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The Impact of Environmental Stressors on Logistics Efficiency: The Serial Mediating Role of Driving Fatigue and Cognitive Impairment Among Truck Drivers in Thailand

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Abstract

This research explores how environmental stressors impact logistics efficiency among truck drivers in Thailand. The study particularly examines driving fatigue and cognitive impairment as connecting factors in this relationship. A total of 538 truck drivers participated in the survey through a validated questionnaire. The collected data underwent analysis using descriptive statistics and Partial Least Square Structure Equation Modeling (PLS-SEM). Results reveal that environmental stressors reduce logistics efficiency in Thai truck drivers through a chain reaction process. Environmental stressors first trigger driving fatigue in drivers. This fatigue subsequently leads to cognitive impairment. Finally, cognitive impairment causes decreased logistics efficiency. The connection between fatigue and cognitive impairment proves particularly strong and represents a crucial element in this sequence. The combined impact of environmental stressors, driving fatigue, and cognitive impairment accounts for 35.2% of the variance in logistics efficiency (R^2 = 0.352). Statistical analysis confirms that driving fatigue and cognitive impairment function as sequential mediating variables linking environmental stressors to logistics efficiency. The proposed research model shows solid predictive capability and yields meaningful results. These outcomes effectively demonstrate how environmental challenges translate into operational performance issues within the trucking industry. The findings offer practical insights for enhancing logistics efficiency by addressing environmental stressors and supporting driver's wellbeing.

Keywords

Cognitive impairment, driving fatigue, environmental stressor, logistics efficiency, truck driver.

INTRODUCTION

The global logistics industry depends heavily on road freight transportation for international commerce and domestic distribution. However, commercial trucking operations expose drivers to environmental stressors, which significantly impact individual performance and overall logistics efficiency [1]. Understanding the relationships between environmental factors, driver health, and operational outcomes has become critical for industry stakeholders.

Environmental stressors in trucking include extreme weather, poor infrastructure, traffic congestion, noise pollution, and irregular schedules that disrupt sleep patterns [2]. These factors primarily cause driving fatigue, a major safety and efficiency concern in commercial transportation. Research shows that approximately 60% of drivers in developed countries and 49% in developing countries experience regular fatigue due to insufficient rest and long working hours [2]. Thai drivers face additional challenges including urban congestion, mountainous terrain, and tropical weather conditions. Current studies often examine isolated variables rather than comprehensive pathways linking environmental stressors to operational outcomes.

Partial Least Squares Structural Equation Modeling (PLS-SEM) offers opportunities to examine these complex relationships. The method handles non-normal data, smaller samples, and formative models, making it appropriate for investigating multifaceted relationships between stressors, driver factors, and outcomes [3].

This research examines how environmental stressors influence efficiency among Thai truck drivers through the serial mediating roles of driving fatigue and cognitive impairment. The study also contributes theoretical understanding and practical solutions to critical logistics industry challenges.

LITERATURE REVIEW

Environmental Stressors in Long-Haul Trucking

Recent research reveals that environmental stressors substantially increase truck driver fatigue through various mechanisms. Environmental stressors including noise (87.95-103.4 dB), whole-body vibration, and heat significantly impair truck driver performance by increasing fatigue and decreasing cognitive function [4-6]. Extreme cockpit temperatures cause driver discomfort and fatigue. Proper climate control maintains alertness and reduces fatigue-related incident risk [7]. Adverse weather, such as, rain, increases cognitive load while sunlight glare strains eyes, both accelerating driver fatigue and reducing vigilance and reaction times [8, 9]. These stressors reduce reaction time and concentration, with performance declining after just two hours of driving [10, 11]. Consequently, fatigue accounts for 31% of truck crashes and was the primary factor in plenty annual accidents, as it shifts drivers from problem-oriented to emotion-oriented coping strategies which impair decision-making [1, 12]. Moreover, The truck driver's seat is also essential for maintaining comfort during long-distance travel, as it greatly affects the vertical movements felt due to uneven road surfaces, in other words, the seat of truck driver significantly impacts the vertical acceleration experienced due to road roughness [13]. Based on the comprehensive literature review on Environmental Stressors, the environmental stressors positively correlate with driving fatigue, cognitive impairment, and logistics efficiency.

Logistics Efficiency

Researchers have documented how driver fatigue and cognitive impairment significantly compromise logistics efficiency, with studies showing driver shortage influences logistics performance and operational efficiency [14]. Moreover, fatigue reduces drivers' calculation ability, increases errors, and impairs information processing [10]. Recent findings indicate fatigue mediates job demands and safety incidents through cognitive overload [15]. Thereby, logistics efficiency could be assumed to have a correlation with driver fatigue and cognitive impairment, which cause increased costs and delays.

Fatigue-Induced Cognitive Decline in Commercial Driving Operations

Driving fatigue significantly impairs cognitive functioning, reducing reaction times and decision-making capacity while degrading logistics efficiency through increased accidents and operational costs [16, 17]. Fatigue contributes to 20% of road crashes and directly influences logistics performance through impaired perception and increased traffic incidents [15, 18]. Moreover, the research shows fatigue mediates work demands and driving performance, particularly affecting commercial drivers facing extended hours and tight schedules [19].

Driving fatigue, characterized by reduced alertness and concentration that makes drivers less able to notice incoming risks [20], significantly impairs cognitive performance through multiple mechanisms. Fatigue is one of the crucial factors in human error-related traffic accidents, and despite the development of highly advanced intelligent transport systems, fatigue-related traffic accidents have not decreased [21]. Cognitive impairment hinders an individual's capacity to process information, make prompt decisions, and react efficiently to ever-changing traffic scenarios, with recent studies emphasizing the vital significance of mental workload and heart rate variability in shaping cognitive performance [22].

Cognitive Impairment

Cognitive impairment from driving fatigue significantly reduces vigilance and decision-making capabilities in truck drivers [11, 23], cognitive impairment mediates work-performance relationships contributing to road crashes [24]. Thus, cognitive impairment resulting from driving fatigue could assumably demonstrate a significant correlation with logistics efficiency.

RESEARCH OBJECTIVES

- To examine the perceptions of truck drivers in Thailand regarding environmental stressors, logistics efficiency, driving fatigue, and cognitive impairment.
- To investigate the influence of environment stressors, driving fatigue, and cognitive impairment on the logistics efficiency of truck drivers in Thailand.
- To explore the serial mediating role of driving fatigue and cognitive impairment in the relationship between environmental stressors and logistic efficiency among truck drivers in Thailand.

RESEARCH CONCEPTUAL FRAMEWORK

Based on the literature review, the research conceptual framework and hypotheses were established as follows:

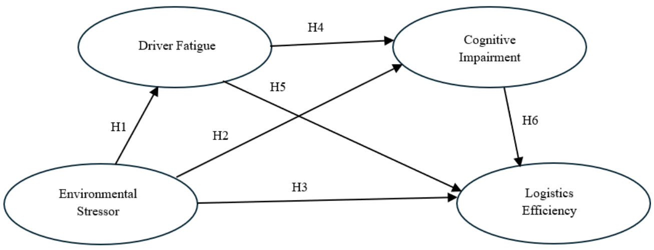

Figure 1. Research Conceptual Framework

RESEARCH HYPOTHESES

H1: Environmental stressors have a direct positive influence on driving fatigue
H2: Environmental stressors have a direct positive influence on cognitive impairment
H3: Environmental stressors influence logistics efficiency, primarily through indirect effects mediated by fatigue and cognitive impairment, with direct effects expected to be weaker.
H4: Driving fatigue has a direct positive influence on cognitive impairment
H5: Driving fatigue has a direct positive influence on logistic efficiency
H6: Cognitive impairment has a direct positive influence on logistic efficiency
H7: Driving fatigue and cognitive impairment serve as serial mediating variables between environmental stressors and logistic efficiency

METHODOLOGY

This research employed a quantitative cross-sectional design conducted from January 2025 to May 2025. The methodology was implemented as follows to achieve the research objectives:

Population and Sample

The population consisted of truck drivers in Thailand holding valid truck driving licenses. In accordance with the database of the Ministry of Transport, there were a total 1,241,250 people (data as of February 29, 2024)[25]. Sample size was calculated using a web application software tool for structural equation modeling analysis [26]. Based on the casual structural model with latent variables, this study included 4 latent variables and 19 observed variables. With a medium effect size of 0.30, desired statistical power level of 0.95, and probability level of 0.001, the minimum required sample size was 330. A total of 538 complete questionnaires were received through convenience sampling via online distribution, exceeding the predetermined minimum sample size.

Research Instrument

The research instrument was a questionnaire comprising 19 items measuring 4 latent variables: Environmental Stressors, Driving Fatigue, Cognitive Impairment, and Logistics Efficiency. All variables were measured using a 5-point Likert Scale. For validity assessment, three experts evaluated the consistency between questions and research objectives using the Index of Item Objective Congruence (IOC), with each item achieving an IOC value greater than 0.5, confirming the questionnaire's validity. Reliability was assessed through a pilot test with 30 respondents, yielding Cronbach's alpha coefficients greater than 0.70 for all constructs, indicating high reliability [27].

Data Analysis

The collected data were analyzed using descriptive statistics including means, standard deviations, skewness, and kurtosis for both latent and observed variables. Subsequently, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed, which is a technique for detecting or creating predictive models, particularly suitable for analyzing causal relationships between latent variables. This method is superior to conventional linear structural relationship models and is especially appropriate for exploratory research [3] PLS-SEM was designed specifically to detect whether causal relationships have statistically significant linear correlations. This method is relatively suitable for theoretical model building. This study used PLS-SEM to explore relationships between research variables, primarily using the PLS algorithm and bootstrapping with 5,000 resamples to determine path coefficients and significance levels that can describe relationships and influences between variables [28].

RESULTS

The sample respondents were predominantly male (95.4%), with the majority aged 35-54 years (68.7%), having primary-secondary education (81.2%), more than 10 years of truck driving experience (69.1%), primarily driving trailers (77.9%), and working as salaried permanent employees (87.0%). The research results are presented in three sections according to the research objectives:

Section 1: Perceptions of Truck Drivers in Thailand Regarding Environmental Stressors, Logistics Efficiency, Driving Fatigue, and Cognitive Impairment

Table I. Measurement Items Used in the Questionnaire

	Descriptive statistics for variables					Construct validity			
Items / Latent variables	**SK.**	**KU.**	**Mean**	**SD.**	**Level**	**Std. Loadings**	**CA**	**CR**	**AVE**
ES1 (-)	-0.834	-0.527	3.987	1.251	More	0.833			
ES2 (-)	-0.716	-0.757	3.835	1.340	More	0.860			
ES3 (-)	-1.146	0.035	4.080	1.297	More	0.819			
ES4 (-)	-1.505	0.974	4.251	1.255	Much	0.791			
ES (-)	**-0.927**	**-0.058**	**4.038**	**1.065**	**More**	-	0.847	0.896	0.683
DF1 (-)	0.366	-0.686	2.446	1.203	Low	0.624			
DF2 (-)	0.657	-1.184	2.329	1.577	Low	0.816			
DF3 (-)	0.454	-1.350	2.526	1.580	Low	0.804			
DF4 (-)	0.514	-1.462	2.483	1.690	Low	0.798			
DF5 (-)	-0.297	-1.441	3.290	1.601	Medium	0.757			
DF6 (-)	-0.264	-1.428	3.247	1.583	Medium	0.778			
DF7 (-)	-0.486	-1.356	3.474	1.611	More	0.575			
DF (-)	**0.313**	**-0.879**	**2.828**	**1.149**	**Medium**	-	0.860	0.894	0.550
CI1 (-)	0.517	-1.122	2.409	1.445	Low	0.826			

	Descriptive statistics for variables					Construct validity			
Items / Latent variables	**SK.**	**KU.**	**Mean**	**SD.**	**Level**	**Std. Loadings**	**CA**	**CR**	**AVE**
CI2 (-)	0.623	-1.040	2.296	1.443	Low	0.853			
CI3 (-)	0.067	-1.003	2.801	1.327	Medium	0.853			
CI4 (-)	0.108	-1.175	2.777	1.400	Medium	0.803			
CI (-)	**0.475**	**-0.729**	**2.571**	**1.170**	**Low**	**-**	0.854	0.901	0.695
LE1 (-)	-0.410	-1.098	3.455	1.424	More	0.666			
LE2 (-)	-0.303	-1.531	3.284	1.649	Medium	0.848			
LE3 (-)	-0.446	-1.340	3.441	1.584	More	0.838			
LE4 (-)	-0.226	-1.682	3.206	1.737	Medium	0.757			
LE (-)	**-0.243**	**-1.113**	**3.347**	**1.248**	**Medium**	**-**	0.783	0.861	0.610

The descriptive statistical analysis results shown in Table I indicate that the collected data approximate normal distribution, as skewness (SK) and kurtosis (KU) values fall within ±2.00 [29-31]. Regarding the means of the studied latent variables, truck drivers in Thailand reported environmental stressors at a high level, resulting in moderate levels of driving fatigue and logistics efficiency, while cognitive impairment among truck drivers was at a low level.

Table I also presents construct validity analysis results for each latent variable, indicating that the four observed variables (ES1-ES4) effectively represent the Environmental Stressors latent variable, and the four observed variables (CI1-CI4) adequately represent the Cognitive Impairment latent variable, as standardized loadings exceeded 0.70. Internal consistency was appropriate with Cronbach's Alpha (CA) and Composite Reliability (CR) values exceeding 0.70. The convergent validity of the Environmental Stressors latent variable was suitable, with Average Variance Extracted (AVE) values exceeding 0.50.

Although some observed variables explaining the Driving Fatigue and Logistics Efficiency latent variables had standardized loadings below 0.70, their internal consistency measured by Cronbach's Alpha (CA) and Composite Reliability (CR) exceeded 0.70, and their convergent validity was appropriate with AVE values exceeding 0.50. Therefore, all four latent variables demonstrated good construct validity.

Table II. Discriminant Validity

	Cognitive Impairment (CI)	**Driver Fatigue (DF)**	**Environmental Stressor (ES)**	**Logistics Efficiency (LE)**
Cognitive Impairment (CI)	**0.834**			
Driver Fatigue (DF)	0.740	**0.741**		
Environmental Stressor (ES)	0.377	0.413	**0.827**	
Logistics Efficiency (LE)	0.533	0.56	0.326	**0.781**

The assessment of relationships between latent variables examines whether they are at appropriate levels, as correlations between latent variables should not be excessively high to avoid multicollinearity issues. Discriminant validity was evaluated using the Average Variance Extracted versus Shared Variance (AVE-SV) method [32], where correlation coefficients between each pair of latent variables must be lower than the square root of the AVE for that pair. Table II results meet the Fornell and Larcher criteria, confirming that all external latent variables possess discriminant validity. This reflects that the measurement scales used in this research are standardized instruments providing clear, unambiguous data capable of achieving high validity.

Section 2: The Influence of Environmental Stressors, Driving Fatigue, and Cognitive Impairment on Logistics Efficiency of Truck Drivers in Thailand

Following the assessment of construct validity and discriminant validity of latent variables in the research model according to the correct principles, hypothesis testing was conducted, particularly testing direct effects, as shown in Figure2 and Table III.

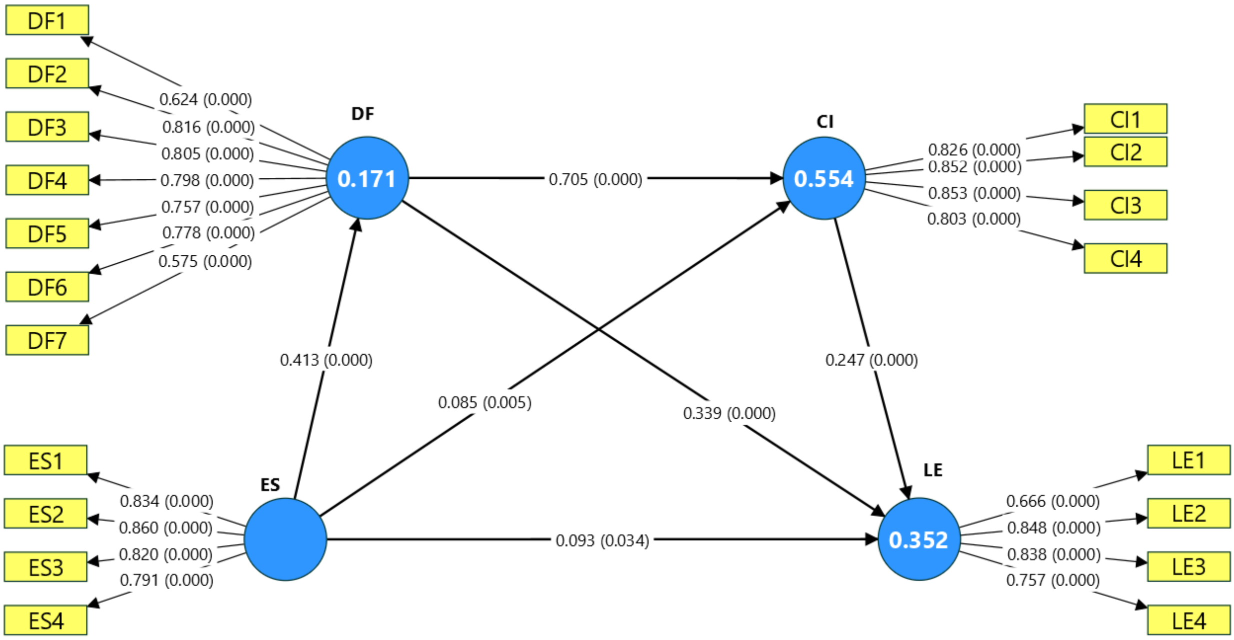

Figure 2. Research Model Analysis Results

Table III. Direct Effects Testing Results of Variables in the Research Model

Hypothesis		β	b	STDEV	T statistics (|b/STDEV|)	p-values	f^2
H1:	ES --> DF	0.414***	0.414	0.034	12.318	0.000	0.206
H2:	ES --> CI	0.085**	0.085	0.030	2.842	0.005	0.014
H3:	ES --> LE	0.093*	0.093	0.044	2.123	0.034	0.011
H4:	DF --> CI	0.707***	0.707	0.027	26.581	0.000	0.924
H5:	DF --> LE	0.340***	0.340	0.057	5.897	0.000	0.076
H6:	CI --> LE	0.247***	0.247	0.056	4.392	0.000	0.042

*Note: *p-value < 0.05, **p-value < 0.01, ***p-value < 0.001
Small effect size: $0.02 < f^2 < 0.15$, Medium effect size: $0.15 < f^2 < 0.35$, Large effect size: $f^2 > 0.35$ [33]

The results shown in Fig. 2 and Table III present hypothesis testing outcomes and effect size levels of causal variables on outcome variables. All research hypotheses were supported:

H1: Environmental Stressors have a direct positive influence on Driving Fatigue (β = 0.414, p-value = 0.000) with a medium effect size ($f^2 = 0.206$).

H2: Environmental Stressors have a direct positive influence on Cognitive Impairment (β = 0.085, p-value = 0.005) with a very small effect size ($f^2 = 0.014$).

H3: H3 was supported, showing that environmental stressors influence logistics efficiency mainly through indirect pathways rather than direct effects. The sequential mediation through driving fatigue and cognitive impairment represents the dominant mechanism in this relationship (β = 0.093, p-value = 0.034) with a very small effect size ($f^2 = 0.011$).

H4: Driving Fatigue has a direct positive influence on Cognitive Impairment (β = 0.707, p-value = 0.000) with a large effect size ($f^2 = 0.924$).

H5: Driving Fatigue has a direct positive influence on Logistics Efficiency (β = 0.340, p-value = 0.000) with a small effect size ($f^2 = 0.076$).

H6: Cognitive Impairment has a direct positive influence on Logistics Efficiency (β = 0.247, p-value = 0.000) with a small effect size ($f^2 = 0.042$).

These findings reveal that truck drivers in Thailand experience reduced logistics efficiency caused by environmental stressors as external factors, with indirect effects mediated through driving fatigue and cognitive impairment. Notably, when drivers experience driving fatigue, it significantly affects cognitive impairment, ultimately leading to decreased logistics efficiency.

The variance explained in Driving Fatigue (DF) by Environmental Stressors (ES) is 17.1% ($R^2 = 0.171$). The variance in Cognitive Impairment (CI) explained by Environmental Stressors (ES) and Driving Fatigue (DF) is 55.4% ($R^2 = 0.554$). The variance in Logistics Efficiency (LE) explained by Environmental Stressors (ES), Driving Fatigue (DF), and Cognitive Impairment (CI) is 35.2% ($R^2 = 0.352$).

Section 3: The Serial Mediating Role of Driving Fatigue and Cognitive Impairment between Environmental Stressors and Logistics Efficiency among Truck Drivers in Thailand

Table IV. Mediation Analysis Results

Hypothesis		β	b	STDEV	T statistics (|b/STDEV|)	p-values
Specific1	ES -> DF -> LE	0.140***	0.141	0.027	5.273	0.000
Specific2	ES -> CI -> LE	0.021*	0.021	0.009	2.358	0.018
Specific3	ES -> DF -> CI -> LE	0.072***	0.072	0.018	3.916	0.000
H7:	ES -> LE	0.234***	0.233	0.026	8.951	0.000

*Note: *p-value < 0.05, **p-value < 0.01, ***p-value < 0.001

Table IV results demonstrate that specific indirect effects from Environmental Stressors to Logistics Efficiency include three statistically significant pathways. The first pathway transmits influence through Driving Fatigue with an indirect effect of 0.140. The second pathway operates through Cognitive Impairment with an indirect effect of 0.021. The third pathway functions through both variables – Driving Fatigue and Cognitive Impairment – with an indirect effect of 0.072. Considering the sum of all three pathways, which characterize serial mediation, Environmental Stressors have a total indirect effect on Logistics Efficiency of 0.234, which is statistically significant. This confirms that Driving Fatigue and Cognitive Impairment function as serial mediating variables between Environmental Stressors and Logistics Efficiency.

MODEL VALIDATION

Final model validation, as suggested by Hair Jr, et al. [34], involves assessing the model's predictive capability using Q^2 values. Q2 values greater than 0 indicate predictive validity. Values between 0 and 0.25 represent small predictive accuracy, values between 0.25 and 0.50 indicate medium predictive accuracy, and values above 0.5 demonstrate high predictive accuracy. Cross-Validation Predictive Ability Test (CVPAT) was conducted to evaluate model predictive capability by comparing average loss with standard criteria. Statistical significance indicates that results did not occur by chance, confirming the proposed model's significant predictive importance.

Table V. Model Predictive Relevance

	Q^2predict	Average loss difference	t value	p value
Cognitive Impairment (CI)	0.139	-0.191	4.889	0.000
Driver Fatigue (DF)	0.167	-0.222	5.174	0.000
Logistics Efficiency (LE)	0.102	-0.158	3.715	0.000
Overall		-0.196	5.507	0.000

Table V results indicate that although the model's predictive accuracy is moderate, it maintains significant validity and delivers substantial theoretical value for interpreting the observed phenomena in line with the proposed conceptual model.

CONCLUSION AND DISCUSSION

This research demonstrates that environmental stressors reduce logistics efficiency mainly through the sequential effects of fatigue and cognitive impairment, confirming H3. The direct effect of stressors on efficiency was statistically significant but small, underscoring the importance of indirect mediation as the dominant mechanism. The model explained 35.2% of variance in logistics efficiency, showing acceptable predictive validity. These findings highlight that driver fatigue and cognitive impairment are the key mechanisms translating environmental challenges into operational inefficiency.

These findings align with established theoretical frameworks in occupational psychology and transportation research. The results support the Conservation of Resources (COR) theory, which suggests that individuals strive to obtain, retain, and protect resources, and stress occurs when these resources are threatened or depleted [35]. In the context of Thai truck drivers, environmental stressors represent resource threats that gradually deplete drivers' cognitive and physical resources, manifesting as fatigue and subsequent cognitive impairment. This finding is consistent with recent research by Ren, et al. [36], who identified similar patterns among Australian truck driver. Moreover, Taylor, et al. [37] also emphasized heat stress; one of the environmental stressors, can lead to quicker onset of fatigue, reducing a driver's alertness and reaction times.

The application of PLS-SEM methodology proved highly effective for examining these complex relationships in the Thai context. The method's ability to handle the non-normal distribution characteristics typical of transportation data, combined with its focus on predictive accuracy rather than theory confirmation, made it particularly suitable for this exploratory investigation. The model's predictive validity shows substantial explanatory power, especially considering the complexity of factors influencing logistics efficiency. The serial mediation approach revealed insights that would have been missed through traditional direct-effects modeling. Previous studies in similar contexts typically examined fatigue or cognitive impairment as separate phenomena, still this research demonstrates their interconnected roles in translating environmental challenges into operational outcomes. This methodological approach provides a template for future investigations in logistics and transportation research.

This study has several limitations. The cross-sectional design prevents causal inference, although theoretical foundations and statistical modeling support the proposed relationships. The focus on Thai drivers may limit generalizability due to cultural and operational differences. Cognitive impairment measurements relied on self-reported data, potentially introducing social desirability bias. Future research employs longitudinal designs and objective cognitive assessments. This research also demonstrates that driver wellbeing significantly impacts logistics efficiency in Thailand's trucking industry. Addressing environmental stressors and fatigue management provides better operational returns than focusing solely on technology. Early interventions targeting environmental stressors prove more cost efficient than reactive approaches managing cognitive impairment. These findings offer practical guidance for improving efficiency through enhanced driver wellbeing, which becomes increasingly important as Thailand develops as a regional logistics hub.

The findings indicate that logistics managers should prioritize driver wellbeing to boost operational performance. Installing fatigue monitoring systems, creating better rest schedules, and upgrading vehicle interiors can minimize stress-related productivity losses. Policymakers need to focus on building climate-controlled rest areas, strengthening driving hour regulations, and promoting vehicle monitoring technologies. Taking preventive action is more economical than reactive measures, as it tackles environmental stress factors before they cause fatigue and reduced mental performance.

RECOMMENDATIONS

Authorities should expand regulated rest periods, enforce fatigue detection technologies, and provide climate-controlled rest areas along major freight routes. Future research should also conduct longitudinal studies evaluating intervention effectiveness across different operational contexts and investigate cultural variations in stress response patterns among Southeast Asian trucking populations compared to Western contexts. Academics should also develop AI-based predictive models for cognitive impairment and create personalized fatigue management systems using IoT sensors and machine learning algorithms to enhance real-time intervention capabilities in commercial trucking environments.

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