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Confirmatory factor analysis of safety culture in discrete manufacturing industry for Thailand

Phongdej Khawinpat[1)], Fasai Wiwatwongwana*[1)] and Arroon Ketsakorn[2)]

[1)]Department of Advanced Manufacturing Technology, Faculty of Engineering, Pathumwan Institute of Technology, Bangkok, Thailand
[2)]Faculty of Public Health, Thammasat University, Pathum Thani, Thailand

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Abstract

The Confirmatory Factor Analysis of Safety Culture in the Discrete Manufacturing Industry for Thailand is important for developing standards to assess safety culture. This study explores the confirmatory factor analysis of safety culture within Thailand's discrete manufacturing sector, utilizing structural equation modeling to assess six key elements of safety culture. It innovatively validates various sub-elements, offering critical insights for enhancing safety standards. This research aimed to analyze the confirmatory factor analysis of safety culture in discrete manufacturing industry for Thailand. The research method involved Confirmatory Factor Analysis (CFA) with a sample of observations. By examining the consistency of the six elements and indicators, along with their respective factor loading, the process initiates with the specification of model-specific data. This was accomplished through a confirmatory measurement model, starting with the assignment of data to the model based on the confirmatory ranking of the first and second orders, sequentially, considering chi-square (χ^2), relative chi-square (χ^2/df), CFI, TLI, RMSEA, and SRMR. These indices were used to evaluate the adequacy of the measurement model. The study identified six core elements of safety culture, each with specific sub-elements and observed variables meeting established criteria: Input, encompassing Man, Method, Material, and Machine; Processing, including Workforce and Work Systems; Output, with Accident Rate and Enterprise Damage; Working Environment, comprising Climate, Facilities, and Cultural Differences; Ergonomics, involving Job and Personal Characteristics; and Safety Experience, consisting of Duration, Involvement, Training, and Leadership. This structure offers a comprehensive framework for understanding and enhancing safety culture in the workplace. The research offers an in-depth analysis of safety culture in Thailand's discrete manufacturing sector, utilizing Confirmatory Factor Analysis to delineate various elements and sub-elements. This study significantly advances the understanding and assessment of safety culture, underlining the crucial role such evaluations play in enhancing workplace safety across the manufacturing industry.

Keywords: Safety culture, Discrete manufacturing, Confirmatory factor analysis

1. Introduction

Currently, there is intense competition in the business world, and economic and social situations both within and outside the country are rapidly changing. This has a direct and swift impact on the operational plans of entrepreneurs in various industries, including factory expansion, production capacity increase, and process improvement. The accompanying issue is the risk arising from dangers associated with business operations or the possibility of unsafe working conditions for employees in the manufacturing industry.

To assist these individuals in performing their tasks safely, many often employ methods or processes that focus on managing the work environment to ensure safety. Several approaches are used to reduce the risks of workplace accidents and unsafe conditions, such as controlling engineering design, safety assessments, accident investigations, and preventing the recurrence of incidents.

When considering the causes of accidents based on Heinrich's concept, there are two main factors: 1) Unsafe Acts, which are the primary and significant causes of accidents, accounting for approximately 85% of all accidents, and 2) Unsafe Conditions, which are secondary causes, accounting for about 15% of all accidents [1] What is essential to drive behavioral changes in safety performance is the safety culture. Currently, the concept of safety culture is receiving increased attention in safety research, especially in high-risk industries such as nuclear power plants, petrochemical industries, and mass transportation. It is observed that personal and organizational factors play crucial roles in defining risk mitigation measures and accident prevention. The safety culture within an organization has a direct impact on the level of risk in the workplace and the occurrence of accidents. Key findings indicate that safety culture within an organization is significant in reducing workplace risks and accidents through safety-focused awareness and behavior. [2, 3] The importance of safety culture emphasizes the significance of measuring and assessing safety culture to reduce risks and accidents in challenging workplaces. Establishing an appropriate safety culture and adhering to safety standards in high-risk workplaces to reduce risks and accidents is crucial. [4]

Additionally, the research reinforces the importance of safety culture by highlighting its negative relationship with employee injury rates. In other words, organizations with a strong safety culture provided lower employee injury rates than those with a weak safety culture. Factors related to safety culture that were associated with employee injury rates included: 1) Safety as a Priority: Organizations

*Corresponding author.
Email address: fasaiw227@gmail.com
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that prioritize safety made employees more aware of safety risks and the importance of safety at work, which could help reduce the chances of accidents and injuries. 2) Employee Participation: Employees who actively participated in safety activities were more aware of safety risks and the importance of safety at work, reducing the chances of accidents and injuries. [5]

Utilizing mixed methods could deepen insights into safety culture dynamics and examining the influence of emerging technologies, such as artificial intelligence, on safety practices offers a promising direction. Cross-cultural studies could reveal how national culture affects safety culture's implementation and effectiveness, while exploring the regulatory impact and psychological factors, including leadership styles and employee motivation, could provide further valuable insights into safety culture. [6-9]

Ensuring a robust safety culture is paramount in workplace safety, emphasizing the need for organizations to focus on nurturing a strong safety ethos to minimize workplace hazards and injuries. This becomes especially critical amid global challenges like the COVID-19 pandemic, environmental issues, and digitalization, which have placed the manufacturing sector under intense pressure. This research investigates how a well-established safety culture can address these evolving risks, advocating for the implementation of solid safety standards within Thailand's manufacturing landscape to enhance safety measures and risk management practices during significant industrial transformations.

2. Methods

The purpose of this study was to analyze the confirmatory factor analysis of safety culture in discrete manufacturing industry for Thailand. The research investigated the structural congruence to validate the theoretical relationships between the six major elements and safety culture in the context of discrete manufacturing. This analysis helped to confirm the theoretical alignment of safety culture in the discrete manufacturing industry systems.

2.1 Population and sample

The target population for this research consists of safety professionals, industry practitioners, and relevant personnel involved in safety management within the discrete manufacturing industry. Advanced statistical methods, including structural causal modeling with latent variables, were used for data analysis. Consequently, selecting an appropriate sample size was crucial for the accurate estimation of parameter coefficients in the LISREL model. In this study, there were 108 observed variables, requiring a sample size of at least 200-400 respondents. The researchers distributed 1,000 questionnaires, but only 729 were returned, which fell within an acceptable range. [10] The sample group (n=729) was categorized by their roles related to safety, detailing the number and percentage of individuals in each position: 1). Safety officers 176 people, (24.10%), 2). Engineers involved with safety 412 people (56.50%), 3). Entrepreneurs in the manufacturing industry 14 people (1.90%), 4). Executives in the manufacturing industry involved with safety 82 people (11.20%), and 5). Other roles related to safety 45 people (6.20%), totaling 729 individuals (100%).

2.2 Research instruments

The research instrument utilized in this study was a Confirmatory Factor Analysis (CFA) questionnaire designed to assess safety culture standards in the context of discrete manufacturing for Thailand. The questionnaire consisted of two parts: Part 1 collected personal information from the respondents with eight questions, while Part 2 comprised 108 Likert-scale questions assessing opinions on safety culture standards. To ensure the content validity of the questionnaire, experts in industrial engineering and occupational health and safety reviewed and confirmed the relevance of each question. All questions scored above 0.8, indicating the high quality of the instrument.

2.3 Data collection

The researchers distributed the questionnaires to the sample group and collected the responses. A specific timeframe was established for data collection, followed by the retrieval of completed questionnaires from safety managers, business owners, and safety professionals working in the discrete manufacturing industry in Thailand.

2.4 Data analysis

Confirmatory Factor Analysis (CFA) was used to analyze the structural congruence of safety culture standards in the discrete manufacturing industry for Thailand. This involved testing the fit indices, chi-square (χ^2), relative chi-square (χ^2/df), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR) to evaluate the model's goodness of fit.

The findings of this research would contribute to a better understanding of safety culture in the context of discrete manufacturing in Thailand and validate the theoretical alignment of safety culture standards within the industry.

3. Results

The results of the structural congruence analysis of safety culture standards in the discrete manufacturing industry for Thailand, conducted by analyzing the confirmatory factor analysis with data from the research sample, are as follows:

3.1 Model for measuring latent variables of the 1st element: Input (X1)

The model for measuring latent variables of the 1st element: Input (X1) consisted of four sub-elements: 1) Man (A), 2) Method (B), 3) Material (C), and 4) Machine (D). In total, there were 33 observed variables associated with these sub-elements. When analyzing the confirmatory factor analysis for both the first and second orders, it was found that 25 observed variables met the criteria. The goodness-of-fit indices for the first-order model were as follows: χ^2=292.95, df=261, p=0.057, CFI=0.999, RMSEA=0.014, SRMR=0.018, and χ^2 /df =1.122. These results indicated that the model fit the observed data well, as illustrated in Figure 1.

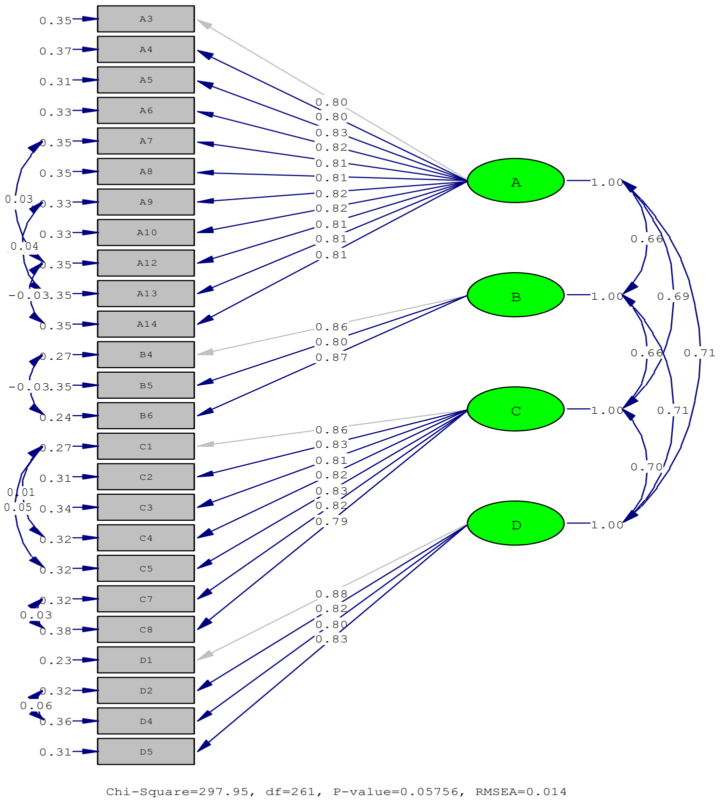

Figure 1 First-Order of Latent Variable: Input (X1)

Subsequently, the researcher proceeded with the analysis at the second rank. The confirmatory factor analysis (CFA) yielded the following fit indices: χ^2 = 299.82, df = 262, p = 0.058, CFI (Comparative Fit Index) = 0.999, RMSEA (Root Mean Square Error of Approximation) = 0.014, SRMR (Standardized Root Mean Square Residual) = 0.019, χ^2/df = 1.144. These results met the criteria for goodness of fit, indicating a strong alignment between the model and the observed data, as illustrated in Figure 2. The detailed factor loading could be found in Table 1.

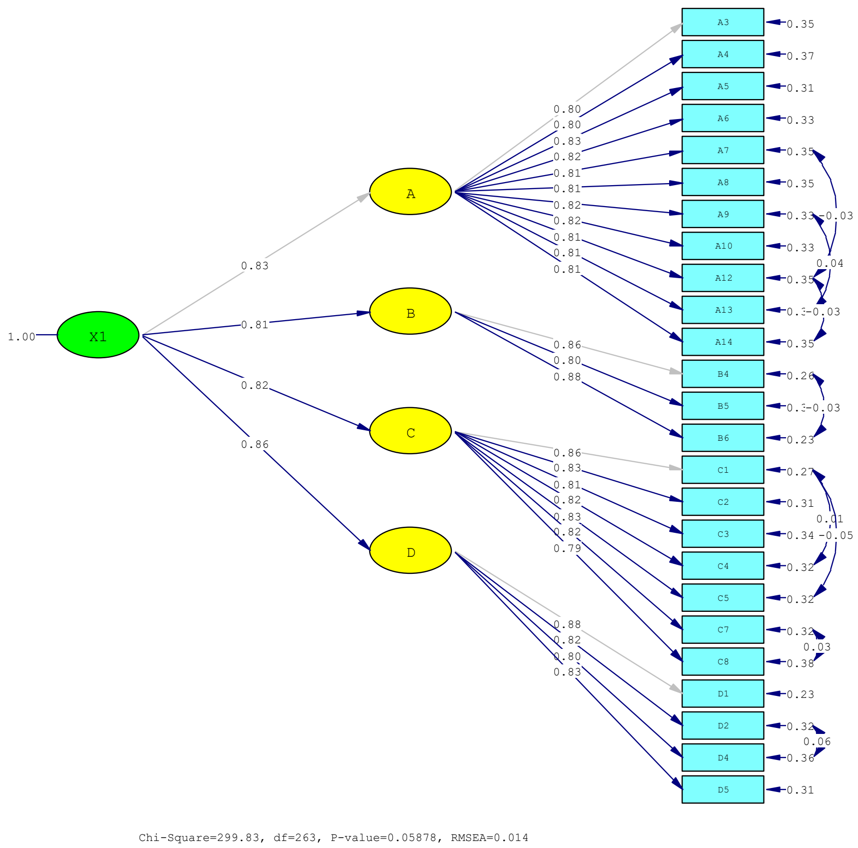

Figure 2 Second-Order of Latent Variable: Input (X1)

Table 1 The results of the analysis of the second-order latent variable elements of Input (X1)

Observed Variable	λ (Standard)	S.E. (Standard Errors)	t	R^2
Man (A)	0.83	-	-	0.68
Method (B)	0.81^{**}	0.06	17.32	0.65
Material (C)	0.82^{**}	0.06	17.79	0.67
Machine (D)	0.86^{**}	0.06	18.53	0.73

**<p.01

From the table, it was evident that the measurement model of the second-order primary latent variable, Input (X1), showed factor loading in the range of 0.81 to 0.86 at the second-order level. These factor loading were statistically significant at the 0.01 level for all variables, and there was confidence in the interrelationships between the elements, the values of the element's reliability (R^2) ranging from 0.65 to 0.73, respectively. Such findings underscore the model's efficacy in capturing the essence of the Input variable, reflecting its significant contribution to understanding the underlying constructs being studied. The factor loadings (λ) for variables like Method, Material, and Machine being significant at $p<0.01$ strongly suggests these relationships are not by chance, supporting their reliability and validity. The R^2 values denote how much variance in observed variables is explained by the latent variable, showcasing a strong model-data fit for these components.

3.2 Model for measuring latent variables of the 2nd element: Processing (X2)

The model for measuring latent variables of the 2nd element: Processing (X2), consisted of two sub-elements: 1) Workforce System (E) and 2) Work System (F). There were 22 observed variables in total. Upon analyzing the confirmatory factor model for both the first-order and second-order levels, it was found that 17 observed variables met the threshold criteria. The goodness-of-fit statistics for the first-order model were as follows: χ^2=131.76, df=118, p=0.182, CFI=1.000, RMSEA=0.013, SRMR=0.015, and χ^2/df=1.116. These values all met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 3.

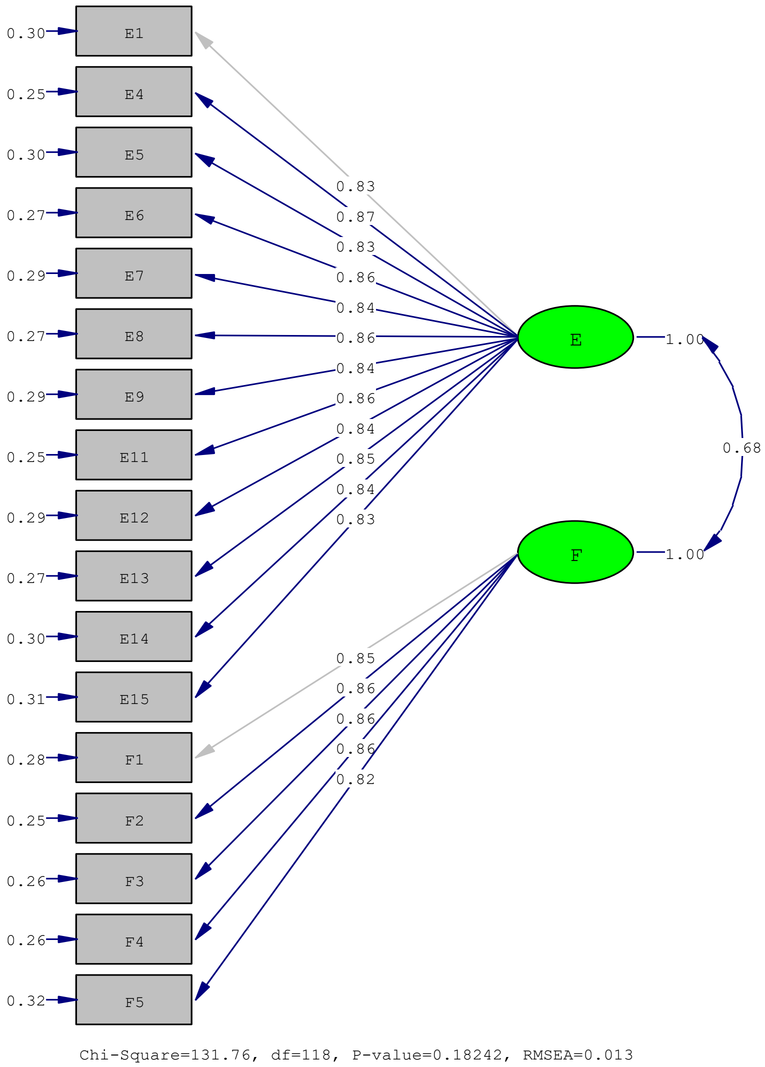

Figure 3 First-Order of Latent Variable: Processing (X2)

Subsequently, the researchers proceeded with the analysis at the second-order level, and the goodness of fit of the second-order model was as follows: χ^2=118.74, df=117, p=0.437, CFI=1.000, RMSEA=0.005, SRMR=0.015, and χ^2/df=1.014. These values met the criteria, indicating a good fit with the empirical data, as illustrated in Figure 4, and detailed factor loading was presented in Table 2.

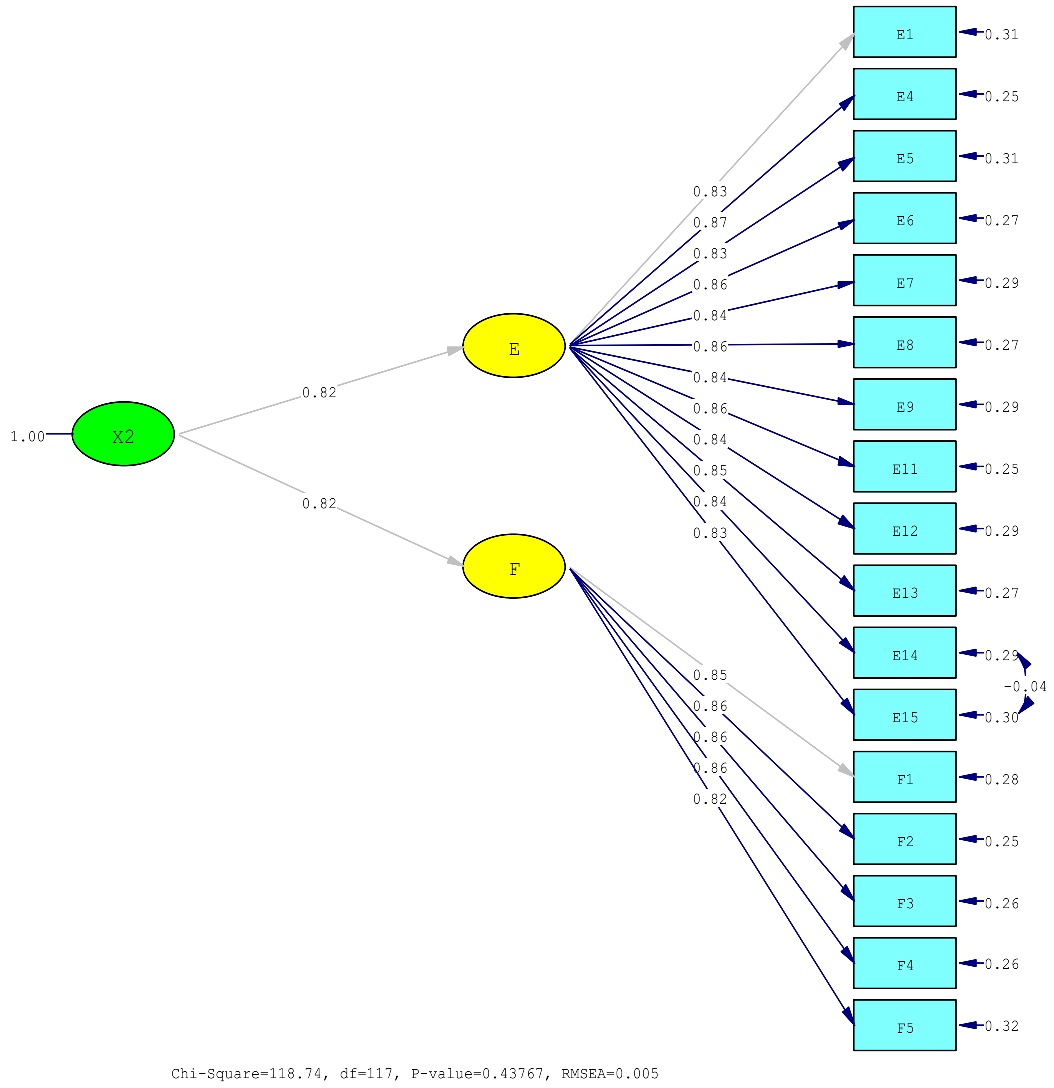

Figure 4 Second-Order of Latent Variable: Processing (X2)

Table 2 The results of the analysis of the second-order latent variable elements of Processing (X2)

Observed Variable	λ (Standard)	S.E. (Standard Errors)	t	R^2
Workforce System (E)	0.82	-	-	0.67
Work System (F)	0.82	-	-	0.68

From the table, it was found that the second-order main element variable analysis for Processing (X2) revealed factor loading values in the second order between 0.82 and 0.82. However, due to parameter constraints, the values of S.E. and t could not be displayed. Nevertheless, with factor loading exceeding 0.7, it was considered to have sufficient reliability and met the criteria. Additionally, the values of the element's reliability (R^2) ranged from 0.67 to 0.68, slightly below the ideal threshold but still considered acceptable. The R^2 values for Workforce System (E) at 0.67 and Work System (F) at 0.68 suggest that the Processing construct explains 67% and 68% of the variance in these observed variables, respectively. These high R^2 values indicate a good fit of the model to the data for these elements, reflecting that a significant portion of the variability in Workforce System and Work System can be accounted for by the Processing construct.

3.3 Model for measuring latent variables of the 3rd element: output (X3)

The model for measuring latent variables of the 3rd element: Output (X3) consisted of 2 sub-elements: 1) Accident Rate (G) and 2) Enterprise Damage (H). There was a total of 8 observed variables. When analyzing the confirmatory factor analysis (CFA) for both the 1st and 2nd order models, it was found that 8 observed variables passed the threshold. The goodness-of-fit statistics for the 1st order model were as follows: χ^2=18.45, df=19, p=0.492, CFI=1.000, RMSEA=0.000, SRMR=0.011, and χ^2/df=0.971. These statistics indicated a good fit with the empirical data, as shown in Figure 5.

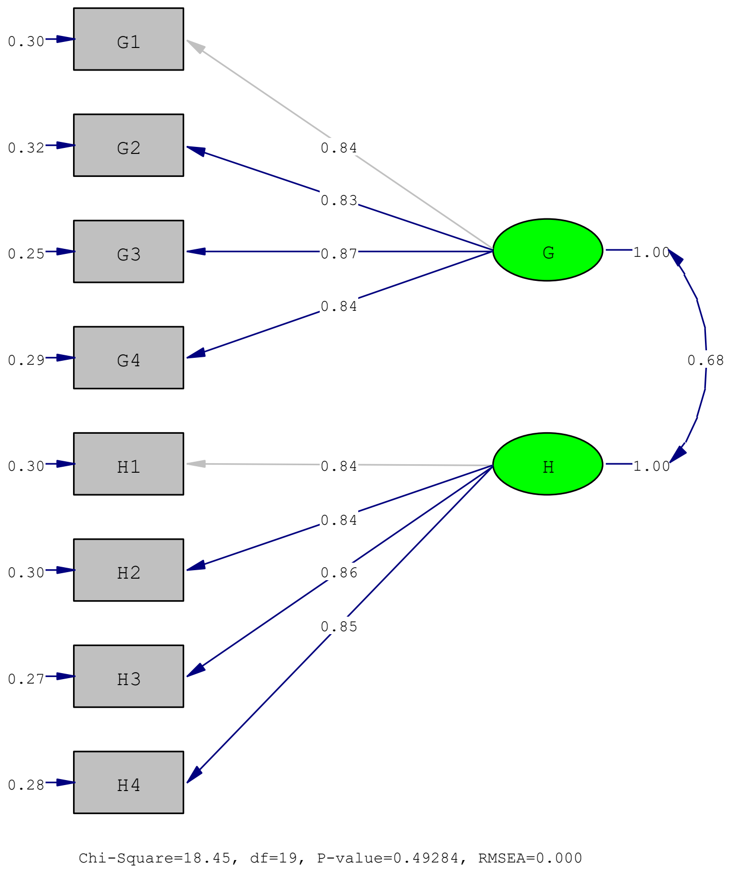

Figure 5 First-Order of Latent Variable: Output (X3)

Then, the researchers proceeded with the analysis at the second-order level, and the goodness-of-fit statistics for the second-order model were as follows: $\chi2$=15.44, df=18, p=0.631, CFI=1.000, RMSEA=0.000, SRMR=0.012, and $\chi2$/df=0.857. All these values met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 6, and the details of the factor loading values could be found in Table 3.

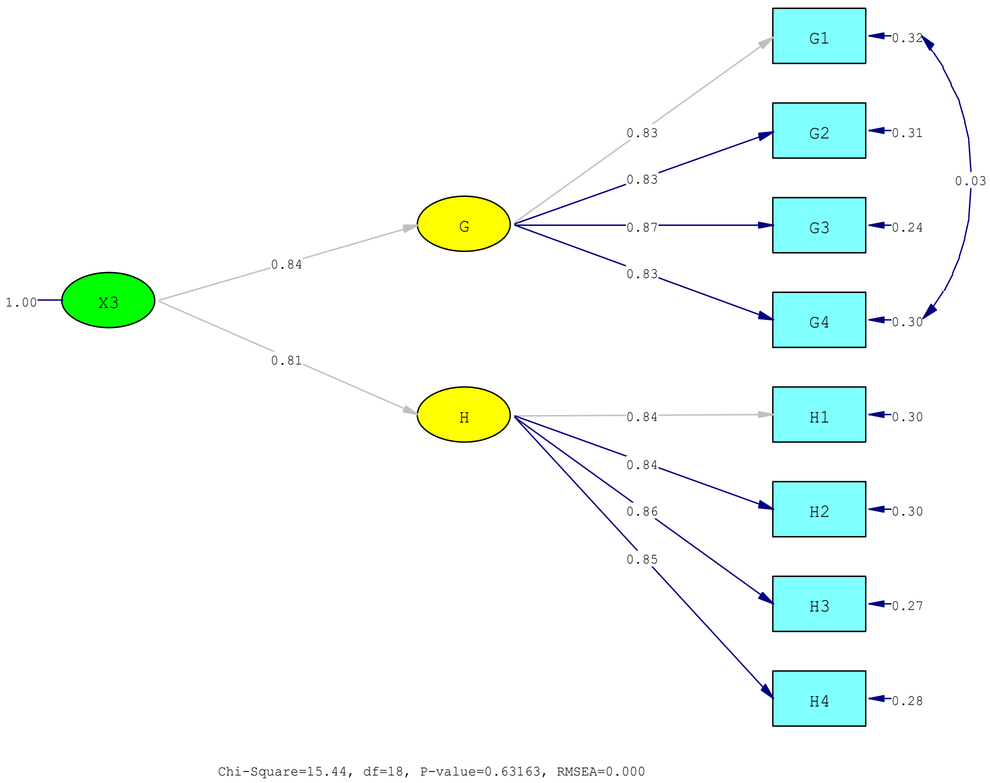

Figure 6 Second-Order of Latent Variable: Output (X3)

Table 3 The results of the analysis of the second-order latent variable elements of Output (X3)

Observed Variable	*λ* (Standard)	S.E. (Standard Errors)	t	R^2
Accident Rate (G)	0.84	-	-	0.71
Enterprise Damage (H)	0.81	-	-	0.66

From the table, it was found that the measurement model for the second-order latent variable, Output, showed loading ranging from 0.81 to 0.84. However, due to parameter constraints, the standard error (S.E.) and t-values could not be displayed. Nevertheless, with loading exceeding 0.7, they were considered sufficiently reliable and met the criteria. Moreover, the composite reliability values ranged from 0.66 to 0.71, indicating that the model passed the criteria. The R^2 values, which represent the proportion of variance in the observed variables explained by the latent Output factor, are 0.71 for Accident Rate and 0.66 for Enterprise Damage. These high R^2 values suggest that the Output factor significantly explains the variance in Accident Rate and Enterprise Damage, indicating the importance of these elements in understanding the overall Output construct within the safety culture framework.

3.4 Model for measuring latent variables of the 4th element: Working Environment (X4)

The model for measuring latent variables of the 4th element: Working Environment (X4), consisted of three sub-elements: 1) Climate (I), 2) Facilities (J), and 3) Cultural Differences (K). There were 11 observed variables in total. Upon analyzing the confirmatory factor model for both the first-order and second-order levels, it was found that 10 observed variables met the threshold criteria. The goodness-of-fit statistics for the first-order model were as follows: χ^2=43.11, df=32, p=0.090, CFI=1.000, RMSEA=0.022, SRMR=0.013, and χ^2/df=1.347. These values all met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 7.

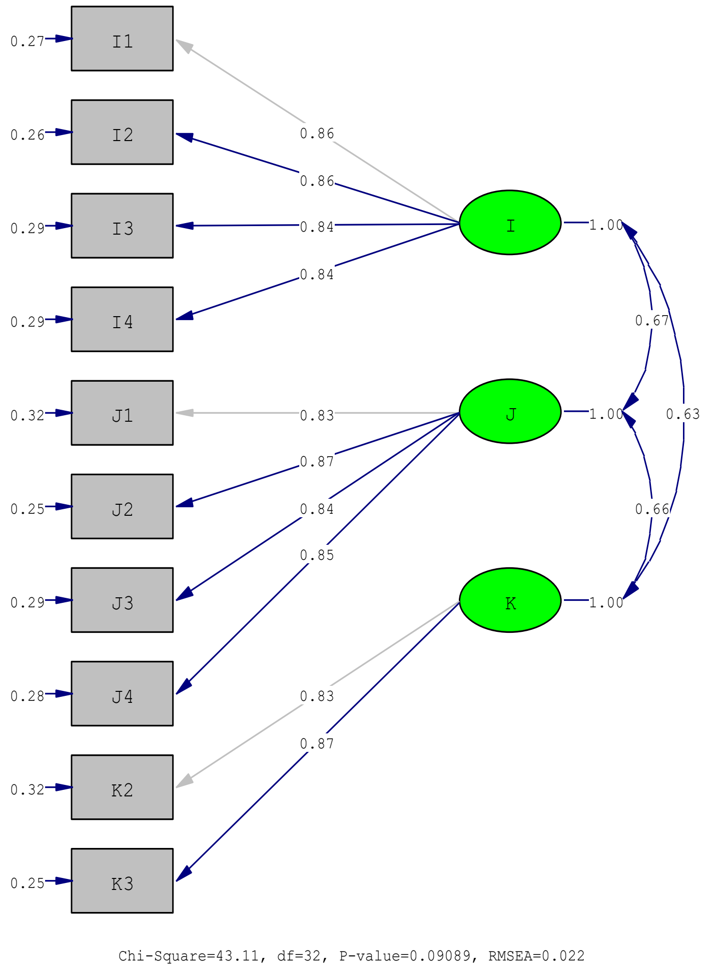

Figure 7 First-Order of Latent Variable: Working Environment (X4)

Subsequently, the researchers analyzed the second-order level, with the goodness-of-fit statistics for the second-order model as follows: χ^2=43.11, df=32, p=0.090, CFI=1.000, RMSEA=0.022, SRMR=0.013, and χ^2/df=1.347. These values met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 8. Detailed factor loading values could be found in Table 4.

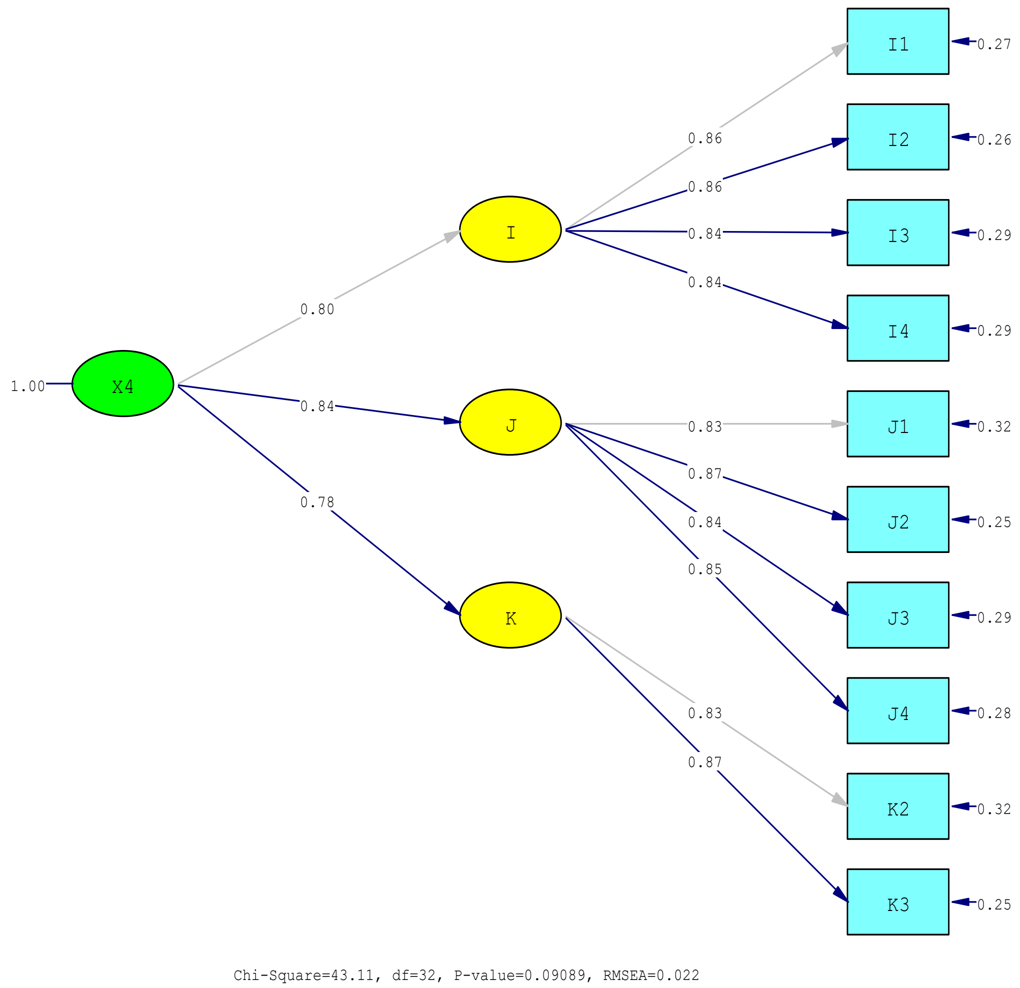

Figure 8 Second-Order of Latent Variable: Working Environment (X4)

Table 4 The results of the analysis of the second-order latent variable elements of the Working Environment (X4)

Observed Variable	λ (Standard)	S.E. (Standard Errors)	t	R^2
Climate (I)	0.80**	-	-	0.64
Facilities (J)	0.84**	0.07	15.10	0.71
Cultural Differences (K)	0.78**	0.07	14.50	0.61

**<p.01

From the table, it was evident that the second-order model for measuring the latent variables of the 4th element, Working Environment (X4), had factor loading values ranging from 0.78 to 0.84. These factor loading values were statistically significant at the 0.01 level for all variables, and there was a satisfactory level of confidence, the values of the element's reliability ranging (R^2) from 0.64 to 0.71, suggest that a significant portion of the variance in the Working Environment construct is explained by the model, meeting the criteria for satisfactory reliability. This detailed analysis confirms the element's reliability within the acceptable range, providing a clear insight into its predictive validity and relevance in the research context. The factor loading values (λ), significant at the $p<0.01$ level, affirm the strong and reliable connection between the Working Environment's latent variables and their indicators: Climate, Facilities, and Cultural Differences. These findings are statistically robust, ruling out random chance. R^2 values highlight how much variance in these indicators is accounted for by the latent variable, showcasing a significant impact of each indicator on the Working Environment construct.

3.5 Model for measuring latent variables of the 5th element: Ergonomics (X5)

The model for measuring latent variables of the 5th element: Ergonomics (X5), consisted of two sub-elements: 1) Job characteristics (L) and 2) Personal characteristics (M). There were 7 observed variables in total. Upon analyzing the confirmatory factor model for both the first-order and second-order levels, it was found that 6 observed variables met the threshold criteria. The goodness-of-fit statistics for the first-order model were as follows: χ^2=2.03, df=8, p=0.980, CFI=1.000, RMSEA=0.000, SRMR=0.006, and χ^2/df=0.253. These values all met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 9.

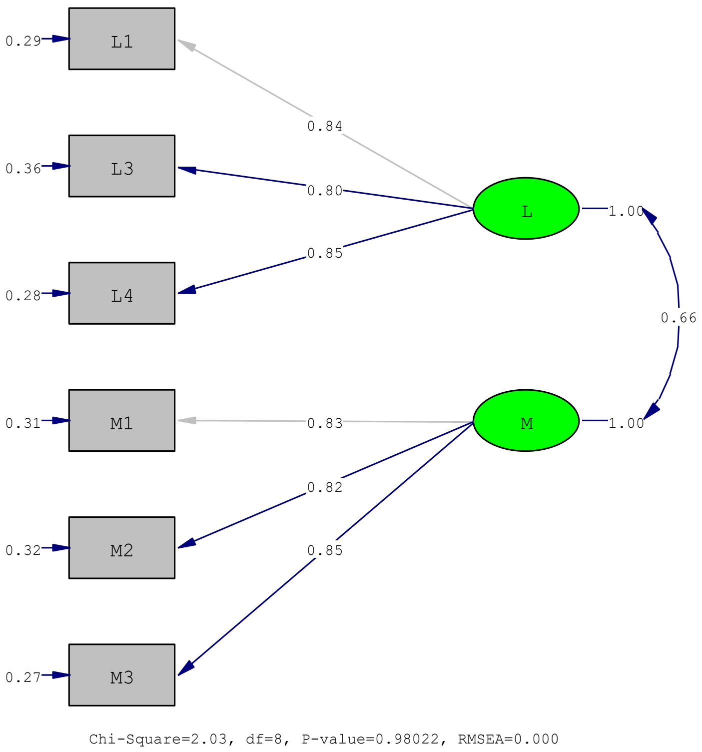

Figure 9 First-Order of Latent Variable: Ergonomics (X5)

Then, the researchers proceeded to analyze the second-order model. The goodness-of-fit statistics for the second-order model were as follows: χ^2=2.03, df=8, p=0.980, CFI=1.000, RMSEA=0.000, SRMR=0.006, and χ^2/df=0.253. These values met the criteria, indicating a good fit with the observed data, as shown in Figure 10. Details of the factor loading could be found in Table 5.

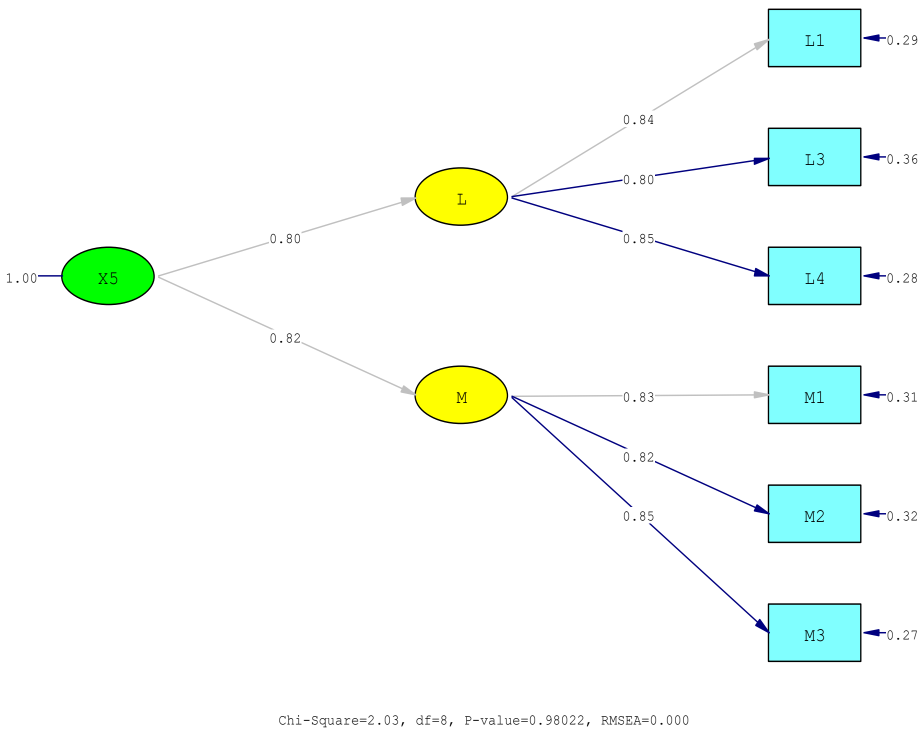

Figure 10 Second-Order of Latent Variable: Ergonomics (X5)

Table 5 The results of the analysis of the second-order latent variable elements of Ergonomics (X5)

Observed Variable	λ (Standard)	S.E. (Standard Errors)	t	R^2
Job characteristics (L)	0.80	-	-	0.64
Personal Characteristics (M)	0.82	-	-	0.68

From the table, it could be observed that the model for measuring the latent variables of the 5th main element, Ergonomics (X5), showed factor loading in the second order ranging from 0.80 to 0.82. However, due to parameter constraints, standard errors (S.E.) and t-values could not be displayed. Nevertheless, with factor loading exceeding 0.7, there was sufficient reliability to consider the model as passing the criteria. The values of the element's reliability ranging (R^2) from 0.64 to 0.68, reinforcing the model's robustness in capturing the latent variable effectively. These high R^2 values suggest that both job and personal characteristics are significant predictors of the ergonomics construct, with a substantial portion of their variances being accounted for by their relationship to ergonomics.

3.6 Model for measuring latent variables of the 6th element: Safety Experience (X6)

The model for measuring the latent variables of the 6th main element, Safety Experience (X6), consisted of 4 sub-elements, namely: 1) Duration (N), 2) Involvement (O), 3) Training (P), and 4) Leadership (Q). There were 15 observed variables in total. Upon analyzing the confirmatory factor model for both the first-order and second-order levels, it was found that 14 observed variables met the threshold criteria. The goodness-of-fit statistics for the first-order model were as follows: χ^2=87.57, df=69, p=0.065, CFI=1.000, RMSEA=0.019, SRMR=0.015, and χ^2/df=1.269. These values all met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 11.

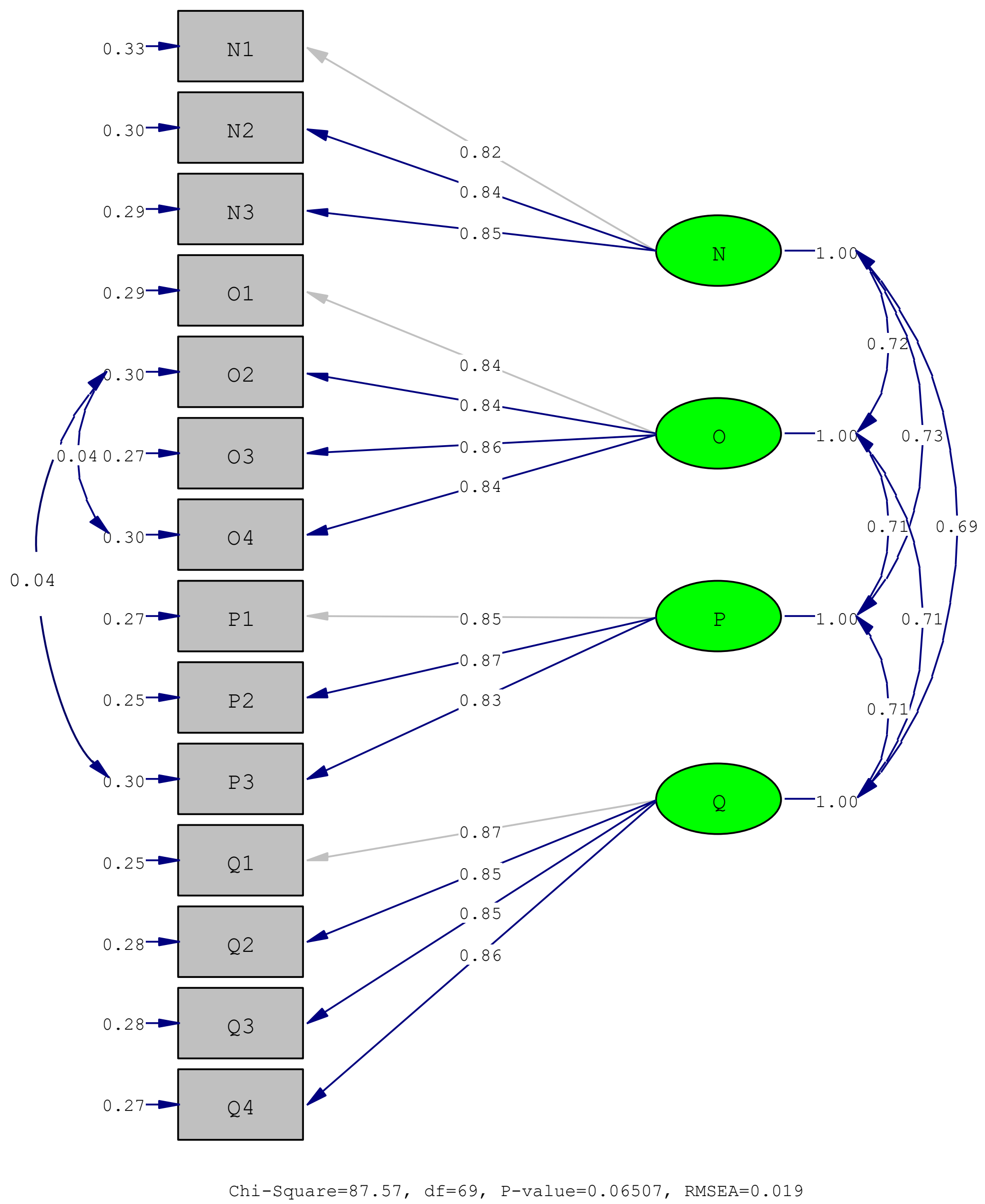

Figure 11 First-Order of Latent Variable: Safety Experience (X6)

Then, the researchers proceeded to analyze the model at the 2nd level, with the goodness-of-fit statistics for the 2nd-order model as follows: χ^2=88.75, df=71, p=0.075, CFI=1.000, RMSEA=0.019, SRMR=0.016, and χ^2/df=1.250. These values all met the established criteria, indicating a good fit with the observed data, as illustrated in Figure 12, and the factor loading details were shown in Table 6.

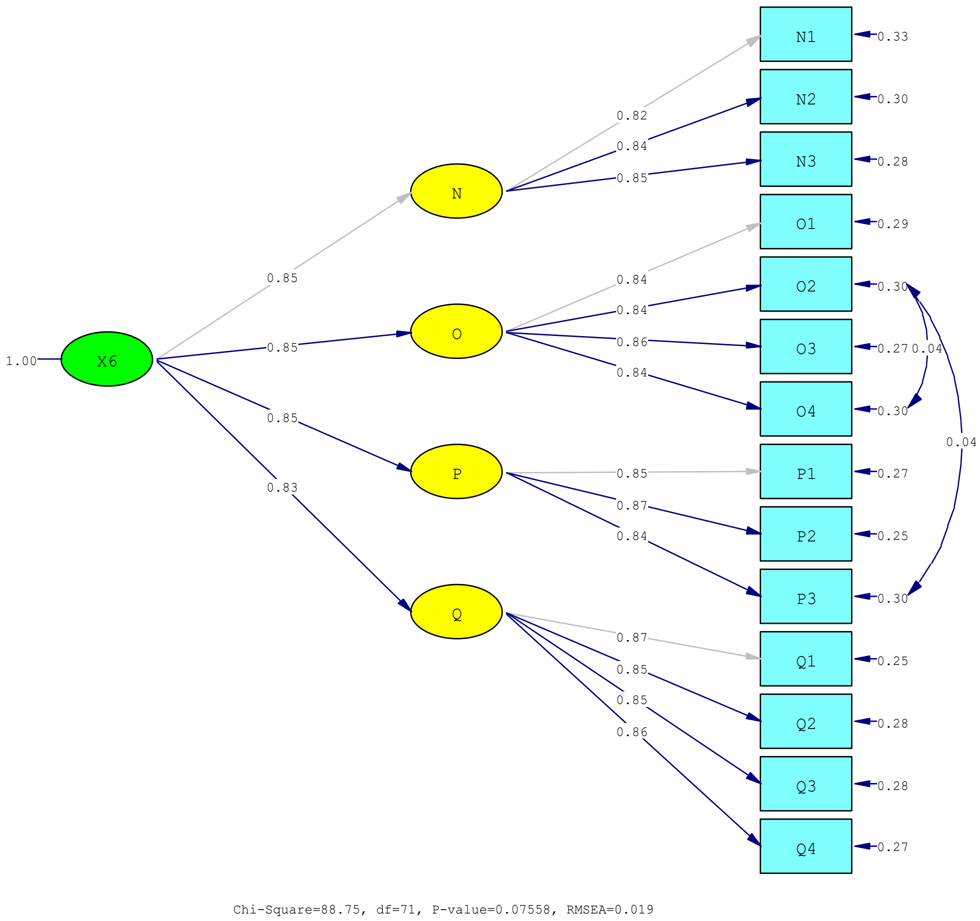

Figure 12 Second-Order of Latent Variable: Safety Experience (X6)

Table 6 The results of the analysis of the second-order latent variable elements of Safety Experience (X6)

Observed Variable	λ (Standard)	S.E. (Standard Errors)	t	R^2
Duration (N)	0.85	-	-	0.72
Involvement (O)	0.85^{**}	0.06	18.02	0.72
Training (P)	0.85^{**}	0.06	18.14	0.73
Leadership (Q)	0.83^{**}	0.06	18.15	0.69

**<p.01

From the table, it was found that the model for measuring the latent variables of the 6th primary element, Safety Experience (X5), showed factor loading in the 2nd order ranging from 0.83 to 0.85, which were statistically significant at the 0.01 level for all variables. Furthermore, the reliability range (R^2) for the interrelationships among the elements was between 0.69 and 0.73, suggesting that these variables have a good degree of explained variance and meet the reliability criteria set forth for the model. Factor loadings (λ) of 0.85 for Involvement, Training, and Leadership, related to Safety Experience, show a significant relationship at the 0.01 level (99% confidence). This demonstrates the strong reliability of the links between observed and latent variables, confirming the study's robustness. The R^2 values, which represent the proportion of variance explained in the observed variables by the latent factor, are high, ranging from 0.69 to 0.73. This suggests that Safety Experience significantly explains the variance in Duration, Involvement, Training, and Leadership within the context studied. The high t-values indicate that these relationships are statistically significant, underscoring the importance of these aspects in contributing to safety experience in the workplace.

4. Discussion

From the results of the research, it could be summarized as following:

4.1 For the latent variables of the 1st element

Input, when considering the coefficient of determination (R^2) and Factor Loading (λ), it was crucial that the sub-elements related to machines in the production process, which used for manufacturing, did not pose risks to workers. Machines in the production process must meet safety standards, and their maintenance, inspection, and readiness for use should be regularly ensured. These aspects were of the utmost importance at the forefront of establishing a safety culture. This was aligned with [11, 12] explained that what leaded to the path of safety was the physical elements introduced, such as operations and machinery.

4.2 The latent variables of the 2nd element

Processing, consisted of two sub-elements: 1) Workforce System and 2) Work System. When analyzing the confirmatory factor loading for both the 1st and 2nd orders, it was found that 17 observed variables met the threshold. Both sub-elements, Workforce System and Work System, had nearly identical predictive power and factor loading. Therefore, it could be concluded that within the sub-element of the Workforce System, the details that started with identifying risks and finding preventive measures for safety in the work process, communication channels for feedback from employees to identify ways to make work safer, establishing safety standards for work practices, having procedures for reporting, investigating accidents and incidents, conducting up-to-date job safety analysis, addressing newly discovered risks, and, in the case of the Work System, training, regularly reviewing safety training courses, teaching employees appropriate work methods, all these aspects were of the utmost importance in establishing a safety culture. This was aligned with Kim [13] investigated the relationship between injury frequency and the work environment in Korea, with a specific focus on shift work and environmental factors. This relationship was examined at the secondary level by dividing workers into those who worked in shifts and those who did not, and by comparing shift work to regular and overtime work. The research findings were as follows: 1) The work environment and welfare factors had an impact on the frequency of workplace injuries. 2) Workers who worked in shifts had a lower frequency of injuries compared to those who did not work in shifts. 3) Shift workers had more flexibility in choosing their work hours compared to non-shift workers. 4) Shift workers had longer working hours compared to non-shift workers. 5) A favorable work environment had a positive impact on workplace safety, consistent with the research of Hopkins [14] explored the success and factors that promote safety culture in the oil and natural gas industry. The research found that organizations should implement effective systems and processes to promote workplace safety. They should regularly assess safety risks to identify and address safety concerns. Effective safety communication was crucial, allowing employees to exchange information and opinions about safety. Employee involvement in safety activities and support from management and the organization were essential. Moreover, the research by Wang et al. [15] supported these findings. It examined the safety culture in organizations and analyzed factors that contributed to its development. The research identified five key elements of safety culture: 1) Safety awareness: All employees in the organization should be aware of safety risks and the importance of safety in their work. 2) Safety communication: Effective and open communication about safety was essential for employees to exchange information and opinions about safety. 3) Employee involvement: Employees should be actively involved in safety activities and received support from management and the organization. 4) Safety governance: Organizations should have an effective safety governance system to ensure that safety activities comply with standards and policies. 5) Organizational culture: The organizational culture should support workplace safety and prioritize safety as a top concern.

4.3 For the latent variables of the 3rd element

Output, when considering the coefficient of determination (R^2) and factor loading (λ), the sub-element related to Accident Rate, which had the highest factor loading, was analyzed. Therefore, in the sub-element of Accident Rate, it was crucial that regardless of whether the accident rate was zero, there should be no work-related fatalities, no recurring unsafe events from the same causes, and no unsafe events from previously analyzed risks. These aspects were of paramount importance in establishing a safety culture. In alignment with Fatima et al. [16], study found a positive correlation between workplace accidents and business performance, indicating that as the accident rate increased, business performance tended to decrease. These findings support previous research suggesting that the accident rate was a significant sub-element of safety culture and had the highest impact on output. This study was also consistent with Wang et al. [17], their findings demonstrated that a strong safety culture in the workplace helped reducing accident rates and improving business performance. This study also aligned with previous research indicating that the accident rate was a significant sub-element of safety culture with the highest impact on output. This study also aligned with previous research indicating that the accident rate was a significant sub-element of safety culture with the highest impact on output.

4.4 For the latent variables of the 4th element

Working Environment, when considering the coefficient of determination (R^2) and Factor Loading (λ), the sub-element related to facilities had the highest factor loading. Facilities encompass the provision of equipment suitable for each individual's work, appropriate safety equipment, standard safety equipment, and an adequate supply of equipment for each worker. These aspects were of the utmost importance in establishing a safety culture. In alignment with the research by Arcuri et al. [18], their study found that safety culture was related to safety performance. It highlighted the use of safety measures in environments where individuals perceived and had a positive attitude toward safety in the workplace. This was consistent with the findings of Sedani et al. [19], which showed that workplaces with safe and conducive conditions had a positive impact on productivity and increased profitability. Safe working environments resulted in more efficient work, higher productivity, and ultimately increased profits. Moreover, it aligned with the research conducted by Rahimi Pordanjani and Mohamadzade Ebrahimi [20], which found that the safety culture and atmosphere could predict ergonomic behaviors, emphasizing the importance of reducing negative safety atmospheres and their impact on the workforce. Additionally, it corresponded to the research by Cui et al. [21], who found that employees' perception of hazardous environments significantly affected their safety behaviors. This was achieved through psychological processes, recognizing commitment to safety management and individual beliefs. Furthermore, it aligned with the research by Cox and Cheyne [22], which emphasized the importance of a safety-supportive environment in creating a positive safety culture. This included installing safety equipment and fostering support and good relationships between employees and management, among other factors. Lastly, it corresponded to the research by Dekker and Nyce [23], which highlighted the need for organizations to have efficient systems and processes to promote workplace safety. This included safety management systems, risk assessment systems, incident reporting systems, and employee participation, where employees should be actively involved in safety-related activities and receive support from management and the organization.

4.5 For the latent variables of the 5th element

Ergonomics, when considering the coefficient of determination (R^2) and Factor Loading (λ), the sub-element related to Personal Characteristics had the highest factor loading within the 5th primary element, Ergonomics. Personal Characteristics encompassed factors such as the importance placed on cognitive abilities, learning capability, and analytical skills, as well as the compatibility of individuals with their jobs based on personal characteristics such as age, gender, height, weight, and existing medical conditions. These aspects were of the utmost importance in fostering a safety culture. According to Manolescu et al. [24] their study investigated the relationship between ergonomics and human resource management. Ergonomics, in this context, was related to efficiency, safety, and health, with implications for organizational development processes and employees. The link between ergonomics and human resource management was crucial, not just in terms of awareness but also in the need to analyze its impact on organizations. This perspective was also consistent with the research conducted by Ponprathom et al. [25] revealed that most employees believed the successful implementation of ergonomics largely depended on effective organizational management. Organizational ergonomics encompass policies, budgets, organizational structures, management, job design, and work processes. Employees recognized that job design involved planning work processes comprehensively from the outset to suit employee tasks. This included task allocation, risk analysis, and improvements to ensure that employees could work comfortably and safely. Furthermore, this perspective aligned with the research by Batool and Yasir [26] which found a positive correlation between ergonomics and safety culture. In most cases, factories with work environments conducted to employee health and safety exhibited stronger safety cultures. This underscored the significant role of ergonomic factors in fostering a robust safety culture. Additionally, it corresponded to the research conducted by Kurd et al. [27] on the relationship between ergonomics and safety culture in an Iranian manufacturing company. Their study emphasized the positive impact of ergonomics on safety culture. They found that workplaces that supported employee health and safety, such as designing workspaces suitable for the workforce and using safe equipment and machinery, tended to have a stronger safety culture. Such environments foster greater awareness among employees, who prioritize safety in their work, ultimately leading to a stronger safety culture. In summary, ergonomics plays a crucial role in promoting a positive safety culture and enhancing organizational efficiency. Organizations should prioritize improving the work environment for employee health and safety to cultivate a strong safety culture, thereby increasing overall workplace effectiveness. This perspective is also supported by the research of Khandan et al. [28] argue that promoting ergonomics also helps promote a safety culture, and different cultures influence job design to be suitable for employees. Additionally, it aligns with the research by Sirat [29] which emphasized the significant role of ergonomics in promoting a strong safety culture. Organizations should prioritize improving the work environment for employee health and safety to strengthen the safety culture further. Ergonomics helps employees work efficiently and safely, reduces the risk of accidents and work-related illnesses, and fosters a sense of responsibility for safety among employees. This research underscores the importance of ergonomics in promoting a strong safety culture. Organizations should prioritize improving the work environment for employee health and safety to strengthen the safety culture further.

4.6 For the latent variables of the 6th element

Safety Experience, when considering the coefficient of determination (R^2) and Factor Loading (λ), the sub-element related to Training had the highest factor loading within the 6th primary element, Safety Experience. Training encompassed receiving safety training from work, the frequency of safety training, and the number of days of safety training. These aspects were of utmost importance in fostering a safety culture. This was consistent with the research of Beatrice [30], which studied factors influencing safety culture in the oil and gas industry in the UK. It was found that factors influencing safety culture in the UK oil and gas industry included 1) training, 2) rewards and recognition, 3) communication, and 4) involvement and support from management. The findings also aligned with the research by Casey et al. [31], which studied safety training that engaged and emphasized the importance of employee participation, awareness, and learning behaviors in safety training. This leaded to the acquisition of new knowledge and skills, attitude and behavioral changes, and the integration of safety into workplace practices. After training, it was important to follow up and ensure that the newly acquired safety concepts aligned with the existing safety systems. These findings were also consistent with the research by Karanikas et al. [32], which found that safety training could improve employees' safety awareness, communication, and involvement in safety activities. Furthermore, O'Dea and Flin [33] found that safety training could enhance safety communication among employees. In the study by Lingard [34] safety training was found to improve employee involvement in safety activities. Ambituuni et al. [35] found that safety training showed a positive impact on safety culture in the Nigerian manufacturing industry, improving employees' safety perception, communication, and involvement in safety activities. Nordlöf et al. [36] also found that safety training provided a positive impact on safety culture in the Swedish steel industry, improving employees' safety perception, communication, and involvement in identifying and mitigating safety risks. Finally, Singh and Misra [37] found that safety training provided a positive impact on safety culture in the Indian manufacturing industry, improving employees' safety perception, communication, and involvement in safe work practices.

From these research findings, it was evident that safety training played a crucial role in building a safety culture. Safety training could improve safety awareness, safety communication, and employee involvement in safety activities, all of which were important elements of a safety culture. However, safety training alone might not be sufficient to establish a safety culture. Organizations should have other factors that contribute to promote a safety culture, such as exemplary safety leadership, employees who were aware of safety risks, and an efficient safety management system.

5. Conclusion

The conclusion emphasizes that safety culture in the discrete manufacturing sector in Thailand is multifaceted, comprising six core elements: Input, Processing, Output, Working Environment, Ergonomics, and Safety Experience. The study identifies sub-elements with the highest predictive power and factor loading, highlighting areas where organizations can actively enhance safety culture. This comprehensive approach underscores the importance of each element in fostering a safer workplace, suggesting that targeted improvements across these dimensions can significantly impact overall safety performance.

6. Limitations

The generalizability of our findings may be restricted by the sample size and demographic characteristics of the study population. Future research should aim to include a more diverse sample to enhance the applicability of the results across different industries and countries. Additionally, the reliance on self-reported measures for assessing safety culture could potentially introduce bias. Objective measures or observations should be integrated into future studies to validate findings. Moreover, this research, focusing on discrete manufacturing in Thailand, leaves the applicability of its results to continuous manufacturing or other sectors unexplored.

7. Future research

To address these limitations and expand the body of knowledge on safety culture, future research could:

- Explore the impact of cultural differences within the workforce on safety culture in manufacturing industries. Understanding how diverse workforces interpret and implement safety standards could provide valuable insights.

- Conduct longitudinal studies to gain insights into how safety culture evolves over time with the introduction of new safety protocols or technologies.

- Examine the relationship between safety culture and other organizational outcomes, such as employee satisfaction, productivity, and financial performance. This could highlight the broader implications of investments in safety culture.

Further, employing mixed methods could offer a more comprehensive understanding of safety culture dynamics, while exploring the role of emerging technologies like artificial intelligence in enhancing safety practices presents a promising avenue. Comparative studies across different cultural contexts could illuminate how national culture influences safety culture implementation and effectiveness. Investigating the regulatory impact on safety culture and the psychological aspects influencing it, such as leadership styles and employee motivation, would also contribute valuable insights to the field.

8. References

[1] Heinrich HW. Industrial accident prevention. New York: McGraw-Hill; 1931.

[2] Antonsen S. Safety culture and the issue of power. Saf Sci. 2009;47(2):183-91.

[3] Nævestad TO, Blom J, Phillips RO. Safety culture, safety management and accident risk in trucking companies. Transp Res F Traffic Psychol Behav. 2020;73:325-47.

[4] Mokarami H, Alizadeh SS, Rahimi Pordanjani T, Varmazyar S. The relationship between organizational safety culture and unsafe behaviors, and accidents among public transport bus drivers using structural equation modeling. Transp Res F Traffic Psychol Behav. 2019;65:46-55.

[5] Griffin MA, Neal A, Parker SK. A new model of work role performance: positive behavior in uncertain and interdependent contexts. Acad Manag J. 2007;50(2):327-47.

[6] Wang Y, Zhu J, Wang X, Li X, Zhang W. Navigating cross-cultural port tourism: unleashing the psychological safety valve for risk management. Ocean Coast Manag. 2023;246:106888.

[7] Sirgo G, Olona M, Martín-Delgado MC, Gordo F, Trenado J, García M, et al. Cross-cultural adaptation of the SCORE survey and evaluation of the impact of real-time random safety audits in organizational culture: a multicenter study. Medicina Intensiva. 2022;46(10):568-76.

[8] Newaz MT, Wang D, Davis P, Wang X, Jefferies M, Sheng Z. A cross-cultural validation of the psychological contract of safety on construction sites. Saf Sci. 2021;141:105360.

[9] Parker SK, Axtell CM, Turner N. Designing a safer workplace: importance of job autonomy, communication quality, and supportive supervisors. J Occup Health Psychol. 2001;6(3):211-28.

[10] Hair JF, Black WC, Babin BJ, Anderson RE. Multivariate data analysis. 7th ed. New York: Pearson; 2010.

[11] Hughes B. The need for independent safety investigation and regulation of road infrastructure. J Road Safety. 2022;33(3):76.

[12] Hughes BP, Falkmer T, Anund A, Black MH. The relevance of U.S. strategic highway safety plans in a future context. PLoS ONE. 2019;14(10):e0223646.

[13] Kim J. The relationship between frequency of injuries and workplace environment in Korea: focus on shift work and workplace environmental factors. Saf Health Work. 2018;9(4):421-6.

[14] Hopkins A. Safety culture, mindfulness, and safe behavior: converging ideas? [Internet]. 2022 [cited 2023 Dec 2]. Available from: https://openresearch-repository.anu.edu.au/bitstream/1885/41764/3/WorkingPaper7.pdf.

[15] Wang B, Wu C, Huang L. Emotional safety culture: a new and key element of safety culture. Process Saf Prog. 2018;37(2):134-9.

[16] Fatima SH, Rothmore P, Giles LC, Varghese BM, Bi P. Extreme heat and occupational injuries in different climate zones: a systematic review and meta-analysis of epidemiological evidence. Environ Int. 2021;148:106384.

[17] Wang Y, Chen H, Liu B, Yang M, Long Q. A systematic review on the research progress and evolving trends of occupational health and safety management: a bibliometric analysis of mapping knowledge domains. Front Public Health. 2020;8:81.

[18] Arcuri MC, Gandolfi G, Melloni R. Key aspect of safety at work: a comprehensive literature review. EPH - Int J Sci Eng. 2020;6(1):15-29.

[19] Sedani A, Stover D, Coyle B, Wani RJ. Assessing workplace health and safety strategies, trends, and barriers through a statewide worksite survey. Int J Environ Res Public Health. 2019;16(14):2475.

[20] Rahimi Pordanjani T, Mohamadzade Ebrahimi A. Safety motivation and work pressure as predictors of occupational accidents in the petrochemical industry. Health Scope. 2015;4(4):e26492.

[21] Cui L, Fan D, Fu G, Zhu CJ. An integrative model of organizational safety behavior. J Saf Res. 2013;45:37-46.

[22] Cox SJ, Cheyne AJT. Assessing safety culture in offshore environments. Saf Sci. 2000;34(1-3):111-29.

[23] Dekker SWA, Nyce JM. There is safety in power, or power in safety. Saf Sci. 2014;67:44-9.

[24] Manolescu A, Verboncu I, Lefter V, Marinaş C. Linking ergonomics with human resources management. Rev Int Comp Manag. 2010;11(2):201-9.

[25] Ponprathom Y, Horadal P, Sawangcharoen K, Sarawong N, Meemamae P. Occupational health hazards and work safety climate in the furniture industry of small enterprises. Adv Sci J. 2023;23(2):R105-24. (In Thai)

[26] Batool Z, Yasir A. The influence of sleep quality, safety culture, and cabin ergonomics on work-related stress and burnout of bus drivers in Lahore. J Transp Health. 2018;9(Suppl):S24-5.

[27] Kurd N, Ala Y, Yousefi H, Mohammadfam I, Nasrolahi A. A review of studies in the field of evaluation of industrial safety culture & safety climate in Iran. Int J Occup Hyg. 2020;12(1):1-8.

[28] Khandan M, Aligol MH, Shamsi M, Poursadeghiyan M, Biglari H, Koohpaei A. Occupational health, safety, and ergonomics challenges and opportunities based on organizational structure analysis: a case study in selected manufacturing industries in Qom Province, Iran, 2015. Annals of Tropical Medicine and Public Health. 2017;10(3):606-11.
[29] Sirat RBM. Relationship between ergonomics and safety culture among safety and health officers in manufacturing companies in Malaysia [dissertation]. Malaysia: Universiti Teknologi Malaysia; 2017.
[30] Beatrice OO. Influencing safety culture in the UK offshore oil and gas industry: the importance of employee involvement. [thesis]. Aberdeen: Robert Gordon University; 2011.
[31] Casey TW, Krauss AD, Turner N. The one that got away: lessons learned from the evaluation of a safety training intervention in the Australian prawn fishing industry. Saf Sci. 2018;108:218-24.
[32] Karanikas N, Melis DJ, Kourousis KI. The balance between safety and productivity and its relationship with human factors and safety awareness and communication in aircraft manufacturing. Saf Health Work. 2018;9(3):257-64.
[33] O'Dea A, Flin R. Site managers and safety leadership in the offshore oil and gas industry. Saf Sci. 2001;37(1):39-57.
[34] Lingard H. The effect of first aid training on Australian construction workers' occupational health and safety motivation and risk control behavior. J Safety Res. 2002;33(2):209-30.
[35] Ambituuni A, Amezaga J, Emeseh E. Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: problems and prospects. Environ Dev. 2014;9:43-60.
[36] Nordlöf H, Wiitavaara B, Winblad U, Wijk K, Westerling R. Safety culture and reasons for risk-taking at a large steel-manufacturing company: Investigating the worker perspective. Saf Sci. 2015;73:126-35.
[37] Singh A, Misra SC. Safety performance & evaluation framework in Indian construction industry. Saf Sci. 2021;134:105023.