A comparative analysis of safety management and safety performance in twelve construction projects

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Acknowledgements

This study is a part of a research project about construction safety funded by the Research Council of Norway and the Norwegian Labour Inspection Authority. The funding sources had no involvement in study design, in the collection, analysis and interpretation of data, in the writing of the report, and in the decision to submit the article for publication. Study's content, conclusions, and the opinions expressed are those of the authors alone. The authors are grateful to Statsbygg and Tanja Dugstad for letting us study their construction projects, showing an extraordinary willingness to be open and to learn from successes and non-successes. The authors are also grateful to the interviewees (OHS-experts and project leaders at Statsbygg) for taking time to contribute their professional insight into the causes of safety performance in the projects studied. The authors are also grateful to Urban Kjellén and Trond Kongsvik for discussions and comments.

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Abstract

Introduction: Safety management in construction is complicated due to the complex "nature" of the construction industry. The aim of this research was to identify safety management factors (e.g. risk management and site management), contextual factors (e.g. organisational complexity) and combinations of such factors connected to safety performance.

Method: 12 construction projects were selected to compare their safety management and safety performance. An analytical framework was developed based on previous research, regulations and standards, where each management factor was defined. We employed qualitative comparative analysis (QCA) to produce case knowledge, compare the cases, and identify connections between the factors and safety performance. The material collected and analysed included e.g. construction planning documents, reports from OHS-inspections, safety indicators, and interviews with project leaders and OHS experts.

Results and conclusions: The research showed that: (1) the average score on 12 safety management factors was higher among projects with high safety performance compared to projects with low safety performance; (2) high safety performance can be achieved with both high and low construction complexity and organisational complexity, but these factors complicate coordination of actors and operations; (3) it is possible to achieve high safety performance despite relatively poor performance on many safety management factors; (4) eight safety management factors were found to be "necessary" for high safety performance, namely roles and responsibilities, project management, OHS management and integration, safety climate, learning, site management, staff management, and operative risk management. Site management, operative risk management, and staff management were the three factors most strongly connected to safety performance.

Practical implications: Construction stakeholders should understand that the ability to achieve high safety performance in construction projects is connected to key safety management factors, contextual factors and combinations of such factors.

Keywords:

- Occupational health and safety management
- Safety performance
- Construction safety
- Construction project
- Comparative methods
- Qualitative comparative analysis
- Causal complexity

1 Introduction

The construction industry in Europe (EU-28) had the highest share of fatal occupational accidents in 2015, with more than one in five accidents (Eurostat, 2018). Safety management in construction is demanding, since construction projects are technologically and organizationally complex (Lingard, 2013).

Previous research on the effectiveness of occupational health and safety management (OHSM) on safety performance is ambiguous, and the importance of different factors are debated (Zwetsloot, 2013). There is little research on the effect of safety management systems and programs on safety performance in construction. There is however some research that have identified factors potentially connected to safety performance in construction, for example management commitment (Loushine, Hoonakker, Carayon and Smith, 2006), subcontractor selection and management (Hallowell and Gambatese, 2009), worker involvement (Chen and Yin, 2013), interrelations between various project partners (Terwel and Jansen, 2014), site-specific safety plans (Hallowell and Calhoun, 2011), and safety culture (Choudhry, Fang and Mohamed, 2007).

The aim of this research is to identify how safety management factors, contextual factors and combinations of such factors influence safety performance. To do that, we (1) developed an analytical framework iteratively based on relevant literature and empirical results, (2) analysed documents (e.g. health and safety plans, inspection reports), safety indicators, and interviewed project leaders and OHS inspectors from 12 construction projects, and (3) assessed factors and combinations of factors connected to safety performance employing Qualitative comparative analysis (QCA) (Ragin, 1987; 2008). The study was performed in cooperation with Statsbygg, a Norwegian government client organisation who build and rehabilitate public buildings.

Construction contractors have traditionally been held responsible for OHS on construction sites (Lingard and Rowlinson, 2005). In 1992, the EU Construction Sites Directive (92/57/EEC) (European Commission, 1992, 2011) put heavy responsibility for OHS on the client. The motivation for the directive was the recognition that many occupational accidents had been attributed to unsatisfactory architectural and/or organisational options, poor planning and inadequate co-ordination (Berger, 2000). Clients can play a positive role in safety management during construction projects (Huang and Hinze, 2006; Spangenberg, 2010; Lingard, Oswald and Le, 2018). This paper focuses on safety management in construction projects primarily from a client's perspective.

2 Literature on safety management

Safety management can be defined as "the *process* to realise certain safety functions", and a safety management system (SMS) is commonly defined as "… the management procedures, elements and activities that aim to improve the safety performance of and within an organisation" (Li and Guldenmund, 2018, p. 96). An occupational health and safety management system (OHSMS) is defined as "A set of interrelated or interacting elements to establish OSH policy and objectives, and to achieve those objectives" (ILO, 2001, p. 19). The purpose of an OHSMS is to "provide a framework for managing OH&S risks and opportunities" (ISO, 2018, p. vi). In this research we use the term *safety management* to include both specific safety management factors as well as general management factors that can influence safety performance.

Tinmannsvik and Hovden (2003) distinguish between safety specific factors (management factors mainly to promote safety) and general management factors (management factors to improve the production system and organisation in general). In this research we include both safety specific factors as well as other management factors with a potential of influencing safety performance, like e.g. staff management and project management. This is in line with Hale (2003b), who argues that safety management should be seen as an aspect system, not a subsystem, of the organisation.

The literature reviewed use different terms – safety management (SM), occupational health and safety management (OHSM), and safety programs. In this research we use the term *safety management* to include all these terms. Risk control and safety management is often seen in terms of a hierarchy of system levels (Rasmussen, 1997; Reason; 1997; Hale, 2003a). The operational work is at the lowest level, where the accidents happen, being controlled by technology and human behaviour, which is in turn controlled by management provision of resources, information and instruction. These in turn are influenced by policy, regulation, market and other societal forces (Hale, Guldenmund, Van Loenhout and Oh, 2010).

Hale (2003a; 2005) argues that we know "quite securely" the structure of a good safety management system, including, (1) an anchorage to the specific hazards of the production, (2) a life cycle approach, (3) problem-solving at three levels (operational, tactical, strategic), (4) systems at the tactical level delivering the crucial resources and controls for safety-critical tasks at the operational level, and, (5) feedback and monitoring loops ensuring assessment against performance indicators at each of the three levels.

The research on the effectiveness of OHSMSs on safety performance is however ambiguous. In a literature review, Gallagher, Rimmer and Underhill (2001) concluded that OHSMSs can deliver more healthy and safe workplaces under the right circumstances. In another review, Robson et al. (2007) concluded that the body of evidence was insufficient to make recommendations either in favour of or against OHSMSs. In a review of the effectiveness of safety management systems (SMS), Thomas (2011) concluded that organisations with a certified SMS had significantly lower accident rates. There was however a lack of agreement about which components of a safety management system contributed the most to safety performance. Zwetsloot (2013) argue that the difficulties in demonstrating the effects of OHSMS on safety performance can be explained that many do not consider "contextual factors" like the ambitions and commitment of management, the participation of workers, and the continual adaptation to changing circumstances. Zwetsloot (2013) also argues that the system is more than the sum of its parts and the interactions between the elements are just as important as the elements.

A literature review of 49 studies of safety management and quality management in construction projects supported the use of integrated safety and quality management (Loushine, Hoonakker, Carayon and Smith, 2006). The characteristics found to contribute to improved construction safety were management commitment, employee involvement, a formal safety management program, training, audits and observations, continuous improvement, and communication.

Hallowell and Gambatese (2009) identified from previous research 13 critical elements of an effective construction safety program: a written and comprehensive safety and health plan, upper management support, job hazard analyses and hazard communication, safety and health orientation and training, frequent worksite inspections, emergency response planning, record keeping and accident analyses, project-specific training and regular safety meetings, safety and health committees, substance abuse programs, safety manager on site, subcontractor selection and management, and employee involvement safety and evaluation. Hallowell and Calhoun (2011) quantified the interrelationships between these 13 elements and concluded that the most central elements in an effective program were the site safety manager, worker participation and involvement, a site-specific safety plan, and upper management support and commitment. Another important conclusion was that many of the strategies found to be effective in isolation also provided a high level of synergistic effects that enhance the effectiveness of other elements.

In a review of 90 papers, Mohammadi, Tavakolan, and Khosravi (2018) identified 13 factors influencing safety performance in construction: motivation, rules and regulation, competency, safety investment and costs, financial aspects and productivity, resource and equipment, work pressure, work condition, culture and climate, attitude and behaviour, lesson learned from accidents, organization, and safety programs and management systems. They also concluded that safety performance is not only determined by management activities within project levels, but also by the interactions among factors at different hierarchical levels.

The ISO 45001 (Occupational health and safety management systems, ISO, 2018) also states that effectiveness and the ability to achieve the outcomes of an OHS system are dependent on a number of key factors, for example top management leadership and commitment, communication, consultation and participation of workers, allocation of necessary resources, risk management, continual performance evaluation and monitoring, integration of the OHSM system into the organisation's business processes (ISO, 2018).

Summarised, the research on safety management in construction shows several factors connected to safety performance. Some studies also show that certain combinations of factors increase the effect on safety performance. Based on a literature review, Mohammadi et al. (2018) suggested that more research is needed to investigate the interaction between the identified factors and determine how they are able to affect safety performance, which is one of the aims of this research.

3 Material and methods

3.1 Analytical framework

In qualitative comparative analysis (QCA), explanatory models are developed in an *iterative* manner to facilitate a dialogue between theory and evidence as described by Ragin (2014). The analytical framework (Table 1) was therefore developed in an iterative manner and employed for measuring and comparing safety performance and safety management in 12 construction projects.

A preliminary framework was developed based on previous research, regulations and standards. Important sources were: (1) The ConAC framework (Haslam et al., 2005), which we had used to identify deficiencies in management factors (and other factors) in construction accidents (Winge and Albrechtsen, 2018); (2) Hale et al. (2012), who developed an analytical framework for understanding underlying causes of construction fatal accidents; (3) Törner and Pousette (2009) who carried out an inductive, qualitative interview study of experienced workers (worker safety representatives) and first-line supervisors in construction to identify "preconditions and components of high safety standards" in the construction industry; (4) The Directive 92/57/EEC (European Commission, 1992) and the Norwegian version, the Construction Client Regulations (Directorate of Labour Inspection, 2009), which specify key elements for OHS management systems in construction; (5) The OHSM system standards by ILO (2001) and ISO (2018). Many of the detailed analytical questions underlying the relatively broadly defined factors in the framework were adapted from the safety management and organisation review technique (SMORT) which was originally based on the management oversight and risk tree MORT (Johnson, 1980). SMORT was originally published by Kjellén, Tinmannsvik, Ulleberg, Olsen, and Saxvik (1987) and is later revised based on more recent experiences and standards (Kjellén and Albrechtsen, 2017).

The preliminary analytical framework consisted of 18 main categories and 83 subcategories. The framework was then tested on the documentation collected (see section 3.4 and 3.5) from eight projects and revised. Then the framework was tested as an interview guide for semi structured "pilot interviews" with three projects leaders (for client) and revised to the final version with the 16 categories displayed in Table 1.

The factors in the framework can be divided into different categories. Since we focus primarily on the execution stage of construction projects, factors 1-4 are treated as "contextual factors". They are to some extent "contextual" factors and/or decisions made at an early stage. Factor 5 (contract management) can be seen as both as a contextual factor and a safety management factor. Factors 6-16 represent the safety management process of the project. Factors 13-16 to large extent manage the workplace – the "sharp end".

Table 1. Operational definitions of outcome and factors

Name	Description
OUTCOME:	
Safety performance (SP)	Assessment of the overall safety at site based on: (1) interviews with OHS-inspectors about their assessments of the relative extent of hazards and dangerous situations; (2) interviews with the client project leaders about their assessments of the relative extent of hazards and dangerous situations; (3) reports from audits/inspections; (4) analysis of all registered dangerous situations (RUOs and SDs); and (5) the total recordable injury rate (TRI-rate).
CONDITIONS /FACTORS:	
1. Construction complexity (CC)	The characteristics and inherent complexity of the project, the structure being constructed (buildability), location, and physical restrictions of the site.
2. Organisational complexity (OC)	The extent of use of subcontractors, other companies and hired workers relative to project size.
3. Time (TI)	Progress plans, time pressure and delays.
4. Economy (EC)	Whether the project was on budget, and whether contractors made money.
5. Contract management (CO)	Contracting strategy, contract type, cooperation between client and contractors, and the contractor's commitment to OHS.
6. OHS-planning (PL)	Whether OHS was part of project planning and activities: Adequate SH-plan communicated to all actors and regularly updated; assessment of risks in advance with specific measures; and progress plans.
7. Roles & responsibilities (RO)	The presence, clarity and performance of roles central to OHS (client, principal enterprise, coordinators for the planning stage and execution stage, HS staff).
8. Project management (PM)	Coordination, cooperation, communication and follow-up of actors on OHS.
9. Management commitment to OHS (MC)	Commitment to OHS by managers (client and contractors) and emphasis on and integration of safety management with project management.
10. Safety climate (SC)	Attitudes, communication, openness and trust regarding OHS.
11. Learning (LE)	Learning from incidents, accidents and deviations through reporting, safety walks and inspections.
12. Performance evaluation (PE)	Ability to evaluate OHS performance and implement measures.
13. Operative risk management (RM)	Operative risk management by people in direct control of the risk at the operational level (planning of operations to reduce risk).
14. Site management (SI)	Site organisation, storage, logistics, housekeeping and provision of physical barriers.
15. Staff management (SM)	Planning to ensure the availability of sufficient workers with adequate capacity that is competent and suitable. Supervision and follow up of safety behaviour (short-cuts and compliance) on site.
16. Hardware management (HA)	Availability, condition, usability and suitability of materials and equipment.

3.2 Qualitative comparative analysis (QCA)

Hale (2003a) argued that we need to do comparative studies of good and bad companies to see "… what features are crucial" (ibid. p. 192). We employed Qualitative comparative analysis (QCA) (Ragin, 1987; Ragin, 2008) to identify conditions and combinations of conditions connected to safety performance. QCA uses the terms "condition" (causal factor), outcome, and connections (associations). In this research we use the term *condition* when using QCA, and otherwise use the term *factor* since that is the term used in most of the safety literature studied.

QCA is a methodological approach for comparing cases, producing case knowledge and identifying associations between conditions and the outcome. QCA strives to meet two apparently contradictory goals of in-depth insight into cases and complexity, and the production of generalisations (Ragin, 1987). Comparative studies of "good" and "bad" construction projects is also an opportunity to study both what goes right (safety I) and what goes wrong (safety II) in safety management in construction projects (Hollnagel, 2014).

QCA is a set-theoretic approach where concepts are understood as sets in which cases have membership. There are two types of sets. Crisp sets allow only full membership (1) and full non-membership (0). Fuzzy sets allow for partial membership in addition to full membership and non-membership where the point of maximum ambiguity (fuzziness) is .5. A fuzzy set can be seen as a continuous variable that has been calibrated to indicate degree of membership. Researchers must use substantive and theoretical knowledge to calibrate membership.

The approach is based on a notion of causal complexity, where outcomes are produced by combinations of conditions (configurations), and that different configurations can produce a similar outcome (equifinality). QCA is very well suited to researching complexity (Gerrits and Verveij, 2018). When QCAs are undertaken, we look for conditions that are *necessary* parts of a combination of conditions (configurations). A condition (X) is necessary if, whenever the outcome (Y) is present across cases, the condition (X) is also present. We also look for configurations that are *sufficient* to explain the outcome. A condition or configuration is *sufficient* if, whenever it is present across cases, the outcome is also present (If X, then Y). There can, however, be several configurations that are sufficient for the outcome (equifinality). Sufficient conditions or configurations can produce the outcome alone, but there can also be other conditions/configurations with this ability.

QCA has gained increased in popularity in recent decades, especially in the disciplines of comparative politics, business and economy, sociology, and management and organisation (Roig-Tierno, Gonzalez-Cruz and Llopis-Martinez, 2017). As QCA is a relatively new technique, we explain its basic logic and steps (for a detailed treatment, see Ragin, 2008, and Schneider and Wagemann, 2012). Data analysis was performed using the fsQCA 3.0 for Windows software (Ragin and Davey, 2017) and its software manual (Ragin, 2017).

3.3 Case selection

The study was performed in cooperation with Statsbygg, a government client organisation responsible to the Norwegian Ministry of Local Government and Modernisation (KMD). Statsbygg build and rehabilitate state public buildings, such as court buildings, prisons, museums and university buildings. Statsbygg is actively involved in safety management in projects with project staff present at the site and following up production and OHS regularly.

The sampling was carried out in dialogue with OHS experts in Statsbygg based on their familiarity with projects. The cases were selected based on three criteria: 1) Projects initially assessed to have relatively high or low safety performance were selected, because it is advantageous to include cases with a "positive" or a "negative" outcome in comparative methods (Berg-Schlosser, De Meur, Ragin and Rihoux, 2009). 2) Projects relatively similar in size (working hours), building type, and contractual arrangements were selected to keep these conditions as constant as possible; 3) Projects that were finished or more than halfway finished were selected making it possible to compare safety performance.

Materials from eleven different projects were collected. One project was much larger than the others. This project experienced many problems in the first part of the executions stage regarding project management and safety management. It was paused for some weeks and several measures were implemented. Since the two parts of the execution stage were very different as regards safety management, it was decided to analyse it as two cases. The number of cases analysed is therefore 12.

Statsbygg is one of Norway's largest clients, with a top management strongly committed to OHS. The client and projects are therefore not "representative" for construction projects, and the projects are not representative of Statsbygg's projects, since most Statsbygg projects have a high safety performance.

3.4 Measuring safety performance

Oswald, Zhang, and Lingard (2018) argue that great care needs to be taken when using safety indicators to evaluate organisational safety policy and practices. Common health and safety indicators can for example be subject to manipulation and misinterpretation. In this research we found indications that some injuries that should have been registered as lost time injuries (LTIs) were registered as medical treatment injuries (MTIs). LTI-rate was therefore assessed to be a relatively unreliable indicator since systems of registration were different across the projects studied, in addition to other weaknesses of the LTI-rate (see Kjellén and Albrechtsen, 2017). The total recordable injury rate (TRI-rate) was assessed to be the only reliable quantitative injury indicator with which to indicate safety performance. TRI-rate is more robust than LTI-rate since the number of injuries is higher. TRI-rate includes mostly less severe injuries and is therefore primarily an indicator of the presence of less severe hazards and occurrences.

The data collection took place after the projects were finished, or in some cases, more than halfway, making it possible to assess results from most of the construction period. It was therefore not practicable to use safety climate surveys or other leading indicators. Because of limitations in the safety indicators, and difficulties using more leading indicators, we chose to do a researcher-based assessment of safety performance based on five sources (triangulation):

1. The total recordable injury rate (TRI-rate).
2. Analysis of all registered dangerous situations (RUOs and SDs).
3. Reports from OHS audits/inspections (see section 3.5.2).
4. Interviews with client project leaders about their assessments of the extent of hazards and dangerous situations relative to the project size.
5. Interviews with OHS-inspectors about their assessments of the extent of hazards and dangerous situations relative to the project size.

Table 2 describes the indicators used. We interpret the number of "registered dangerous situations" (RUO & SD) primarily as an indicator of willingness to report and tackle safety issues, not as an indicator of high levels of danger (Hale et al., 2010).

Table 2. Materials, numbers and indicators used to assess safety performance and willingness to report.

Abbreviations	Description
WH	Working hours registered by main contractor, subcontractors and hired workers. Working hours by designers not included.
LTI-rate	Lost time injuries (LTI) per 1 million working hours. LTIs are injuries resulting in more sick leave than just the day of injury as reported by the contractors to the client.
MTI-rate	Medical treatment injuries (MTI) per 1 million working hours. MTIs are reported from the contractors to the client.
TRI-rate	Total recordable injuries (TRI=LTI+MTI) per 1 million working hours. Reported from the contractors to the client.
RUOs & SDs	Registered unwanted occurrences (RUO) include accidents and near accidents. Site deviations (SD) include deviations from regulations registered by contractors and client on mostly safe job analysis (SJAs), working instructions, lack of personal protective equipment, failure of scaffolding, and danger zones not defined.
WTR	Willingness to report: RUO&SD per 1 000 working hours.

3.5 Measuring safety management factors and contextual factors

Different materials were used and triangulated to assess the factors in Table 1: safety and health plans, inspection and audit reports, logs of OHS-related information, and interviews with OHS coordinators and project managers.

3.5.1 The client's safety and health plan (SH plan)

Directive 92/57/EEC (European Commission, 1992) and the Norwegian version, the Construction Client Regulations (Directorate of Labour Inspection, 2009), require the client to produce a plan for safety and health plan (SH plan), which must be communicated to all actors in the construction project. The SH plan is the client's documentation that the work is planned and that risks are assessed in advance, and a *tool* for the client ensuring that the work is carried out without health and safety risks. The SH plan must describe (1): the organising of the project, including roles and responsibilities for OHS; (2) a progress plan describing when and where the various work operations are to be carried out, for example, coordinating various work operations; (3) specific measures connected to activities that may involve risks to life and health with specific measures for work involving risk; and (4) procedures for handling deviations. During the execution phase the SH plan must be updated after any changes that may affect health and safety. There can thus be many versions of the SH plan during a project. Between two and four SH plans from different phases for each project were analysed.

3.5.2 Reports from OHS audits/inspections

OHS audits/inspections of projects are regularly conducted and led by OHS experts from the OHS department at Statsbygg. Other participants include representatives of project management in Statsbygg and representatives from the main contractor (e.g. project leader, supervisor, OHS expert). The OHS inspection reports consist of: (1) document reviews (SH plan, progress plans, SJAs, list of workers, companies, RUOs, etc.); (2) interviews with central persons (e.g. managers, coordinators, safety representatives); (3) description of site inspection focusing on deviations; and (4) requirements for following up deviations. The reports also include descriptions and pictures from the sites.

3.5.3 Log on OHS related information

OHS related occurrences and activities were registered continually during the projects, including results from safety rounds, SJAs, deviations, RUOs, dangerous operations, accidents, near accidents, OHS inspections and updates of the SH plan. More information was registered in the "poor" projects than the "good" projects. The descriptions gave a good overview of the projects and their development.

3.5.4 Interviews

After analysing indicators, SH plans, OHS inspection reports and OHS logs, interviews with client project leaders (PL) were undertaken. The interviews lasted between 60 and 90 minutes using videoconferencing or telephone. Interviews with OHS inspectors/experts were undertaken after all the documents and PL interviews were analysed. Four OHS experts who had each been inspecting several of the projects were interviewed about each of the projects. OHS experts who had inspected a project at least twice were selected for interview for that particular project. Before the interviews, the OHS experts read summaries of the preliminary analysis. All interviews were undertaken to supplement the documented information and to triangulate (verify or contradict) information from documents. The interviews were recorded and transcribed by the first author. One of the OHS experts and co-author of this article (Arnesen), had participated at inspections of all the projects and knew all projects well. He also participated in the analysis, which was a crucial advantage for data collection and analysis.

All in all, 22 interviews were carried out. Eleven interviews with client project leaders (one assistant project leader) and eleven interviews with OHS inspectors for each project were carried out. The interviews were semi-structured, using the analytical framework as an interview guide with both project leaders and OHS inspectors. The interviews were conducted as a dialogue, exploring how different factors affected the situations on site, and safety performance. The dialogue enabled the quality of different aspects of project performance to be compared.

4 Results

4.1 General characteristics of the projects

We do not present detailed information about the cases, and the projects are anonymised for reasons of sensitivity regarding the companies and persons involved. The buildings were museums and university buildings, mostly new buildings and rehabilitations of old buildings. Some projects also included groundworks and demolition. The number of working hours varied from some 17,000 to 1,150,000, with an average of 305,000.

4.2 Employing qualitative comparative analysis (QCA)

The results of the calibration of the outcome and the conditions (factors) are presented in Table 3. Recall that the calibration of the outcome and the condition scores are based on assessments of different types of data (triangulation) (see Section 3). The choice of the number of values for the outcome and each condition was based on the characteristics of each condition. For the outcome (safety performance) we used the six-value set with the values *very good* (1.0), *relatively good* (.8), *adequately* (.6) etc. We used the crisp set (0 or 1) for five conditions and the four-value set (0, .33, .67, 1) for eleven conditions.

The second column in Table 3 shows the assessment of the outcome safety performance (SP). Half of the projects were considered to have relatively *high* safety performance (HSP) (.5<) and the other half relatively *low* safety performance (LSP) (.5>). This was not a coincidence since we selected projects that were initially assessed to have relatively high or low safety performance (see Section 3.3). The average score for the safety management factors (factors 5-16 in Table 1) was .53., for all projects, .77 for the HSPs, and .30 for the LSPs. Hardware management (HA) was assessed as good in all projects. The opinion of the client project leaders and OHS inspectors was that poor material and equipment is not tolerated, and when identified, measures are taken immediately. This means that hardware management cannot be included in QCA because it is a constant, and not a variable.

Table 3. Raw data for 12 construction projects

Case	SP	CC	OC	TI	EC	CO	PL	RO	PM	MC	SC	LE	PE	RM	SI	SM	HA
A	1	1	1	1	1	1	.67	1	1	1	1	1	1	1	.67	1	1
B	.8	.33	0	1	1	1	.67	1	1	1	.67	.67	1	1	.67	.67	1
C	.8	.33	.67	1	1	1	.33	.67	1	1	.67	.33	1	.67	.67	.67	1
D	.8	1	.67	0	0	0	.33	.33	.33	.33	.33	.33	1	.67	.67	.33	1
E	.6	.33	1	1	1	1	.33	.67	1	1	1	1	1	.67	.67	1	1
F	.6	0	0	1	1	1	.33	1	.67	.67	.67	1	1	.67	.67	.33	1
G	.4	.33	.33	1	1	0	.33	.33	.33	.33	.33	.67	0	.33	.33	.33	1
H	.4	.33	0	0	0	0	0	.33	.33	.33	0	.33	0	.33	.33	.33	1
I	.4	0	0	0	0	0	0	.33	.33	0	.33	.33	0	.33	.33	.33	1
J	.2	.33	.33	1	0	1	.33	.67	.33	.33	.33	.33	0	.33	.33	.33	1
K	.2	.67	.67	0	0	0	.33	.33	.33	.33	.33	.33	0	.33	.33	.33	1
L	0	0	.67	1	0	0	0	0	0	0	0	0	0	0	0	0	1

Note: Safety Performance (SP), Construction Complexity (CC), Organisational Complexity (OC), Time (TI), Economy (EC), Contract Management (CO), OHS-Planning (PL), Roles and responsibilities (RO), Project Management (PM), Management Commitment (MC), Safety Climate (SC), Learning (LE), Performance Evaluation (PE), Operative Risk Management (RM), Site (SI), Staff management (SM), Hardware management (HA).

4.3 Set coincidence

Set coincidence is the degree to which two or more sets overlap, or, in other words, the extent to which they constitute one and the same set (Borgna, 2013). Fuzzy-set coincidence is "… a special case of correlation" (Ragin, 2008, p. 59). A set coincidence score close to 1 indicates that most of the cases share exactly the same degree of membership in two sets. If two conditions have the same values in all projects, they can be merged into one, if it is theoretically advisable. The procedure was used to assess which conditions strongly coincide (.75≤), and whether they should be included in further analysis. Table 4 shows that staff management, operative risk management, roles and responsibilities, site management, project management, and safety climate strongly coincide with several conditions.

Table 4. Set coincidence matrix for 16 conditions in 12 construction projects.

Conditions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1. Construction complexity															
2. Organisational complexity	.58														
3. Time	.27	.43													
4. Economy	.28	.36	**.75**												
5. Contract management	.28	.36	.48	.71											
6. OHS-planning	.56	.42	.35	.38	.38										
7. Roles and responsibilities	.47	.44	.57	.58	.65	.55									
8. Project management	.48	.50	.57	.65	.65	.55	**.82**								
9. Management commitment	.50	.52	.59	.68	.68	.58	**.77**	**.95**							
10. Safety climate	.47	.57	.52	.59	.59	.64	**.76**	**.85**	**.80**						
11. Learning	.50	.46	.53	.61	.54	.58	**.77**	**.77**	.73	**.80**					
12. Performance evaluation	.40	.42	.56	.71	.71	.38	.58	.65	.68	.59	.54				
13. Operative risk management	.57	.52	.48	.54	.54	.58	**.86**	**.86**	**.81**	**.80**	.73	.61			
14. Site management	.55	.50	.42	.46	.46	.64	**.76**	**.76**	.72	**.79**	.71	.53	**.90**		
15. Staff management	.55	.57	.46	.52	.52	.65	**.76**	**.85**	**.80**	**.89**	**.80**	.52	**.80**	**.79**	
16. Hardware management	.39	.45	.67	.50	.50	.30	.56	.55	.53	.47	.53	.50	.53	.47	.47

4.4 Necessary conditions

Consistency and coverage are parameters used to assess how well the cases in a data set fit a relation. *Consistency* resembles significance in statistical approaches where 0 indicates no consistency and 1 indicates perfect consistency. The consistency value for conditions should be higher than 0.75 (Schneider and Wagemann, 2012). If a relationship is established to be consistent, the coverage should be calculated. *Coverage* assesses the degree to which a condition accounts for instances of an outcome, or empirical relevance (Ragin, 2008). With a consistency threshold of 0.80, the results indicate that eight of the OHSM conditions are "necessary" for high safety performance, indicating that high safety performance cannot be achieved without high performance on that specific condition (e.g. operative risk management) (if Y, then X). The coverage (empirical relevance) is also high for these eight conditions. Hardware was previously identified as a constant and therefore cannot be included in the analysis.

Table 5. Necessary conditions for the outcome safety performance. N=12. Consistency and coverage.

Condition	Consistency	Coverage
1. Construction complexity	.62	-
2. Organisational complexity	.59	-
3. Time	.71	-
4. Economy	.68	-
5. Contract management	.64	-
6. OHS planning	.55	-
7. Roles and responsibilities	.87	.81
8. Project management	.89	.83
9. Management commitment	.84	.82
10. Safety climate	.80	.87
11. Learning	.80	.79
12. Performance evaluation	.74	-
13. Operative risk management	.92	.91
14. Site management	.85	.93
15. Staff management	.81	.89
16. Hardware management	-	-

4.5 Conditions and models for QCA analysis

The aim of QCA analysis is to identify combinations of conditions that are *sufficient* for the outcome (if X, then Y). This process requires four steps: (1) presenting the data in a truth table; (2) minimising the truth table; (3); reporting the parameters of fit for the solution formula, and (4) interpreting the results.

The number of conditions in QCA must be kept quiet low; three to eight conditions are recommended (Ragin, 2008). The problem is that as the number of binary conditions increases, the number of possible combinations of these variables increases exponentially, so-called limited diversity (Ragin, 1987). One strategy for including more conditions is to conduct separate QCAs for different sets of conditions (Gerrits and Verweij, 2018). We decided to conduct two QCAs, one including "contextual conditions" and one for "OHSM conditions".

4.6 QCA for contextual factors combined with operative risk management

The aim of this first QCA was to detect combinations of "contextual conditions" (project complexity, organisational complexity and contract management) combined with OHSM. Operative risk management is included in the analysis to represent OHSM. Operative risk management was selected because it coincides (overlaps) strongly with many of the other OHSM conditions (see Table 4).

4.6.1 Truth table

A truth table lists all possible logically possible configurations. Each row in the truth table represents one logically possible configuration (Ragin, 1987). Each case in the raw data matrix (Table 3) is assigned to the respective truth table row which it belongs. The fuzzy conditions need to be dichotomised to match calibrated fuzzy cases into a truth table. A fuzzy set score below 0.5 is dichotomised to 0, and a fuzzy set score above 0.5 is dichotomised to 1. The truth table shows the configurations as dichotomies, but the calibrated cases remain fuzzy. Since we include four conditions that can score either 0 or 1, there are 16 logically possible combinations of the four conditions. The truth table for the outcome *high* safety performance (Table 6) shows that there are cases in eight out of the 16 possible configurations. Column number 2-5 indicate the qualitative status of the four conditions (present 1 vs. not present 0). Column "SP" indicates whether the given row is sufficient for the outcome "high safety performance" (score of 1) or not sufficient (0). The decision about sufficiency is based on each row's consistency score ("Cons."). Consistency expresses the degree to which empirical evidence supports the claim that a set-theoretic relation exists. Values below 0.80 indicate substantial inconsistency. PRI is a consistency score that is more sensitive to the possibility that one row can be a subset of the outcome as well as its negation. This yields four rows which include six cases that are considered *sufficient* for high safety performance, and four rows including six cases that are considered *not sufficient* for high safety performance. The "Cases" column shows the labels of cases that are members of a given row.

Table 6. Truth table for contextual conditions with high safety performance.

Row	**CC**	**OC**	**CO**	**RM**	**SP**	**Cons.**	**PRI.**	**Cases**
1	1	1	1	1	1	0.93	0.90	A
2	1	1	0	1	1	0.90	0.78	D
3	0	0	1	1	1	0.90	0.80	B, F
4	0	1	1	1	1	0.88	0.77	C, E
5	1	1	0	0	0	0.65	0.22	K
6	0	0	1	0	0	0.65	0.22	J
7	0	0	0	0	0	0.52	0	G, H, I
8	0	1	0	0	0	0.40	0	L

Note: Construction Complexity (CC), Organisational Complexity (OC), Contract Management (CO), Operative Risk Management (RM), and Safety Performance (SP).

The occurrence and non-occurrence of the outcome require separate analysis because the concepts often contain various qualitatively different notions, so-called causal asymmetry (Ragin, 2008). Table 7 shows the truth table for the outcome *low* safety performance. It shows four rows which include six cases that are considered *sufficient* for *low* safety performance, and four rows which include six cases that are considered *not sufficient* for low safety performance.

Table 7. Truth table for contextual conditions with low safety performance.

Row	CC	OC	CO	RM	SP	Cons.	PRI.	Cases
1	0	1	0	0	1	1	1	L
2	0	0	0	0	1	0.92	0.83	G, H, I
3	1	1	0	0	1	0.90	0.78	K
4	0	0	1	0	1	0.90	0.78	J
5	1	1	0	1	0	0.65	0.22	D
6	0	0	1	1	0	0.57	0.13	B, F
7	0	1	1	1	0	0.56	0.15	C, E
8	1	1	1	1	0	0.43	0.10	A

4.6.2 Minimising the truth table into a solution formula

Each of the four first rows in Table 6 has been identified as sufficient for *high* safety performance, and each of the four first rows in Table 7 has been identified as sufficient for *low* safety performance. The rows of each truth table can be made simpler using logical minimisation (Quine-McCluskey Algorithm): "If two Boolean expressions differ in only one causal condition yet produce the same outcome, then the causal condition that distinguishes the two expressions can be considered irrelevant and can be removed to create a simpler, combined expression" (Ragin, 1987, p. 93).

Table 8 shows the results of the minimisation process. The table shows two configurations sufficient for *high* safety performance covering 80% of the outcome, and two configurations sufficient for *low* safety performance covering 78% of the outcome. Results using QCA are often presented using circles. Black circles (●) represent present conditions, white circles (○) represent absent conditions, and empty cells represent redundant conditions, that is, conditions that have been minimised away through pairwise comparison. *Consistency* measures the degree to which solution terms and the solution as a whole are sufficient for the outcome (sufficiency). *Raw coverage* calculates how much of the outcome is explained by each solution separately. *Unique coverage* measures the proportion of memberships in the outcome explained solely by each individual solution term and indicates the unique contributions to covering the outcome.

Table 8. Consistent configurations for high and low safety performance (Complex solution). (Algorithm: Quine-McCluskey)

	High safety performance configurations (frequency cut-off; 1, consistency cut-off; .90)		*Low* safety performance configurations (frequency cut-off; 1, consistency cut-off; .87)	
Conditions	**HP1**	**HP2**	**LP1**	**LP2**
Construction complexity	○	●	○	○
Organisational complexity		●	○	●
Contract management	●			○
Operative risk analysis	●	●	○	○
Consistency	.91	.92	.92	.94
Raw coverage	.44	.49	.63	.32
Unique coverage	.30	.35	.46	.15
Cases	B, C, E, F	A, D	G, H, I, J	K, L
Overall solution consistency	.93		.91	
Overall solution coverage	.80		.78	

●, core condition (present); ○, core condition (negated); empty cells, redundant conditions.

4.6.3 Interpretation

The part of QCA using the software is only one step in the QCA process. Interpreting means returning to the cases and asking more focused causal questions about the mechanisms producing the outcome (Rihoux and Lobe, 2009). There are two "paths" that produce high safety performance. Configuration HP1 combines high safety performance with high project complexity, good contract management, and good operative risk management. Since the projects differ in organisational complexity yet produce high safety performance, organisational complexity is considered redundant (irrelevant) for this configuration according to the logical minimisation process. Configuration HP2 includes two projects with low construction complexity and organisational complexity, and with good operative risk analysis. Contract management is considered redundant since one project has good contract management and the other projects poor contract management. Configuration LP1 has high project complexity and organisational complexity, combined with poor operative risk management. Contract management is considered redundant since one project has poor contract management while the others have good contract management. Configuration LP2 has low project complexity, high organisational complexity, poor contract management and poor operative risk analysis.

The results indicate that high safety performance can be achieved with both high and low construction complexity and organisational complexity, showing that the conditions are not "necessary" for high safety performance. What seems to be important is how project complexity and organisational complexity are handled by OHSM, here represented by operative risk management. The results also indicate that high safety performance can be achieved with both good and poor contract management, showing that contract management is not "necessary" for high safety performance. What seems to be more important than contract management is operative risk management. Operative risk management is good in all high safety performance projects and poor in all low safety performance projects, suggesting that it is "necessary" for high safety performance.

Similar explanations are also found for the time and economy conditions. Poor economy and time makes it more challenging to achieve high safety performance but can be handled by good OHSM. The results are interpreted in more depth in the next section, jointly with the QCA of OHSM conditions.

4.7 QCA for safety management factors

The aim of the second QCA was to detect combinations of safety management factors connected to safety performance.

4.7.1 Truth tables

Table 9 shows the truth table for OHMS configurations connected to *high* safety performance. There are four rows which include six cases that are considered *sufficient* for high safety performance, and two rows including six cases that are considered *not sufficient* for high safety performance.

Table 9. Truth table for OHSM conditions with high safety performance.

Row	RM	PL	RO	MC	SM	SP	Cons.	PRI	Cases
1	1	1	1	1	1	1	0,93	0,84	A, B
2	1	0	1	1	1	1	0,92	0,79	C, E
3	1	0	1	1	0	1	0,89	0,64	F
4	1	0	0	0	0	1	0,89	0,64	D
5	0	0	1	0	0	0	0,77	0,18	J
6	0	0	0	0	0	0	0,44	0,05	G, H, I, K, L

Note: Operative Risk Management (RM), OHS planning (PL), Roles and Responsibilities (RO), Management Commitment (MC), Staff management (SM) and Safety Performance (SP).

Table 10 shows the truth table for OHMS configurations connected to *low* safety performance. There are two rows which include six cases that are considered *sufficient* for *low* safety performance, and four rows including six cases that are considered *not sufficient* for high safety performance.

Table 10. Truth table for OHSM conditions with low safety performance.

Row	RM	PL	RO	MC	SM	SP	Cons.	PRI	Cases
1	0	0	1	0	0	1	0.95	0.82	J
2	0	0	0	0	0	1	0.92	0.87	G, H, I, K, L
3	1	0	0	0	0	0	0.80	0.36	D
4	1	0	1	1	0	0	0.78	0.28	F
5	1	0	1	1	1	0	0.67	0.16	C, E
6	1	1	1	1	1	0	0.61	0.16	A, B

4.7.2 Minimising the truth table into a solution formula

The next step is to minimise the configurations from the truth tables into a solution formula. The four configurations producing high safety performance in Table 9 are reduced to three configurations in Table 11. The three configurations are *sufficient* for high safety performance covering 90% of the outcome. The two configurations producing *low* safety performance in Table 10 are reduced to one configuration in Table 11. The configuration is *sufficient* for low safety performance covering 93% of the outcome.

Table 11. Consistent configurations for high and low safety performance (Complex solution). (Algorithm: Quine-McCluskey)

	High safety performance configurations (frequency cut-off; 1, consistency cut-off; .89)			Low safety performance configuration (frequency cut-off; 1, consistency cut-off; .92)
Conditions	**HP1**	**HP2**	**HP3**	**LP1**
Staff management	●		○	○
Operative risk management	●	●	●	○
OHS planning		○	○	○
Roles and responsibilities	●	●	○	
Management commitment	●	●	○	○
Consistency	.93	.91	.89	.94
Raw coverage	.75	.63	.33	.70
Unique coverage	.16	.04	.11	.06
Cases	A, B, C, E	C, E, F	D	G, H, I, J, K, L
Overall solution consistency	.93			.93
Overall solution coverage	.90			.93

4.7.3 Interpretation

4.7.3.1 High safety performance configuration 1 (HP1)

HP1 in Table 11 includes four cases with high safety performance. Project C and E are also part of HP2 and interpreted with HP2. Projects A and B performed relatively well on all

OHSM conditions. One difference between project A and B was that A had low project complexity and organisational complexity, while B had relatively high project complexity and organisational complexity. This was analysed in the first QCA (Table 8). Project A had a main contractor directly employing many workers themselves, using few subcontractors and hired workers. Project B had many subcontractors and had to coordinate and follow all subcontractors and work operations closely (project management). Project B was good at following up the contractors to ensure that each contractor was responsible for the risks they brought into the project. The good project management had an impact on operative risk management and safety performance. OHS planning was relatively good for project A and B, compared to the other 10 projects.

4.7.3.2 High safety performance configuration 2 (HP2)

The three cases in HP2 performed relatively well on most OHS conditions and achieved relatively high safety performance. One difference between HP2 and HP1 was that OHS planning was relatively poor in HP2, indicating that good OHS planning might be "necessary" for the highest safety performance.

4.7.3.3 High safety performance configuration 3 (HP3)

Configuration 3 includes one project (D) that is different from the other high safety performance projects. Despite many deficiencies regarding project management and OHS management (e.g. planning, organising, roles and staff management), the project managed to respond to some of the deficiencies relatively early and implement a few decisive measures. A new project leader and a coordinator for the execution stage established a strong control regime, following up contractors and workers, handling hazards and potentially dangerous operations on site. The measures were time-consuming and labour-intensive for the client, taking over many of the responsibilities from the contractors. However, the measures worked as an improvised solution in the most safety-critical phase of the project to achieve high safety performance, showing the importance of operative risk management. The case demonstrates that OHSM is not deterministic: It is possible to achieve high safety performance despite many problems and deficiencies in OHSM. Contributory conditions were that this project (D) (like project A) combined low construction complexity and low organisational complexity that reduced the difficulties of managing safety.

4.7.3.4 Low safety performance configuration (LP1)

The combination of conditions connected to *high* safety performance are not necessarily the same as those which produce *low* safety performance, so-called causal asymmetry. The same conditions can play different roles in different contexts. A separate truth table analysis and minimisation process was therefore performed for *poor* safety performance.

The projects with poor safety performance were more similar to each other than the high safety performance projects, and the minimisation process produced only one solution for low safety performance. The solution combines poor staff management, poor operative risk management, poor OHS planning, and poor safety management commitment, while "roles" is redundant.

Project J performed relatively well on many factors (roles and responsibilities, contract management, and parts of the project management), but still had low safety performance. The main deficiency was that the focus on, and commitment to, OHS as a process was low and poorly integrated into production management. This implied, for instance, that the involvement and supervision of workers (staff management) was poor, and that planning of operations to reduce risk (operative risk management) was poor. As a consequence, safety behaviour was poor and there was a high TRI-rate. The project indicates that it is not sufficient to have a relatively good production and project management, it is also necessary to emphasise the OHSM management process on its own in order to achieve high safety performance.

Project L stands out as a project where almost all OHSM conditions and safety performance were very poor and is the total opposite of Project A where all OHMS conditions were good. Project L had many similarities with Project D, where most OHSM conditions were poor. Both projects experienced major problems during the execution stage, but Project D managed to implement measures to improve OHSM and achieve high safety performance while Project L did not. One reason that Project D managed to implement sufficient changes and Project L did not, was that Project L was more complex regarding both organisation and the building and site (see Table 8).

4.8 Analysis of the 16 factors

This section analyses and discuss the influence of each of the 16 factors. The operational definitions of the factors are described in Table 1.

4.8.1 Construction complexity

Construction complexity was not found to be "necessary" for high safety performance. The results indicate that high safety performance can be achieved with both high and low construction complexity. What seemed to be important is how project complexity and organisational complexity were handled by operative risk management, and probably other management factors. The result is consistent with Törner and Pousette (2009), who found that project characteristics and nature of the work are "… the limiting conditions to which safety management must be adjusted", are difficult to change, and "establish the outer limits of safety management" (ibid. p. 404).

4.8.2 Organisational complexity

Organisational complexity was treated as a "contextual" in this research, even though it is also the result of management decisions. The results indicate that low organisational complexity is not "necessary" for high safety performance. The results do not contradict that there is an association between increased on-site subcontracting and increased risks of injuries (Azari-Rad, Philips and Thompson-Dawson, 2003). The results do, however, indicate that high organisational complexity complicates the coordination of actors and operations and achieving high safety performance. What seems to be important is how the organisational complexity is handled by safety management, particularly operative risk management.

4.8.3 Time and economy

Time and economy are tightly connected and are therefore described jointly. The hypothesis was that "poor" time and economy can bring about reduced effort on safety which can lead to poor safety performance. Adequate time and economy were not found to be "necessary" for safety performance. In most projects, there was a connection between time/economy and safety performance, but there was also one project with poor "time/economy" with high safety performance, and one project with good "time/economy" and poor safety performance. The results indicate, like organisational complexity, that poor contextual factors can be handled by good safety management. Previous studies have found connections between time/economy and safety performance (Holmes, Lingard, Yesilyurt & De Munk, 1999; Mullen, 2004; Han, Saba, Lee, Mohamed & Peña-Mora, 2014). Mullen (2004) found that when resources (i.e., time and money) were inadequate, there was pressure from both managers and co-workers to prioritise performance over safety, and that such pressure swiftly socialised individuals to adapt and consider unsafe practices as normal.

4.8.4 Contract management

Except for two projects, the contracts were different variants of *design and build* (turn-key) contracts where a main contractor is given a performance specification by the client and must undertake the project from design to construction, and to a completed building. What seemed to be most important in achieving a high safety performance was how well the client and contractors were able to cooperate, communicate and avoid conflicts, not the formal contract management and contract. The result is broadly consistent with Bolt, Haslam, Gibb, and Waterson (2012) who found that a key factor was that systems (contracts, processes, systems and equipment etc.) and people work in tandem. The choice of main contractor was also important for safety performance. Limited availability of suitable contractors was a contributory factor to poor safety performance in some projects. Like Hinze and Gambatese (2003), we also found that subcontractor safety performance was affected to a large extent by the actions of the general contractor and construction management. Hale et al. (2012) also found that contracting strategy (competitive tendering and contractorization) was an important causal factor in fatal accidents.

4.8.5 OHS-planning

OHS-planning was not found to be "necessary" for high safety performance. Most projects did not have an adequate SH-plan including assessment of risks in advance with specific measures. The results indicate that much residual risk was left for the frontline workers to handle. Only two projects had an adequate OHS-planning including adequate risk assessments and specific measures. These two projects also had the highest safety performance, indicating that good OHS planning might be "necessary" for high safety performance. The research also showed that assessment of risks in advance with specific measures is very demanding because of the dynamic nature and new risks being produced consecutively. Conventional OHS risk management methods, assuming that that work can be decomposed into its parts, is of limited value in construction because system elements are in constant dynamic interaction with one another (Cooke-Davis et al., 2007). Hallowell and Gambatese (2009) found that a written and comprehensive safety and health plan was an essential safety program element, and Hallowell and Calhoun (2011) found that a site-specific safety plan is one of the most central elements in an effective safety program.

4.8.6 Roles and responsibilities

Roles and responsibilities was found to be "necessary" for high safety performance. The results indicated that two types of roles were important for high safety performance. First, that OHS was to a large degree a management responsibility with active project leaders. Second, that at least one of the roles with specific responsibilities for OHS (coordinator for the execution stage, OHS-leader, OHS-coordinator etc.) was very active in the OHS activities and coordination. These results are consistent with results from literature reviews about the importance of top management generally (e.g. Hale and Hovden, 1998, and Shannon, Mayr and Haines, 1997) and in construction (Tam, Zeng and Deng, 2004; Hallowell, Hinze, Baud, and Wehle, 2013). The results are also similar to Hale et al. (2010) who found that the amount of energy and creativity injected by top managers and coordinator (safety professional) appeared to be a distinguishing factor.

4.8.7 Project management

Project management was found to be "necessary" for high safety performance. Projects with adequate project management managed to follow up OHS, coordinate the activities and ensure adequate communication between the actors. Project management is defined differently in different studies and it is hence problematic to compare to many studies. Our definition is similar to the ConAC model (Haslam et al., 2005; Winge, Albrechtsen and Mostue, 2019). In different accident studies using the ConAC framework, deficiencies in project management was found to one of the most frequent "originating" factors (Gibb, Lingard, Behm, & Cooke, 2014; Winge et al., 2019).

4.8.8 Management commitment to OHS

Management commitment to OHS was found to be necessary for high safety performance. In projects with high safety performance and adequate management commitment to OHS, the managers expressed clearly that safety was prioritised before production, and actively participated in OHS and other OHS-related management factors like project management, safety climate, planning and staff management. The results are consistent with literature reviews (Shannon et al., 1997; Mohammadi et. al., 2018). Hallowell et al. (2013) concluded that safety performance is exceptionally strong when top management is visibly involved in safety.

4.8.9 Safety climate

The aim of including safety climate as a factor, was to assess the "informal aspects" of safety management. Antonsen (2009, p. 17) describes a "good" safety climate as "… one where managers at all levels are highly committed to safety; where the workforce express satisfaction with and adherence to the organization's safety system; where everyone is risk adverse; where there is no pressure towards maximizing profits at the expense of safety and where operators as well as managers are highly qualified and competent". Safety climate was found to be "necessary" for safety performance. Table 4 shows that safety climate coincides with several other factors, and the analysis suggests that safety climate both influence, and is influenced by, several other factors. Safety climate coincide with staff management, which indicates that safety climate is connected to the selection of personnel, and the safety climate they bring with them. What characterise the projects with a high score on safety climate, was that the project management and OHS coordinators followed up the frontline workers closely regarding safety behaviours, and that they had several social arrangements focussing on OHS where both managers and frontline workers participated. The results are consistent with Törner and Pousette (2009) who found that "interaction and cooperation and conditions supporting cooperation through empowerment, mutual trust, and having a keen ear were important in relation to safety" (p. 405). Based on a literature review, Mohammadi et al. (2018) concluded that an adequate safety climate is a key aspect to prevent accidents and illnesses.

4.8.10 Learning

Learning was found to be "necessary" for high safety performance. Projects with high performance on learning had regular inspections and safety walks, and safety representatives that were active and participated on safety walks. These projects had a high willingness to report unwanted occurrences (see Table 2) and risks were mostly handled consecutively. Mohammadi et al. (2018) identified "lesson learned from accidents" as one of the factors influencing safety performance in construction. Hallowell and Gambatese (2009) found in their literature review that "recordkeeping and accident analyses" was a central program element, but one of the least effective.

4.8.11 Performance evaluation

Performance evaluation was not found to be "necessary" for high safety performance. All projects had some problems regarding OHS management early in the execution stage, all tried to solve them, but not all succeeded. What seems to be important was how early problems were identified, which types of measures were implemented, and how extensive the measures were. It is also clear that construction complexity and organisational complexity described above influenced the opportunities for implementing the measures successfully. The result is similar to a literature review by Loushine et al. (2006) who concluded that continuous improvement requires continuous monitoring of work or collection of data, analysis, and changes in the work processes to ensure that work is progressing towards goals. Performance evaluation (continual performance evaluation and monitoring of the OH&S management system) is also a key factor in ISO 45001 (ISO 2018) for continuous improvement.

4.8.12 Operative risk management

Operative risk management was found to be "necessary" for high safety performance. Operative risk management was good in all high safety performance projects and poor in all low safety performance projects. One project illustrates the importance of operative risk management. The project performed poorly on most safety management factors but had good operative risk management and high safety performance (.8). The results also indicate that projects with high project complexity and organisational complexity can achieve high safety performance, if the operative risk management is good. Operative risk management does not, however, operate in isolation. An analysis indicated that project management and roles and responsibilities were consistent "necessary" factors for operative risk management.

One central explanation why operative risk management is important, is probably that many risks were not handled in early stages, and that many residual risks had to be handled consecutively. The factor OHS-planning (section 4.8.5) showed that most projects did not have an adequate OHS-planning, including assessment of risks in advance with specific measures, and that many risks therefore were left for the frontline workers to handle. These residual risks hence had to be handled by operative risk management. Poor risk management was also found to be a dominant organisational factor in accident analyses in construction (Haslam, 2005: Behm and Schneller, 2013, Winge and Albrechtsen, 2019).

4.8.13 Site management

Site management was found to be "necessary" for high safety performance. Projects that had adequate site management were well organised, had clearly defined danger zones, pathways, areas for storage, good housekeeping, and few hazards. The importance of site condition is evident in falls from height. In a literature review of 75 studies about falls from height, Nadhim, Hon, Xia, Stewart and Fang (2016) found that site condition was one of the most common factors. Falls from height could occur when there were e.g. unprotected walkways, improper guardrails, slippery or sloped surfaces.

4.8.14 Staff management

Staff management was found "necessary" for high safety performance. In projects with adequate staff management, the share of skilled (trained) workers was high, the companies and workers had often worked together in previous projects, the safety climate was good, and supervision and safety behaviour were good. Staff management coincide strongly with safety climate and project management (Table 4). The results are consistent with Choudhry and Fang (2008), who concluded that management behaviour plays an important role in improving workers' behavioural safety performance. They also concluded that management can help workers to improve safety behaviours through the influence of rules and regulations, training and increased communication. Several studies also show the importance of the supervisors in enhancing good safety behaviour (Fang, Wu, and Wu, 2015; Mohamed, 2002; Rowlinson, Mohamed, and Lam, 2003; Kines, Andersen, Spangenberg, Mikkelsen, Dyreborg and Zohar, 2010; Winge and Albrechtsen, 2019).

5 Discussion and conclusion

The aim of this research was to identify how safety management factors, contextual factors and combinations of factors influence safety performance.

5.1 Combinations of factors

The results showed that the average score for the 12 safety management factors was far better among the high safety performance projects compared to the low safety management projects. The result is broadly consistent with literature reviews that safety management systems can deliver more healthy and safe workplaces (Gallagher et al., 2001) and lower accident rates (and Thomas, 2011). The results are also broadly consistent with Loushine, et al. (2006) who in a literature review on safety management and quality management found that construction projects with integrated safety and quality management systems/programs have better safety performance.

The results showed that high safety performance can be achieved with both high and low construction complexity and organisational complexity. The results indicated, however, that high construction complexity and organisational complexity complicate safety management. What seemed to be important was how project complexity and organisational complexity was handled by operative risk management. Regarding construction complexity, the results are broadly consistent with Törner and Pousette (2009) who concluded that the inherent complexity of construction work restricts and complicates safety management and demands comprehensive safety management. Regarding organisational complexity, the results do not contradict that there is a statistical association between increased on-site subcontracting and increased risks of injuries (Azari-Rad, Philips and Thompson-Dawson, 2003). The results do, however, indicate that high organisational complexity complicates the coordination of actors and operations and the production of a high safety performance. In projects with high organisational complexity and high safety performance, the organisational complexity was adequately planned for, and extensively managed by, for example, involvement, cooperation and follow-up of the contractors. The results are consistent with Hallowell and Gambatese (2009) who found that strategic subcontractor selection and management is among the most effective elements in safety programs.

The results also showed that it is possible to achieve high safety performance despite many relatively poor safety management factors, and that it is possible to produce low safety performance despite many relatively good safety management factors. The results indicate that it is not sufficient to have a relatively good production and project management, it is also necessary to emphasise the safety management process on its own to achieve high safety performance. The result showing that single *necessary* factors can be jointly *sufficient* to produce high and low safety performance is broadly consistent with the understanding of causality in many accident models. (Reason, Hollnagel and Paries 2006; Hopkins, 2014, Winge et al., 2019). This research also showed that there can be different combinations of factors producing high and low safety performance, so-called equifinality. The results support that the combination of many factors play a key role in safety management (e.g. Shannon et al., 2001; Hale et al, 2005; Hallowell and Calhoun, 2011; Dyreborg et al. 2013). Similarly, ISO 45001 (ISO, 2018) states that the effectiveness and ability to achieve outcomes of an OHS system are dependent on several key elements.

5.2 Single factors

Safety performance is the result of a complex interplay between different factors as demonstrated by the QCA analysis. At the same time, single factors have special characteristics and can have a specific causal influence. All factors are analysed and discussed in the results section. The analysis showed how each factor influenced safety performance. Eight safety management factors were found to be "necessary" for high safety performance: (1) roles and responsibilities, (2) project management, (3) OHS management and integration, (4) safety climate, (5) learning, (6) site management, (7) staff management, and (8) operative risk management. Site management, operative risk management, and staff management were the three factors most strongly connected to safety performance. This is probably because the factors are the most proximal, with most direct influence on what is going on at the sharp end, and essential in the daily control of the safety at site.

5.3 Limitations, contributions and future research

One contribution of this research is the comparative approach studying "good" and "bad" construction projects employing QCA and the QCA software, which gives an opportunity to study what goes right and what goes wrong (Hollnagel, 2014). Our experience was that the approach and software helped to identify the patterns of causal complexity producing high and low safety performance. Employing QCA helped us identify complexity in combinations of factors (configurations) and different paths producing high and low safety performance (equifinality). There are however some methodological and empirical limitations in this research that we recommend is followed up by future research.

First, the results are not based on hard facts but on the researchers' assessment of each causal factor and safety performance. Regarding measurement of safety performance, there is much evidence of under-reporting of workplace injuries (Shannon et al., 2001) and safety indicators can be subject to manipulation and misinterpretation (Oswald et al., 2018). Several data sources and methods were therefore combined by triangulation (Denzin, 1970) and mixed methods (Tashakkori and Teddlie, 2010) to increase internal validity. Second, the assessment of safety performance and safety management performance was problematic in some of the construction projects since performance often varies during a project. Third the study focuses on safety management in construction projects primarily from a client’s perspective, and the cases could have been studied more in depth from other actors' perspective, for example from contractor's perspective or frontline workers' perspective. It would have been preferable to study more documents and interview more managers and safety representatives at the sharp end. There is, however, always a trade-off between depth and width. Forth, it was challenging to compare the results to previous research due to different definitions and poorly described definitions of factors in many studies. It is important for the accumulation of knowledge that key factors are clearly described. Fifth, the number of factors using QCA must be kept relatively low. The problem is that as the number of binary factors increases, the number of possible combinations of these variables increases exponentially – so-called limited diversity (Ragin, 1987). Therefore, two different QCAs involving different combinations of factors were employed. Sixth, aiming for both in-depth insight into cases and complexity, and to produce generalisations, might seem to be contradictory goals (see Ragin, 1987). Twelve cases are relatively few to produce generic results, and the results must therefore be treated with caution. The research is therefore seen as a building-block type of research (George and Bennett, 2005), and we encourage researchers to undertake similar studies with larger N which makes it easier to include more factors and study how they operate together. We also encourage more case studies and intermediate-N studies to increase our knowledge of associations between safety management factors, combinations of factors, and safety performance in construction projects.

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