Implementing Resilience Engineering in Engineering Project Teams in South African Fast-Moving Consumer Goods Manufacturing Companies

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ABSTRACT

The volatile, uncertain, complex, and ambiguous nature of modern manufacturing, intensified by the Fourth Industrial Revolution and competition, requires resilient systems for safe operations. This study examines resilience engineering in the fast-moving consumer goods sector, emphasising its role in managing safety within complex socio-technical systems. Resilience emerges from management, decision-making, and system participants' actions. A key finding is the limited practical understanding of resilience engineering, highlighting the importance of a learning culture. A conceptual framework links resilience engineering principles to essential organisational cultures, guiding implementation. The paper suggests future research on the application of resilience engineering in African manufacturing sectors.

OPSOMMING

Die wisselvallige, onsekere, komplekse en dubbelsinnige aard van moderne vervaardiging, vererger deur die Vierde Industriële Revolusie en mededinging, vereis veerkragtige stelsels vir veilige bedrywighede. Hierdie studie ondersoek veerkragtigheidingenieurswese in die vinnig bewegende verbruikersgoedere-sektor en beklemtoon sy rol in die bestuur van veiligheid binne komplekse sosio-tegniese stelsels. Veerkragtigheid spruit voort uit bestuur, besluitneming en die optrede van stelseldeelnemers. ’n Belangrike bevinding is die beperkte praktiese begrip van veerkragtigheidingenieurswese, wat die belangrikheid van ’n leer kultuur beklemtoon. ’n Konseptuele raamwerk verbind veerkragtigheidingenieurswese-beginsels met noodsaaklike organisasiekulture om implementering te lei. Die studie beveel verdere navorsing oor veerkragtigheidingenieurswese-toepassing in Afrika se vervaardiging-sektore aan.

1. INTRODUCTION

The modern manufacturing environment poses many different and often more significant safety risks to the operational staff, and is often described as a volatile, uncertain, complex, and ambiguous (VUCA) environment. Advances in digital and informational technology have increased interactions between operational staff and safety systems [1]. These increased interactions in the socio-technical environment require new skills to address emerging challenges, and require a shift in risk management paradigms. The journey of migrating to new ways of working with standard operating procedures requires staff to develop the skill of absorbing new knowledge into the organisation and adjusting the internal processes to form new standard operating procedures.

"Fast-moving consumer goods" (FMCG) refers to products that have a limited shelf life. Common examples of these products are food and beverages such as baked goods, snack foods, soft drinks, cereals, and meat and dairy products. The FMCG industry consists of many organisations operating in a highly competitive environment with a high demand for product innovation. This demand forces organisations to be highly responsive to market changes, and companies must have well-developed forecasting to allow them to build the necessary capabilities. The pursuit of enhanced capabilities is revealed in numerous fast-track engineering projects to develop new products and processes to improve operational efficiency, increase customer offerings, and reduce the manufacturing costs associated with a value-creating strategy [2].

Companies achieve this competitive advantage with an increased need for automation and improved efficiency. The combination of market demands, legal requirements, and new technologies creates a highly complex socio-technical system [3]. This interconnectedness increase interface complexity, forcing project and engineering teams to adapt to deal with this complexity [4]. Madni and Jackson [4] add that pressures of rapid and efficient reliable production can lead to the slackening of safety practices, which might go unnoticed or be ignored. Production pressure and daily trade-offs lead to higher-risk conditions that should be regarded as intolerable. The result of these trade-offs is increased occupational injuries.

The South African Department of Labour has observed that the number of yearly claims from the Compensation of Occupational Injuries and Diseases Fund per 100 000 hours worked is significantly higher in the manufacturing sector than in others. They recognise the manufacturing sector's maturity gap with safety management systems. The Department of Labour identifies poor interpretation and implementation of the existing legal requirements as a main contributor to the growing number of injuries [5].

Resilience engineering (RE) offers a potential approach to developing the capability to meet this requirement for developing industry-specific safety systems [6]. Safety systems engineering is the application of a systems engineering and thinking approach to limit the potential for any conditions that could harm people, property, or the environment [7]. Various analytic methods and approaches are used to identify, analyse, and classify hazards in a system. Each hazard is analysed to determine the requirements to ensure that the associated risk is engineered out or reduced to a tolerable level.

The system's safety performance is a combined result of the management perspective, decision-making, behaviour, and actions taken by all persons who interact in the operational system [8]. As predicting all the possible interactions in a complex system is impossible, the system's safety performance is considered an emergent property. The preliminary investigation of the theory and research review suggests a limited understanding of the practical implementation of RE in engineering teams in the FMCG sector. RE theory is focused on a high-level view of the whole organisation [9]. The shortcomings in the definitions of the existing frameworks are that the implementation barriers are only partially defined. This research study aims to provide a framework for improving RE use in project teams' engineering that addresses critical barriers to implementing RE.

2. LITERATURE REVIEW

A systematic literature review was done to identify core competencies and barriers to implementation. Through the structured screening process, 32 papers were selected for detailed review. The selection process is described in Section 4. This section covers the elements arising from the literature review.

2.1. Definition of resilience engineering

The concept of resilience has led to multiple interpretations and approaches to engineering resilience as an alternative method for managing safety at different levels as part of complex socio-technical systems [6, 10, 11, 12, 13]. Implementing RE forces a renewed understanding of the user's interpretation of safety systems. In addition, revisiting how the participants receive information from the system is critical to improving the decision-making capabilities of those on the front line. RE addresses risks proactively: it depends on the insights gained from understanding the past failures of complex systems and the internal and external organisational factors contributing to the risk [6].

Unlike previous approaches to safety, which sought to minimise disruption and variations through actions triggered by events and even proactive prevention actions, RE assumes that disruptors in the regular operation of systems cannot be avoided, and must be factored into the system design. However, the systems need to be able to dampen the effects of this disruption. The key is the ability of the system to recover from the disruption and to return to a normal state. We can measure the system's potential for resilience rather than resilience itself [14]. While there are many accepted definitions of resilience, the definition adopted in the context of its application to engineered systems is the one from International Council on Systems Engineering (INCOSE): "Resilience is the ability to prepare and plan for, absorb or mitigate, recover from, or more successfully adapt to actual or potential adverse events" [7].

2.2. Historical development and current state of knowledge

The evolution of the safety culture identified distinct phases, known as the five ages of safety, shown in Figure 1. Each focused on developing an aspect of the safety system [11, 14]. Accident prevention in the early stages was based on solving specific technical failures and identifying the causes of human error [14]. The focus was on using safe behaviours and ergonomic designs to improve the equipment's reliability and to limit undesired disturbances. This view has led to the typical view of eliminating human factors by adopting increased levels of automation. Safety management focuses on the behavioural aspects, and relies on organisations developing a strong safety culture. RE is focused on the recovery phase of the system after the occurrence of a disruptive event. The most common causes of disruption are human errors and software failures, which could be regarded as external system factors [15]. Wildavsky [16] first introduced the term "RE" in the discourse of improving safety. Many organisations adopt and maintain the views developed in the cultural age, as seen in Figure 1, and view safety as a compliance function only [8]. During this time, a strong focus was placed on compliance with safety procedures and policies.

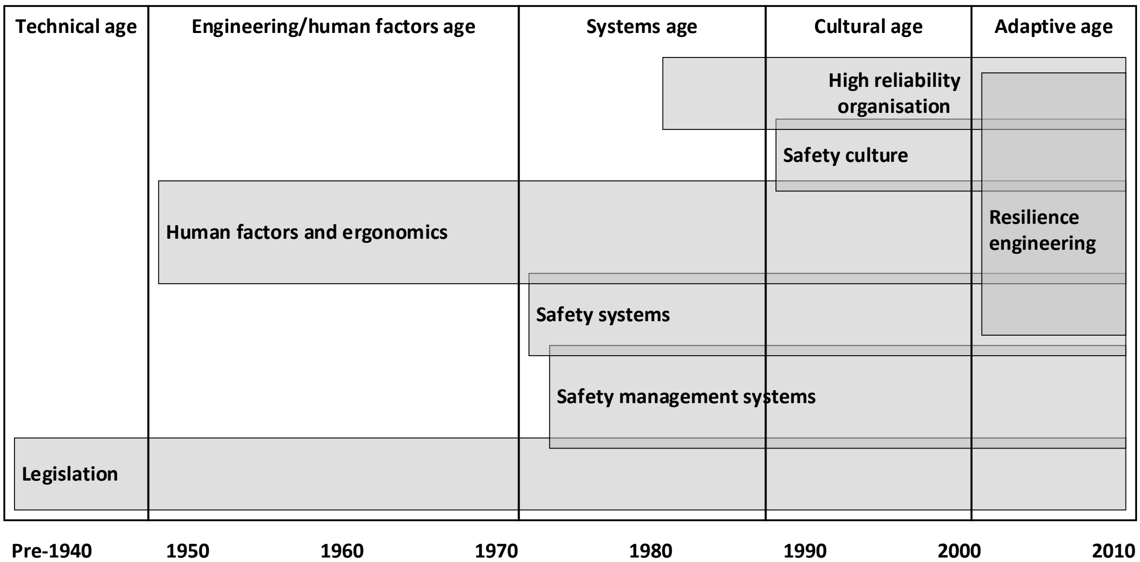

Figure 1: Timeline of five ages of safety management (adapted from [11])

2.3. Safety models

The development of safety over the years has resulted in three safety modes, labelled Safety-I, Safety-II, and Safety-III, each taking a different perspective on implementing safety management. Table 1 indicates the differences in the safety management principles between the various modes [17].

Table 1: Safety management principle (adapted from [18])

	Safety-I	Safety-II	System safety engineering	Safety-III
Safety management principle	Reactive, responds when something happens	Proactive, continually trying to anticipate events	Preventing hazards and accidents, learning from accidents and audits	Preventing hazards and losses, but learning from accidents and audits of system performance

Some organisations attempt to introduce hybrid models with strict centralised standards, and try to empower front-line managers to enable more flexibility. Luthans [19] describes Theory X, whose perspective is production-centred and assumes that strong central control and guidance are required. The Theory-Y perspective is employee-centred, with the belief that the correct environment and support structure would lead to employee motivation and improved performance. There has been a movement of organisations to adopt Theory-Y thinking. Leveson [19] expands on the comparison of the two models together with the view of current practices in safety engineering and the proposed Safety-III model. Many industries are explored, but not the manufacturing or FMCG sectors.

2.4. Principles and attributes of resilient systems

Figure 2 shows the desired attributes of a resilient system. Woods [20] explored two concepts related to resilience: rebounding from disruption, and returning to a normal state. Madni and Jackson [4] describe resilience as avoidance, recovery, and survival. Anticipation is the ability to predict possible scenarios based on the feedback from both strong and weak signals. “Recovery speed” refers to the rate at which a system can return to a stable state. “Survival” is the ability to withstand expected or unexpected disturbances, and it differs from the system’s resilience. “Resilience” is the system’s elasticity that allows it to return to its original form [4]. The system can be described as resilient or brittle; the latter is the risk of sudden failure when a system is pushed to its boundary limits.

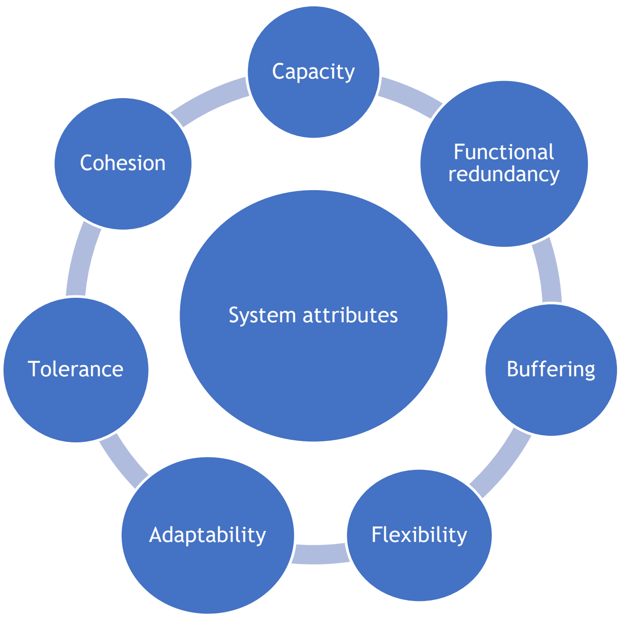

Figure 2: System attributes of resilient systems (adapted from [7])

RE is concerned with building resilient systems that can circumvent accidents through anticipation, survive disruptions through recovery plans, and grow through adaptation. The opportunities for the system to incorporate these principles exist at the employee level rather than at the organisational level, which suggests that a top-down push from management would most likely result in weak systems being developed [11].

RE provides a different perspective on safety versus conventional approaches, in that failures and successes are closely coupled. An unsafe state arises because the system's response and adjustments are insufficient instead of the result of component failure. Therefore, the perceived functional failure is part of routine performance variability, and the aim is to seek ways to dampen the variability that leads to unsafe conditions [10]. Three of the reviewed articles identify and expand on the principles and characteristics of resilient systems [11, 12, 14]:

- **Top management commitment**: Integrates health and safety into company values and strategic vision, guiding trade-offs under production pressures.
- **Just culture**: Encourages open reporting of safety concerns, accepting human error without fear of consequence.
- **Learning culture**: Emphasises learning from variations, and cautions against relying on past success as a safety indicator.
- **Awareness**: Ensures understanding of system boundaries, risks, and trade-offs between safety and productivity.
- **Preparedness**: Involves anticipating harmful events and responding to weak signals in dynamic environments.
- **Flexibility**: Supports error-tolerant systems by empowering front-line supervisors to manage real-time variability.

With the shift in focus to implementing RE, deficiencies might be discovered that would require re-examining the selection of the principles.

2.5. Establishing a learning culture

A learning culture allows the organisation to draw suitable lessons from its safety management system, and is willing to embrace change when needed. The significant difficulty is the speed of learning and adaptation before the next disruptive event [21]. The ability to learn from failure and to adapt designs is a critical skill that needs to be learnt during the development of young engineers. Simpson *et al.* [22] established that this skill is developed by designing and delivering an innovative curriculum that provides students with the opportunity for failure, learning, and feedback loops, unlike most educational systems that encourage success at the first attempt and discourage negativity and failure.

While this is encouraging, and demonstrates one of the ways to develop resilience, it does not address how to develop critical skills in existing project teams or organisations. It does suggest that a deliberate training intervention is required to plant the seed for the change. Nevertheless, a sustainable programme is needed to provide the managers and the projects with the same opportunities to learn from failure and, more importantly, to challenge the paradigm of conventional performance management. Failure and adaptation should be rewarded and should encourage innovative thinking. Simpson *et al.* [22] address the design of the assessment practice further by designing assessments for individuals that combine technical knowledge and soft skills. Introducing more open-ended problem-based learning that directs the student to the process rather than to pursuing a single correct solution should be beneficial. Organisations need adequately equipped training teams with the necessary skills and resources to implement various delivery methods. It is not advisable to conduct this type of training internally, as there might be organisational bias that prevents the required opportunities to learn from failure from happening. It is recommended that a skilled external facilitator be used to create the required paradigm shift.

Macrae and Draycott [23] show how systematically running in-situ simulations improves operational activities: "The process of simulating, debriefing and reflecting on practice creates a safe space to identify and strengthen the activities that produce success" [23]. Simulations conducted in actual organisational settings allow other emergent properties to be identified that cannot always be seen during a virtual simulation. The problem with such simulations is providing the required time in and disruption of everyday operations. Organisations cannot simply stop bad habits, but have to replace them gradually with desired behaviours over time. Similarly, the replacement of poor practices with desirable ones can be a complicated and lengthy process. Steen and Pollock [24] showed how scenario-based training could enhance the operators' cognitive abilities and their ability to interact with the system in the context of natural decision-making.

2.6. Barriers experienced

Although a few studies identified barriers to RE implementation in teams, many looked at the core principles of RE as enablers of RE implementation. The barriers identified by Sell *et al.* [25], De Melo and Costa [26], Harvey *et al.* [11], and Madni and Jackson [4] were grouped into related RE principles, shown below in Table 2. We could observe that some of these problems and identified barriers recur in industries and case studies. This would suggest that they are expected to be similar in the manufacturing industry.

Table 2: Summary of identified barriers and related RE principles

Articles	***Barriers***	***Top management commitment***	***Just culture***	***Learning culture***	***Awareness***	***Pre-paredness***	***Flexibility***
Sell *et al.* [25]	1	X					
	2		X		X		X
	3			X			
	4	X	X	X	X		
De Melo and Costa [26]	1				X		
	2	X	X			X	X
	3					X	X
	4	X	X		X	X	
	5		X	X	X	X	X
	6	X	X	X	X		X
	7	X					
Harvey *et al.* [11]	1		X				
	2	X					X
	3	X					X
	4					X	
Madni and Jackson [4]	1	X	X	X	X		X
	2	X	X	X	X	X	
	3	X	X	X			X
Count		11	10	7	8	6	9

3. CONCEPTUAL FRAMEWORK OF RESILIENCE ENGINEERING

3.1. Existing frameworks

Two frameworks are examined from the reviewed articles. The left side of Figure 3 depicts the conceptual model from De Melo and Costa [26], into which unmanned aerial systems technology is incorporated to gather information. The framework shows the capability of the system to anticipate, monitor, respond, and learn. This framework focuses on safety planning and control, among the many activities performed during a project's execution. This offers only part of how to develop RE project teams. The framework provides a single feedback loop through the technology, suggesting only an improvement in the measurement system. This could be useful for large-scale distributed projects when risk visualisation is impeded. The human factors and the role of the front-line worker are absent. A key success factor is the representation of front-line workers. The pressures of production and the trade-off decisions are also absent.

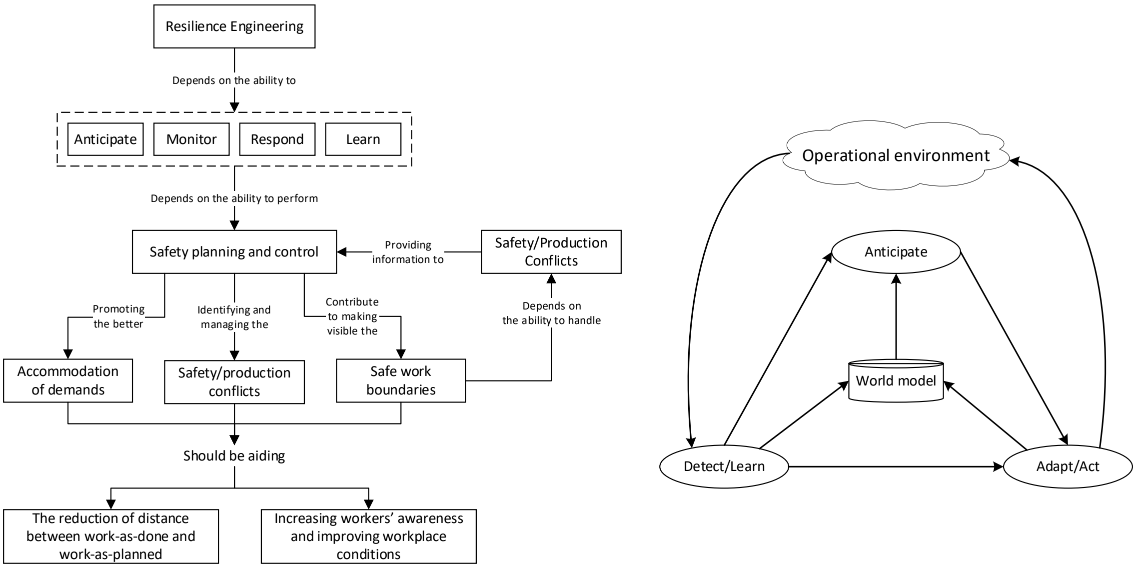

Figure 3: A Conceptual Framework for RE (adapted from [4], [26])

The second framework on the right side of Figure 4 is by Madni and Jackson [4], which includes interaction in the operational environment. The system's resilience is an emergent property that arises from the complex interactions of the elements; RE must focus on the principles and methods used to create these capabilities [4]. The framework uses four key system attributes, methods, disruptions, and metrics pillars. The framework provides an excellent holistic view, but does not explore the elements of the systems at the different levels of the organisation, and does not depict how learning is built into the framework; the feedback from the metrics is unclear.

Although many articles acknowledge the need for RE implementation at every organisational level, the frameworks do not reflect this. The frameworks also fail to show the feedback loops for the learning culture and the metrics that are required to enable the paradigm shift. The frameworks also do not indicate the empowerment of the front-line supervisors, as their view is of the organisation's overall level.

3.2. Proposed conceptual model

The frameworks above show a need to expand to a multilevel view and link to the barriers experienced at these levels. The improved metrics and increased feedback from the front-line workers must be represented to show how the learning culture could be developed. This cannot be a top-down approach in which top management pushes the changes in the organisation to get front-line workers' buy-in. Top management commitment is required to embrace front-line worker input if they are to co-develop the required organisational cultures. RE is about creating resilience potential, using the principles to build the right capabilities on every level of the organisation. Combining the principles of RE and the researcher proposes the framework for RE in Figure 4, which shows this concept in the form of the "resilience house", which is built on the foundation of top management commitment and supported by the fundamental principles of RE to enable the realisation of the resilience potential of the organisation. It has the three dimensions of anticipation, absorption, and restoration to determine this potential.

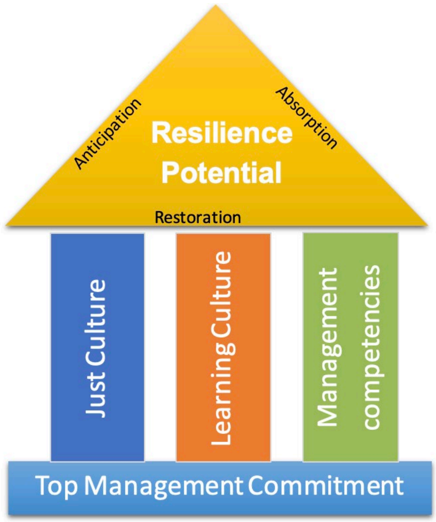

Figure 4: "House of resilience potential" as a conceptual model of RE

4. RESEARCH METHOD

This study's research method is shown in Figure 5 below. It began with a systematic literature review of relevant research and an understanding of the current frameworks. A quantitative research methodology was used, with a survey questionnaire as the source for data collection, which followed the literature review and the creation of a conceptual framework and the generation of hypotheses.

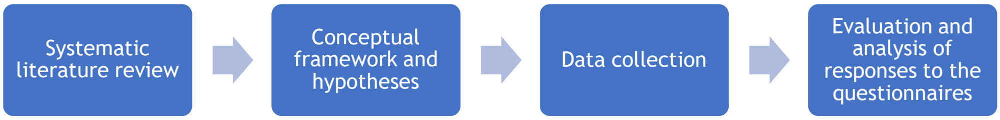

Figure 5: Research methodology

The systematic literature review followed the structured selection process, shown in Figure 6. Four databases were used in the systematic literature review. These were Web of Science, Scopus, Wiley Online Library, and Google Scholar. The chosen keywords for the search criteria using an "and" Boolean operator were "resilience engineering", "safety management systems", and "project teams". Initial searches were conducted with additional keywords, but this was determined to be too restrictive and failed to provide sufficient publications for the review. It was also decided to omit the keyword "manufacturing" to allow studies conducted in other industries and those related to organisational RE to be included.

Based on the conceptual model in Section 3, four proposed relationships were tested through primary data collection. These hypotheses were:

- H1: Top management commitment (TMC) is the most critical requirement for resilience potential
- H2: Current learning cultures are negatively affecting resilience potential
- H3: Just culture positively affects resilience potential
- H4: Management skills are not equally important

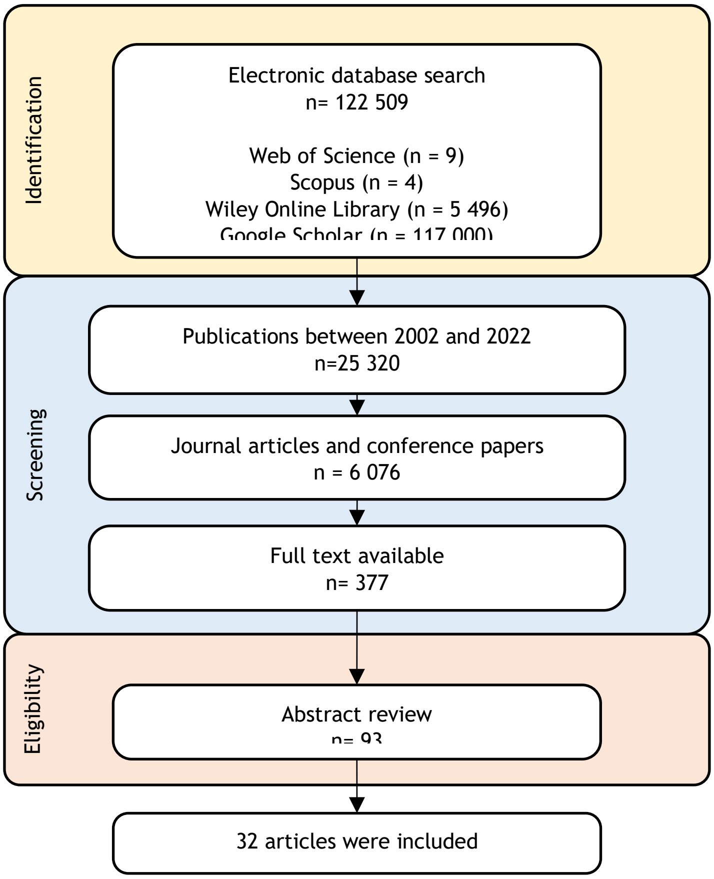

Figure 6: The process of selecting articles is included

Figure 7 shows the research model with four independent variables and one dependent variable. The primary data collection was done using an online questionnaire comprising six sections to capture demographic data and data for each variable. The variables were measured using a five-point Likert scale.

5. RESULTS

The collected data was analysed using Minitab to provide descriptive and inferential statistical results. Thirty-seven responses to the online questionnaire were received from the 335 submitted requests, which was an 11% response rate. Likert scale results are often subject to various sources of distortion. These include different biases from the respondents, such as central tendency bias, in which the respondent avoids extreme responses, or a tendency to agree with all presented statements, such as acquiescence bias. Senior managers might wish to portray a more favourable image of the organisation, as they view themselves as the creators and stewards of the organisation; this would lead to social desirability bias. The responses on the Likert scale were coded to allow for the statistical analysis of the responses received from the questionnaire.

While the data might be declared to be ordinal data, for statistical analysis one can treat the responses as interval data, assuming that the distance between the Likert item responses is equal. Thus, “strongly agree” is twice as strong as “agree”, which is exactly halfway between “neither agree nor disagree” and “strongly agree” [27]. The responses to the different statements received from each respondent were averaged to provide a value for each independent variable. These averages formed the sample population for the dependent variables. Descriptive statistics gives an overview of the state of each variable by examining the measures of central tendency, using means and modes and measures of the spread of the data using the standard deviation. Inferential statistics is used to conclude the population of FMCG companies from the collected sample data. The inferential statistical tools used were multiple linear regression for H1, correlation analysis for H2 and H3, and comparison of means for H4.

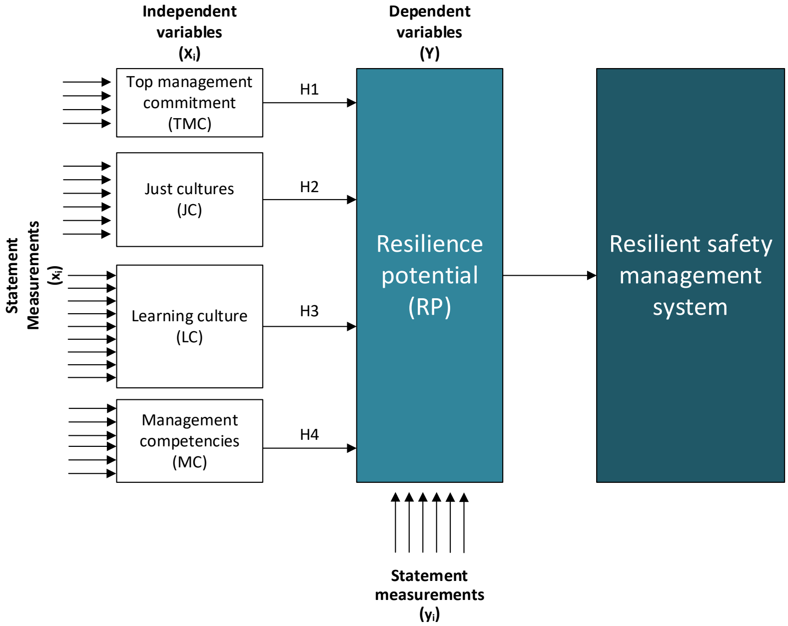

Figure 7: Proposed research model

5.1. Proposed conceptual model

The demographic data was analysed to understand the quality of the responses; it is summarised in Appendix A, Table A.1. There was a good representation of each level, from the shop floor to the executive level: 22% from the shopfloor and front-line managers, 65% from senior managers, and 14% from executive management. 81% of the responses were from individuals with more than ten years' experience, which indicates that the respondents had a good level of experience with implementing management systems and the typical problems that are experienced. Of the responses, 46% were received from medium-sized teams, which was helpful in understanding the dynamic environments that require strong resilience potential. Smaller teams require team members to perform multiple roles and functions; they can often deal with disruptive events more quickly, and experience different barriers from larger teams. Larger teams tend to develop more structured systems for day-to-day operations, and team members can specialise in their skill sets. The beverage sector represented 60% of the responses, with 14% from the groceries sector. The responses and perspectives were skewed in favour of the beverage industry, and thus were not an accurate cross-sectional representation. Project teams represented 32%, and operational teams represented 38%. This was a good balance between the functions that are responsible for creating systems and those that are the end users of the systems.

5.2. Descriptive statistics on variables

This section discusses the captured data's descriptive statistics, which are summarised in Table A.2.

5.2.1. Top management commitment

There was overall agreement that top management support (mean = 3.912) was present. The analysis showed that the director and senior managers believed that sufficient support was being received from the top management. This was to be expected, as the upper levels of management would be least critical of the commitment they provided. Front-line managers and the engineering projects teams showed strong disagreement in a wide range of responses. There was overall agreement (mean = 4.270) that employees were encouraged to speak about their safety concerns, but this did not seem to be translated into making tough decisions about safety, as the most significant variation was seen in the measure where management should make sacrificial decisions in the interest of safety.

5.2.2. Just culture

The overall view on just culture was neutral (mean = 3.275). There was a large spread in the data, with extreme agreement values (Statement 12 mean = 3.730) and disagreement (Statement 11 mean = 2.676). Project managers and team leaders showed more disagreement. These roles are on the front line of disruptive events, and would be expected to have the highest levels of the required flexibility. The disagreement that was observed could suggest that many adverse events were not being reported for fear of the consequences. This contrasted with the general agreement about having top management support.

5.2.3. Learning culture

There was overall agreement (mean = 3.913) about the current safety performance measures, which provided learning opportunities. The lowest level of agreement (mean = 3.514) was observed with new projects formally incorporating learnings from past incidents.

5.2.4. Management competencies

The responses strongly agreed (mean = 4.703) that all the proposed competencies were required for adequate safety management. The most extensive perspectives from the responses were received from the team leaders, with neutral responses for leadership skills, technical knowledge, and change management. Senior managers and executive managers felt that a more rounded skill set was required.

5.2.5. Resilience potential

The projects overall appeared to have a good safety performance record, with first aid cases being mainly experienced (mean = 4.243). This could be misunderstood as an outcome of the safety management systems being resilient; however, it was noted in the earlier analysis that the employees were not forthcoming with negative information and that organisations were not learning from incidents. Thus, it could be concluded that many incidents were not reported or were not visible to senior management.

There was a slight agreement with projects being able to recover from setbacks (mean = 3.784); this could have arisen from true resilience being present or from excessive contingencies in the project planning phases as a way to buffer disruptions. The overall perspective was neutral to slight agreement (mean = 3.427). The slight agreement could have been based on the past performance of project recovery from setbacks. However, agreement with statement 18, that past performance is not a good measure for future success, would suggest that some resilience potential was present. The large extent of modifications from safety concerns (mean = 2.811) indicated a gap in the anticipation capability of developing resilience potential; this was also reflected in the projects exceeding their budgets (mean = 2.676).

5.3. Results of hypotheses testing

The regression models were iterated several times, retaining significant terms for just culture and learning culture. Equation (1) below shows the final regression model, which accounted for 30.22% (R2) of the variation observed in the resilience potential. The final model did not include the TMC term, as this was not statistically significant for resilience potential; thus, hypothesis H1 was rejected. The low R2 value indicates that other unidentified variables could contribute to increasing resilience potential (RP). Large residual values and unusual responses could also significantly affect the low sample size.

$$RP = -4.48+0.28\ JC+3.73\ LC-0.487\ (LC)^2 \quad (1)$$

The correlation analysis to test H2 and H3 indicated that TMC had a significant and strongly positive correlation with just culture ($p < 0.05$, $r = 0.708$) and learning culture ($p < 0.05$, $r = 0.778$). Just culture had a significant and moderately positive correlation ($p < 0.05$, $r = 0.665$) with learning culture. Just culture had a moderately positive correlation with resilience potential, which was also significant ($p < 0.05$, $r = 0.406$); thus, H2 was accepted. Learning culture's correlation with resilience potential, which was weak, was not statistically significant ($p > 0.086$, $r = 0.286$), and so H3 was rejected.

The comparison of means for the management competencies showed that the different skills for management competencies were not equally important for developing resilience potential. Since management competencies was determined to be non-normal, based on the descriptive statistics, Levene's test was done for non-normal data to test for equal variances, and the means with the Kruskal-Wallis test were compared with the Moods median test. The results from Levene's test produced P-value = 0.041 < 0.05, which meant that at least one variance was different. For both tests, P-value < 0.05 meant that the null hypothesis was rejected. Thus, H4 was accepted, which meant that there was a difference in the importance of management competencies. The hypotheses testing is summarised in Table 3.

Table 3: Summary of hypotheses tests

Hypothesis	*Description*	*Result*
H1	Top management commitment (TMC) is the most critical requirement for resilience potential	Rejected
H2	Current learning cultures are negatively affecting resilience potential	Accepted
H3	Just culture positively affects resilience potential	Rejected
H4	Management skills are not equally important	Accepted

6. CONCLUSIONS AND RECOMMENDATIONS

This study aimed to answer four research questions. The first question was about the most important barrier inhibiting the implementation of RE. Based on prior research, TMC was chosen as the foundational pillar of the "house of resilience" potential conceptual framework. The results of the hypotheses testing indicated that this was not the case, but that the learning culture was the most significant barrier.

Questions two and three were related to organisational culture, open communication, and safety metrics that lead to system improvements. The results of the study showed that the current learning culture and just culture were positively correlated with RP. This suggests that the current safety management model in South African FMCG companies is not a classic case of the Safety-I management principle, and is closer to the Safety-III safety management principle.

The fourth research question related to the key competencies required of management. A comparison of means analyses was made, highlighting that some skills are more critical to developing resilience potential. While further information would be needed properly to rank the competencies in order of impact, the implications of this are that companies need to redesign management competency acquisition and training programmes, and that there needs to be a deliberate effort to foster learning opportunities for managers to develop the required skills to realise resilience. Critically, management development should be done with a holistic view of the resilience engineering conceptual model. The foundational pillars and the developed cultures are required for this development to be meaningful and long lasting.

This conclusion led to reforming the house of resilience conceptual model as a framework for resilience engineering; its revised form appears in Figure 10 below. The results have indicated that organisational cultures are the most important, and form the foundational pillars. The link between these cultures is where the role and importance of management fit in. TMC and management competencies are enabling pillars that allow for the realisation of resilience potential. The revised model also indicates communication flows between the different cultures. Management concentrates on preventing hazards and losses by learning from past incidents and building capability into future systems. This flow of communication is shown as an upward feedback mechanism by encouraging learning opportunities from both success and failure; this improves the openness of employees to reporting incidents. This communication flow builds on establishing an improved just culture, which would allow for increased transparency and freedom of reporting from employees, which in turn would increase discussions about systems improvement and enhance the learning culture. In the revised model, this reflects the positive relationships between the cultures.

The starting point for companies on how to approach improved resilience potential in project teams is to redefine the measurement systems of the safety metrics to have a balanced view of proactive and reactive measures. This approach should be supported with training programmes to build management competencies in the six identified core management competencies. TMC is required, as many capital investments might be needed for proactive projects. The combined approach should lead to a rapid increase in resilience potential.

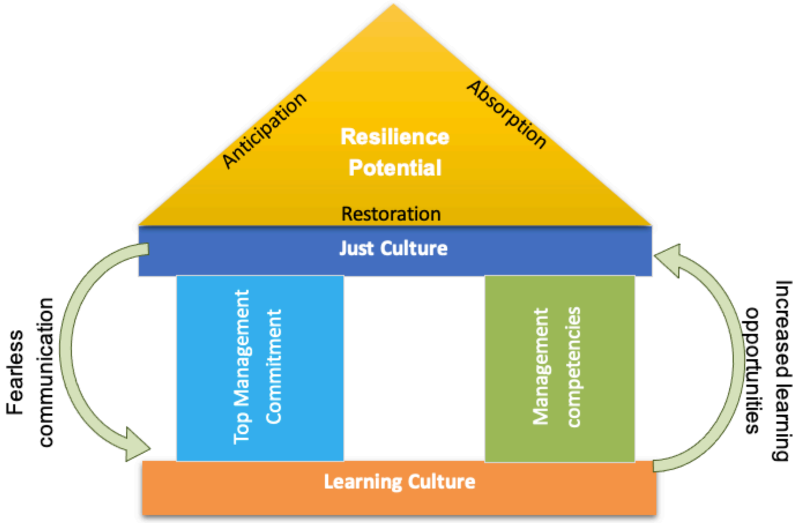

Figure 8: Revised conceptual framework for resilience engineering

The revised conceptual framework reflects our contention that the study's four research objectives have been achieved, and that the critical barrier to implementing RE in engineering projects lies in developing learning cultures that are focused on a balanced view of performance metrics.

Future research should aim to expand on this model beyond the FMCG sector and to determine its applicability to other African countries. The regression model showed that unidentified factors contribute to the organisation's resilience potential. Primary research should be completed to extract a more comprehensive list of factors and to test the impact on resilience potential; this would allow for refined interpretations of the framework. It would be helpful to extend the research into RE into educational systems, as primary education models would also be improved if these skills could be developed earlier in the educational system to provide students with the ability to be more resilient.

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APPENDIX A: RESULTS

Table A.1: Demographic Data Analysis

Organisational Roles	Frequency	Per cent
Senior manager	13	35.14%
Technical manager	8	21.62%
Director	5	13.51%
Team leader	4	10.81%
Project engineer	3	8.11%
Project manager	3	8.11%
Artisan	1	2.70%
Total	**37**	**100.00%**

Years of Experience	Frequency	Per cent
>10 years	30	81.08%
5-10 years	4	10.81%
0-1 years	1	2.70%
1-5 years	2	5.41%
Total	**37**	**100.00%**

Team Size	Frequency	Per cent
5-15 members	17	45.95%
>15 members	12	32.43%
< 5 members	8	21.62%
Total	**37**	**100.00%**

Sector Represented	Frequency	Per cent
Beverage Manufacturing	22	59.46%
Food manufacturing – groceries	5	13.51%
Multiple sectors	4	10.81%
Food manufacturing – baked goods	2	5.41%
Food manufacturing – grains	2	5.41%
Consultant for grains, groceries, and beverages	1	2.70%
Abattoir	1	2.70%
Total	**37**	**100.00%**

Organisation Function	Frequency	Per cent
Operations	14	37.84%
Projects	12	32.43%
Management	7	18.92%
Maintenance	4	10.81%
Total	**37**	**100.00%**

Table A.2: Descriptive Statistics for Variables

Descriptive Statistics of Top Management Commitment	Mean	SE Mean	Std. Dev.
6. Senior management in my organisation recognises human performance concerns and tries their best to address them.	3.703	0.168	1.024
7. Senior management in this organisation makes sacrificial decisions in favour of safety when faced with production and economic pressures (i.e., they know when to relax production pressure and efficiency goals and to put safety first).	3.757	0.217	1.321
8. Senior management in this organisation encourages people to speak up when concerned about safety.	4.270	0.176	1.071
9. Senior management in this organisation encourages people to stop or slow down production if there are unforeseen safety concerns.	3.919	0.183	1.115
Total	**3.912**	**0.154**	**0.940**

Descriptive Statistics of Just Culture	Mean	SE Mean	Std. Dev.
10. In my organisation, the boss is keen to hear bad news.	2.865	0.182	1.110
11. In my organisation, one is (also) rewarded for reporting bad news.	2.676	0.160	0.973
12. In my organisation, people are empowered to help intervene, change, and improve the organisation.	3.730	0.153	0.932
13. It is recognised that honest, unintentional human errors will occur.	3.568	0.153	0.929
14. In my organisation, disclosing information does not negatively affect my career or job prospects.	3.351	0.178	1.086
15. A confidential reporting system exists that allows and encourages employees to freely disclose their errors, correct their mistakes, and raise safety-related concerns without fear of consequence.	3.459	0.200	1.216
Total	**3.275**	**0.117**	**0.714**
Descriptive Statistics of Learning Culture	**Mean**	**SE Mean**	**Std. Dev.**
16. My organisation truly learns from past failures by implementing actual reforms instead of responding to such events with denial.	3.595	0.147	0.896
17. My organisation can rebound when placed under enormous pressure.	4.027	0.091	0.552
18. Past success is not taken as a guarantee for future success.	3.946	0.122	0.743
19. In my organisation, lessons from incidents and other events are handled seriously.	4.108	0.139	0.843
20. Feedback on past incidents and other events is provided throughout the organisation.	3.919	0.152	0.924
21. Safety performance indicators measure proactive activities	3.865	0.146	0.887
22. New projects incorporate the learnings from past incidents formally	3.514	0.176	1.070
23. Safety performance measures measure the occurrence of past incidents	4.081	0.112	0.682
24. Discussions regarding safety and risk continue to occur despite no serious incidents.	4.162	0.142	0.866
Total	**3.913**	**0.098**	**0.595**
Descriptive Statistics of Management Competencies	**Mean**	**SE Mean**	**Std. Dev.**
25. Leadership skills	4.892	0.085	0.516
26. Technical knowledge	4.432	0.143	0.867
27. Managing change	4.622	0.131	0.794
28. Communication skills	4.730	0.107	0.652
29. Decision-making ability	4.865	0.079	0.481
30. Continuous improvement mindset	4.676	0.103	0.626
Total	**4.703**	**0.086**	**0.521**
Descriptive Statistics of Resilience Potential	**Mean**	**SE Mean**	**Std. Dev.**
31. Delays in the project delivery were due to safety concerns.**	2.811	0.168	1.023
32. The project was able to recover from setbacks experienced	3.784	0.129	0.787
33. What were the final costs of the project?	2.676	0.190	1.156
34. To what extent were modifications required after the handover due to safety concerns?	3.486	0.172	1.044
35. How severe were safety incident/s that were experienced during the project, if any?	4.243	0.152	0.925
Total	**3.400**	**0.096**	**0.583**

** Values reverse-coded