Iran J Public Health, Vol. 53, No.3, Mar 2024, pp.691-703

Original Article

Investigating the Human Reliability in the Healthcare Sector Using the Fuzzy Analytic Network Process and the Success Likelihood Index Method

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(Received 12 Jul 2023; accepted 21 Sep 2023)

Abstract

Background: We aimed to identify the factors contributing to human error in hospital emergency departments using scientific methods.

Methods: We used the Fuzzy Analytical Network Process (FANP) and Success Likelihood Index Method (SLIM) to investigate human reliability in 54 hospital emergency departments in 15 provinces of Iran from 2021 to 2022.

Results: The study classified 17 general factors affecting human errors in hospital emergency departments. Organizational (0.349), occupational (0.330), and personal factors (0.320) had the most significant impact on human error. Based on a matrix of paired comparisons for nine emergency tasks using the probability of success index method, "checking test results and diagnosis" had the highest probability of error when referring patients to intensive care or discharge. Although the study prioritized patients, there was still a cumulative probability of human error before disease diagnosis at 0.01332, highlighting the need for further training to minimize these risks.

Conclusion: The FANP and SLIM were effective in identifying the factors contributing to human error in hospital emergency departments. Doctors and nurses working in these departments require more knowledge, experience, and responsibility to avoid errors. By identifying factors influencing the occurrence of human error and finding solutions to reduce risks, hospitals can improve the quality of their care and prevent errors.

Keywords: Human reliability; Fuzzy analysis network process; Healthcare; Hospital emergency

Introduction

Human error is a significant factor in media and accident investigations, causing disasters like Chernobyl and plane crashes (1). It can occur during structure design, construction, and use, destroying high-tech systems. Identifying and preventing errors and adverse events is crucial for improving safety (2). Employee reliability analysis helps identify system errors and weaknesses, and human reliability methods challenge healthcare professionals. The rapid growth of technology has increased manpower's role in system performance, reliability, and safety. Understanding implicit conditions and human error is essential to identify and clarify reasons for operator performance deviations. Healthcare are good sector to check performance and eliminate errors.

Human error is a significant cause of medical errors in various fields, including disease diagnosis, drug prescription, and emergency care (3). The study also employed Success Likelihood Index Method (SLIM) to estimate human error, with experts rating it using performance shaping factors and expert opinions. Reliability systems are also used to reduce human error.

Human reliability analysis (HRA) is a crucial tool for assessing the likelihood of human error in complex systems and processes (4,5). It has been successfully applied in various industries to improve safety and reduce accident risks. HRA is often used in conjunction with other safety engineering approaches for a comprehensive assessment. It is interdisciplinary due to understanding human error causes, mechanisms, and factors like training and interface design. System engineering must also consider the intended and unwanted interaction of man and system for error potential and effect (5).

Zarei et al (6) identified HRA needs, gaps, and challenges in the chemical process industry using Web of Science and Scopus databases. They examined maintenance, emergency, and control room human factors, identified research gaps, and used a fuzzy analytical network to assess Mashhad urban railway employees' performance. Ahn et al (7) proposed a systematic human reliability assessment, highlighting the importance of human performance in complex systems involving humans, machines, and software. Table 1 shows a summary of the characteristics of the studies conducted on the reliability of human resources.

Table 1: characteristics of the studies conducted on the reliability of human resources

References	*Data type*	*Suggested method*	*Case Study*
Mohammadfam et al (2016) (8)	Certain	SPAR-H - CREAM	Nursing Practice
Wang et al (2018) (9)	Uncertain	HEART-FANP	Duties of railway dispatch
Nurdiawati et al (2018) (10)	Certain	SLIM-DEMATEL-ANP	Overhead crane operation
Hsieh et al (2018) (11)	Uncertain	HFACS-Fuzzy TOPSIS-AHP	Emergency departments
Ung (2019) (12)	Uncertain	Fuzzy Bayesian Network-CREAM	Tanker approach
Evans et al (2019) (13)	Certain	HEART-IS	Information security incidents
Zhou et al (2020) (14)	Certain	SLIM	Railway driving process
Erdem and Akyuz (2021) (15)	Uncertain	Fuzzy Slim	Maritime Transportation
Aliabadi (2021) (16)	Uncertain	HEART	Furnace startup operation
Zhang et al (2021) (17)	Uncertain	Fuzzy CREAM	Unloading operations at oil terminals
Velmurugan et al (2022) (18)	Uncertain	Fuzzy AHP-TOPSIS	Maintenance management system
Aydin et al (2022) (19)	Certain	HFACS-PV & SLIM	Marine pilot transfer operation
Kayisoglu et al (2022) (20)	Certain	SLIM	Spills in marine operations
Nam et al (2023) (21)	Certain	HEISM-DA & AHP	Putting the nuclear power plant into operation
Bafandegan emroozi and Fekoor (2023) (22)	Certain	CREAM-DANP	Financial services
Current Paper	Uncertain	FANP-SLIM	Hospital emergency

In this study, the primary goal was to prioritize worker safety and evaluate the healthcare procedures in emergency departments. To accomplish this, the researchers utilized a methodology known as Fuzzy Analysis Network Process (FNAP). The FNAP approach was employed to investigate and analyze human errors occurring within emergency departments, along with their root causes. By utilizing FNAP, the study aimed to enhance comprehension of these errors and develop effective strategies and interventions to mitigate their occurrence. This research seeks to contribute to overall improvements in safety and quality of care within emergency departments.

Methods

Human operational error analysis (HOEA) is a method used to analyze errors made by human operators in complex systems. It aimed to identify root causes and develop strategies to prevent future errors (23). HOEA has been successfully used in various industries to improve system performance by identifying and addressing the root causes of errors. By implementing HOEA analyses, organizations can create safer, more reliable systems that perform better and are less prone to errors. Common approaches to HOEA include incident investigation, root cause analysis, human factors analysis, human reliability analysis, observational studies, simulation and scenario-based analysis, and literature review and case studies. These methods help organizations reduce the likelihood of errors and address underlying issues that contribute to errors. By implementing these strategies, organizations can create safer, more reliable systems that perform better and are less prone to errors.

This study employed a comprehensive approach to delve into the realm of human operational errors within hospital emergency departments. It combined library research, field studies, expert opinions, and the FANP method to gain a thorough understanding of these errors. The investigation encompassed 54 hospital emergency departments spanning 15 provinces across the country, with data collected between 01/10/2021, and 30/10/2022.

In order to analyze and classify the effective factors, we classified them into three main categories: individual, occupational, and organizational. Additionally, the research identifies 17 subcriteria that play a role in causing medical errors. The primary audience targeted by this article is the hospital emergency departments, and information was solicited from 10 experts, comprising 8 professionals specializing in healthcare and 2 experts focusing on human resources reliability.

The choice of approach for addressing these errors depends on several factors, including the nature of the error, available resources, and the specific industry context. The research methodology framework is visually depicted in Fig. 1, providing a clear illustration of the study's overall approach and structure.

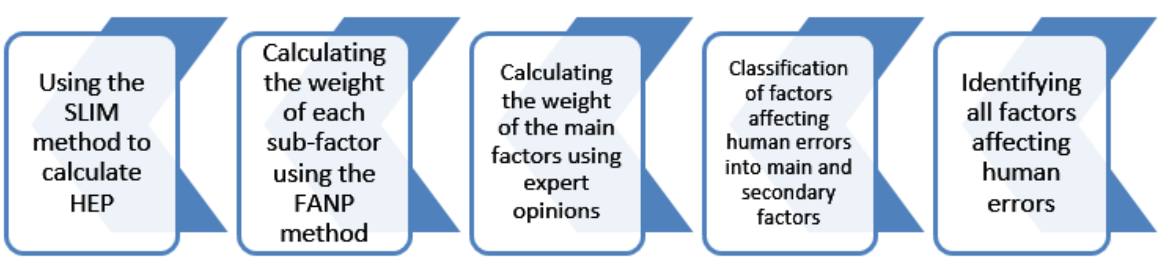

Fig. 1: Research methodology framework

According to the framework of the research implementation method presented in Fig. 1, the implementation steps of each phase are described below:

Phase 1: Identifying all factors influencing human errors

- Literature review study

- Examining human resource allocation techniques

Phase 2: Classification of factors affecting human errors into main and secondary factors

- Classification of all identification factors affecting human errors in three categories: individual, occupational and organizational factors

Phase 3: Calculating the weight of the main and secondary factors using experts' opinions

- Determining experts in the field of healthcare
- Calculate the relative weight of each expert
- Collecting the questionnaire and determining the weight of each of the main factors
- Normalizing the weight of each of the main factors

Phase 4: Calculating the weight of each of the sub-factors of job duties using the FANP method

- Determining experts in the field of healthcare
- Determining the value of the fuzzy extent according to the i_{th} factor using the following relationship

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} \quad [1]$$

In order to obtain the fuzzy addition operation (the first part of the S equation), the analysis values of the extent m of a specific matrix are performed as follows:

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad [2]$$

To obtain, the additional fuzzy operation (the second part of the S equation) of the values is performed as follows:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad [3]$$

Then, we calculate the inverse of the vector in the above equation in such a way that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad [4]$$

Determining the degree of possibility $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ through the following relations:

$$V(M_2 \geq M_1) = sup_{y \geq x}\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad [5]$$

And it can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad [6]$$

where the selected d is the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare M_1 and M_2, we need both values of $V(M_2 \leq M_1)$ and $V(M_2 \geq M_1)$.

- Determining the degree of possibility of a convex fuzzy number being larger than k convex fuzzy numbers

$M_i\ (i = 1,2, \dots, K)$ can be defined as follows:

$$V(M \geq M_1, M_2, \dots, M_K) = V[(M \geq M_1) and (M \geq M_2) and, \dots (M \geq M_k)] = \min V(M \geq M_i), i = 1,2, \dots, K \quad [7]$$

Suppose $d'(A_i) = \min V(S_i \geq S_K)$ for $k = 1,2, \dots, n$, then the weight vector is obtained as follows:

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T \quad [8]$$

- Determination of normalized weight vectors

$$d(A_i) = \frac{d'(A_i)}{\sum_{i=1}^{n} d'(A_i)} \quad [9]$$

$$W = \left(d(A_1), d(A_2), \ldots, d(A_n)\right)^T \quad [10]$$

where W is a non-fuzzy number.

Phase 5: Using the SLIM method to calculate HEP

- Analyzing hierarchical tasks
- Determining the rank of each factor affecting human error for the assigned tasks
- Calculate the probability of human error

An equation using fuzzy sets and SLIM was created to calculate the HEP from the factors identified in the previous step. This reliable method is widely used to assess human reliability. PSFs affect the probability of an error at a position. SLIM calculates HEP using these equations:

$$SLI = \sum_{i-1}^{n} R_i W_i \,, 1 \leq SLI \leq 9 \quad [11]$$

$$log(HEP) = a.SLI + b \quad [12]$$

Where SLI stands for success likelihood index, R_i is the weight of each PSF and W_i is the weight of each PSF. a and b are two constants that should be calculated based on the minimum and maximum HEP. Two steps should be taken to develop the SLI equation. In the first step, called PSF weighting, the weight of PSFs should be determined. In the second step, called ranking of PSFs, PSFs should be ranked based on the actual situation of the organization.

Case study: Analysis of the emergency department of the hospital

The research framework and phases identified factors affecting human errors in healthcare, using literature, research, and human resources capability allocation. Overall, in Fig. 2, 17 factors were classified into individual, occupational and organizational groups with main factors (PSF) and sub-factors (subPSF).

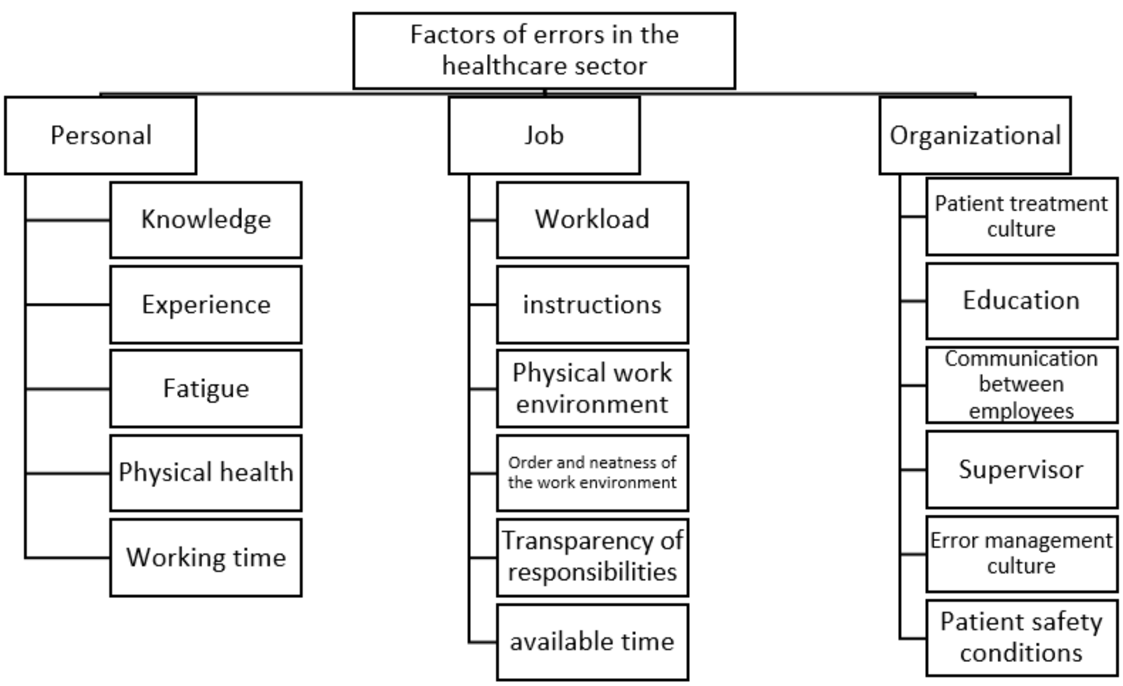

Fig. 2: Main and secondary factors influencing the occurrence of human errors

The study identifies primary and secondary factors affecting human errors in the hospital's healthcare department, and analyzes hierarchical tasks using field studies as described in Table 2.

Table 2: Hierarchical tasks in the emergency department of the hospital

1- Accepting the patient and recording information
1-1- Registering the patient's demographic information on all pages of the patient's file
1-2- Prioritizing patients based on disease status (determining the level of the disease)
1-3- Reference to different sections based on available sources
2- Examination and performing diagnostic and therapeutic services
2-1- Initial patient examination by doctor and nurse
2-2- Referral to receive diagnostic and treatment services
2-3- Examining the results of the tests and diagnosing referral to the special care department or discharge
2-4- Prescribing medicine and home care for level 4 and 5 patients
2-5- Acute action of diagnosis or treatment by specialized staff for level 1, 2 and 3 patients and transferring it to the department
2-6- Completing the patient's medical record

Experts surveyed 10 emergency department experts using a 5-point Likert scale to assess the importance of personal factors like knowledge, Tiredness, physical health, and working time in hospital emergency errors, occupational factors like workload, procedures, and physical environment, and organizational factors like patient safety conditions, treatment culture, training, communication, and error management culture in preventing hospital emergency room human errors (Table 3). In Table 4, the opinions of each of the experts are expressed for the questions presented to determine the weight of the main factors.

Table 3: Details of experts and relative weight of each expert

Expert	*Area of Expertise*	*Work experience*	*The level of familiarity with the reliability of manpower*	*Level of Education*	*Relative weight*
1	Shift doctor	20	Top	P.H.D	0.12
2	Shift doctor	16	Top	P.H.D	0.11
3	Shift doctor	18	Medium	P.H.D	0.09
4	Shift doctor	20	Top	P.H.D	0.11
5	Shift nurse	6	Medium	MA	0.08
6	Shift nurse	8	Medium	MA	0.08
7	Shift nurse	17	Top	Masters	0.08
8	Triage manager	7	Medium	Masters	0.06
9	Human resources specialist	12	Top	P.H.D	0.12
10	Human resources specialist	18	Top	Masters	0.15

Table 4: Details of experts' answers to each of the questions

Main factor	*Secondary factors*	*Experts*										*Weighted average scores*
		1	2	3	4	5	6	7	8	9	10	
		0.12	0.11	0.09	0.11	0.08	0.08	0.08	0.06	0.12	0.15	
Personal	Knowledge	5	5	3	4	5	5	2	3	2	5	0.399
	Experience	5	2	3	2	4	5	5	4	3	2	0.333
	Fatigue (Tiredness)	5	2	5	3	3	4	5	5	3	2	0.352
	Physical health	2	4	4	4	2	3	5	2	2	4	0.324
	Working time	3	2	4	4	4	5	4	5	3	4	0.368
Job	Workload	5	4	5	5	2	3	4	2	3	2	0.354
	Procedures	2	3	4	3	4	3	5	5	2	3	0.321
	The physical environment	3	4	5	2	4	3	4	2	4	3	0.340
	Order and neatness of the work environment	2	2	3	2	4	2	3	4	4	5	0.314
	Transparency of responsibilities	3	3	5	4	4	5	3	3	3	4	0.368
	Available time	4	2	4	2	2	2	2	3	3	5	0.305
Organizational	Patient safety conditions	4	5	3	5	3	4	3	4	4	3	0.382
	Patient treatment culture	2	4	2	2	2	4	4	4	3	3	0.293
	Education	3	5	2	4	3	3	5	3	2	2	0.313
	Communication between employees	3	2	3	2	2	2	5	3	2	4	0.281
	Supervisor	2	4	2	3	4	3	5	4	3	5	0.350
	Error management culture	2	4	2	4	2	5	4	2	4	4	0.338

The table reveals that knowledge significantly impacts human error in the emergency department, while physical health has the least impact. Transparency of responsibilities is the most important factor, while available time is the least. Patient safety conditions have the most significant effect, while employee communication has the least. Fig. 3 shows the weighted mean scores of HEP sub-factors. Table 5 also shows the obtained weight and the normalized weight of each of the main factors.

Table 5: The final weight of each main factor and its normalized weight

Main factor	*Average final weight*	*Normalized weight*
Personal	0.355	0.349
Job	0.336	0.330
Organizational	0.326	0.320

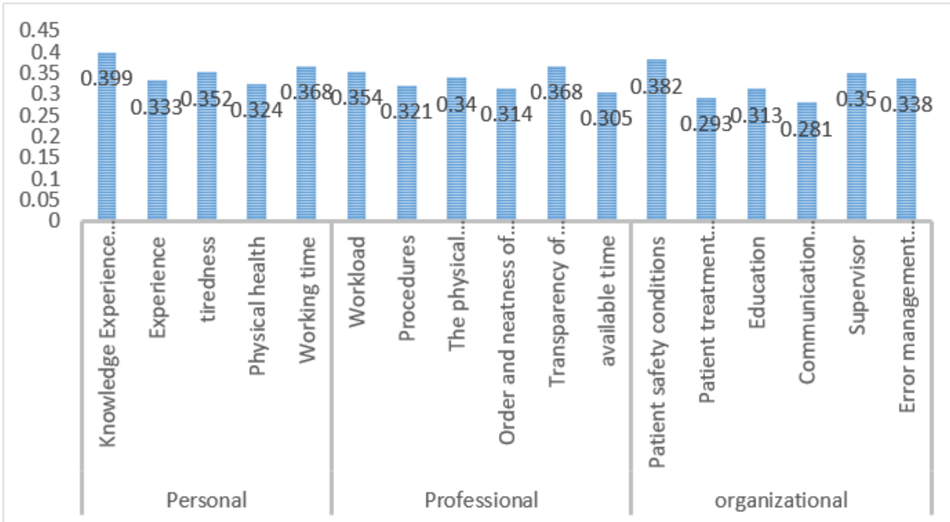

Fig. 3: Weighted mean scores of HEP subfactors

According to analyses carried out in the first stage, the weight of the personal factor is equal to 0.349, the weight of the job factor is equal to 0.330 and the weight of the organizational factor is equal to 0.320. Therefore, the SLI equation will be as follows.

$$SLI = 0.349PSF_p + 0.330PSF_j + 0.320PSF_o \quad [13]$$

In the above relationship, PSF_p‘ PSF_j‘PSF_o are the rank of personal, job and organizational factors respectively.

Moreover, the conceptual model of factors affecting human errors in the emergency department of the hospital, extracted from SPSS, can be expressed as shown in Fig. 4:

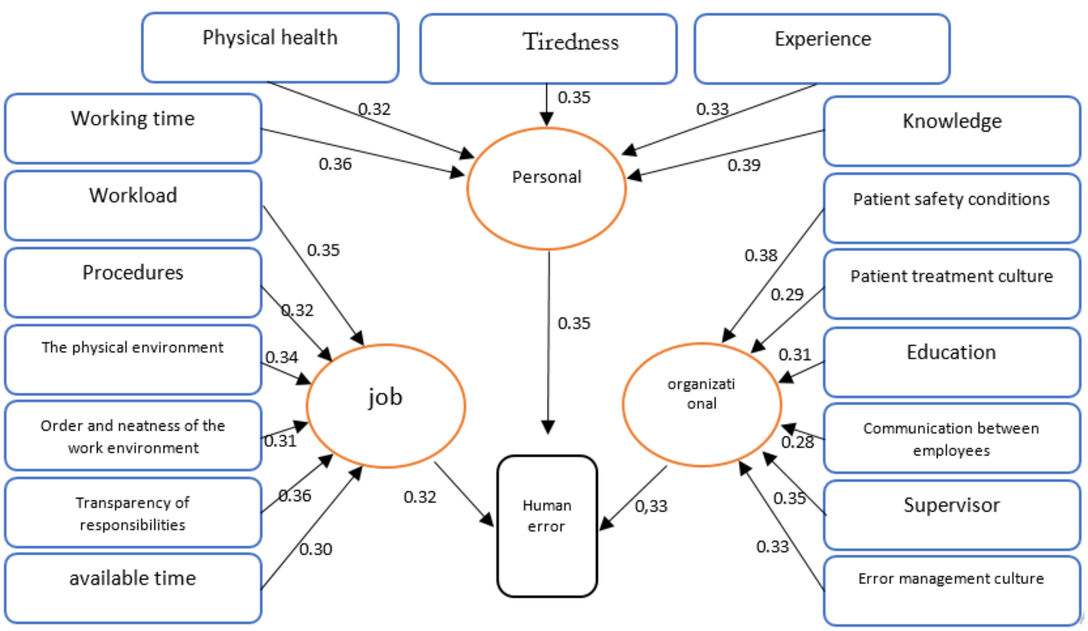

Fig. 4: Conceptual model of factors affecting human errors in the emergency department of the hospital

The FANP method has been used to determine the rank of the factors expressed in each of the tasks defined in Table 1. Due to the fuzziness of the proposed method, language terms and fuzzy numbers corresponding to Table 6 were used.

Table 6: Linguistic terms and corresponding fuzzy numbers

Linguistic term	*Scored*	*fuzzy number*
very little	1	(1 - 1 - 1)
Low	2	(1 - 1,5 -2)
medium	3	(1,5 - 2 - 2,5)
Much	4	(2 – 2,5 – 3)
very much	5	(2,5 – 3 – 3,5)

Thus, for each task in Table 1, paired comparison matrices have been created using the experts' main factors (personal, occupational, and organizational). The matrix of paired comparisons data was used to rank and weight the main job duties factors in Table 7. In the estimation of HEP according to Table 8, constant values of a and b are considered equal to 0.00035 and -0.0027.

Table 7: Rank, weight of PSFs and SLI for each task

Task		PSF_p	PSF_j	PSF_o	*SLI*
1-1	R_i	5.707	4.978	4,111	4.912
	W_i	0.327	0,322	0.351	
2-1	R_i	5.786	4.695	5.958	5.512
	W_i	0.277	0.316	0.407	
3-1	R_i	5.732	5.188	4.544	5.153
	W_i	0.326	0.344	0.331	
1-2	R_i	4.681	5.051	4.736	4.808
	W_i	0.366	0.294	0.341	
2-2	R_i	5.285	4.354	4.791	4.816
	W_i	0.314	0.298	0.388	
3-2	R_i	4.306	4.239	4.993	4.537
	W_i	0.278	0.351	0.371	
4-2	R_i	4.109	5.820	4.805	4.910
	W_i	0.288	0.301	0.412	
5-2	R_i	5.185	4.155	5.315	4.887
	W_i	0.368	0.328	0.304	
6-2	R_i	4.660	4.824	5.127	4.871
	W_i	0.345	0.313	0.342	

Table 8: HEP value for each task

Task	*SLI*	*Log (probability of success)*	*Probability of success*	*HEP*
1-1	4.912	-0.00098	0.998	0.002256
2-1	5.512	-0.00077	0.998	0.001773
3-1	5.153	-0.00090	0.998	0.002062
1-2	4.808	-0.000102	0.998	0.002339
2-2	4.816	-0.000101	0.998	0.002333
3-2	4.537	-0.000111	0.997	0.002557
4-2	4.910	-0.00098	0.998	0.002557
5-2	4.887	-0.00099	0.998	0.002276
6-2	4.871	-0.000100	0.998	0.002289

Emergency department data shows that the most common human error is in checking test results and diagnosing referrals to special care or discharge, while the triage department has the least human error in prioritizing patients based on disease status. Fig. 5 shows HEP for each emergency department task. Fig. 6 also presents the reliability system for the emergency department of the hospital.

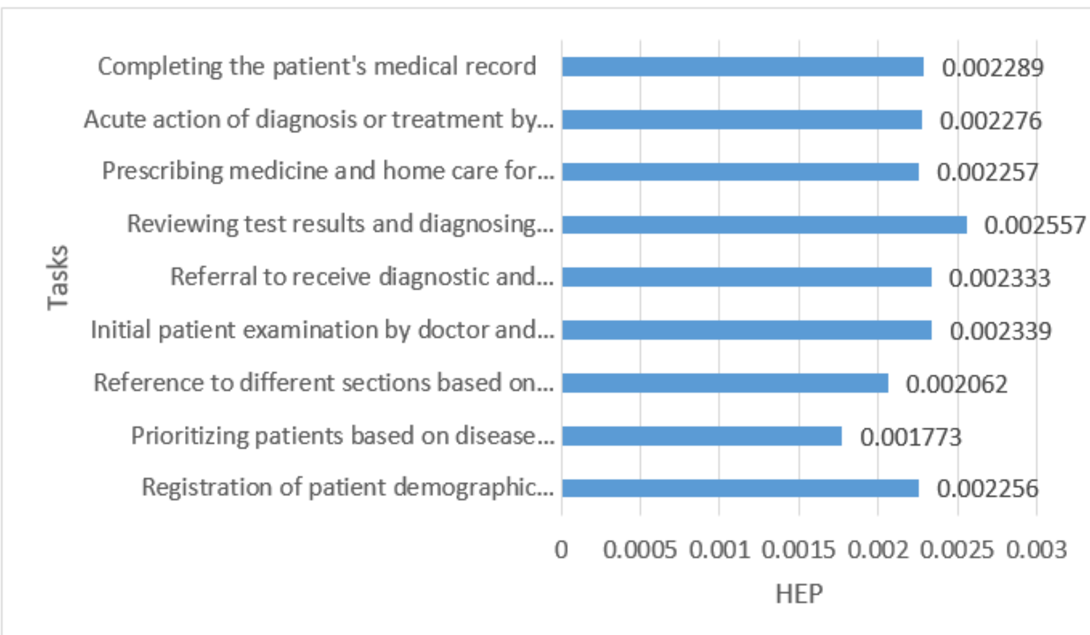

Fig. 5: HEP value for each hospital emergency department task

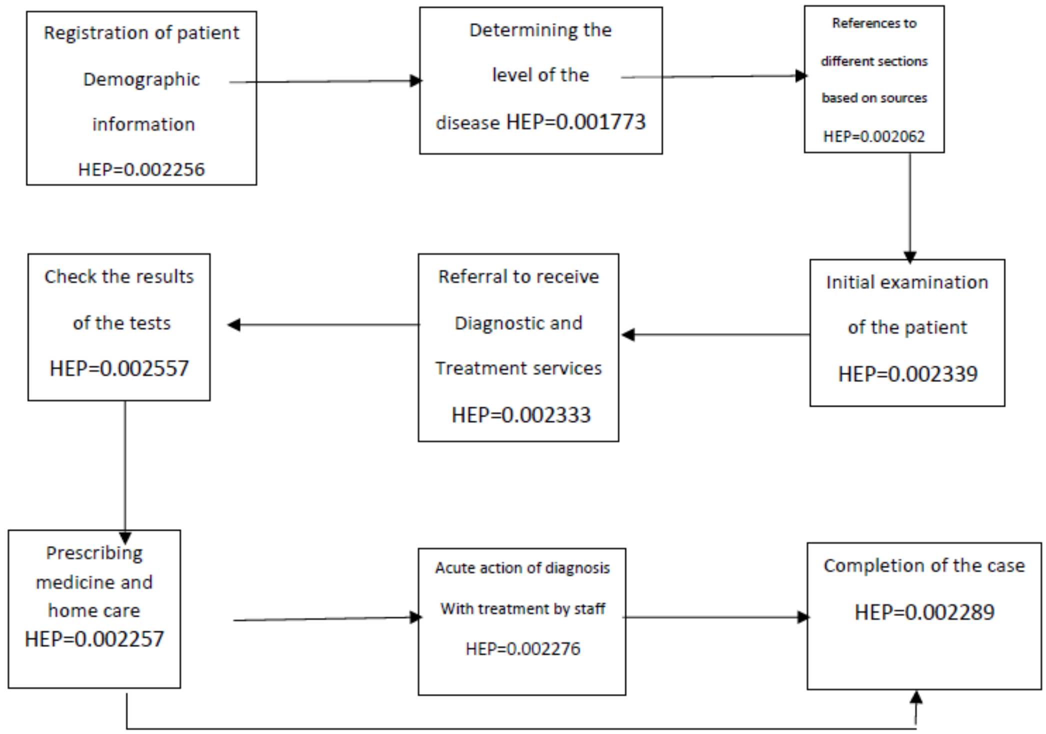

Fig. 6: Hospital emergency department reliability system

According to the system, HEP is highest when doctors diagnose a patient based on tests and paraclinical results. The reliability system reports 0.01332 HEP cumulative values. Due to limited treatment time, misdiagnosis can lead to amputation or death.

Discussion

Errors in healthcare systems can have serious consequences for patients and burden the healthcare system. HEP analysis is a method used to quantify the likelihood of human error in a particular task or system. It involves dividing a task into its parts and assessing the likelihood of error occurring at each step. HEP analysis can identify high-risk tasks, error-prone processes, and error mitigation strategies. Accurately quantifying the likelihood of human error can be challenging due to factors such as individual differences and environmental factors (24). To address this issue, probabilistic models are used to estimate the likelihood of error by considering factors such as cognitive workload and distraction. In healthcare, HEP analysis is used to improve patient safety and prevent adverse events. The development of a more accurate and appropriate technique to determine the human reliability in the healthcare system is a promising area for future research.

The literature on errors in healthcare systems is extensive, with a high rate of publications and citation activity. Key themes include the nature and causes of errors, measurement and analysis of errors, impact on patient safety, strategies for reducing errors, and policies and regulatory measures (25). The complexity of the healthcare system, weak interprofessional collaboration, inconsistent training, and systemic issues are key causes of errors (25,26). Different methods have been employed to understand errors, but there is ongoing debate about their reliability and validity. Errors are increasingly recognized as a significant threat to patient safety, contributing to adverse events and even death. Strategies for reducing errors include systemic changes, health information technology, and safety culture enhancement, but their effectiveness remains contested

(26). Policymaking is a key part of addressing errors, but implementation variance across different regions and healthcare systems is a concerning issue.

Future research is crucial to develop more accurate techniques to assess human reliability in the healthcare system. Existing methods, such as HEP analysis and human error analysis, offer valuable insights, but there is room for improvement. Future research could focus on refining quantitative models, integrating real-time data, assessing cognitive factors, incorporating machine learning and artificial intelligence, collaborating multidisciplinary, and conducting validation studies. This will advance our understanding of human reliability in the healthcare system, leading to improved patient safety, healthcare outcomes, and a more resilient and efficient system. New algorithms for calculating importance measures have been developed to estimate the influence of components or subsystems on the healthcare system's functioning. Reliability theory and simulation can also be used to analyze the healthcare system macroscopically. Human Reliability Analysis aims to identify potential failures resulting from human errors, identifying causes and implementing appropriate countermeasures.

The study identified 17 factors affecting human error in the healthcare sector, categorized as personal, occupational, and organizational. Knowledge has the most significant impact on personal errors, while physical health has the least. Job transparency and available time have the most significant effects. Patient safety conditions and employee communication have the least significant impact on organizational errors. The study used fuzzy data to highlight uncertainty in expert opinions, aiding healthcare organizations in developing strategies to reduce human error and improve patient safety.

Conclusion

According to the combination of FANP and SLIM methods, human errors occur most often in ``confirmation of test results, referral to specialized departments, and diagnosis for discharge," indicating that misdiagnosis due to test results is a possibility. The area with the least amount of human error was triage, especially prioritizing patients based on medical condition (determining the severity of illness).

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgements

The authors appreciate all participants in the study.

Conflict of Interests

All authors declare no conflict of interest.

References

1. Asadayoobi N, Taghipour S, Jaber MY (2022). Predicting human reliability based on probabilistic mission completion time using Bayesian Network. *Reliab Eng Syst Saf*, 221:108324.
2. Mahmoudi Sefidkouhi H, Najafi E, Haji A, Arasteh A (2023). Identification and Introduction of a New Classification of Key Performance Shaping Factors in Staff Performance in the Healthcare System. *Iran J Health Sci,* 11 (2):127-36.
3. Lyons M, Adams S, Woloshynowych M, Vincent C (2004). Human reliability analysis in healthcare: a review of techniques. *Int J Risk Saf Med*, 16 (4):223-37.
4. Spurgin AJ (2009). *Human reliability assessment theory and practice*. CRC press, USA, pp.: 178-211.
5. Levine CS, Al-Douri A, Paglioni VP, Bensi M, Groth KM (2024). Identifying human failure events for human reliability analysis: A review of gaps and research opportunities. *Reliab Eng Syst Saf,* 245:109967.

6. Zarei E, Khan F, Abbassi R (2021). Importance of human reliability in process operation: A critical analysis. *Reliab Eng Syst Saf*, 211:1-15.
7. Ahn SI, Kurt RE, Turan O (2022). The hybrid method combined STPA and SLIM to assess the reliability of the human interaction system to the emergency shutdown system of LNG ship-to-ship bunkering. *Ocean Engineering*, 265:112643.
8. Mohammadfam I, Movafagh M, Bashirian S (2016). Comparison of standardized plant analysis risk human reliability analysis (SPAR-H) and cognitive reliability error analysis methods (CREAM) in quantifying human error in nursing practice. *Iran J Public Health*, 45 (3):401-2.
9. Wang W, Liu X, Qin Y (2018). A modified HEART method with FANP for human error assessment in high-speed railway dispatching tasks. *International Journal of Industrial Ergonomics,* 67:242-58.
10. Nurdiawati AA, Handoko L, Amrullah HN, Dermawan D, Shah M, Hamzah F (2018). Human error probability analysis of overhead crane operation in steel fabrication company using SLIM-DEMATEL-ANP method. *MATEC Web of Conferences,* 204: 05012.
11. Hsieh MC, Wang EM, Lee WC, et al (2018). Application of HFACS, fuzzy TOPSIS, and AHP for identifying important human error factors in emergency departments in Taiwan. *Int J Ind Ergon*, 67:171-9.
12. Ung ST (2019). Evaluation of human error contribution to oil tanker collision using fault tree analysis and modified fuzzy Bayesian Network based CREAM. *Ocean Eng*, 179: 159-72.
13. Evans M, He Y, Maglaras L, Janicke H (2019). HEART-IS: A novel technique for evaluating human error-related information security incidents. *Computers and Security*, 80:74-89.
14. Zhou JL, Lei Y (2020). A slim integrated with empirical study and network analysis for human error assessment in the railway driving process. *Reliab Eng Syst Saf*, 204:107148.
15. Erdem P, Akyuz E (2021). An interval type-2 fuzzy SLIM approach to predict human error in maritime transportation. *Ocean Engineering*, 232:109161.
16. Aliabadi MM (2021). Human error analysis in furnace start-up operation using HEART under intuitionistic fuzzy environment. *J Loss Prev Process Ind*, 69:104372.
17. Zhang R, Tan H, Afzal W (2021). A modified human reliability analysis method for the estimation of human error probability in the offloading operations at oil terminals. *Process Saf Prog (AIChE J)*, 40 (3):84-92.
18. Velmurugan K, Saravanasankar S, Venkumar P, Sudhakarapandian R, Di Bona G (2022). Hybrid fuzzy AHP-TOPSIS framework on human error factor analysis: Implications to developing optimal maintenance management system in the SMEs. *Sustain Futures*, 4:100087.
19. Aydin M, Uğurlu Ö, Boran M (2022). Assessment of human error contribution to maritime pilot transfer operation under HFACS-PV and SLIM approach. *Ocean Engineering*, 266:112830.
20. Kayisoglu G, Gunes B, Besikci EB (2022). SLIM based methodology for human error probability calculation of bunker spills in maritime operations. *Reliab Eng Syst Saf*, 217:108052.
21. Nam CS, Lee BS (2023). Development of an Integrated Human Error Simulation Model in Nuclear Power Plant Decommissioning Activities. *Sci Technol Nucl Install*, 2023: 8133223
22. Bafandegan Emroozi V, Fakoor A (2022). A new approach to human error assessment in financial service based on the modified CREAM and DANP. *Journal of Industrial and Systems Engineering*, 14 (4):95-120.
23. Dhillon BS (2014). *Human reliability, error, and human factors in power generation*. Springer International Publishing, Switzerland, pp.:27-63.
24. Abbaspour A, Saremi M, Alibabaei A, Moghanlu PS (2020). Determining the optimal human reliability analysis (HRA) method in healthcare systems using Fuzzy ANP and Fuzzy TOPSIS. *J Patient Saf Risk Manag,* 25 (3): 251604351990043
25. Makary MA, Daniel M (2016). Medical error—the third leading cause of death in the US. *BMJ*, 353:i2139.
26. Johnson DH, Shapiro DW (1999). The Institute of Medicine Report on Reducing Medical Error and Its Implications for Healthcare Providers and Attorneys. *Utrecht Law Rev*, 12:1.