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Relationship Between Frontline Workers' Risk Perception and Safety Characteristics of Turnaround Maintenance: An Empirical Study During Turnaround Maintenance in the Chemical Process Industries

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ABSTRACT

Turnaround maintenance (TAM) in the chemical process industries (CPI) poses elevated safety risks with increased likelihood of human error. Human error, largely driven by inherent human fallibility and shaped by risk perception, remains a major cause of incidents. Despite extensive research on risk perception in other contexts, its role in TAM within CPI is underexplored. This study investigates the relationship between TAM safety characteristics and frontline workers' risk perception, identifying critical safety factors for the safe execution of TAM. A mixed-methods design was employed, comprising self-reporting questionnaires, focus group, and literature reviews. 12 TAM safety characteristics were identified and grouped into three categories. Safety climate (38%) and simultaneous operations (21%) emerged as the most influential factors. Also, cognitive risk perception (probability and severity) positively affects affective risk perception, while work environment strongly influences affective risk perception and perceived risk severity. Conversely, safety climate negatively affects affective risk perception. Overall, work environment exerts a greater influence on risk perception than safety climate. These findings advance understanding of risk perception in TAM operation and inform targeted strategies to mitigate human error and incidents, as well as the critical safety factors to be considered to reduce incident risk.

Keywords: Risk perception, Safety climate, Work environment, Turnaround maintenance, Human error, Oil and gas

INTRODUCTION

Turnaround maintenance (TAM) refers to the planned, periodic shutdown of process plants for maintenance and inspection to enhance reliability, ensure safety, comply with regulations, and extend asset life. TAM operation is characterised by high risk and uncertainty, increasing the likelihood of incidents and human errors (Ghazali et al., 2014). Human error is a major cause of industrial accidents, driven by inherent human fallibility. Addressing these errors requires understanding human limitations within their operational contexts. Risk perception—a key human fallibility element—is influenced by contextual factors that diminish its effects on safety outcomes (Sharit, 2006;

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Pandit et al., 2019). Although the effects of several factors on risk perception have been examined across different domains, research on how TAM-specific safety factors influence workers' risk perception in the TAM operations context is absent, and the critical TAM-specific safety factors for the safe execution of TAM remain to be fully explored (Al-Turki et al., 2019; Priolo et al., 2025). Thus, this study aims to identify and prioritise TAM safety characteristics, investigate the relationship between frontline workers' risk perception and these characteristics, and examine interdependencies among the risk perception components in the TAM context in the oil and gas sector.

RISK PERCEPTION

Risk perception is a subjective evaluation of risk that comprises cognitive (probability and consequence) and affective dimensions (Slovic et al., 2004). Although research emphasises examining the causal interrelations among these components (Ferrer and Klein, 2015), such empirical evidence remains limited. Contemporary theories suggest emotions are post-cognitive (Lazarus, 1998), and Xia et al. (2017) reported that the rational components directly influence emotional risk perception. Discrepancies have been reported in prior risk perception studies due to the use of only cognitive components, unconditional risk estimates, and not specifying referents (Priolo et al., 2025; Wolff et al., 2019). This work addressed these gaps by examining the interrelations among the risk perception components, utilising the three components, conditional risk questions, and specifying referents.

TAM SAFETY CHARACTERISTICS AND RISK PERCEPTION

Given that risk perception is threat-specific and influenced by contextual factors, this study examined the effect of TAM-specific safety factors—operationalised as safety climate and work environment—on risk perception during TAM operation.

Safety Climate

Safety climate refers to individual perceptions of safety in their work environment (Neal and Griffin, 2006). Despite extensive research, its conceptualisation, dimensions, and measurement remain inconsistent. But a common theme is the differentiation of its dimensions across industries (Cheng, 2021). Flin et al. (2000) identified management/supervision, safety systems, risk, work pressure, and safety competence as key dimensions across industries. This study adapted these factors for their relevance to TAMs in the oil and gas sector. The relationship between safety climate and risk perception can be explained by the Job Demands–Resources (JD-R) theory, with safety climate as a job resource that affects the motivational process advocated in the JD-R model, resulting in positive safety outcomes (Bakker and Demerouti, 2017). This relationship is underexplored in existing literature (Pandit et al., 2019) and absent in TAM contexts. Thus, this study examined the effect of safety climate on perceived risk in the TAM context.

Work Environment

Given the hazardous and unique nature of TAM, the work environment construct is conceptualised as workers' perception of the critical elements in the TAM environment—increased SIMOPs execution within work sites congested with equipment and increased personnel—and the realisation of their safety significance. This idea is drawn from the principles of situation awareness (Endsley, 2012) as advocated by Mearns and Flin (1995), who stressed the need to examine workers' perceived work environment in this context. The impact of work environment on risk perception has been sparsely studied and is absent in the TAM context. The available studies measured risk perception as perceived probability of injury rather than the three components (Oah et al., 2018; Mearns and Flin, 1995).

Diverse Workforce

Typically, the workforce engaged in TAM is diverse in age, gender, employment conditions, personal traits, and educational background, among others (Ghazali et al., 2014). These personal attributes were utilised as control variables in this study.

Research Hypotheses

These research hypotheses were proposed to achieve the aim of the study.

Hypothesis 1: *Perceived risk probability and perceived risk severity will be positively related to the affective risk perception of TAM frontline workers.*

Hypothesis 2: *The safety characteristics of TAM (safety climate and work environment) will have direct relationships with risk perception. Specifically:*

- *Safety climate will be positively related to the affective risk perception, perceived risk probability, and perceived risk severity of TAM frontline workers.*
- *Frontline workers' perception of work environment will be positively related to their affective risk perception, perceived risk probability, and perceived risk severity.*

RESEARCH METHODS

The research was carried out in three phases, using a mixed-methods approach that combined qualitative and quantitative research techniques.

Research Instrument, Participants and Procedure

Phase 1 combined literature reviews with a focus group of six experts (three TAM Operations Advisors and three HSE Specialists) to identify TAM safety characteristics. Phase 2 utilised a structured questionnaire comprising four sections—Main TAM safety characteristics (10 paired comparisons), safety climate dimensions (6), diverse workforce dimensions (3), and demographics—evaluated using the Saaty scale (Saaty et al., 2014) for relative importance.

Phase 3 implemented a cross-sectional survey with 96 items, predominantly measured on a 5-point Likert scale, except personality traits (Gosling et al., 2003) (7-point) and demographics. The items and scales include (references indicates adapted scales): Sections A–C (3 risk perception components): 15 items each, Section D (Supervisors' safety behaviour (Hayes et al., 1998)): 10 items, Section E (Management commitment (Neal and Griffin, 2006)): 3 items, Section F (Work pressure (Mearns et al., 2003), safety competence (Kvalheim and Dahl, 2016), and safety system (Kvalheim and Dahl, 2016)): 3 items each, Section G had 3 subscales: Increased simultaneous operations (5 items), Confined and congested worksite (3 items), and Increased staffing/large workforce in worksite (3 items). Questionnaires were administered over ten weeks (Phase 2) and nine weeks (Phase 3) following a pilot study; participation was voluntary and anonymous. The response rates were 92.7% (phase 2) and 48.5% (phase 3), with item content validity indices (> 0.78 minimum) and the content validity ratios (Lawshe's method) (> 0.75 and 0.62 for 8 and 10 reviewers, respectively) (Taherdoost, 2016).

Data Analysis

Priority vectors were derived from judgement matrices using the Geometric Mean Method (GMM)—due to its ease of use and reliability—validated by Normalised Column Method (NCM), and consistency assessed using Consistency Ratio ($CR< 0.1$) (Saaty et al., 2014). Individual judgments were aggregated by the Aggregation of Individual Priorities (AIP) using geometric means (Brunelli, 2015).

Statistical analyses were conducted using IBM SPSS Statistics 26 and SPSS Amos 26. Descriptive statistics and correlations, EFA, CFA, and hierarchical multiple regression were computed with assumptions tested. For EFA, data adequacy was confirmed with bivariate correlations ($r \geq 0.3$), KMO (> 0.5), and Bartlett's test ($p < .05$). Factors were retained (eigenvalues > 1, loadings ≥ 0.4), discriminant validity (no cross-loadings, item-total correlations > 0.3), and convergent validity (loadings ≥ 0.5). CFA model fit was assessed with RMSEA (< 0.08), SRMR (< 0.08), χ^2/df (< 3), CFI (> 0.90), and PCLOSE (> 0.05). Discriminant validity was confirmed with MSV and squared inter-construct correlations < AVE. Model fit for multiple regression was assessed using R^2, adjusted R^2, and F-statistic. Hypotheses were supported when β was significant ($p < .05$), with β indicating the effect size and direction (Hair et al., 2019).

Measures

Safety Climate: Safety climate was assessed with five subscales adapted from prior studies (Section 4.1). EFA (PCA with Oblimin rotation) identified 4 factors, explaining 64% of the variance across 20 items after excluding 3 items with low communalities. Management commitment, supervisors' safety behaviour, and work pressure retained their hypothesised structure, while safety systems and safety competence loaded together. Reliability was acceptable (Cronbach's α = 0.70–0.92). CFA supported a second-order model, with superior fit ($\chi^2 = 211.62$, $df = 115$, $\chi^2/df = 1.84$, CFI = .96, SRMR = .050, and RMSEA = .057 (C.I. 90%: .044, .069), PCLOSE = .176), over a first-order model that aggregated all items, consistent with the literature (Beus et al., 2019). The standardised factor loadings (.57–.92) were statistically significant, as were the AVE (.52) and the CR (.81).

Work Environment: Work environment was assessed using three developed subscales: increased SIMOPs, confined and congested worksite, and increased staffing/large workforce. EFA (PCA with Oblimin rotation) on 11 items yielded a three-factor solution, explaining 69% of the variance after removing two items with low communalities and cross-loadings. Reliability was acceptable (Cronbach's α = 0.73–0.82). CFA supported the second-order three-factor structure, having superior fit (χ^2 = 16.39, df = 11, χ^2/df = 1.49, CFI = .99, SRMR = .032, and RMSEA = .043 (C.I. 90%: .000, .084), PCLOSE = .555) over a first-order model aggregating all items, confirming the relationship between the construct and its subdimensions; which represents its different aspects during TAM. The standardised factor loadings (.64–.87) were statistically significant, as were the AVE (.56) and the CR (.79), indicating convergent validity.

Risk Perception: Risk perception was assessed across the 3 risk perception components. EFA (PCA with Promax rotation) on 15 items per component yielded a two-factor structure for each component. After excluding two low-loading items, 13 items explained 66%, 67%, and 63% of variance for affect, probability, and severity, respectively. Reliability was high (Cronbach's α = 0.79–0.94). The factors were labelled "Major Risk Sources" and "Common Risk Sources", consistent with prior categorisations (Rundmo, 1992, Mearns and Flin, 1995).

RESULTS AND DISCUSSIONS

The respondents' background information for phases 2 and 3 is shown in Tables 1 and 3, respectively. The standard deviation, mean and correlation coefficients of the measured variables for phase 3 (risk perception study) are shown in Table 2.

Relative Importance of TAM Safety Characteristics

The focus group (phase 1) identified 12 TAM safety characteristics (see Table 4), organised into a "main safety characteristics category" and two subgroups: safety climate and diverse workforce dimensions. Phase 2 analysis showed 95% of the data within Chebyshev's bounds (Salman et al., 2007), validating the dataset.

Table 4 shows that TAM safety climate has the most influence on safe TAM execution, consistent with prior studies that it is a key predictor of safety outcomes (Cheng, 2021). Increased SIMOPs was next, aligning with literature and practice (Kannan and Siddiqui, 2018). Among safety climate dimensions, management commitment was most critical, affirming leadership role in safety (Mearns et al., 2003). Among diverse workforce dimensions, employment status was most critical, reflecting a higher incident risk among temporary workers; usually less safety-aware (Clarke, 2003), and the need for subgroup-specific safety strategies. At low *CR*s, similar GMM and NCM weights show methodological consistency.

Hypotheses Testing for the Relationship Between TAM Safety Characteristics and Risk Perception

Assumption testing preceded hypothesis testing. Multicollinearity was acceptable (maximum VIF = 2.77), and no influential outliers were detected (maximum Cook's distance = 0.08), and interdependence (Durbin–Watson = 1.74–2.07). The Breusch–Pagan test indicated heteroskedasticity at some stages of the hierarchical multiple regression; therefore, HC3 robust standard errors were applied to ensure valid *p*-values without altering coefficient estimates (Hayes and Cai, 2007).

Tables 5–7 present the regression analyses results, controlling for covariates. Aside from personality traits, no other control variables have significant effect on risk perception. Of the five personality factors, openness to experience positively affects perceived risk probability, but not severity or affective components. Prior meta-analyses (Salgado, 1997) suggest that individuals high in openness exhibit a strong learning tendency. Such that, workers with higher openness may actively seek to understand inherent risks, be better informed and thus be more attuned to the probability component, similar to experts (Rundmo and Moen, 2006).

Table 5 shows that perceived risk probability and severity affect affective risk perception, aligning with prior research that cognitive appraisals of person–environment interactions shape perceived threats to personal safety and guide risk evaluations, driving emotional responses (Lazarus, 1998). Also, cognitive components directly influence affect in the construction setting (Xia et al., 2017).

Tables 5–7 show that perceived work environment positively affects affective risk perception and severity, but not the probability component, indicating that contextual exposures shape hazard appraisal (Ferrer and Klein, 2015). Thus, awareness of TAM safety-critical conditions may heighten situation awareness and vulnerability, increasing perceived associated risks. Also, excessive environmental and system demands can induce stress, biasing affective risk perception and elevating human error (Smith and Sainfort, 1989). These results affirm the direct role of perceived work environment in shaping risk perception, as reported in the literature (Oah et al., 2018, Mearns and Flin, 1995) and that laypeople are less sensitive to probability than experts (Rundmo and Moen, 2006).

Table 1: Background information of TAM Operations and HSE Specialists/Inspectors engaged in phase 2 (pairwise comparison).

		Work Team				Previous TAM Experience			
		1	2			Yes		No	
	Freq	25	58			63		20	
	%	30.12	69.88			75.90		24.10	
		Work Experience (years)							
		0–5	>5–10	>10–15	>15–20	>20–25	>25–30	>30–35	>35–40
Ops	Freq	-	2	11	4	3	1	1	3
	%	-	8.00	44.00	16.00	12.00	4.00	4.00	12.00

(Continued)

Table 1: Continued.

		Work Experience (years)							
		0–5	>5–10	>10–15	>15–20	>20–25	>25–30	>30–35	>35–40
HSE	Freq	12	10	16	17	2	1	-	-
	%	20.69	17.24	27.59	29.31	3.45	1.72	-	-
Total	Freq	12	12	27	21	3	3	2	3
	%	14.46	14.46	32.53	25.30	3.61	3.61	2.41	3.61

N = 83. Work team coded as 1 = TAM Operations, 2 = HSE. Ops – TAM Operations, Freq – Frequency

Table 2: Means, correlations and standard deviations (phase 3 variables).

	SAC	WEN	ARP	PRP	SRP
Safety climate (SAC)					
Work environment (WEN)	.27**				
Affective risk perception (ARP)	−.01	.19**			
Perceived risk probability (PRP)	.07	.11	.74**		
Perceived risk severity (SRP)	.04	.21**	.71**	.68**	
Mean (*M*)	4.20	4.40	3.33	3.23	3.57
Standard deviation (*SD*)	.52	.47	.90	.94	.92
No of items	17	7	13	13	13

*Notes: N = 263. *p < .05 level, **p < .01 level, two-tailed.*

Table 3: Demographic and background information of phase 3 samples.

	Number	Percentage (%)
Gender		
Male	238	90.5
Female	25	9.5
Age		
20–29 years	24	9.1
30–39 years	120	45.6
40–49 years	99	37.6
50–59 years	20	7.6
Work experience		
≤ 5 years	74	28.1
6–10 years	94	35.7
11–15 years	56	21.3
16 years and above	39	14.8
Educational background		
Secondary school	32	12.2
Diploma	57	21.7

(Continued)

Table 3: Continued.

	Number	Percentage (%)
Bachelor's degree or higher	174	66.2
Work team		
Construction	38	14.4
HSE	118	44.9
Logistics	9	3.4
Maintenance	52	19.8
Operations	46	17.5
Employment Type		
Permanent company employee	33	12.5
Permanent contract personnel	92	35.0
Temporary contract personnel	138	52.5

Note: N = 263

Table 4: Relative degree of importance of the safety characteristics of TAM (phase 2).

Main TAM Safety Characteristics Category	Relative Importance within each Category	
	GMM	NCM
Safety climate	0.382	0.382
Increased SIMOPS	0.213	0.213
Increased staffing/ large workforce	0.166	0.166
Diverse workforce	0.128	0.128
Confined/congested worksite	0.111	0.111
Safety Climate Dimensions Category		
Management commitment to safety	0.336	0.335
Safety systems	0.275	0.275
Safety competence	0.241	0.241
Work pressure	0.148	0.148
Diverse Workforce Dimensions Category		
Varying workers' employment status	0.423	0.423
Diverse workers' personality traits	0.355	0.355
Diverse workers origin	0.222	0.222

Note: N = 83. Maximum CRs with GMM: 1.3%, 2.3% and 1.7% for the main safety characteristics category, safety climate and diverse workforce dimensions, respectively.

Table 5: Hierarchical multiple regression analysis results for affective risk perception.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Predictors	β	t	β	t	β	t	β	t	β	t
Control Variables										
Gender	–.03	–.47	–.01	–.24	–.01	–.23	.02	.40	–.01	–.26

(Continued)

Table 5: Continued.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Age	.09	1.07	.09	1.21	.11	1.34	.09	1.56	.09	1.87
Work Experience	−.02	−.27	−.03	−.44	−.04	−.56	−.05	−.90	−.05	−.96
Educational Background	−.08	−1.31	−.08	−1.36	−.10	−1.69	−.02	−.57	−.03	−.94
EC-Temporary Contract	.11	1.07	.13	1.33	.14	1.46	.06	.78	.07	.90
EC-Permanent Contract	−.04	−.43	−.02	−.21	−.04	−.46	.05	.68	.07	1.02
Extraversion	.04	.62	.04	.63	.07	1.04	.03	.69	.04	.95
Agreeableness	.02	.29	.03	.37	.01	.17	.06	1.22	.05	1.10
Conscientiousness	−.12	−1.94	−.13*	−2.20	−.13*	−2.13	−.05	−.85	−.03	−.59
Emotional Stability	−.05	−.73	−.05	−.77	−.02	−.33	.01	.20	−.01	−.20
Openness to Experience	.12	1.62	.09	1.23	.09	1.25	−.04	−.87	−.05	−1.17
Independent Variables										
Work Environment			.21**	3.33	.24**	3.91	.16**	3.20	.10*	2.37
Safety Climate					−.14*	−2.29	−.11**	−2.85	−.09*	−2.49
Perceived Risk Probability							.73**	13.23	.49**	5.93
Perceived Risk Severity									.36**	5.22
ΔF	1.71		11.09**		5.26*		175.01**		27.20**	
ΔR^2	.06		.04		.02		.47		.06	
R^2	.06		.10		.11		.59		.65	
Adjusted R^2	.02		.06		.07		.56		.63	

Notes: $N = 263$. $^*p < .05$, $^{**}p < .01$, two-tailed. EC – Employment Condition. Gender coded: 0 = female, 1 = male; EC coded as 0 = Permanent Company Employee.

Table 6: Hierarchical multiple regression analysis results for perceived risk probability.

Steps	Model 1		Model 2		Model 3	
Predictors	***β***	***t***	***β***	***t***	***β***	***t***
Control Variables						
Gender	−.05	−.83	−.04	−.72	−.04	−.72
Age	.02	.24	.02	.29	.03	.33
Work Experience	.02	.24	.01	.16	.01	.13
Educational Background	−.10	−1.54	−.10	−1.55	−.11	−1.63
EC – Temporary Contract	.09	−1.41	.11	−1.29	.11	−1.35

(Continued)

Table 6: Continued.

Steps	Model 1		Model 2		Model 3	
Predictors	***β***	***t***	***β***	***t***	***β***	***t***
EC – Permanent Contract	–.14	.91	–.13	1.04	–.13	1.07
Extraversion	.05	.75	.05	.74	.05	.84
Agreeableness	–.06	–.80	–.06	–.77	–.07	–.83
Conscientiousness	–.11	–1.60	–.11	–1.69	–.11	–1.67
Emotional Stability	–.05	–.72	–.05	–.74	-.04	–.62
Openness to Experience	.20**	3.03	.18**	2.81	.18**	2.83
Independent Variables						
Work Environment			.11	1.95	.12*	2.05
Safety Climate					–.04	–.63
ΔF	2.67**		3.79		.40	
ΔR^2	.10		.01		.00	
R^2	.10		.11		.11	
Adjusted R^2	.06		.06		.06	

Notes: *N* = 263. **p* < .05, ***p* < .01, two-tailed. EC – Employment Condition. Gender coded: 0 = female, 1 = male; EC coded as 0 = Permanent Company Employee.

Table 7: Hierarchical multiple regression analysis results for perceived risk severity.

Steps	Model 1		Model 2		Model 3	
Predictors	***β***	***t***	***β***	***t***	***β***	***t***
Control Variables						
Gender	.03	0.50	.05	0.71	.05	0.72
Age	.00	–0.04	.00	0.06	.01	0.14
Work Experience	.01	0.17	.00	0.03	.00	–0.04
Educational Background	–.03	–0.41	–.03	–0.43	–.04	–0.63
EC - Temporary Contract	.03	–1.56	.05	–1.31	.06	–1.47
EC - Permanent Contract	–.15	0.29	–.13	0.58	–.14	0.64
Extraversion	–.01	–0.14	–.01	–0.16	.01	0.09
Agreeableness	–.01	–0.08	.00	–0.02	–.01	–0.14
Conscientiousness	–.12	–1.90	–.13*	–2.16	–.13*	–2.12
Emotional Stability	.00	0.05	.00	0.03	.02	0.25
Openness to Experience	.18**	2.61	.15*	2.32	.15*	2.32
Independent Variables						
Work Environment			.21**	3.47	.23**	3.70
Safety Climate					–.09	–1.37

(Continued)

Table 7: Continued.

Steps	Model 1	Model 2	Model 3
ΔF	1.42	12.07**	1.87
ΔR^2	.06	.04	.01
R^2	.06	.10	.11
Adjusted R^2	.02	.06	.06

Notes: $N = 263$. *$p < .05$, **$p < .01$, two-tailed. EC – Employment Condition. Gender coded: 0 = female, 1 = male; EC coded as 0 = Permanent Company Employee.

Tables 5–7 present partial support for the hypothesised direct positive effect of safety climate on affective risk perception, but no significant effect on probability or severity components. Contrary to assumptions, the positive safety climate seems to reduce affective risk perception (Pandit et al., 2019), likely because workers in such climates feel protected, thereby lowering their perceived risk or vulnerability to accidents (Oah et al., 2018). However, if safety initiatives are inconsistently reinforced, this perceived sense of safety may erode workers' risk sensitivity, as observed by Mearns and Flin (1999), where a positive safety climate exists at the surface but the safety culture is laden with latent issues. These results affirm prior studies that safety climate affects risk perception (Pandit et al., 2019, Oah et al., 2018). Safety climate seems less influential than work environment, likely due to the dynamic nature of safety risks and the weak social relationships during TAM.

IMPLICATIONS FOR THEORY AND PRACTICE

This study advances understanding of the interrelationships among risk perception, work environment, and safety climate in the TAM setting, providing a basis for targeted safety strategies, such as enhancing risk perception through virtual reality safety training under TAM conditions. It adds to the literature by utilising multi-dimension risk perception, conditional risk questions, and specifying referents. The TAM safety characteristics, if grouped under the work system elements of human performance—individual, environment, technology, organisation, and task—can help workers identify potential human error traps (Smith and Sainfort, 1989).

CONCLUSIONS AND RECOMMENDATIONS

This study extends prior research by examining TAM safety characteristics and their influence on frontline workers' risk perception. Safety climate, SIMOPs, and management commitment were identified as critical for safe TAM execution. Perceived risk probability and severity positively affect affective risk perception, while work environment exerts more influence than safety climate. These findings highlight the key role of TAM safety characteristics in shaping individual risk perception. Further research should examine their applicability across high-hazard industries and the role of different management levels in safe execution of TAM.

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