maintained according to schedule	0.57	0.64	**0.51**	0.74			Retained
techstate.pl_06	are easy to operate	0.54	0.54	**0.49**	**0.50**			Removed

Items were developed with a focus on plain and straightforward language and reviewed extensively by representatives from participating organisations. There was no indication that questions were too difficult for the respondent in these organisations; however the method still requires that participants have sufficient language and intellectual abilities. The questions have not been tested and may not be suitable for employees with underdeveloped language abilities.

The study has been conducted in a relatively homogenous group of organisations in terms of activity and safety performance. This limits generalisability. All participating organisations put substantial effort into safety and had an active safety program. The approach should be expanded towards other types of organisations and safety domains, e.g., construction companies, hospitals.

In future research the safety survey results should be correlated to concurrent measures such as the outcomes of an audit of the safety management system or other safety and operational outcomes.

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