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An analysis of the relationship between project management and safety management in the Norwegian construction industry

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ABSTRACT

The significance of general project management performance for safety performance in construction projects is studied in a sample of Norwegian construction projects. The data used are from a benchmarking tool for performance assessment and incident data from construction projects across the industry. Statistical analysis through independent-sample Mann–Whitney *U*-tests is performed to test for and identify significant relationships between project management, safety management and safety performance. The analysis confirms that good overall management of a construction project positively impacts safety management. The results advocate for applying safety management as an integral aspect of all management activities in a project rather than as a disconnected sub-system. The work is novel by empirically demonstrating the impact of project management aspects on safety management in construction projects.

1. Introduction

The construction industry is one of the most hazardous industries to work in, having one of the highest work fatality rates in most countries (ILO, 2022). Many studies address accident causes in the construction industry, which are summarised in review articles by, e.g., Khosravi et al., (2014); Birhane et al. (2022). Most of these studies point to individual behaviour (e.g., competency, experience), safety deviations on site (e.g., unsafe equipment, unsafe conditions) and inadequate safety management (e.g., safety education, supervision, risk management, safety leadership) as contributing factors. The literature on accident causes shows that few contributing factors are directly related to project management factors, such as project schedule, project team leader characteristics, client consultation and procurement. A literature review on factors influencing safety performance in construction projects by Mohammadi et al. (2018) shows the same pattern. Most of the influencing factors described in the literature are about safety management and safety practices, and to a limited extent, related to project management. Furhtermore, Mohammadi et al. (2018) identifies that procurement systems, work scheduling and leadership matter for the safety performance in projects. Much research has been done to contribute to reducing the number of accidents in the construction industry, and lots of research has been done to improve productivity, but few studies look at both safety and production (Ghodrati et al., 2022). A literature review by Badri et al. (2012) indicates a poor integration of safety management into project management in research and practice. This research gap is confirmed in later publications by, e.g., Goh et al. (2012), Ershadi et al. (2019), Lingard and Wakefield (2019), and Ghodrati et al. (2022).

Some studies have studied the integration of safety and project management in the construction industry; however, these tend to be conceptual without empirical evidence supporting them. Fonseca et al. (2014) demonstrate that integration can happen through common anticipation among different actors during construction. By using a system dynamics model, Jiang et al. (2015) indicate that safety and production can support each other through management conditions on a supervisory level. Another system dynamics-driven approach by Goh et al. (2012) studies how a lack of integration may lead to weaker safety performance and even weaker production performance. Mohammadi and Tavakolan (2019) conceptually model the relation between production pressure and safety performance. The lack of integration is also visible in practices. System-wide relations in project management that influence safety performance are found to not be sufficiently considered in accident investigations (Woolley et al., 2018). Furthermore, the integration of safety management is not a topic in the management

Abbreviations: H1, Hypothesis 1; H2, Hypothesis 2; H3, Hypothesis 3; LTI-rate, Lost time injury rate; Mdn, Median; OARU, Occupational Accident Research Unit; PM, Project management; TRI-rate, Total recordable injury rate; SM, Safety management; SP, Safety performance.

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standards widely used by industrial project managers (Ershadi et al., 2019).

Safety performance and management cannot be seen as independent of other organisational activities. Project management is thus a key contributing factor to controlling hazards in construction projects. A need to integrate safety into specific parts of the management of projects has been advocated in several studies for the prevention of accidents, e.g. in the project team, or in planning, production or cost (Ershadi et al., 2019; Haslam et al., 2005; Lingard and Wakefield, 2019).

Although the conceptual studies described in the sections above have explored the influence of project management on safety performance, the empirical evidence of the influence is vague. Some studies have identified the importance of different project characteristics, project management capabilities and work practises on safety performance (Törner and Pousette, 2009; Winge et al., 2019), but the main body of literature address the influence in a conceptual perspective.

The purpose of the study is to address this knowledge gap by empirically exploring the significance of general project management for safety in construction projects. In addition, the relationship between project management, safety management and safety performance is studied to provide insight into safety aspects from a project management perspective.

The study contributes with a quantitative exploration through statistical analyses of a comprehensive database on project performance of Norwegian construction projects (Nordic 10-10) and injury rates from the same construction projects. The statistical tests performed examine how and to what extent the above-mentioned associations between project management and safety exist.

The paper is structured in the following way. The next section presents a theoretical background for the study, which explains an integrated model of safety management and project management. Based on the theoretical background, three hypotheses are developed and explained in section 3. Section 4 presents the research design and the statistical analysis, including the data material. Subsequently, section 5 describes the results of the statistical analysis. Sections 6 and 7 discuss the implications of the results before the paper concludes in section 8.

2. Theoretical background

To fully understand safety performance of construction projects, management of projects and management of safety must be seen in an integrated view (Ershadi et al., 2019; Haslam et al., 2005; Lingard and Wakefield, 2019). This section introduces a theoretical model that shows such a link between the value creation in projects (section 2.1) and an accident model (section 2.2).

2.1. Value creation in projects

Construction projects involve temporary organisations with a specific objective to be completed within certain specifications and a defined start and end date (Pinto, 2020). Project management is about managing such a temporary project organisation to reach its objectives (Rolstadås et al., 2014), within time, cost and resource constraints (CIOB, 2014). The project objectives may include effectiveness, quality, fulfilling a customer need, the economy, production, and safety, among others.

The goal of customer value creation is common to all projects. A company creates value by carrying out activities that result in a product (physical product or service) that provides value for the customer or user that exceeds the cost of execution (Fjeldstad and Lunnan, 2019). Value creation is therefore determined by the value created for someone and the resources (e.g., labour, raw materials, intellectual and financial capital) used. Project value creation has often been related to project management success measured in terms of time, cost and quality (Cooke-Davies, 2002). However, a strategic aspect of projects, i.e., what effect the project is intended to have, has not been given much attention (Shenhar, 2015).

2.2. Accident process model

Several accident models (Khanzode et al., 2012; Kjellén and Albrechtsen, 2017) describe the relationship between different causes and the sequence of events. Process models are one category of accident models that emphasise that deviations from normal operations are a key direct cause of accidents. It explains how weaknesses and inadequacies in normal operations lead to situations where there is a lack of control of hazards (energy sources). The OARU (Occupational Accident Research Unit) by Kjellén and Larsson (1981) is an example of a process model, see Figure 1. Here, the accident sequence is divided into three phases: the initial phase, where things are normal and faultless; the concluding phase of loss of control of energy; and the injury phase, where a victim is exposed to energy. Across these three phases, there are four transitions: 1) from normal conditions to a state of lack of control; 2) from lack of control of hazards to loss of control of hazards (uncontrolled release of energy); 3) a victim absorbs energy; and 4) energy absorption ceases. The state of lack of control is characterised by the presence of deviations, i.e., events or conditions that depart from the norm of the faultless planned processes of the system. Furthermore, the OARU-model shows how contributing factors (i.e., the technological, human, and organisational factors) of the work system, the company, and the project affect the accident sequence.

2.3. An integrated model of project management and safety management

The links between the value creation (section 2.1) and the accident model in section 2.2 are 1) deviations from normal value creation that lead to a state of lack of control of hazards that may lead to loss of control and injury, and 2) contributing factors related to technology, humans and organisations that contribute to value creation if they work properly, or they contribute to accidents if they are inadequate. Figure 2, based on Kjellén and Albrechtsen (2017), illustrates this relationship. Through a normal production process, value is created (e.g., the activities needed to construct a building that is of value to the owner). Contributing factors, such as plans, competency, resource availability, management commitment and similar, are required for the value-creation process. The lower part of the model shows how accidents can develop and result in injury to personnel or damage to the environment or material assets. Normal, faultless production is not likely to lead to an incident, as deviations will be avoided.

3. Hypotheses

The starting point of this study is an assumption that good overall project management has a positive influence on 1) safety management (Tinmannsvik and Hovden, 2003) and 2) safety performance (Haslam et al., 2005; Teo et al., 2005). Thirdly, we assume that good safety management influences safety performance positively (Jaselskis et al.,

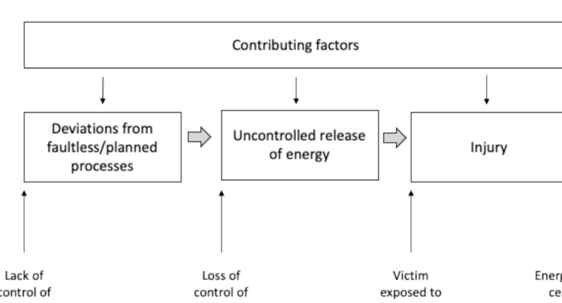

Figure 1. Accident process model, the OARU-model (Kjellén and Larsson, 1981)

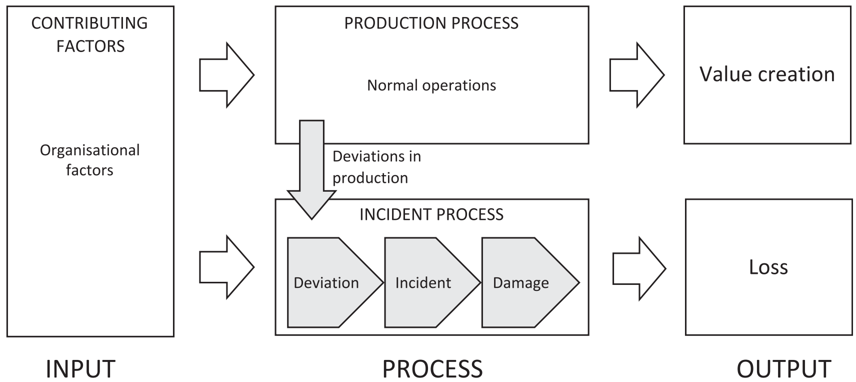

Figure 2. Project management and safety management in a process model

1996; Sawacha et al., 1999; Fernández-Muñiz et al., 2009).

The three key elements compared in the study are defined:

- *Project management:* Management of a project organisation by the application of knowledge, skills, tools, and techniques to reach the objectives of the project (Rolstadås et al., 2014). Examples of factors: project mission; top management support; project schedule; client consultation; personnel; monitoring and feedback; communication; troubleshooting; project team leader characteristics; power; environmental events; urgency (Pinto and Slevin, 1988)
- *Safety management:* All formal and informal activities performed to control hazards in an organisation (Hale, 2006). Examples of factors: higher management commitment; employee participation; safety policy and goals; performance measures; system planning; procedures; training system; hazard control system; procurement; communication system; management reviews and continual improvement (Redinger and Levine, 1998)
- *Safety performance:* An expression of an organisation's effectiveness in controlling hazards in its activities (Kjellén and Albrechtsen, 2017). Examples: lost-time injury (LTI) rate, total recordable injury (TRI) rate, and leading safety performance indicators (Kjellén and Albrechtsen, 2017)

3.1. *Safety management as an integrated part of project management*

Project management is a core component for value creation. Herein, project management elements influence a project's processes and outputs. Yet, prior research on the influence of project management on safety management in construction is very limited and very often, a positive relationship is *assumed* (Tinmannsvik and Hovden, 2003). It is clear that the underlying goal of project management is to reach the project objectives, including safety objectives (Rolstadås et al., 2014), and that safety management should be an integrated part of project management (Hale, 2006). Based on the above, the relationship between the selected elements of project management and safety management is explored with the following hypothesis:

- Hypothesis 1 **(H1):** Projects that perform well on project management also perform better on safety management than projects that perform poorly on project management.

Several studies have examined the relationship between project management and safety performance in projects. Significant relationships have been found between factors such as managerial activities, including procurement, human resources, economic investments, labour management, management involvement, resources, culture and pre-task planning (Fang et al., 2004; Mohammadi et al., 2018). A study looking at contributing factors in construction accidents found project management to be a clear influencing factor in 24 per cent of accidents (Haslam et al., 2005). Also, the project manager's experience level has been associated with safety performance in the construction industry (Jaskelskis et al., 1996). A study of production companies found strong correlations between general management factors and the injury frequency rate (Tinmannsvik and Hovden, 2003). With this background, the relationship between project management aspects and safety performance, measured by injury rates, is explored by the following hypothesis:

- Hypothesis 2 **(H2):** Projects that perform well on project management have lower personal injury rates than projects that perform poorly on project management.

Safety management is expected to be closely linked to safety performance. In a study by Hinze et al. (2013a), several safety practices were found to be significantly associated with improved safety performance, ranging from site-specific factors to organisational factors involving the practices of contractors and the client. Also, the implementation of safety management systems has, in many cases, been found to be associated with reduced accident rates and a strategy for a vision zero in construction (Noetel, 2018; Yiu et al., 2018). With this background, the relationship between safety management and safety performance is explored by the following hypothesis:

- Hypothesis 3 **(H3):** Projects that perform well on safety management have lower personal injury rates than projects that perform poorly on safety management.

Figure 3 illustrates the hypothesised relationships between project management, safety management and safety performance explored in this study. By looking at data in the Nordic 10-10 database and injury rates of the same projects, differences in safety management (H1) and safety performance (H2) between projects that perform both well and poorly on project management are studied. Similarly, safety performance (H3) is evaluated based on projects doing well and poorly on safety management. As can be inferred from the literature, the model is

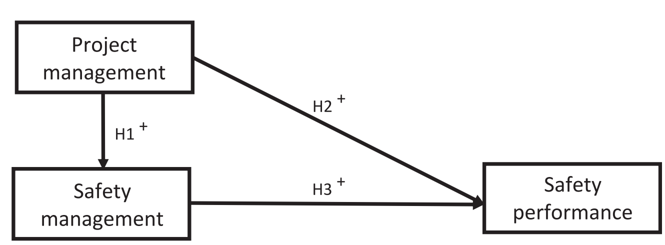

Figure 3. Theoretical model showing the hypothetical relationships between factors

constructed assuming that a positive relationship exists between project management and safety management, and further, with safety performance.

4. Materials and methods

4.1. Research design

A quantitative study design was applied, as illustrated in Figure 4. Empirically, the study is based on existing data from an established database. An analysis of project data from the Nordic 10-10 database was performed to look at the relationships between project management, safety management and safety performance. Additionally, lost-time injury rates (LTI) and totally recordable injury (TRI) were collected from the projects and included in the analysis. An exploratory factor analysis was performed to develop variable constructs. Through independent-sample Mann–Whitney *U*-tests, the study examines differences in safety management and safety performance between projects that perform well and poorly on project management, as well as differences in safety performance between projects that perform well and poorly on safety management. All statistical tests were conducted with the statistical software SPSS version 26.

4.2. Nordic 10-10

Nordic 10-10 is a benchmarking tool for project performance assessment in the construction industry. It is a Norwegian translation and adaption of the acknowledged CII 10-10, developed by the Construction Industry Institute (CII) at the University of Texas (Nordic 10-10, 2021; Yun et al., 2016). Data are collected through questionnaires for different project phases and distributed to partners in the Nordic 10-10 programme (Construction Industry Institute, 2021a). Each phase is surveyed by two types of measures: *input measures* (e.g., planning, organising, leadership, controlling, design efficiency, human resources, quality, supply chain and safety) based on respondents' considerations of statements on different issues and *output measures* showing if the project is performing according to the set targets (Construction Industry Institute, 2021a; Construction Industry Institute, 2021b). There are 10 input measures and 10 output measures, hence the name 10-10. Furthermore, the tool benchmarks projects based on the assessed phase, type of industry and projects with similar complexity. The tool has been considered to potentially contribute to diagnosing improvement areas in projects and at the industry level (Langlo et al., 2017). Previous analyses of the Norwegian dataset have investigated aspects of project success, performance and costs, among others (e.g., Bang et al.,2022; Haaskjold et al., 2020; 2021).

4.3. The database and data collection

Data was collected from members of the Nordic 10-10 programme (actors across the Norwegian construction industry) and the data gathering was facilitated by a trained and certified project coordinator from the Nordic 10-10 programme. This Nordic 10-10 coordinator is employed in the company where data is collected, and is associated with the project where data is collected. The data collection consisted of two parts: 1) entering of descriptive project information by the project manager and project cost controller through an online portal, and 2) a questionnaire answered by key project team members (Haaskjold et al., 2021). The project manager and the Nordic 10-10 project coordinator select relevant participants in the project organisation for answering the questionnaire based on their role in the project and their expertise. The manager and the coordinator are instructed that the respondents should be representative for those working in the construction phase and belong to the Nordic 10-10 coordinator's organization. The content of the questionnaire is research based (Yun et al., 2016; Haaskjold et al., 2020), and consists of three parts (part 1 'general', part 2 'input', and part 3' output – facts on the projects') (see the Programme website https://wikis.utexas.edu/display/CII1010/). For most of the companies, the survey is performed as a group workshop led by the Nordic 10-10 coordinator, but responses from each participant are submitted independently during or after the workshop (Haaskjold et al., 2020). The individual answers are aggregated to the group level, resulting in one input per project phase. Thereafter, a report is aggregated from the online portal for use in the project to find the causes of low scores and define improvement actions (Langlo et al., 2017). When the company's 10-10 coordinator submits data to the database, the data are validated by Construction Industry Institute (CII) as a final check of the dataset (Haaskjold, 2021)

At the time of the analysis, the dataset had 170 cases across different project phases, divided across 111 unique projects and 26 actors (i.e., clients (public and private), contractors, consulting engineers or architecture firms). For the study, infrastructure and building projects in the construction phase were selected for the analysis, as these two project types have large similarities in terms of operations, risks and involved actors. Also, the number of participating projects from infrastructure was limited and not suitable for statistical analysis. The limitation to the construction phase was done as this phase is very relevant for accident prevention and where both safety management and safety performance can be studied.

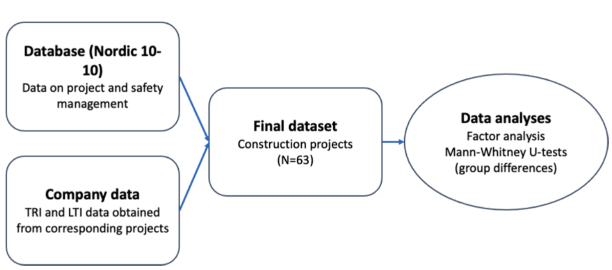

Figure 4. Research design

4.4. Constructed variables

To explore the hypotheses, measures for project management, safety management and safety performance were constructed. Available Nordic 10-10 measures, as well as measures based on items from the 10-10 questionnaires, were applied for variable construction. For project management, a factor analysis was performed based on selected questionnaire items available from the database. The relevance considerations were based on previous research (Luu et al., 2008; Ling et al., 2009; PMI, 2017) and on face-value considerations by the research group. The chosen items reflect some of the most characteristic features of project management, as described in section 3. For safety performance, lost time injury rate (LTI-rate) and total recordable injury Rate (TRI-rate) were obtained from the projects. Table 1 shows the different variables used in the study.

4.4.1. Project management

The Nordic 10-10 questionnaire contains several items that relate to different aspects of project management. The items were presented to

Table 1
Variables used in the analysis

Topic	Variable	Origin
Project Management	Teams and system functioning Leadership	CII 10-10 QuestionnaireFactor analysis
Safety Management	Safety management index	CII 10-10 Input Measure
Safety Performance Indicators	TRI rates LTI rates	Company data Company data

the respondents of the questionnaire as statements, to which they indicated their agreement on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). By using an exploratory factor analysis (see section 5.1), a final set of 13 items was identified (see Table 2).

4.4.2. Safety management

Safety management was measured by the 'safety' input measure developed by the CII 10-10 Program (Yun et al., 2016), here denoted the *safety management index*. It measures practices followed by the project teams for personal injury or property damage prevention (Construction Industry Institute, 2021a). The variable includes a set of questions, with formats including multiple choice with one and multiple answers allowed, binary and Likert. The weighting and formulas behind the measures are developed by the CII, where each answer is given a score, weighted, and compiled into the variable (Construction Industry Institute, 2021a). For example, for the Likert scale items, 'Strongly agree' is given the score 5, 'Agree' 4, 'Neutral' 3, 'Disagree' 1 and 'Strongly disagree' 0. The average score for the respondents within a specific project is then multiplied by a weight and included as a part of an overall score. Binary and multiple-choice questions followed the same procedure, as each response option was given a score and multiplied with a weight. The questions included in the *safety management index* are available from CII 10-10 and are presented in Table 2.

4.4.3. Safety performance

Safety performance was measured by LTI and TRI rates for the selected projects. The LTI and TRI rates were collected by contacting companies. During projects, incident data are reported through the companies' deviation systems. It is required by law to detect, correct and prevent deviations. Workers and managers can choose to report incidents anonymously. Most of the projects (over two-thirds) were completed at the point of data collection. The LTI and TRI rates are comparable across projects since they are a normalised measure (per one million working hours).

Table 2
Questions included in the safety management index from CII 10-10.

Item	Question	Type of question
S1	This project used the following methods: Plan Per Cent Complete | Workforce Planning/Last Planner Work Packaging | Subcontractor Prequalification | Ongoing craft training programmes | Substance abuse testing | Preassembly | Prefabrication | Modularisation | Offsite Fabrication	Multiple choice (multiple answers allowed)
S2	Formal (classroom) safety training was attended: Monthly | Quarterly | Annually | Initially/Once | Never	Multiple choice (one answer)
S3	Overall, how many workers per safety professional were typically (i.e., in terms of the average workforce) on site?(1:20 | 1:21–40 | 1:41–60 |1:61–100 | 1:over 101)	Multiple choice (one answer)
S4	Were accidents, including near misses, formally investigated?	Binary (Yes/No)
S5	Was safety performance a criterion for contractor and subcontractor selection?	Binary (Yes/No)
S6	Were safety toolbox meetings held daily?	Binary (Yes/No)
S7	The availability and competency of craft labour were adequate.	5-point Likert scale
S8	Project safety procedures were well defined and strictly followed.	5-point Likert scale
S9	The project employed regular safety audits or observations.	5-point Likert scale
S10	Key stakeholders, including the public, were properly identified and involved during Front End Planning.	5-point Likert scale
S11	The initial site and/or existing facility conditions were fully verified for the deliverables of this phase.*	5-point Likert scale
S12	All applicable national, regional and local compliance requirements were well defined and understood by all relevant project stakeholders.*	5-point Likert scale
S13	Regulatory requirements (e.g., permitting and environmental issues) were properly managed, and construction is in compliance.*	5-point Likert scale

* Additional questions for infrastructure projects

4.5. Statistical analysis

An exploratory factor analysis was performed for the project management items (Table 4) to identify underlying themes and construct indexes. To test if factor analysis was appropriate, the Kaiser–Meyer–Olkin (KMO) test was performed, indicating if the sample size (the number of observations) was adequate. The KMO statistic could vary between 0 and 1 and should as a minimum be above .5. Also, the Bartlett's test of sphericity was performed, indicating if the correlations between the project management items were significantly different from 0. This is a basic premise for performing factor analysis, and the test should be statistically significant (Field, 2018). These tests both indicated the appropriateness of applying exploratory factor analyses for the project management items.To test hypotheses 1 and 2, a median split on the project management indices was performed (see Table 6) to create two groups; one that performed well on project management and one that performed poorly on project management. The mean rank on safety management in the two groups was compared (testing hypothesis 1), as well as the mean rank on the safety performance variables, and LTI and TRI rates (testing hypothesis 2). Similarly, a median split on the safety management variable was performed, and the mean ranks on the safety performance variables were compared to test hypothesis 3.

The comparisons of means were made using the Mann–Whitney *U*-test. This is a non-parametric test, which can be used if conditions for parametric tests are not satisfied. The assumption of normality was not met for the data in the study, excluding the use of t-tests in the analyses, as t-tests require normal sampling distributions of means ('the assumption of normality'). The Kolmogorov–Smirnov test scores were non-normal for the safety management and safety performance variables

Table 3
Descriptive statistics for items included in the exploratory factor analysis

Item	Mean	SD	N
Q1: The project's work processes and systems (e.g., document management, project controls, business and financial systems) supported project success.	3.57	0.82	63
Q2: The interfaces between project stakeholders were well managed.	3.60	0.78	62
Q3: Project team members had the information they needed to do their jobs effectively.	3.87	0.70	63
Q4: The project team members were familiar with the project execution plan (PEP), and they used it to manage their work.	3.95	0.59	63
Q5: Project team members had the authority necessary to do their jobs.	4.03	0.71	63
Q6: When issues arose, there were effective mechanisms to ensure they were resolved.	3.66	0.74	63
Q7: Key project team members understood the owner's goals and objectives for this project.	4.23	0.60	63
Q8: The project team including project manager(s) had skills and experiences with similar projects/processes.	4.15	0.64	63
Q9: Project leaders were open to hearing 'bad news', and they wanted input from project team members.	4.22	0.67	62
Q10: Project leaders recognised and rewarded outstanding personnel and results.	3.44	0.79	63
Q11: The project's commissioning objectives were appropriately communicated to the relevant project team members.	4.06	0.74	63
Q12: A formal project quality management system was used for the construction of this project.	3.66	0.85	63
Q13: The project team members attended sufficient professional training directly related to their work in the phase.	3.54	0.68	63

Table 4
Exploratory factor analysis

Items		Factor loadings			Com.
		1	2	3	
Q1	The project's work processes and systems (e.g., document management, project controls, business and financial systems) supported project success.	.866			.779
Q2	The interfaces between project stakeholders were well managed.	.805			.841
Q3	Project team members had the information they needed to do their jobs effectively.	.786			.748
Q4	The project team members were familiar with the project execution plan, and they used it to manage their work.	.727			.678
Q5	Project team members had the authority necessary to do their jobs.	.719	.401		.700
Q6	When issues arose, there were effective mechanisms to ensure they were resolved.	.718	.424		.787
Q7	Key project team members understood the owner's goals and objectives of this project.	.710	.466		.695
Q8	The project team including project manager(s), had skills and experiences with similar projects/processes.	.678			.566
Q9	Project leaders were open to hearing 'bad news', and they wanted input from project team members.		.831		.793
Q10	Project leaders recognised and rewarded outstanding personnel and results.		.802		.782
Q11	The project's commissioning objectives were appropriately communicated to the relevant project team members.	.410	.666		.612
Q12	A formal project quality management system was used for the construction of this project.			.845	.737
Q13	The project team members attended sufficient professional training directly related to their work in the phase.			.770	.830
	Rotated sum of squared loadings (% of variance)	38.73	22.68	12.04	
	Eigenvalues (Total)	7.318	1.212	1.018	

Notes: Factor loadings below 0.4 are suppressed. Bartlett's test of sphericity (approx. chi-square) = 571.42 ($p < 0.001$) df = 78. KMO measure of sampling adequacy: .865

Table 5
Pearson's correlations between factors; Cronbach's alpha on the diagonal

Factor	Items	1	2	3
1. Teams and system functioning	8	(.939)		
2. Leadership	3	.706	(.836)	
3. Compliance	2	.413	.293	(.578)

Table 6
Descriptive statistics for variables

Variable	N	Mean	SD	Median
Teams and system functioning	62	3.88	.60	3.92
Leadership	62	3.90	.64	3.88
Safety management index	63	69.84	10.08	71.00
LTI rate	32	8.99	14.05	3.27
TRI rate	32	17.68	20.64	13.48

($p < .05$). By using the ranking of the scores rather than the scores directly, the Mann–Whitney *U*-test is robust towards skew and non-normality. Although the test itself does not provide an effect size *r*, approximate effect sizes can be estimated from the z-scores (using the formula $r = z/\sqrt{N}$), where *r* below 0.3 is considered a small effect, *r* up to 0.5 is regarded as a medium effect, and *r* above 0.5 is a large effect (Field, 2018). The test determines if the mean ranks in two groups are significantly different. One-way tests were applied since the hypotheses are directional. The level of statistically significant associations was set to .05. The steps and decisions related to the statistical analyses is illustrated in Figure 5.

4.6. *Data quality and study limitations*

The study is based on existing comprehensive data from the Nordic 10-10 database. The authors did not construct the questionnaires that yielded the inputs to the analysed database, and thus the study is limited to only examining the relationships between specific aspects of project management, safety management and safety performance. One benefit of using these data is that the projects and companies are part of a network and have support in using the tool. The respondents have been facilitated while responding to the questionnaire and have had the opportunity to clarify doubts. This enhances the uniformity of the question understanding and strengthens the reliability and validity of the data. Participating in benchmarking might also affect the results since these construction projects devote resources to responding to questionnaires, which might create a bias in the answers.

Values for safety performance (LTI and TRI rates) were collected as far as possible. For certain projects, data was not available either because they were not maintained by the companies or because the companies did not reply. The LTI and TRI rates were self-reported by the companies, and the rates' accuracy and quality could not be controlled. However, companies have internal control procedures for their incident data collection. The familiarity of the LTI and TRI rates in the industry and the wide availability of such data in companies justify the use of these rates in the research as they can provide new insights and contribute to the improvement of occupational safety.

The database contained N=63 cases relevant for analysis, spread across 47 projects and 13 companies. Although the limited N put restrictions on the statistical analyses that could be applied (e.g., structural equation modelling), and affects the possibility of generalising the study and increases the possibility of type II error (where the null hypothesis is false but not rejected), the study contributes valuable knowledge about the relations between project and safety management and safety performance.

The study is performed in the construction industry in a developed country, which has different safety management challenges than developing countries. Boadu et al. (2020) argue that the construction industry in developing countries has safety management challenges related to lack of a skilled and educated workforce, reliance on labour intensive methods and lack of single regulatory authority. Another main difference from developed countries, demonstrated by e.g. Durdyev et al. (2017) is the lack of safety equipment and safe practices in the sharp end which is very different from what is experiences in e.g. Norway. Boadu et al. (2020) also demonstrates that developing countries have a much higher fatal accident rate than developed countries. This implies that the needs to think differently about safety is even more important in developing countries than in developed countries, which makes the findings and recommendations in this paper relevant to the construction industry in all countries. Conducting an identical empirical research study in a developed nation could yield different results compared to those outlined in this paper. This could be attributed to the unique safety management issues encountered in these countries. Additionally, the distinct project management challenges and practices in these nations (Yap et al., 2019), such as design alterations during the

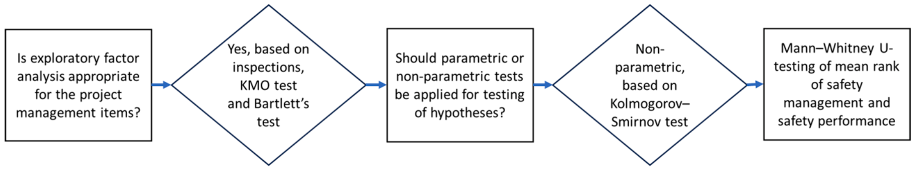

Figure 5. Steps in the statistical analyses

construction phase, exceeding budget, delayed completions, competitive bidding processes, and overdue payments, could also contribute to the variation in results

5. Results

5.1. Exploratory factor analysis – project management items

A principal component analysis (PCA) with varimax rotation and Kaiser normalisation was performed. Thirteen items related to project management were included in the analysis (Table 2). Descriptive statistics for the items are provided in Table 3.

Tests in the preliminary analysis, involving the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity, gave satisfactory results (see notes for Table 4). The correlation matrix did not give any correlations above 0.9, which could suggest collinearity. The ratio between sample size and the number of items is often recommended to be 10–15 cases per item, but researchers have shown that rules of thumb are not always valid and that the commonalities play an important role in the sample size (MacCallum et al., 1999).

After a listwise exclusion, 62 cases were included in the factor analysis. The scree plot and Kaiser's criterion (requiring eigenvalues greater or equal to 1) suggested three factors. The commonalities after extraction were examined, and the majority were above .7. However, since not all items had a value above .7, the average communality was calculated and found to be .735, which was acceptable. As Kaiser's criterion and the scree plot both suggested three factors, this was the chosen solution, explaining 73% of the variance. The cross-loadings between items were considered acceptable, given that for the majority, they are below .4. The highest cross-loading for an item was .466 (Q7); this was deemed acceptable, as the main loading was high (.710).

The items associated with factor 1 thematically address the *project team and system functioning*. The factor consists of eight items describing the project team members and system characteristics. The first factor accounts for 38.7% of the variance. Factor 2 consists of three items addressing project *leadership*, and the factor accounts for 22.7% of the variance. Factor 3 includes two items, considers compliance with systems and requirements, and accounts for 12% of the variance.

Table 5 presents Pearson's correlations between the factors and Cronbach's alpha for each factor. The correlations between the factors indicate satisfactory discriminant validity. The highest correlation was between factors 1 and 2 (.706), still not indicating a majority of shared variance. Alpha scores > .7 indicate adequate internal consistency and reliability (Nunnally, 1978). For factors 1 and 2, Cronbach's alpha was 'excellent' and 'good', respectively. However, for factor 3, Cronbach's alpha was considerably below the .7 limit. Consequently, factor 3 was not included in further analyses.

5.2. Mann–Whitney U-test

Independent sample Mann–Whitney *U*-tests were performed to explore the relationship between project management ratings and these projects' scores on safety management and safety performance. Project management included two indices: *teams and system functioning* and *leadership*. One-way tests were applied, with the significance level set at .05. Table 6 gives an overview of the variable characteristics and the cut-off criterion, which was set to the median (for the project management and safety management variables). The N differed between the variables describing project management, safety management and safety performance given that the data come from two independent sources and data are available for more cases in the Nordic 10-10 database.

5.3. Testing the hypotheses

The results of the tested hypotheses are presented in this section giving the ranks for the safety management index, LTI rates and TRI rates of projects performing well and poorly of selected variables.

The first hypothesis explored was related to a positive association between project management and safety management. It was hypothesised that projects performing well on project management perform better on safety management as compared to projects performing poorly on project management (H1). Results related to the two project management indexes are presented in Table 7.

The Mann-Whiney *U*-test indicates that the rank on the *safety management index* is significantly higher for projects performing well on *teams and system functioning* (Mdn = 75) compared to projects performing poorly on *teams and system functioning* (Mdn = 69), U = 735.0, z = =3.59, p < .001, r = 0.46, supporting hypothesis 1. The r value was calculated and demonstrates a moderate effect of this factor.

The Mann-Whitney *U*-test also indicates that the *safety management index* is significantly higher for projects performing well on the second project management factor, *Leadership* (Mdn = 75), compared to projects performing poorly on *leadership* (Mdn = 65), U = 777.0, z = 4.18, p < .001, r = 0.53, also supporting hypothesis 1. For the leadership factor, a large effect is demonstrated.

Further, we explored the relationships between projects scoring well and poorly on the two project management factors (H2) and safety management (H3), along with their respective scores on safety performance measured by LTI and TRI rates. These are presented in Tables 8 and 9.

The results in Table 8 show no significant differences in safety performance measured by LTI rate between projects performing well and poorly on the two project management factors, *teams and system functioning* and *leadership*, thus not supporting hypothesis 2. Also, no significant differences in LTI rates are found between projects performing well and poorly on the *safety management index*, not supporting hypothesis 3.

The results in Table 9 also show no significant differences in *safety performance* measured by TRI rate between projects performing well and

Table 7
Ranks for the safety management index of projects performing well and poorly on the project management variables.

	Safety management index					
	Meanrank	N	Mann-Whitney *U*	z	p-value	r
Teams and system functioning > 3.92	39.71	31	735.0	3.59	<.001	0.46
Teams and system functioning ≤ 3.92	23.29	31				
Leadership > 3.88	41.06	31	777.0	4.18	<.001	0.53
Leadership ≤ 3.88	21.94	31				

Table 8
Ranks for the LTI rate of projects that perform well and poorly on the project management variables and the safety management index.

	LTI rate				
	Meanrank	N	Mann-Whitney *U*	z	p-value
Teams and system functioning > 3.92	15.84	19	111.0	-.51	.307
Teams and system functioning ≤ 3.92	17.46	13			
Leadership > 3.88	14.86	21	81.0	-1.08	.141
Leadership ≤ 3.88	18.40	10			
Safety management index > 71	14.50	18	90.0	-1.44	.075
Safety management index ≤ 71	19.07	14			

Table 9
Ranks for the TRI value of projects that perform well and poorly on the project management variables and the safety management index.

	TRI rate				
	Meanrank	N	Mann-Whitney *U*	z	p-value
Teams and system functioning > 3.92	16.55	19	124.5	.04	.485
Teams and system functioning ≤ 3.92	16.42	13			
Leadership > 3.88	15.19	21	88.00	-.74	.231
Leadership ≤ 3.88	17.70	10			
Safety management index > 71	14.83	18	96.00	-1.16	.123

poorly on *teams and system functioning* and *leadership*, thus not supporting hypothesis 2. Also, no significant differences in TRI rates are found between projects performing well and poorly on *safety management*, not supporting hypothesis 3.

6. Discussion

The results of the study show that projects that perform well on project management also perform well on safety management. These results give two implications for research and practice which are discussed in this section. First, we discuss safety as an integrated aspect of all management activities in the project organisation. Second, we investigate the flaws in loss-based measures of safety performance. The results are summarised in Table 10 with implications for further discussion.

Table 10
Summary of hypothesis and testing results

No.	Relationship	Result	Implication
H1	PM (*teams and systems functioning*; *leadership*) → SM	Supported	Safety is an integrated part of project management (discussed in section 6.1)
H2	PM (*teams and systems functioning*; *leadership*) → SP (*TRI; LTI*)	Rejected	LTI-rate and TRI-rate are misrepresentative indicators of safety performance (discussed in section 6.2)
H3	SM → SP (*TRI; LTI*)	Rejected	LTI-rate and TRI-rate are misrepresentative indicators of safety performance (discussed in section 6.2)

PM – project management, SM – safety management, SP – safety performance

6.1. The relationship between project management and safety management: safety as an integrated aspect of all project management activities

The study demonstrates a significant positive relationship between factors of project management and safety management in construction projects. These results confirm the relationship illustrated in Figure 3, which implies that the same contributing factors both create value and enable the control of hazards. Safety needs to be an essential component of the overall system to provide value across business processes. Some recent studies advocate for perceiving safety along with other systems and activities and across projects (Le Coze, 2019; Lingard and Wakefield, 2019). However, the implementation of safety management as an aspect system needs more attention. For example, project managers' reference to safety (Agyekum et al., 2021) and the top management's commitment are key organisational capabilities required to integrate safety management (Asah-Kissiedu et al., 2021).

The empirical findings support the concept of including safety as an integral part of project management and fall in line with the argument of Hale (2006) to consider safety as an aspect system. Leaving safety management merely as a side unit, without the strings to steer the factors that affect the safety objectives, hinders satisfactory safety management. Not integrating safety into overall management can have downsides for the whole system. The project manager is the operational responsible for safety on a project, and the study shows a strong and significant relationship between good *leadership* and good safety management. The characteristics of a project manager seem to be influential and of particular importance. Furthermore, project managers' capabilities and commitment are found to be important factors for construction projects' success (Gunduz and Yahya, 2018; Toor and Ogunlana, 2009). This shows that these project management-related contributing factors lead to both project success and good safety management. The importance of such competence and having it in-house is pointed out by Hovden (2004), who warns about outsourcing safety competence and states that the operative safety responsibility should be with the line organisation. According to Choudhry et al. (2008), changing safety officers' titles to safety advisors can, to a larger degree, reflect the safety responsibility of higher management personnel (i.e., the project director, project manager and line managers), thus integrating safety management into project management.

6.2. The relationship between safety performance and project/safety management: monitoring safety performance in projects

Although LTI and TRI rates are criticised for several reasons (e.g., Hallowell et al., 2020; Kjellén and Albrechtsen, 2017; Oswald et al., 2018), the indicators are widely used as measures of safety performance across industries. The rates are used both during projects and in companies to track and assess safety performance. The results from the study do not show significant differences in LTI and TRI rates between projects that perform well and poorly on project management and safety management, respectively. Although statistical significance is not demonstrated in this study, it does not exclude such relations from existing, meaning that the results could be prone to type II error, or false negative results. Earlier studies have pointed to significant relationships between safety practices, the safety climate (including managerial aspects) and lagging safety indicators (Hinze et al., 2013a; Alruqi et al., 2018). The results might thus elucidate the limitations of using incident rates such as TRI and LTI rates as indicators for measuring safety performance during projects. As these indicators give delayed feedback on performance, underreporting and possible manipulation are issues.

Further, as incidents and outcomes mostly occur randomly and require large sample sizes for statistical analyses, the measures might not give sufficient reliable information to control or improve safety during the project lifespan (Hallowell et al., 2020; Kjellén, 2009). The randomness in the injury rates, the short measuring span and the limited size of the sample can thus be reasons that no significant relations between project management, safety management and LTI and TRI rates were found in our study. The possibilities for analysing influencing and dependent variables are quite different in other domains, e.g. traffic safety which can be analysed over longer time spans and also could involve more comprehensive data (Ahmadpur and Yasar, 2023).

In summary, using these safety performance measures as success factors for safety – and comparing and benchmarking projects and companies with them – has some clear limitations due to the weaknesses of the measures as well as characteristics of the industry and its unique, temporary projects. Furthermore, looking at incident rates with a time lag can only contribute to improvement after incidents have occurred (Hinze et al., 2013b), and more incidents can occur during the time lag instead of improving hazard control immediately.

Adopting leading safety performance indicators is an alternative. Leading indicators provide early warning signals regarding an organisation's hazard control before incidents occur (Kjellén and Albrechtsen, 2017). Based on the results of this study that emphasise the integration of safety management and project management, measuring the quality of project management elements could function as a leading safety performance indicator.

Empirical studies on leading indicators for safety performance in the construction industry are scarce (Alruqi and Hallowell, 2019) and focus, to a large extent, on indicators directly associated with safety (Lingard et al., 2011). Our study provides evidence that factors related to general project management activities and characteristics should be considered for leading safety indicators. This is in accordance with Lingard et al. (2017), who suggest looking into project performance measures and their possible influence on and prediction of safety performance.

7. Implications for practice and research

There are two main contributions from this study for practice and research. First, there is an implication related to the relationship between project management and safety management: safety in construction projects is created and maintained both by project management, aiming at reaching the objectives of a project and safety management, aiming at supporting decisions for hazard control. This implies that one should avoid polarisation between value creation and safety which can lead to conflicting objectives (Rasmussen, 1997). Safety should not be treated as a fifth wheel and should be integrated as a part of all activities in a project. The empirical results supporting the integration of project management and safety management is an important contribution to the innovative safety science direction of "Safety II" (Hollnagel, 2014), which aims to understand safety as things that work well rather than focusing on things that go wrong. Safety II research has mainly been at a conceptual level with a lack of empirical support. Furthermore, there are several conceptual studies that call for safety to be an aspect of all strategic and operative management activities in project organisations (Benjaoran and Bhokha, 2010; Hale, 2006; Le Coze, 2019; Woolley et al., 2020). Our study provides empirical support for this conceptual argument.

The second implication is related to the relationship between safety performance and management: safety performance indicators should be complemented by leading safety performance indicators that measure expected control of hazards. This can be done by measuring project management factors such as the characteristics of project managers and their leadership and factors related to information flow and project management systems. Different weaknesses of lagging safety performance indicators have been identified, and several arguments have been presented for the need to develop and implement leading safety performance indicators (Dekker and Conklin, 2022; Kjellén and Albrechtsen, 2017). Also, this development follows the innovative safety science approach, Safety II. One way to develop leading safety performance indicators is to identify critical success factors that matter for the achievement of safety and develop ways to measure and analyse these factors (OECD, 2014). Our empirical findings suggest that project management aspects related to *teams, systems* and *leadership* are critical success factors that should be developed into leading indicators.

Leading safety performance indicators is thus one way to enhance the connection between safety and project management in practice, integrating and enhancing safety management as an aspect system. There are still considerable challenges related to constructing good and valid leading indicators (Kongsvik et al., 2010), partly related to the complexity of how safety performance is 'produced', but also related to specific characteristics of industries, projects and workplaces that involves a need for tailor-making leading indicators for specific contexts. Also, conditions that 'produce' safety performance change over time, for example by changes in top management and turnover of personnel, illustrating the need to maintain indicators to ensure their validity (ibid.). Implementing leading safety performance indicators thus requires resources and maintenance, which might explain why lagging indicators still seem to be dominant in the construction industry. Still, there is a considerable upside related to a more proactive approach to safety management, most importantly preventing accidents before they take place.

8. Conclusions

The relationships between project management, safety management and safety performance were explored in this study. They were studied by using data from a set of Norwegian construction projects that provide insights into the quality of elements of project management and safety management. A strength of this data is that they were collected by an acknowledged tool for project performance assessment developed by the Construction Industry Institute (CII) at the University of Texas (Nordic 10-10, 2021; Yun et al., 2016). As a supplement to the assessment of management elements, safety performance data measuring the injury frequency were applied. Such injury frequencies come with weaknesses (Hallowell et al., 2020; Kjellén and Albrechtsen, 2017) but are nevertheless what the industry often uses to measure safety performance.

The results show significant differences in the *safety management index* between projects that perform well and poorly on project management (measured by *teams and systems functioning* and *leadership* indices). This result has statistically proven the close relationship between project management and safety management. It can therefore be concluded that safety in construction projects is created through good general project management, in particular steering and leadership aspects. This also underlines the importance of safety not being treated as separate and independent from other processes in projects, but rather perceiving safety management as an aspect system. To develop safety practices further, it is advised to strengthen and maintain the inclusion of safety aspects in all management activities in a project. This is, however, not an argument for reducing the importance of safety management as a staff function.

Further, the lack of statistical significance between both project management and safety management towards safety performance confirms the limitations in the use of LTI and TRI rates as safety performance indicators. The study suggests developing supplementary leading indicators for safety performance. For instance, measuring aspects related to *teams and system functioning,* and *leadership* could be investigated as an alternative. Thus, further relationships between aspects of project management, safety management and safety performance should be examined, as well as evaluating components of indicators for project management that could be used to determine the current safety status in projects.

One future direction of the research would be to develop, implement and evaluate leading safety performance indicators measuring aspects related to teams and system functioning and leadership. Another direction would be to apply the study design and results to develop the project performance assessment tools Nordic 10-10 and CII 10-10 for improved assessments of safety in construction projects. And finally, we encourage more empirical studies on the integration of project management and safety management, which should benefit best practices as well as move the safety research frontier.

Data Availability Statement

Restrictions apply to the availability of these data. Data were obtained from the Nordic 10-10 consortium and are available on request from the contact persons at https://nordic10-10.org/kontakt-oss/.

CRediT authorship contribution statement

Kinga Wasilkiewicz Edwin: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Trond Kongsvik:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **Eirik Albrechtsen:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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