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MANAGERIAL MEASURES TO REDUCE REWORK AND IMPROVE CONSTRUCTION SAFETY IN A DEVELOPING COUNTRY: MALAYSIAN CASE

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Abstract. Previous studies demonstrate that rework can lead to more safety incidents. However, there is an inadequate understanding of how construction rework reduction measures may significantly decrease the likelihood of safety incidents in developing countries. To explore how construction organisations can integrate rework minimisation and safety management in practice, this study examines the effectiveness of the management strategies that can reduce rework and improve safety. Based on a two-stage detailed literature review of both rework- and safety-related studies, 13 managerial measures are recognised that are capable of jointly reducing rework and safety incidents for construction projects. A field survey involving construction professionals in Malaysia was used to analyse and rank these measures according to effectiveness indices for rework, safety and joint rework-safety management. Factor analysis yielded a two-factor solution comprising (1) project management best practices and (2) proactive competency management. It is suggested that the construction industry would benefit from simultaneously ameliorating the quality and safety performance of projects by adopting effective joint measures that are predominantly guided by process (best practices) and people (competency management) components.

Keywords: rework, safety management, project management, construction industry, best practice.

Introduction

The construction industry plays an essential role in national socio-economic development but is also recognised as one of the most dangerous industries, particularly in the developing world (Mohammadi et al., 2018) – contributing to a high rate of job-related accidental injuries and workplace fatalities. In Malaysia, using secondary data from the Department of Occupational Safety and Health and Social Security Organisation, Ayob et al. (2018) reported that construction work tops the list of the riskiest jobs of all sectors of the economy. Against this backdrop, construction being a high-risk industry is stigmatised as 3D (dirty, difficult and dangerous) where accidents remain prevalent and costly (Yap & Lee, 2020). High construction accident rates and appalling work conditions are the key reasons local youths shun construction jobs – further exacerbating the labour shortages within this vital sector (Yap et al., 2019a).

As Oswald et al. (2020, p. 1) accentuate, "construction accidents can have major social, financial, reputational and legal implications". However, construction site accidents continue to occur (Ayob et al., 2018; Wanberg et al., 2013), with a considerable amount of research and endeavour to improve construction safety revealing several persisting issues, that existing standalone safety management approaches and supervision systems are inadequate to overcome safety problems and improve construction safety, and the need for them to be better integrated with other management systems to obtain multi-faceted performance improvements (Das et al., 2008; Loushine et al., 2006; Yap et al., 2020). Hence, strategies are needed to jointly im-

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prove safety and such other facets of project performance as cost, schedule and quality (Love et al., 2018b; Pereira et al., 2020).

Rework is an important indicator of quality, with previous studies showing it to be associated with construction site accidents (Love et al., 2020). When there is rework, there is a higher chance of errors due to poor working knowledge and a lack of well-planned processes (Love & Smith, 2016; Wanberg et al., 2013). Schedule pressures associated with abortive rework caused by quality deficiencies can also significantly affect safety performance, as workers are pressed to work faster. Working under schedule pressures and in a stressful environment is detrimental mainly due to out-of-sequence work, a higher rate of defects, cutting corners and lack of worker motivation (Ajayi et al., 2021).

Despite an increasing amount of research into construction rework (e.g., Asadi et al., 2021; Garg & Misra, 2021), the association between its reduction and safety improvement has become a significant knowledge gap, and improvements have been minimal. Most studies investigating measures to minimise and control rework in construction have the ultimate aim of improving labour productivity and time-cost performance (e.g., Chiu et al., 2021; Hwang & Yang, 2014), which aligns with Das' et al. (2008) assertion that safety has been inexplicably overlooked in the operations management literature. Others investigate rework minimisation (e.g., Zhang et al., 2019) and safety management and improvements (e.g., Hallowell & Gambatese, 2009; Pereira et al., 2020) independently, although safety and rework management processes are somewhat comparable. Love et al. (2018b), for example, highlight the lack of a robust theoretical underpinning of the nature and interplay of quality and safety issues in construction projects; while Loushine's et al. (2006) literature search identifies 49 articles relating to construction quality and safety management, only 10% of which investigated quality together with safety aspects – indicating a lack of empirical studies integrating rework and safety management in a project-based construction setting. Wanberg et al. (2013) and Xia et al. (2018) further echo this claim, pointing to the scarcity of empirical studies examining managerial measures to simultaneously reduce rework and safety risks. Ahmed and Anantatmula's (2017) leadership competence and project management model, for example, include cost, schedule, quality and stakeholder satisfaction variables but not a safety variable.

In response, this study aims to explore how construction organisations can integrate rework minimisation and safety management. The objectives are to identify and evaluate the effectiveness of the management strategies that can reduce rework and improve safety. The findings will add to the body of knowledge from the analysis of pertinent rework and safety management measures and uncovering the underlying managerial strategies needed to reduce rework and safety risks to ensure significant improvements in quality and safety.

1. Relating rework and safety management

Love (2002, p. 19) describes reworking as "the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time." As rework involves revision and working again due to non-conformance and change/deviation (Love & Smith, 2018), it is basically a non-value adding (wasteful) activity that lowers labour productivity (Wan et al., 2013) and is regarded as a problematic managerial predicament (Emuze et al., 2014).

Rework is a recurring problem within construction worldwide (Kakitahi et al., 2016; Shi et al., 2014) and with a variety of causes. In Nigeria, for instance, the major observed rework causes are mainly related to errors, omissions and quality deviations (Oyewobi et al., 2016); the contractors' poor field management is the main reason for rework in China (Liu et al., 2020); rework in building projects is attributable to managerial shortfalls in terms of coordination, resources, implementation, design-related issues and site workmanship in Malaysia (Yap et al., 2017, 2021); and lack of constructability planning in Canada (Jergeas & Van der Put, 2001). In terms of outcomes, Yap's et al. (2019b) systemic approach identify the knock-on effects from rework performance, including work rhythm disruptions, workforce resentment, productivity disruptions, cost increases, disputes, excessive claims and an extended duration; generating more material waste on sites (Mahamid, 2022); Hwang et al. (2014) report client-related rework exerting a significant impact on project cost, schedule and quality performance of building projects in Singapore; Love and Smith's (2018) comprehensive literature review found the reported costs of rework can reach up to 20% of the project contract value.

According to Han et al. (2014), rework and schedule delays are critical components associated with organisational pressures to control quality and scheduling that also affect workers' attitudes towards safety management. Their simulation results show that when rework and schedule delays increase, the number of future accidents increases correspondingly. Wanberg's et al. (2013) analysis of empirical data gathered from 32 U.S. building construction projects found a strong positive association between rework and on-site accidents because of destruction, excessive schedule pressure and haphazard working practices – one of their interviewees explicitly mentioned that over 60% of all recordable injuries occurred because of rework. In a subsequent study in Australia employing a sense-making approach, Love's et al. (2018b) interviews with 16 project personnel in safety, quality and environment (SQE) and project-based roles reveal a unanimous agreement concerning the precursors to rework and safety events being related to people, organisational and project issues.

The significance of managerial measures in enhancing quality, labour productivity and safety is emphasised in previous studies (e.g. Ajayi et al., 2021; Ghodrati et al., 2018). With this in mind, the identification of pertinent rework and safety management measures is pivotal to ensuring the success of the present study. According to Love et al. (2016), error management strategies to reduce rework and improve safety relate to three primary aspects of detection (knowing an error has occurred), explanation (knowing what was done wrong and what should have been done), handling and recovery (knowing how to undo the effects of error and achieve the desired state). The rework management framework developed by Zhang et al. (2019) hinges on management competence through people, approach, process, tools and project environment. The impact of management strategies for reducing rework and improving safety performance needs to be recognised. In promoting both safety and quality, useful strategies proposed by Wanberg et al. (2013) include: preplanning, allocating adequate time to complete tasks correctly the first time, inspiring workers to give their best performance through leadership, and motivating workers to take pride in the quality of their work.

Following a detailed review of rework studies, a list of the 13 managerial measures to minimise rework in construction projects is identified. Based on this, the selected safety literature is further analysed to understand how these managerial measures also jointly contribute to improving safety performance. The literature review provided at this stage indicates that shortlisted management measures can potentially contain rework, and simultaneously reduce safety incidents. These are presented concisely for brevity (Table 1). Although there is no single approach to containing rework and safety risks, the identified joint managerial measures are envisaged to significantly contribute to project productivity and performance improvement.

2. Research methodology

A two-stage literature review was adopted to establish the content validity for identifying the managerial measures for rework reduction that also decrease the likelihood of safety incidents. The first round involved synthesising articles relating to rework, to identify the pertinent measures for effective rework management. Based on this list, a second meta-analysis was performed to examine articles within the safety domain to establish the linkage between rework and safety management measures. A preliminary list of 13 common measures was identified (Table 1). In order to have a complete understanding of the effectiveness of common measures identified, the research required a large amount of documented data on completed projects.

Table 1. Summary of rework management measures that also facilitate construction safety management

No.	Managerial measures (reduce rework and improve safety)	References	
		Rework-based study	Safety-based study
1	Provide sufficient training and education for worker	Hwang and Yang (2014); Love and Edwards (2004); Safapour and Kermanshachi (2019); Yap et al. (2017); Ye et al. (2014)	Bavafa et al. (2018); Chen and Jin (2013); Golizadeh et al. (2018); Haslam et al. (2005); Zhao et al. (2018); Zou (2011)
2	Risk assessment and management	Hwang and Yang (2014); Love and Edwards (2004); Yap et al. 2017; Ye et al. (2014)	Bavafa et al. (2018); Golizadeh et al. (2018); Haslam et al. (2005); Zou (2011)
3	Error management	Love et al. (2018a, 2018b); Safapour and Kermanshachi (2019); Ye et al. (2014)	Love et al. (2018a, 2018b)
4	Learning from coaching	Hwang and Yang (2014); Love et al. (2018a); Love and Edwards (2004); Yap et al. (2017)	Love et al. (2018b)
5	Learn from the previous actions, events and experiences	Love et al. (2018a); Love and Edwards (2004)	Haslam et al. (2005); Love et al. (2018a, 2018b); Zou (2011)
6	Proper production planning	Love et al. (2018a, 2018b)	Golizadeh et al. (2018); Love et al. (2018a); Zhao et al. (2018)
7	Continuous learning and knowledge improvement	Hwang and Yang (2014); Love and Edwards (2004); Yap et al. (2017); Ye et al. (2014)	(Love et al. 2018a)
8	Good site management system	Hwang and Yang (2014); Safapour and Kermanshachi (2019); Yap et al. (2017)	Chen and Jin (2013); Haslam et al. (2005)
9	Appropriate handling of materials and delivery	Love et al. (2004)	Haslam et al. (2005)
10	Good coordination and communication network between all parties	Love and Edwards (2004); Safapour and Kermanshachi (2019)	Chen and Jin (2013); Golizadeh et al. (2018); Haslam et al. (2005); Zou (2011)
11	Employment of qualified and experienced personnel	Love et al. (2018b)	Zhao et al. (2018)
12	Effective use of information technology and advanced technology	Love et al. (2004)	Golizadeh et al. (2018); Zou (2011)
13	Effective subcontractor management system	Love et al. (2004); Love and Edwards (2004); Ye et al. (2014)	Bavafa et al. (2018); Chen and Jin (2013)

As documented data on locally completed projects is non-accessible for this study, a questionnaire survey approach was considered the as most efficient tool (Doloi, 2008, 2009). This approach to collecting quantitative data for statistical analysis is of relatively low cost and practical for large samples to enable rigorous statistical analyses. Furthermore, an all-embracing perception of the research topic is maintained by soliciting views from construction professionals, consisting of developers, consultants and contractors – representing the key construction project players.

2.1. Questionnaire design

The questionnaire consists of three parts which are drafted in plain language to enable the respondents to exercise sound judgement. Part I asks for general background information. Based on the literature review, the 13 managerial measures obtained from previous studies (Table 1) were incorporated in Parts II and III. Part II asks *How effective are these managerial measures in reducing rework in a construction project?* and Part III asks *How effective are these managerial measures in improving safety performance in a construction project?* – both questions were rated on a 5-point Likert-type scale from 1 (ineffective) to 5 (extremely effective). A similar approach was also adopted by Le-Hoai et al. (2008), Bagaya and Song (2016) and Yap et al. (2019a) who used relative indices to determine the criticality of the studied variables. The questionnaire is also designed to take less than 15 minutes to complete to avoid survey fatigue which may decrease the veracity of the responses. The quality of the questionnaire was ascertained after pre-testing with three subject matter experts.

2.2. Sampling and data collection

The questionnaire was distributed to targeted construction professionals from the developer, consultant and contractor organisations based in Malaysia, as primary stakeholders from different backgrounds and with direct involvement in the delivery of construction projects. Thus, the sampling frame involved key actors in planning, delivery and controls aspects in the management and execution of construction projects. Using judgemental sampling, the professionals were sourced from the LinkedIn platform using the keywords: *Malaysia*, *construction industry*, *developer*, *civil engineer*, *planning engineer*, *site engineer*, *construction manager*, *project manager*, and *quantity surveyor*. A total of 440 email addresses were obtained in this way for an e-survey, from which 157 valid responses were returned – a satisfactory response rate of 35.7% which is consistent with previous studies in construction management. For example, 33.4% in Mongolia (Usukhbayar & Choi, 2020), 34.0% in the US (Anantatmula & Rad, 2018) and 36.0% in China (Wang et al., 2018). Additionally, the sample size is above Yamane's required response threshold (Damoah & Kumi, 2018; Williams et al., 2020). According to Roscoe's (1975) rule of thumb, sample sizes larger than 30 and less than 500 are appropriate for most perception-based research – often considered sufficient for the central limit theorem (CLT) to hold. In addition, the free parameter ratio exceeding 5 is acceptable for reliable factor analysis (Ye et al., 2014).

Table 2 summarises the demographic profile of the respondents. Contractors account for 72.6% while developers and consultants make up 15.9% and 11.5%, respectively. The majority attended tertiary education and nearly 40% have 10 years or more of construction industry experience. These are considered to be qualified respondents who have sufficient knowledge and experience of the Malaysian construction industry to provide sound judgements for this opinion-based study. Around two-thirds are involved in building projects, with the remainder specialising in civil and infrastructure work.

2.3. Data analysis

Cronbach's coefficient alphas are 0.930 and 0.947 for rework and safety management respectively, which exceed the 0.70 value needed to establish scale reliability

Table 2. Respondents' background

Profile	Description	Frequency (N = 157)	Percentage (%)
Role in project	Developer	25	15.9
	Consultant	18	11.5
	Contractor	114	72.6
Working experience	< 5 years	57	36.3
	6 to 10 years	40	25.5
	11 to 15 years	22	14.9
	≥ 16 years	38	24.2
Education background	Postgraduate degree	25	15.9
	Bachelor's degree	114	72.6
	Diploma, Certificate	16	10.2
	High School	2	1.3
Nature of project	Building	100	63.7
	Civil and infrastructure	57	36.3

(Ye et al., 2014). This technique is widely applied in construction management studies to ensure the internal consistency and reliability of the scale used. The survey data were further analysed using effectiveness indices, taking into view developers, consultants and contractors. This is modified from the importance index (IMP.I) technique widely used to prioritise variables in previous delay studies in construction management domain. The indices provide a good representation in highlighting the perceived importance of the measures in the order of relative effectiveness as perceived by the respondents. Agreement on the ranking of the effectiveness of the management measures between the two groups of parties was also tested. Exploratory factor analysis was then utilised to obtain a greater insight into the numerous correlated, but seemingly unrelated, attributes by reducing them to a much fewer set of underlying factors.

Effectiveness indices

To assess the effectiveness of the management measures for rework and safety, the data was analysed using index techniques akin to the empirical studies of Le-Hoai et al. (2008), Bagaya and Song (2016) and Yap et al. (2019a).

The *effectiveness index for rework management* ($E.I._{rework}$) is

$$E.I._{rework} = \sum_{1}^{5} \frac{a_i\, n_i}{5N}, \tag{1}$$

where a represents the 1–5 score for each response, n the frequency of responses and N the total number of responses.

The *effectiveness index for safety management* ($E.I._{safety}$) is

$$E.I._{safety} = \sum_{1}^{5} \frac{b_i\, n_i}{5N}, \tag{2}$$

where b, n and N represent the same as a, n and N in Eqn (1) and the *joint effectiveness index* ($E.I_{joint}$) of each cause is a function of both the rework and safety management effectiveness indices:

$$E.I._{joint} = E.I._{rework} \times E.I._{safety}. \tag{3}$$

The higher the $E.I._{rework}$ and $E.I._{safety}$ values, the more effective is the managerial measure in addressing rework and safety incidents. The category of effectiveness (CoE) of each measure is further evaluated in consonance with the scale adopted from Yap and Chow (2020), whereby: $0.143 \leq E.I._{rework/safety} \leq 0.286$ denotes not effective (NE); $0.286 < E.I._{rework/safety} \leq 0.428$ (SE); $0.428 < E.I._{rework/safety} \leq 0.571$ is moderately effective (ME); $0.571 < E.I._{rework/safety} \leq 0.714$ is effective (E); $0.714 < E.I._{rework/safety} \leq 0.857$ is very effective (VE); and $0.857 < E.I._{rework/safety} \leq 1.0$ is extremely effective (EE).

Spearman's rank correlation

Following Hwang and Yang (2014), Spearman's rank correlation was employed to ascertain whether the rankings of the 13 managerial measures by the developers, consultants and contractors were significantly correlated.

Exploratory factor analysis

Factor analysis is a statistical technique commonly used to describe variability among observed, correlated variables. In this study, the goal is to aid data interpretation, viz. uncovering the principal managerial factors (subsets of variables) from the 13 joint managerial measures to reduce rework and improve safety performance in construction. The Kaiser-Meyer-Olkin (KMO) test for the 13 variables is 0.906, which is greater than the threshold coefficient of 0.50 (Ye et al., 2014), and Bartlett's test of sphericity is significant (see Table 7). Accordingly, a strong measure of sampling adequacy was established and the variables were sufficiently interrelated – affirming the fitness of the data for factor analysis.

3. Results and discussion

3.1. Effectiveness of rework and safety management measures

For the 13 rework reduction and safety management measures identified from the literature, their effectiveness indices and rankings are shown in Tables 3 to 5. With an effectiveness index higher than 0.571, all the measures were rated as "effective" and beyond. In Table 3, nine measures are "very effective" while the remaining four are effective. On the other hand, a closer examination of Table 4 reveals 11 "very effective" and 2 "effective" safety improvement measures. The topmost "very effective" rework management measure was "*Good coordination and communication network between all parties*" ($E.I._{rework} = 0.839$) (Table 4), whereas the highest-rated safety management measure was "*Good site management system*" ($E.I._{safety} = 0.814$) (Table 4).

Table 5 shows that "*Good coordination and communication network between all parties*" was ranked the highest ($E.I._{joint} = 0.679$) and was therefore considered to be an extremely effective measure for both reducing rework and improving safety. For rework, this is to be expected, as high fragmentation and poor communication between contracting parties are frequently reported as the leading causes of rework in both developed (e.g., Hwang & Yang, 2014; Love & Edwards, 2004) and developing countries (e.g., Emuze et al., 2014; Yap et al., 2017). Better communication and integration between project actors are needed to engender a collaborative culture for effective coordination. Adversarial attitudes lead to misunderstanding and distrust – hampering their willingness to perform duties to the expected quality (Yong & Mustaffa, 2013). Poor performance in turn can lead to more non-compliant work and start a vicious cycle of confrontational relationships between the various parties involved. At the construction site, task unpredictability, high workload and production pressure in a hostile physical environment can be fatiguing and stressful, leading to increased errors and decreased motivation (Mitropoulos et al., 2009). In this light, cross-team coordination is crucial to reduce nonproductive work, avoid mistakes, minimise information

Table 3. Effectiveness index and ranking of rework management measures

Managerial measures – rework reduction	CoE	Overall (N = 157)		Developer (N = 25)		Consultant (N = 25)		Contractor (N = 114)	
		$E.I._{rework}$	Rank	$E.I._{rework}$	Rank	$E.I._{rework}$	Rank	$E.I._{rework}$	Rank
Good coordination and communication network between all parties	VE	0.839	1	0.800	1	0.867	2	0.844	1
Good site management system	VE	0.824	2	0.792	2	0.878	1	0.823	2
Employment of qualified and experienced personnel	VE	0.796	3	0.784	3	0.811	5	0.796	3
Learn from previous actions, events and experiences	VE	0.781	4	0.752	4	0.844	4	0.777	4
Continuous learning and knowledge improvement	VE	0.763	5	0.736	5	0.856	3	0.754	7
Effective subcontractor management system	VE	0.758	6	0.736	5	0.756	10	0.763	6
Appropriate handling of materials and delivery	VE	0.755	7	0.704	10	0.756	10	0.767	5
Proper production planning	VE	0.748	8	0.720	7	0.811	5	0.744	8
Effective use of information technology and advanced technology	VE	0.729	9	0.688	11	0.789	7	0.728	9
Risk assessment and management	E	0.712	10	0.720	7	0.756	10	0.704	10
Provide sufficient training and education for worker	E	0.701	11	0.712	9	0.778	9	0.686	11
Learning from coaching	E	0.680	12	0.656	12	0.789	7	0.668	12
Error management	E	0.652	13	0.608	13	0.733	13	0.649	13

Table 4. Effectiveness index and ranking for safety management measures

Managerial measures – safety improvement	CoE	Overall (N = 157)		Developer (N = 25)		Consultant (N = 25)		Contractor (N = 114)	
		$E.I._{safety}$	Rank	$E.I._{safety}$	Rank	$E.I._{safety}$	Rank	$E.I._{safety}$	Rank
Good site management system	VE	0.814	1	0.808	2	0.889	1	0.804	2
Good coordination and communication network between all parties parties	VE	0.809	2	0.816	1	0.822	4	0.805	1
Employment of qualified and experienced personnel	VE	0.791	3	0.760	3	0.833	2	0.791	3
Learn from previous actions, events and experiences	VE	0.783	4	0.736	6	0.822	4	0.788	4
Continuous learning and knowledge improvement	VE	0.782	5	0.752	4	0.833	2	0.781	5
Appropriate handling of materials and delivery	VE	0.771	6	0.720	8	0.800	6	0.777	6
Provide sufficient training and education for worker	VE	0.763	7	0.728	7	0.756	11	0.772	7
Risk assessment and management	VE	0.757	8	0.744	5	0.789	8	0.754	9
Effective subcontractor management system	VE	0.752	9	0.696	10	0.756	11	0.763	8
Proper production planning	VE	0.750	10	0.704	9	0.789	8	0.754	9
Effective use of information technology and advanced technology	VE	0.722	11	0.672	12	0.789	8	0.723	11
Learning from coaching	E	0.704	12	0.640	13	0.800	6	0.704	12
Error management	E	0.689	13	0.688	11	0.744	13	0.681	13

Table 5. Joint effectiveness index and ranking for rework and safety management measures

Joint managerial measures	Overall (N = 157)		Developer (N = 25)		Consultant (N = 25)		Contractor (N = 114)	
	$E.I._{joint}$	Rank	$E.I._{joint}$	Rank	$E.I._{joint}$	Rank	$E.I._{joint}$	Rank
Good coordination and communication network between all parties parties	0.679	1	0.653	1	0.713	3	0.679	1
Good site management system	0.671	2	0.640	2	0.781	1	0.662	2
Employment of qualified and experienced personnel	0.630	3	0.596	3	0.676	5	0.630	3
Learn from previous actions, events and experiences	0.612	4	0.554	4	0.694	4	0.612	4
Continuous learning and knowledge improvement	0.597	5	0.554	4	0.714	2	0.589	6
Appropriate handling of materials and delivery	0.583	6	0.507	9	0.605	9	0.596	5
Effective subcontractor management system	0.571	7	0.513	8	0.572	12	0.582	7
Proper production planning	0.561	8	0.507	9	0.640	6	0.561	8
Risk assessment and management	0.539	9	0.536	6	0.597	10	0.531	9
Provide sufficient training and education for worker	0.535	10	0.519	7	0.589	11	0.530	10
Effective use of information technology and advanced technology	0.527	11	0.463	11	0.623	8	0.526	11
Learning from coaching	0.479	12	0.420	12	0.632	7	0.470	12
Error management	0.450	13	0.419	13	0.546	13	0.442	13

discrepancies, facilitate work sequence planning and improve constructability (Hwang & Yang, 2014; Yap et al., 2017). As such, the "them and us" attitudes created by contracts (inefficient and ineffective construction practices) are to be eliminated and replaced with a culture of collaboration and open communication (Ahiaga-dagbui et al., 2020) – an understanding of each other's specific role and how it supports common delivery.

Similarly, effective communication, collaboration and coordination are vital for maintaining a safety culture (Mitropoulos & Cupido, 2009), with such good practices as giving clear instructions and providing sound guidance for performing work being known to effectively improve the worksite safety climate (Mohammadi et al., 2018). Hazards need to be effectively communicated to workers as safety communication is significantly associated with safety knowledge (Jiang et al., 2015). Continuing on this line, a safety leadership training module for managers accentuates employee coaching, communications, behaviour modification and team-building skills (Zou, 2011). Upward safety communication, where construction workers can raise safety concerns with their supervisors, is also beneficial for relationship-building exercises and help construction organisations provide a safer workplace at the site (Kath et al., 2010). In this vein, Love et al. (2019) reveal that subcontractors who are directed to "shut up and listen" and "do as you are told" are unable to "speak up" about quality and safety issues arising from the proposed construction methodology. As a result, they are unable to share experiences and insights to ameliorate the performance of the project. Moreover, the extensive use of subcontractors in traditional construction project delivery practice results in a variety of problems relating to the coordination and communication of safety planning and allocation of responsibilities (Kartam et al., 2000). This is consistent with Haslam's et al. (2005) assertion that poor communication within work teams contributes to safety incidents. To this end, inter-organisational teamwork setting such as partnering may be effective in encouraging parties to work together (Fong & Lung, 2007) – addressing problems associated with blurred responsibilities and communication difficulties (Haslam et al., 2005).

"*Good site management system*" was the second-highest in the overall ranking ($E.I._{joint}$ = 0.671). Again, this is unsurprising for rework, as Josephson and Hammarlund (1999) link production errors to field management, better production planning and preparation of work are known to prevent errors (Mitropoulos et al., 2009) and poor site management leads to abortive rework due to inferior quality of work and out-of-sequence workflows (Hwang & Yang, 2014). The active involvement of site supervision is critical for both reducing construction mistakes and managing safety hazards on site (Mohammadi et al., 2018; Yap et al., 2017), with the primary causes of poor site safety management being attributable to the lack of a safe construction site environment, inadequate technical guidance and limited site safety supervision (Durdyev et al., 2017).

"*Employment of qualified and experienced personnel*" was the third most effective measure to contain rework and safety risks ($E.I._{joint}$ = 0.630). This is supported by evidence suggesting that matching skills with task demands help prevent errors and productivity loss due to rework, while less-experienced workers have a higher rate of accidents than their seasoned counterparts (Mitropoulos & Cupido, 2009). Similarly, experienced workers sharing safety knowledge with inexperienced workers help provide feedback and the transfer of safety knowledge to less-experienced workers (Demirkesen & Arditi, 2015).

"*Learn from previous actions, events and experiences*" was ranked in fourth place ($E.I._{joint}$ = 0.612). In terms of rework, this is supported by Love (2020), for instance, propagating the critical need to exercise critical reflection and collective learning to address rework problems and modify work practices to address existing shortcomings, and Love's et al. (2015) development of a learning framework for rework prevention. Previous studies have observed that active project learning advances the aptitude, competency and expert judgment of project personnel (e.g., Love, 2020; Yap et al., 2019b). Corroborating this claim in the context of quality and safety improvement, Love et al. (2018b) place emphasis on learning by doing.

"*Continuous learning and knowledge improvement*" was ranked fifth ($E.I._{joint}$ = 0.597). This is supported by Yap and Skitmore's (2020) suggestion of leveraging best practices and contextualised reusable knowledge to prevent errors and avoid unnecessary rework. This involves networking and communication, experience accumulation, collaborative learning and expert judgement (Yap et al., 2018). To contain and reduce errors and violations in construction, there is a need to not only understand *what went wrong* but also consider *what went right* (Love et al., 2020). To this end, the creation of a learning climate is critical to support continuous learning, where processes and procedures are available to facilitate the creation and transfer of both tacit and explicit knowledge (Love et al., 2015). In analysing survey data obtained from eight leading Turkish contractors, Kivrak et al. (2008) conceptualise a knowledge management platform that can support continuous improvement to reduce rework.

Again in the context of quality and safety improvement, Love et al. (2018b) emphasise a culture of knowledge sharing. According to Mohammadi et al. (2018), sharing lessons learned and institutionalising learning from past incidents will help an organisation to solve safety problems, most notably with the review of past experiences also boosting the safety knowledge and motivation needed for workers to correct unsafe behaviours. Furthermore, improved knowledge also helps to deal with old hazards and increases the personnel's expectations and safety awareness (Kartam et al., 2000). In contrast, unknown processes can decrease quality and safety by increasing mistakes (Wanberg et al., 2013).

Surprisingly, all parties agree that providing sufficient training and education for workers, the effective use of information technology and advanced technology, learning from coaching and error management are perceived as relatively less effective in reducing rework and improving safety. "Error management", for example, is considered by Love and Smith (2016) to ensure significant improvements in safety and quality, with construction organisations needing to "learn from errors" by institutionalising an operational error reporting mechanism and undertaking a shared responsibility for the occurrence of any errors. In this way, construction organisations and projects can avoid such negative error consequences as site accidents or injuries and learn to prevent them in the future. Similarly, Yap and Skitmore's (2020) interviews with 12 experienced construction professionals found mentoring and coaching to be important capacity-building tools, especially in taking advice from experienced people through storytelling to build awareness and boost the transfer of knowledge. Hence, the cognisance of issues before they become problems and added project knowledge are important for making informed decisions and judgements for error management. Investigating effective mentoring in the construction industry, Hoffmeister et al. (2011) conclude that communication skills, knowledge sharing, correcting mistakes and providing negative feedback are the most important mentor characteristics. In this connection, the process of coaching can be used to embrace the change process and shift toward error management (Love et al., 2018b). In this sense, coaching facilitates the transfer of learning through the process of reflection on a previous experience as to *how* and *why* a rework and safety incident happened and exploring the best solution to address the identified problem (Love et al., 2015). In addition, workshop-based coaching activities involving various parties in a project are essential for collective learning, relationship building and joint problem-solving (Love et al., 2015). Ballesteros-Sánchez's et al. (2019) experiment with 30 project managers and observers in Spain, for instance, demonstrates that executive coaching has a major impact on behaviours relating to leading, managing and devising schemes for dealing with challenging circumstances.

It is also likely that Malaysia, being a developing country, has a different perspective. Despite both the rework and safety literature emphasising formal and informal learning in reducing rework and safety risks (e.g., Jiang et al., 2015; Love & Smith, 2016; Zhang et al., 2019), our findings further suggest that the Malaysian construction industry has a half-hearted attitude towards training and upskilling the workforces as well as operating with low levels of automation. Even the global construction industry has been unable to increase productivity due to underinvestment in skills development, R&D and innovation (Mckinsey Global Institute, 2017). In investigating delay issues in the Malaysian construction industry, the practitioners interviewed by Abdul-Rahman et al. (2006) commented that most firms are reluctant to invest in education and training but prefer hiring experienced employees instead. Ironically, the procedures to assure quality and progress have a heavy reliance on experienced and skilled workers (Abdul-Rahman et al., 2006). As such, the growing shortage of skilled workers and experienced managers is a major risk factor hindering the performance of construction projects (Jarkas & Haupt, 2015). In China, low levels of the safety knowledge of construction participants are attributable to poor safety training and education (Cheng et al., 2004), which is also recognised as a critical issue globally (Hon et al., 2010). A limited number of organisations offer systemic safety training while the low percentage of workers being trained in China inadvertently influences everyday practice (Tam et al., 2004). Although safety management is identified as the most important construction management function in Cambodia, accident rates tend to be higher in developing countries than in developed countries (Kang et al., 2018). In this connection, the socioeconomic status of workers and cultural values have a significant impact on attitudes to quality and safety issues in developing countries in Sub-Saharan Africa, where accident figures are very high (Kheni et al., 2010). These observations align with Yap's et al. (2019a) claim that the salient problems undermining the performance of construction projects are fundamentally attributable to human- and management-related predicaments, which are also common in most developing countries worldwide. As underscored by Dulaimi et al. (2003), education and training are vital to the creation of an able workforce. Notwithstanding the importance of competency management, a framework for the assessment of competencies is yet to become available for Malaysian construction project managers (Au et al., 2018). As such, enhancing the commitment and competence of professionals and workers in construction to better rework and safety management is necessary and emergent, particularly in developing countries (Kang et al., 2018; Kheni et al., 2010).

Construction labour-productivity growth lags behind that of manufacturing and the total economy while developed countries are seen to outperform developing countries (Mckinsey Global Institute, 2017). The sector largely continues to rely on traditional methods for many projects. Malaysia has been lagging (low productivity, negative productivity growth), along with other such developing countries as Mexico, Brazil, Columbia, Saudi Arabia and Nigeria (Mckinsey Global Institute, 2017). With the rise of Industry 4.0, automated processes can facilitate the reduction of rework along the project supply chain due to human errors/violations (Love & Smith, 2018). The integration of collaborative and autonomous synchronization systems such as building information modelling (BIM) with digital technologies (e.g., intelligent machines, sensor systems, and smart materials) is expected to effectively deal with uncontrollability and inefficiency problems in the traditional supply chain system (Maskuriy et al., 2019). In reviewing 69 digital engineering studies on safety, Golizadeh's et al. (2018) report various areas of still underexplored potential within digital engineering to address the causes of accidents on construction sites relating to work teams, workplaces, materials, equipment and originating factors. Shahparvari's et al. (2019) detailed review of the literature concerning automated technologies notes that offsite production (OSP), digital twin (DT), the utilisation of robotics in construction and the application of artificial intelligence (AI) provide a range of technological options and advances in automation that can minimise changes and errors, speed up the process, address skills shortages, raise productivity, improve communication and engender collaboration. While the literature supports digitalisation for efficiency and cost reductions, the construction industry has been hesitant to fully embrace the latest technological-driven optimisations (Berlak et al., 2021), traditionally being slow to reap the benefits of process and product innovations (Yap et al., 2019a, 2019b). This view aligns with Nowotarski and Paslawski (2017), indicating that the majority of small and medium enterprises (SMEs) are still quite sceptical about adopting Industry 4.0 concepts. The biggest challenges for digital transformation are the lack of skilled personnel, untested technological solutions and the huge amount of funding involved (Berlak et al., 2021; Nowotarski & Paslawski, 2017). Moving forward, more effort is clearly needed to facilitate and provide training to enhance the knowledge of the construction workforce before Construction Industry 4.0 technologies and processes can be fully exploited, particularly in rework containment and supporting safety.

As Table 6 shows, the rankings are strongly correlated, with the highest agreement being between the developer and contractor groups for all three indices. Overall, the average agreement for the effectiveness index for rework management and effectiveness index for safety management is 77.8% and 77.5% respectively, a consensus that suggests the joint measures for rework and safety management are justified – establishing external validity.

3.2. Principal managerial factors influencing construction rework and safety management

To categorise the 13 management measures, an exploratory factor analysis with varimax rotation was applied. This produced a two-factor solution according to the latent root criterion, with a cumulative variance of 63.43% – exceeding the 60% needed for validity (Hair et al., 2019). All 13 measures have factor loadings above 0.50 and are thus considered practically significant. As Table 7 indicates, the two-factor solution shows high reliability, with Cronbach α values exceeding 0.850. Each factor is interpreted and labelled by combining the meanings of these highly correlated variables. The extracted factors and associated variables are discussed below.

Table 6. Spearman's rank correlation for the rework and safety management measures

Respondent groups	$E.I._{rework}$		$E.I._{safety}$		$E.I_{.joint}$	
	Spearman's rho	Sig.	Spearman's rho	Sig.	Spearman's rho	Sig.
Developer – Consultant	0.755	0.01	0.673	0.01	0.714	0.01
Developer – Contractor	0.868	0.01	0.904	0.01	0.890	0.01
Consultant – Contractor	0.712	0.01	0.747	0.01	0.709	0.01

Table 7. Factor profile

Description of principal factors and associated managerial measures	Factor loading	Variance explained (%)	Cronbach α
Factor 1: Project management best practices		33.27	0.900
Employment of qualified and experienced personnel	0.804		
Effective subcontractor management system	0.801		
Good coordination and communication network between all parties	0.782		
Effective use of information technology and advanced technology	0.714		
Good site management system	0.711		
Appropriate handling of materials and delivery	0.656		
Proper production planning	0.569		
Factor 2: Proactive competency management		30.16	0.864
Learning from coaching	0.796		
Error management	0.730		
Provide sufficient training and education for worker	0.713		
Risk assessment and management	0.666		
Learn from previous actions, events and experiences	0.642		
Continuous learning and knowledge improvement	0.634		
Cumulative variance explained (%)		63.43	0.930
Kaiser-Meyer-Olkin measure of sampling adequacy		0.906	
Bartlett's test of sphericity Approx. $\chi 2$		1303.602	
df		78	
Sig.		0.000	

Notes: Extraction method = Principal component analysis; rotation method = Varimax with Kaiser normalisation. Rotation converged in 3 iterations.

Factor 1: Project management best practices

Factor 1 accounts for 33.27% of the total variance explained, with seven measures relating to best practices for successful project management. The Construction Industry Institute (2012, p. 7) defines a best practice as "a process or method that, when executed effectively, leads to enhanced project performance". The Project Management Institute's (2017) Body of Knowledge (PMBOK) Guide acknowledges benchmarking as being best-practice-oriented to recognise opportunities for improving performance. As underscored by Toor and Ogunlana (2008), the fundamental essentials for project success are comprehension, commitment, competence and communication. According to Safapour and Kermanshachi (2019), the attributes of manageable rework can be categorised under organisation (bureaucracy, participant and communication), project (leadership, location, design and technology, material resources, scope, partnership and finance) and people (skill, experience and sociocultural). Increasing the client's involvement in construction health and safety has resulted in a reduction in rework, accidents and compensation claims, which then leads to an improved client-contractor relationship (Umeokafor, 2018). In recognising the economic benefit of safety, clients are becoming willing to integrate the safety dimension into quality management systems (Votano & Sunindijo, 2014). In terms of mitigation strategies, the adoption of front-end planning is most significant when early clarification of the project goals is needed to ensure the scope and technical specifications are well defined and documented. Other important strategies include quality management and lessons learned. They conclude that best practices for construction assist stakeholders in minimising rework throughout the execution of construction projects. Cost-cutting strategies in hiring inexperienced and cheaper project personnel reduce costs but significantly increase the amount of rework (Oyewobi et al., 2016) and safety risks (Oswald et al., 2020). This being the case, selective hiring of the right people (e.g. personnel, contractors, subcontractors and suppliers) may contribute to good work practices (Kaliba et al., 2009; Wanberg et al., 2013). Construction and safety best practices can actually support each other (Jiang et al., 2015) – creating a positive ripple effect across the industry.

Factor 2: Proactive competency management

This second factor comprised six measures with a total variance of 30.16%. Individual and team competencies are increasingly reliable predictors of successful project delivery (Ballesteros-Sánchez et al., 2019). To prevent any performance shortfall in project delivery, project stakeholders must ensure they have the right personnel with the right qualifications, experience and knowledge as well as the appropriate project management tools (Kaliba et al., 2009). Previous studies document the significance of collaborative learning and effective KM processes and activities for competency development and proactive risk management (e.g., Yap & Skitmore, 2020). Electronic safety knowledge databases enable professionals and discipline experts to share collective data from lessons learned and best practices, so that risk management principles and techniques can be integrated into safety management processes to enhance the organisation's safety management capability and maturity (Zou, 2011). The role of tacit knowledge is crucial for higher performance (Podgórski, 2010). Adding to that, awareness and knowledge directly affect worksite behaviours (Li et al., 2018). As highlighted by Love et al. (2015), a collaborative reflective learning process is needed to make sense of shared experiences within and between contracting organisations to deal with rework. Likewise, the critical elements for continuous learning as noted by Yap et al. (2018) include networking and communication, collaborative learning, experience accumulation and expert judgement. A recent study in China by Zhang et al. (2019) also emphasises managed learning in a project environment to attain an optimised outcome. Similarly, Jiang et al. (2015) conclude that preventive actions are more effective than reactive actions in the enhancement of safety performance, a view consistent with Vredenburgh (2002) highlighting that reactive practices (fixing problems once they have occurred) are ineffective in reducing employee injury rates. In light of this, organisations taking proactive measures to protect their employees are seen to derive a financial benefit from reduced lost time and workers' compensation expenses (Vredenburgh, 2002). A counterpoint is Love's et al. (2018b) view that the construction industry is currently engrossed with an error prevention approach for productivity improvement, seeing this paradigm as unproductive, with an evolutionary shift toward the *management of errors* recommended instead, while still stressing the need for open communication and education to develop new knowledge and skills.

Conclusions

In the construction industry, there is limited systematic knowledge available about the effective measures to jointly reduce rework and improve safety on site, even though both can significantly affect project success. To demonstrate "*how*" construction organisations can improve safety performance by reducing rework, the present study identified 13 pertinent managerial measures capable of jointly reducing rework and safety risks using a two-stage comprehensive literature review. The opinions of targeted construction professionals concerning the effectiveness of these measures were obtained through a questionnaire survey. In this paper, the managerial measures were ranked from different viewpoints of parties with respect to three types of indices – an effectiveness index for rework management, safety management and for both rework and safety. Overall, the study reveals the five most effective joint managerial measures to be a *good coordination and communication network between all parties*, *good site management system*, *employment of qualified and experienced personnel*, *learning from previous actions*, *events*, *and experiences* and *continuous learning and knowledge improvement*. Spearman rank-order correlation tests indicate a good consensus between project parties in ranking these measures and their relevance for construction professionals with disparate project roles. The factor analysis reveals a factor structure comprising two factors identified as project management best practices and proactive competency management. These help to provide a comprehensive understanding of the concepts involved, whereby Process (best practices) + People (competency management) = Successful Rework and Safety Management.

A contribution of the research is in providing empirical evidence prioritising the effectiveness of managerial measures in a developing country such as Malaysia. Although the similarities between safety and the quality management process are noted in the research literature, previous studies do not identify and prioritise the joint rework and safety management measures involved. To the best of the authors' knowledge, this study is the first endeavour devoted to evaluating the effectiveness of the management strategies that can reduce rework and improve safety in the construction industry in a developing nation. Notably, a mismatch with previous work is also found in the degree of perceived importance of the three least effective measures – namely effective use of information technology and advanced technology, learning from coaching and error management – which is likely to be a reflection of the study's location. In particular, the potential of Industry 4.0 technologies and coaching practices are not fully exploited in error and violation management to increase productivity, safety and quality levels. The construction industry often focuses on the traditional error prevention paradigm as a single strategy for dealing with errors. Errors are seen as a nuisance with negative consequences and people try to avoid making an error. Within this paradigm, errors can and need to be prevented – a zero error tolerance mindset. This is reflected in the findings of this study, where preventive measures are highly rated. Hiding errors or blaming others is common with the error prevention approach, more so in the fragmented and adversarial nature of the construction industry. On the other hand, the error management paradigm (acceptance of human error mindset) is comparable to violation management and emphasises lessening the negative consequences of an error and reducing its occurrence in the future through error detection and damage control. Error management strategies engender long-term learning, performance and innovation which then form the foundation for a learning organisation culture.

To support the change required, the construction industries in developing countries need to recognise their prevailing shortcomings in addressing errors through the process- and people-based approach. Best practices supporting reflexivity, justification and substantive reasoning are crucial for effective rework containment with an error management culture. On the other hand, continuous learning, training and development of project stakeholders expand their knowledge and skillsets to prevent knowledge-based errors in the workplace. The construction industry would benefit from cultivating all stakeholders to have the right mindsets, skill sets and toolsets to deliver projects that consistently exceed quality and safety expectations.

The study's findings are limited by the single data collection approach of using a field survey not involving the methodological triangulation provided by a mixed-methods design. The use of a self-completion questionnaire does not allow the researchers to further probe the respondents for their rich experiences to generate further explanations unlike with qualitative data derived from in-depth interviews. The intervals between points on the Likert scale may not present equal changes in effectiveness level for all respondents, for example, the differences between *effective* and *strongly effective*. Moreover, the managerial measures identified may not be exhaustive, as the literature integrating rework and safety management is still limited. The cross-sectional nature of the data also limits our ability to make causal inferences, and therefore longitudinal future research is needed to measure rework and safety improvements in relation to the measures identified in this study over time, as benchmarking data of the rework performance of Malaysian construction projects is unavailable. Finally, further inter-country analysis would help clarify the effects of different national development levels and cultures.

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Author contributions

All authors have contributions to this article. Conceptualization and supervision, JBH, Yap; methodology and formal analysis, JR, Chong; recourses and data curation, CKH, Hon; original draf preparation, M, Skitmore.

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