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A Pilot Study on the Reliability and Validity of an Instrument Assessing Peatland Fire Suppression Techniques

Wan Mohd Nurulhisam Wan Nawang[1,*], Ahmad Faiz Zainuddin[1], Mohd Zamri Yusoff[2], Azfarizal Mukhtar[3], Adam C. Watts[4], Dayang Nur Sakinah Musa[5]

[1] Fire and Rescue Department of Malaysia (FRDM), Malaysia
[2] TNB Research Sdn Bhd, Kajang, Selangor, Malaysia
[3] Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional (UNITEN), Malaysia
[4] U.S. Department of Agriculture (USDA) Forest Service, Washington, D.C., United States of America
[5] Faculty of Tropical Forestry, Universiti Malaysia Sabah (UMS), Sabah, Malaysia

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ABSTRACT

Effective management of peatland fires requires robust, evidence-based assessment tools to measure the performance and limitations of suppression efforts. This research presents the development and psychometric verification of a standardised assessment tool designed to gauge the views of Malaysian firefighters on modern peatland fire suppression methods. Based on Stufflebeam's Context–Input–Process–Product (CIPP) evaluation model, the tool was used to collect responses from 99 firefighters from the Selangor Fire and Rescue Department using a Likert scale questionnaire. Reliability analysis of the five domains ranged from 0.722 to 0.773, indicating high internal consistency. Validity was determined using Principal Component Analysis (PCA) with a Kaiser-Meyer-Olkin value of 0.793 and seven components accounting for 67.6% of the variance. These results confirm the reliability and construct validity of the instrument and provide a sound method for measuring operational complexity, staff shortages, health impacts and equipment effectiveness in suppressing peatland fires. The tool provides a replicable, field- tested method to inform fire management and support a more adaptive, firefighter-led approach to tropical peatland fires. This research directly enhances real-world peatland fire management by providing a standardized, psychometrically validated tool that systematically converts frontline firefighter experiences into actionable data, enabling FRDM to diagnose and address specific operational failures from inadequate equipment and manpower shortages to critical health risks and logistical gaps with empirical evidence. By combining scientific rigour (reliability and validity) with practical relevance, the tool helps translate academic research into ffeasible insights for fire services, fostering a culture of evidence-based continuous improvement.

* *Corresponding author.*
E-mail address: wan190586@gmail.com@gmail.com

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1. Introduction

The critical role of peatlands as carbon sinks and reservoirs for biodiversity has been established by Girkin et *al.*, [1] and Tarigan *et al.,* [2]. Nevertheless, their acute vulnerability to fire, especially during prolonged dry periods and human-induced disturbances, has been documented by Roshani *et al.,* [3]. In tropical regions such as Malaysia, peat fires are becoming more frequent and severe, exacerbated by land-use change and drainage. The challenging nature of these fires is well documented by Akbar *et al.,* [4], who describe them as smouldering fires, a low-temperature, flameless process that is notoriously difficult to suppress. When fires penetrate below the surface, common firefighting techniques become less effective, as the fire's heat can remain insulated beneath layers of ash and soil, making it difficult to extinguish described by Stockwell *et al.,* [5]. Since peatlands can retain moisture yet may be challenging for firefighters to navigate, employing specialized equipment designed for these conditions is critical in improving firefighting efficacy as per defined by Tharima *et al.,* [6]. Figure 1 show the high number of open fires in Malaysia by state from 2021 to July 2025 which can lead to more incident and life safety to fire fighters.

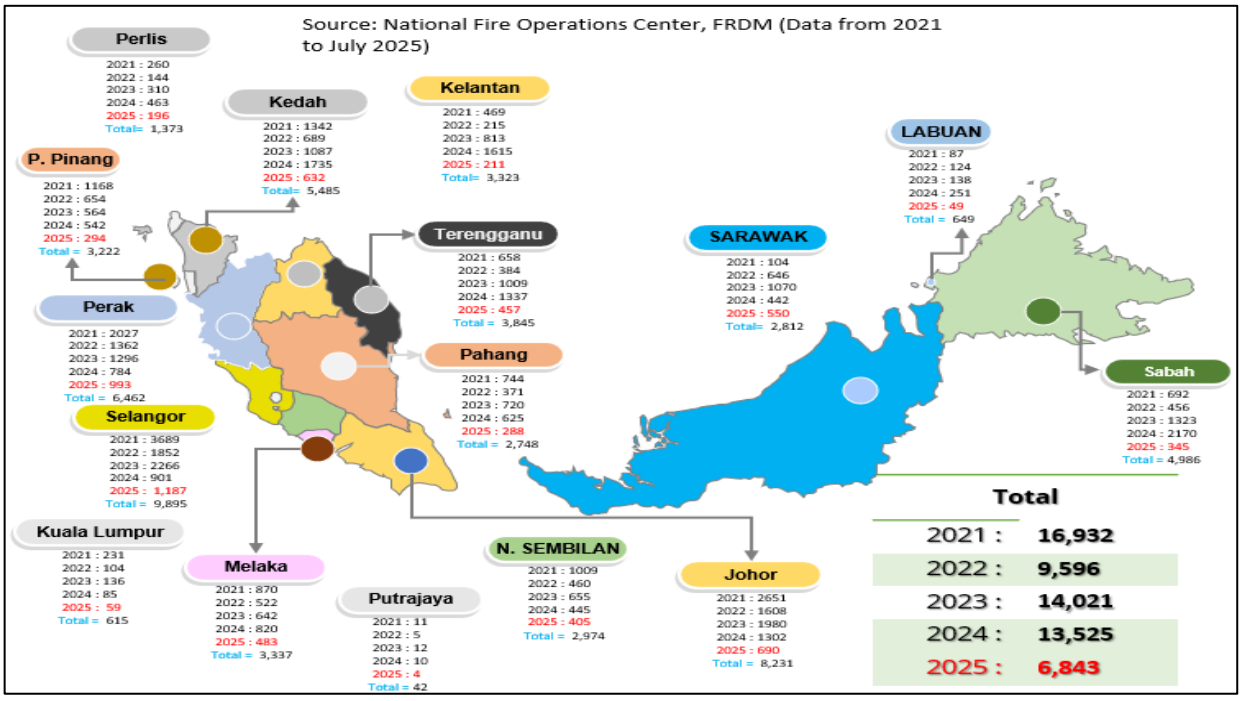

Fig.1. Number of open fires in Malaysia by state from 2021 to July 2025

Research by Smith *et al.,* [7] and Huang and Rein *et al.,* [8] has quantified the enormous releases of greenhouse gases and particulate matter from prolonged peat fires, linking them to severe threats for air quality, ecosystems, and human safety. Fires in Southeast Asian peatlands were found to release more particulate matter in 2015 than previously accounted for in emissions inventories, indicating their role as a major contributor to atmospheric pollution documented by Hein *et al.,* [9]. The duration and intensity of peatland fires cause severe degradation of ecosystems, leading to a loss of biodiversity as flora and fauna adapt poorly to frequent fires established by Taufik *et al.,* [10]. Table 1 show recorded accidents during open fire from 2020 to 2025 that include of fire fighters and utility.

Table 1
Recorded accidents during open fire, 2020-2025 (Credited to FRDM-DOSH)

No	Date	Nature of the Incident		Effects of The Accident
		Utility	Firefighters	
1	18.07.2025		/	Body Injuries
2	15.02.2025		/	Body Injuries
3	13.03.2024		/	Body Injuries
4	07.03.2024		/	Heat Stroke
5	27.04.2024		/	Body Injuries
6	19.05.2023		/	Body Injuries/PPE Failure
7	23.04.2023		/	Body Injuries
8	24.04.2023		/	Body Injuries
9	02.03.2021	/		Overturned Truck
10	21.04.2020		/	Body Injuries

Two main strategies are typically used to control fires in peatlands: direct suppression, where fires are extinguished with water, foam or chemical agents, and indirect suppression, where methods such as firebreaks and controlled fires are used to prevent them from spreading of fire provided by Bandara *et al.,* [11]. Sukach *et al.,* [12] identified key factors influencing the effectiveness of these methods, including landscape accessibility, weather conditions, peat height, and the availability of equipment and personnel. Purnamayani *et al.,* [13] have documented that rewetting, by raising groundwater levels and reducing vegetation combustibility, significantly decreases the likelihood of fire ignition. Restoration efforts that focus on the re-establishment of native plant species also contribute to reducing fire vulnerability, as diverse vegetation can help maintain moisture levels in the soil detailed by Toumbourou *et al.,* [14]. Şuvar *et al.,* [15] demonstrate that technological advances, including remote sensing and predictive analytics, can significantly optimize fire suppression. However, practical challenges such as difficult terrain, equipment failures and health risks to personnel continue to hinder effectiveness on the ground.

Despite increasing investment in suppression technology and tactics, there is little empirical measurement of the effectiveness of existing suppression strategies in actual operational environments, least of all from the perspective of frontline firefighters. Such findings can provide important insights into operational limitations, capabilities and hazards that can benefit more responsive and adaptive fire management. To address this gap, the study proposes a survey tool to assess the views of Malaysian firefighters on the effectiveness, safety and limitations of existing peatland firefighting practises. The tool is based on Stufflebeam's CIPP (Context, Input, Process, Product) model, an all-encompassing framework used extensively in education and programme evaluation employed by Anisa and Moh.Muslih [16] and Prisuna *et al.,* [17]. The CIPP model provides a multifaceted perspective through which interventions, as in the case of fire interventions, can be rigorously examined. All areas of the CIPP approach contribute to a comprehensive assessment:

a. Context is about clarifying the problem or need that the intervention is intended to address.
b. The input assesses the resources, infrastructure and human capital used.
c. The process evaluates the implementation phase, the operational challenges and potential risks.
d. The product measures the effectiveness and undesirable effects.

The study instrument consists of five CIPP-based categories, each of which has a specific focus on examining suppression practises. .

Table 2 provides an overview of the five categories and the assessment framework that guides them.

Table 2
CIPP-based questionnaire structure and evaluation elements

CIPP Domain	Category in Questionnaire	Evaluation Focus
Context	Disadvantages of Current Methods	Identifies limitations and inefficiencies in existing suppression strategies
Input	Manpower Constraints and Weaknesses	Assesses adequacy of personnel and training
Process	Accidents During Operations	Evaluates safety risks and operational hazards during firefighting
Product	Effect on Health	Measures of physical and respiratory health impacts on personnel
	Effectiveness of Equipment Used	Evaluates performance, usability, and adequacy of firefighting tools and technologies

By utilizing this structured evaluation framework, the developed instrument offers a comprehensive means to collect empirical data on the current state of peatland fire suppression from those directly involved. In doing so, it supports evidence-based decision-making for operational improvements and policy interventions tailored to tropical peatland fire contexts identified by Suryana *et al.,* [18].

2. Related Work

Peatland fires are the subject of countless research studies, as they have a serious impact on the environment, ecology and public health. The combination of environmental, health, and ecology aspects surrounding peatland fires underscores the necessity for a coordinated approach to peatland management, integrating community knowledge and scientific research to develop effective mitigation strategies documented by Sinta *et al.,* [19]. Previous work has critically analysed the causes, combustion processes and ecological impacts of peat fires in Southeast Asia, with a particular focus on Indonesia and Malaysia. Amalia *et al.,* [20] and Hasnida and Ghazali [21] have demonstrated that smouldering fires in peat persist and that conventional suppression strategies are not sufficient to extinguish deep-rooted fires. In terms of suppression strategies, an analysis of the integration of direct and indirect suppression strategies by Bandara *et al.,* [11], relied heavily on the increasing reliance on technology in the form of fire modelling, GIS mapping and predictive analysis to improve suppression planning. However, such analyses tend to be technology-centric and neglect the operational and human elements that influence things on the ground.

The literature also reflects a growing interest in evaluating firefighting programmes, but there are very few measurement tools to gauge effectiveness from the perspective of those on the ground. Current evaluations prefer to rely on outcome-based indicators such as area burned or duration of suppression operations, so a method for systematic perception-based measurement is lacking. From a methodological perspective, the use of standardised, validated questionnaires is well established in environmental health studies by Amalia *et al.,* [20] and Hasnida and Ghazali [21] , but there are few examples of their use in fire management situations. Interestingly, studies by Abdul Rahman *et*

al., [22], illustrated the effectiveness of using psychometric surveys in industrial safety assessment, while the application of the same technique in the assessment of mechanisation adoption in agricultural systems by Anto *et al.,* [23], is worth mentioning. These studies show that reliability and validity must be prioritised when developing instruments.

The CIPP assessment model, developed by Stufflebeam and now widely used in educational and organisational programme evaluation by Anisa and Moh.Muslih [16] and Prisuna *et al.,* [17], provides an organised and integrated approach to multidimensional assessments. Arjaya and Suma [24] promoted its implementation in technical and training environments and justified its application in fire service operations as inputs, process and outcomes need to be considered. Although these efforts are noteworthy, there is still a lack of development of holistic, field-tested assessment tools specifically designed for peatland fire suppression. This study fills this gap by presenting a CIPP-based questionnaire that has been validated as a means of capturing the operational realities, challenges, and perceptions of firefighters in suppressing peatland fires in Malaysia.

3. An Overview of the Methods Employed

3.1 Study Area and Respondents

This pilot study took place in Selangor, an important administrative as well as urban state of Peninsular Malaysia, that faces recurring incidents of peatland fires. Participants were recruited from the Fire and Rescue Department of Malaysia (FRDM) Selangor, who are in charge of frontline peatland fire control operations in the area. Conducting a pilot study within a single state's Fire and Rescue Department is more manageable in terms of gaining institutional approval, coordinating data collection and ensuring consistency in how the survey is administered. 99 participants took part in the study. The primary goal of a pilot study is not to represent an entire population, but to test and validate the research instrument. The focus is on the tool's reliability and validity, not on making broad generalizations. A sample size of 99 is more than sufficient for this purpose.Voluntary participation was ensured, and informed consent from all participants was sought through a digital consent form that accompanied the survey instrument. The data were collected online using Google Forms in December 2024. Anonymity and confidentiality were ensured in the study in compliance with the institution's research protocol.

3.2 Instrument Development

The survey instrument was developed based on the CIPP (Context, Input, Process, Product) evaluation model, which is commonly used in the evaluation of programmes and interventions employed by Arjaya and Suma [24] and Prisuna *et al.,* [17].The questionnaire consisted of five main sections and contained a total of 29 questions, including demographic data and 25 essential questions to assess various dimensions of suppression. Traditional fire management evaluations typically focused on outcome-based metrics like "area burned," "suppression time," or "cost of damages." These are post-hoc, ecological, or economic indicators. By using the CIPP (Context, Input, Process, Product) model, a holistic framework from program evaluation, to assess the entire intervention system before, during, and after the firefighting effort. It shifts the focus from mere outcomes to the quality and challenges of the entire operational chain.

The scale typically presents respondents with a statement regarding a specific topic and asks them to indicate their level of agreement or disagreement on a fixed scale, options ranging from "strongly disagree" to "strongly agree" as described by Wang *et al.,* [25]. All items were rated on a 5-

point Likert scale from 1 = strongly disagree to 5 = strongly agree. This These items were designed to measure five thematic areas based on the CIPP model:

a. Shortcomings of prevailing practises,
b. Limitations and weaknesses of the labour force,
c. Occupational accidents,
d. Health impacts, and
e. Equipment effectiveness.

The development of the questionnaire statements was guided by a literature review on peatland fire suppression practises, firefighting operations, and fire safety, notably from Bandara *et al.,* [11] and Hasnida and Ghazali [21]. Initial drafts of the statements were reviewed by two subject matter experts to validate content and contextual appropriateness as recommended by Reethesh *et al.,* [26] and Branscum *et al.,* [27].

3.3 Data Analysis

Reliability and validity are two pivotal concepts in the realm of survey research, serving as standards for evaluating the quality of measurement instruments. Reliability refers to the consistency or stability of a survey instrument, meaning that the same results should be obtained under consistent conditions. One common statistical method for assessing internal consistency reliability is Cronbach's Alpha, which quantifies how closely related a set of items in a questionnaire are, thus indicating their capability to measure the same construct as defined by da Silva *et al.,* [28]. On the other hand, validity is concerned with the accuracy of the measurement, addressing whether the instrument truly measures what it intends to measure.

3.3.1 Reliability analysis

Internal consistency was assessed using Cronbach's alpha coefficient. Values above 0.70 were considered acceptable, with values between 0.70 and 0.80 indicating good reliability as per defined by Abdul Rahman *et al.,* [22] and Amalia *et al.,* [20]. Cronbach's alpha was computed for each of the five thematic categories based on the CIPP framework.

3.3.2 Validity analysis

Construct validity was assessed using Principal Component Analysis (PCA) with Varimax rotation. The process of PCA involves several steps: beginning with the standardization of the data matrix, followed by the extraction of eigenvalues and eigenvectors from the covariance or correlation matrix. Zhang *et al.,* [29] note that the principal components are then derived from these eigenvectors, which represent directions in the data that reflect the maximum variance. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity were used to verify sampling adequacy and the suitability of the dataset for factor analysis. Factors with eigenvalues >1 were retained, and factor loadings ≥ 0.50 were considered acceptable indicators of construct representation as per mention by Pantouvaki *et al.,* [30].

4. Results and Discussion

This section presents the psychometric evaluation of the developed CIPP-based instrument, including its internal consistency and construct validity, followed by a critical interpretation of the findings in the context of peatland fire suppression.

4.1 Reliability Analysis

The internal consistency of the instrument was evaluated using Cronbach's alpha for each of the five core categories aligned with the CIPP evaluation framework. As shown in

Table 3, all components achieved acceptable or good reliability, with alpha values ranging from 0.722 to 0.773, indicating that the instrument demonstrates consistent and dependable measurement properties as defined by Abdul Rahman *et al.,* [22] and Amalia *et al.*, [20].

Table 3
Internal consistency reliability of questionnaire components

CIPP Domain	Category	Number of Items	Cronbach's Alpha (α)	Reliability Interpretation
Context	Disadvantages of Current Methods	5	0.731	Acceptable
Input	Manpower Constraints and Weaknesses	5	0.773	Good
Process	Accidents During Operations	5	0.751	Acceptable
Product	Effect on Health	5	0.759	Acceptable
Product	Effectiveness of Equipment Used	5	0.722	Acceptable

These results confirm that the items grouped under each domain consistently measure their intended constructions, providing a reliable basis for further analysis.

4.2 Validity Analysis (Principal Component Analysis)

To evaluate construct validity, Principal Component Analysis (PCA) was conducted using Varimax rotation. Sampling adequacy was confirmed with a Kaiser-Meyer-Olkin (KMO) value of 0.793, and Bartlett's Test of Sphericity was highly significant ($\chi^2 = 1105.87$; $df = 300$; $p < 0.001$), indicating that the data were suitable for factor analysis. PCA extracted seven components with eigenvalues greater than 1, collectively explaining 67.61% of the total variance, as shown in Table 4. This level of explained variance is considered robust in social science and perception-based studies.

Table 4
Total variance explained by principal components

Component	Initial Eigenvalue	% of Variance	Cumulative %
1	7.113	28.454%	28.454%
2	2.858	11.433%	39.887%
3	1.961	7.842%	47.730%
4	1.416	5.665%	53.395%
5	1.315	5.258%	58.653%
6	1.183	4.731%	63.384%
7	1.057	4.229%	67.613%

Note: Only components with eigenvalues > 1.0 were retained.

The Component Matrix (Table 5 and Table 6) shows how individual items loaded onto these components. Strong factor loadings (≥ 0.50) are observed across several dimensions, indicating that the items are well-aligned with their underlying constructs.

Table 5
Component matrix – context, input, and process categories

Item Statement	C1	C2	C3	C4	C5	C6	C7
Logistical support during operations is insufficient	0.645	-0.111	0.127	0.178	0.106	-0.428	-0.143
Operational planning does not consider ground-level challenges	0.540	-0.280	0.000	-0.217	-0.162	-0.409	0.162
The number of workers is not sufficient for large-scale operations	0.610	-0.014	0.232	-0.014	0.166	0.260	0.194
Lack of training for operations personnel makes tasks in the field difficult	0.418	-0.169	0.592	0.046	0.116	0.431	-0.092
Training for operations personnel is insufficient	0.315	-0.286	0.597	0.076	0.226	0.286	-0.044
Motivation of operational personnel is often affected during long assignments	0.780	0.002	-0.004	0.026	-0.022	-0.008	0.098
Member fatigue in operation affects effectiveness	0.686	-0.007	-0.017	-0.029	-0.105	0.239	0.124
Lack of adequate support staff adds to the challenge	0.726	0.126	-0.057	-0.041	0.188	-0.170	0.084
Current extinguishing systems are not efficient enough for widespread peat fires	0.359	-0.539	0.006	-0.184	0.204	-0.023	0.270
There is no periodic assessment of the shortcomings of the current system	0.710	-0.044	0.175	0.103	-0.054	-0.334	0.167

Table 6
Component matrix – product category (health and equipment)

Item Statement	C1	C2	C3	C4	C5	C6	C7
Exposure to smoke affects respiratory health	0.554	0.015	-0.558	-0.332	0.233	0.121	-0.141
I often experience extreme fatigue after blackout operations	0.510	-0.034	-0.571	-0.144	-0.156	0.258	-0.055
Lack of PPE increased my health risks during operations	0.559	-0.093	-0.209	-0.493	0.199	0.170	-0.126
The equipment used is suitable for peat fires	0.072	0.659	-0.137	0.352	0.378	0.088	0.011
Condition of equipment often affects operational effectiveness	0.448	0.595	0.184	-0.033	0.047	-0.232	-0.214
Equipment often breaks down in the field	0.494	0.498	0.226	-0.245	-0.277	-0.070	-0.281
Equipment quantity is insufficient to meet operational needs	0.506	0.497	0.376	-0.184	-0.159	-0.024	-0.257
Current equipment is easy to use during operation	0.071	0.592	-0.119	0.151	0.263	-0.031	0.491

4.3 Interpretation and Implications

These results strongly demonstrate the validity and reliability of the tool as a viable instrument for evaluating existing peatland fire suppression measures. Bandara *et al.,* [11] and Şuvar *et al.,* [15] defined that the high loading factors identify clear operational issues such as equipment

performance, logistical support and health risks, which align with previous reports on the challenges of managing peatland fires.

Using the CIPP assessment model, the current study presents a dimensional view of assessing suppression tactics. Unlike typical assessments that focus on output (i.e., area burned), the CIPP model considers contextual needs, resource inputs, operational processes, and actual outcomes in the world, allowing for a more holistic assessment. The model enables fire services to diagnose vulnerabilities, better allocate resources and improve subsequent responses to fires. The benefit of the tool is that it focuses on the experiences of firefighters, a perspective that is all too often ignored when developing response strategies. It adds value by methodically recording the observations of those who implement the measures on the ground, adding a welcome operational human aspect to ecological measurements and remote sensing research.

4.4 Integrating the Assessment

The empirical findings from the "Input" and "Product" domains must then be channelled directly into strategic budgeting and procurement justifications, providing undeniable evidence to secure funding for specialized equipment and additional personnel. Concurrently, training academies must use the specific results from the "Process" and "Health" domains to develop targeted, evidence-based training modules that address real-world safety risks, fatigue management, and equipment handling. Furthermore, the quantitative data on health effects should inform new occupational health policies, mandating stricter PPE use and post-deployment medical screenings.

4.5 Limitations and Future Research

This was a Malaysian study in one state (Selangor) with limited generalisability. Furthermore, reliance on self-reported perceptions, although useful, may be prone to subjectivity or response bias. Subsequent studies may rely on a national sample and compare the integration of perceptual data with objective indicators of fire performance, such as duration of suppression, repeated fires, or ecological recovery. The tool can also be adapted to other fire-prone areas or nations. Comparative studies, localisation into other languages, and application in post-incident debriefing protocols can be part of further research to better institutionalise learning and facilitate operational improvements.

4.5 Development of Future Strategies

The proposed assessment tool strengthens practical outcomes by creating a direct feedback loop from frontline experience to systemic improvement. The tool provides the empirical evidence needed for FRDM to justify investing in more effective, peat-suitable technology and to mandate stricter health and safety measures, directly reducing firefighter injury and exposure. This, in turn, enhances ecological outcomes because a safer, better-equipped workforce can suppress smouldering peat fires more effectively and rapidly; for instance, data revealing that "logistical support is insufficient" or "equipment is unsuitable" can lead to strategic pre-positioning of specialized innovation suppression system, which directly curtails the fire's duration and depth.

5. Conclusion

In this study, a structured assessment tool based on the CIPP (Context, Input, Process, Product) assessment model was successfully developed and validated to examine peatland fire suppression

practises from the firefighters' perspective. The pilot application in Selangor, Malaysia, showed that the tool has strong psychometric properties, with all domains demonstrating acceptable to good internal consistency and robust construct validity.

This pilot study, while successfully validating a novel instrument, invites critical reflection on its broader implications and inherent constraints; its true innovation lies in systematically quantifying the subjective, often overlooked experiences of frontline firefighters, thereby challenging the technocratic and outcome-dominated paradigms of traditional fire management by asserting that operational effectiveness is inextricably linked to human factors like health, morale, and perceived equipment adequacy. However, this strength is tempered by significant limitations: the cross-sectional, single-state design captures a static snapshot vulnerable to the social desirability bias inherent in a paramilitary culture, potentially underestimating problem severity, while the application of the linear CIPP model may oversimplify the chaotic, non-linear reality of firefighting, a tension hinted at by the unexpected extraction of seven principal components instead of the five theorized domains, suggesting the firefighters' lived experience is more complex than the model can contain. Furthermore, the tool's reduction of rich operational narratives into quantifiable Likert-scale data, though necessary for psychometric rigor, risks obscuring the contextual stories behind the scores, and the modest reliability coefficients, while acceptable, may actually reveal the multifaceted nature of each domain rather than mere measurement noise. Ultimately, the instrument serves as a powerful diagnostic starting point rather than a definitive solution, its value lying in its ability to provoke necessary conversations and further mixed-methods research that bridges the gap between quantified perception and the qualitative, adaptive realities of saving lives and landscapes.

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