

LITERATURE REVIEW HUMAN RELIABILITY ANALYSIS (HRA) IN HEALTHCARE: METHODS, APPLICATIONS AND OPPORTUNITIES

Tutik Farihah^{*1}, Jamasri² and Rini Dharmastiti³

¹Department of Mechanical and Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta Indonesia.

¹Department of Industrial Engineering, Faculty of Science and Technology, UIN Sunan Kalijaga, Yogyakarta Indonesia.

^{2,3}Department of Mechanical and Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta Indonesia.

¹<https://orcid.org/0009-0008-6436-6788>^{ID}, ²<https://orcid.org/0000-0002-3936-5256>^{ID}, ³<https://orcid.org/0000-0001-8787-9641>^{ID}

E-mail: *tutik.farihah@uin-suka.ac.id

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ABSTRACT

Human Reliability Analysis (HRA) approach used human-system interaction approach to determine human error probability. This approach has been widely used to identify, determine, predict errors and provide recommendations for errors reduction in various fields of research such as nuclear, petrochemicals, offshore, mining, maritime, railways, manufacturing, healthcare, etc. In this study, a literature review was conducted to examine the distribution of HRA themes and its applications in the healthcare sector. Several nuclear industry-based HRA methods are commonly used in healthcare, including: Systematic Human Error Reduction and Prediction Approach (SHERPA), Technique for Human Error Rate Prediction (THERP), Human Error Assessment and Reduction Technique (HEART), Success Likelihood Index Methodology (SLIM), Cognitive Reliability and Error Analysis Method (CREAM), and Standardize Plant Analysis Risk Human Reliability Analysis (SPAR-H). Recently, some adaptation in Influencing Factor (IFs) based on healthcare cultural system characteristics have been made for surgery and radiotherapy areas. Methods proposed according to healthcare cultural system characteristics were also made by developing the Observational Clinical Human Reliability Analysis (OCHRA) method in surgery and Systems Analysis for Formal Pharmaceutical Human Reliability (SAFPHR) in pharmacy, but further development remains open for other areas. This literature review is expected to serve as sources for researchers to determine the techniques and development to pursue in the healthcare field.



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I. INTRODUCTION

HRA is a systematic approach to assessing human error probability within a system or process and its impact. HRA is a study of human reliability that combines psychology, ergonomics, system reliability, and system analysis. The concept of HRA focuses on identifying and analyzing factors that may affect human performance, such as physical and psychological conditions, training, organization, technology, and work environment. The main objectives of HRA methods are to determine error values and perform system improvement analysis, eliminate failure modes, design error tolerance and improve system safety, identify potential risks, analyze and predict error rates related to human interactions with equipment, procedures, and other characteristics behavior system, and provide recommendations to reduce or manage human errors. [1] HRA was introduced when the USNRC developed HRA approach through THERP method [2] for use in the nuclear industry due to the high number of workplace accidents caused by human reliability and the severe consequences of such accidents, including Three Mile Island, Chernobyl, and others. With more than 79 techniques, HRA has been used extensively for over 50 years to determine, evaluate, and improve companies with complicated well-defined processes and high levels of risk and procedure. In HRA methods, there are several stages, including: identifying the goal or scope of the study, task analysis, error identification, representation, determining the error probability value, impact assessment, and error reduction [3].

HRA is utilized for routine, detailed procedures, high-risk sectors, and complicated industries. For every process subtask, HRA offers a thorough examination of the possible mistakes committed in human-system interaction. Otherwise, HRA approach is quite adaptable and can be integrated with other approaches thus it has developed significantly and applied in various industrial sectors [3]. The healthcare sector has particular characteristics that set it apart in terms of the types of activities carried out. Healthcare activities have a highly diverse field, requiring specific and detailed expertise, ranging from routine procedures to highly unpredictable tasks, which vary from one individual to another and can be potentially hazardous, such as surgery. Patient recovery also involves long-term relationships between patients, nurses, and doctors in primary care, treatment of acute psychosis requiring quick responses, and tolerance for unusual behaviors, along with many other specializations. Some of these are structured and routine, such as blood transfusion management and chemotherapy.

Other areas of healthcare have different characteristics with dynamic complexity, high risk, and significant uncertainty, such as surgery. This diversity sets the healthcare sector apart from industries that are more predictable and focused on activities of limited scope, in line with designs agreed upon at the start of production [4]. The dynamics and complexity of activities in the healthcare sector are individualistic and more difficult to predict compared to many other industries. The COVID-19 pandemic also highlighted how rapidly medical challenges can evolve, with a very broad scope. The highly mutated virus, comorbidities, and extremely high infectious rates even led to the paralysis of healthcare systems in some countries, overwhelming stress levels, work complexity, and workloads that resulted in high levels of healthcare worker fatigue and burnout [5], [6], [7], [8], [9], [10], [11], [12], [13], which could be one of the contributing factors to HEP [14]. In such conditions, healthcare worker must manages a vast amount of uncertainty, stress and work complexity. Unlike many industries that rely on human-machine interaction, the healthcare sector involves more human-to-human and human-to-machine interactions, an individualistic context of a larger flow of patients.

II. MATERIALS AND METHODS

In this literature study, a search was conducted using English-language journals/articles based on the Scopus, CINAHL, PsycINFO, PubMed, Scopus, and Google Scholar. Several keywords were used, such as : human reliability analysis, human error probability, human reliability analysis in healthcare, human unreliability, human error probability in healthcare, human error analysis in healthcare, and human reliability in healthcare. The literature selection process used in this study follows the PRISMA approach (Figure 1). The data obtained is then checked for paper duplication. Subsequently, the papers will be analyzed for relevance based on the research objectives, methods used, and research location (healthcare/non-healthcare). As a result, 63 papers on human reliability analysis in healthcare were identified and mapped in the next stages. The paper will be analyzed based on six steps: task analysis, human error analysis (error identification, representation), human error quantification, impact assessment, error reduction strategy [15], with a detailed discussion (Table 1) given to papers that perform proposed methods while only some the application of the basic method of HRA in it.

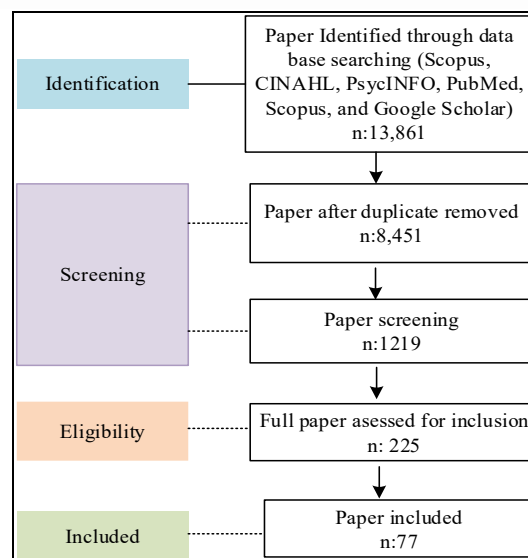


Figure 1. PRISMA Flowchart.

Source: Authors, (2026).

III. RESULTS AND DISCUSSIONS

The paper analyzed based on six steps: task analysis, human error analysis (error identification, representation), human error quantification, impact assessment, error reduction strategies [15] enabling a systematic evaluation of human error.

III.1. TASK ANALYSIS

Task analysis provides an overview and analyzes the interaction between each subsystems and personnel with the system to provide an overview of the subtasks that must be performed, stopped, and controlled by the operator. Hierarchical Task Analysis (HTA) is the most commonly used in task analysis method for several domains [16]. HTA widely used in healthcare areas : pharmacy [17], surgery [18], [19], [20], [21], [22], [23], emergency [24], [25].

III.2. HUMAN ERROR ANALYSIS (HEA)

HEA is the identification of possible errors that may occur, which is needed to understand the complexity of system characteristics when errors happen and the contribution of the error to the system's risk level. A less detailed depiction of system complexity may trigger errors in determining human error rates. Error identification is a key point in this analysis, which allows the HEI technique to be used to predict parts of activities that fail due to "normal" human errors, such as slips, deviations, and mistakes. Human factors researchers often use the HEI technique to analyze and predict operator errors in complex and dynamic systems. In healthcare, there are several applications of the HEI method, including External Error Modes (EEM)s, Human Error Identification System Tools (HEIST), Systematic Human Error Reduction and Prediction Approach (SHERPA), and Human Factor and Analysis Classification System (HFACS).

3.2.1. HEIST

HEIST method is used to identify types of errors in the intensive care unit (ICU) among nurses, with 56.8% being determined by management factors. 29 causes of error identified with management had the highest rank in the cause of errors (64.063%) and the obligation high workload, consequently fatigue had the highest responsibility (21.448%) to cause human errors in this task. Beside that, lack of training for nurses, inadequate knowledge and supervisors' commitment were the other major causes of nursing errors. [26].

III.2.1. HFACS

HFACS is a risk analysis technique that systematically analyzes several human error factors and provides reliable risk ranking results by considering interactive relationships quantitatively. HFACS uses error classification for unsafe acts, precondition unsafe acts, unsafe supervision, and organizational influence, with various categories of potential errors. HFACS has been applied in healthcare to analyze potential error mitigation at various levels of public healthcare systems [27], [28], [29], [30]. In pharmacy, this method integrated with linguistic Z-number, DEMATEL method, and ORESTE method for analyzing the risk of human error factors [31].

III.2.2. EEM

EEM is used in surgery and includes the following stages: steps not performed, steps not completed, steps repeated, second steps performed only as an addition, second steps not performed, wrong order of steps, steps performed with excessive force, direction, depth, speed, distance, and time, steps performed with insufficient force, direction, depth, speed, distance, and time, incorrect orientation, and incorrect object [32]. Studies using the EEM approach in various surgery: [21], [22], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42].

III.2.3. SHERPA

SHERPA method is one of the most widely used approaches due to its flexibility, ease of analysis, and comprehensive stages. This is an approach where the subgoals from an HTA are scrutinized in order to identify where errors in the task may occur and to suggest the most suitable solutions to mitigate these errors. In the healthcare industry, this method already used in various healthcare areas [17], [20], [23], [24], [25], [43], [44], [45], [46], [47], [48], [49], [50] and combined with other techniques to determined, and classified of risk error including: Healthcare Failure Mode and Effect Analysis (HFMEA) [46], [47], [48], [50], HTA[20], [43], [44], [45], [51], Failure Mode and Effect Analysis (FMEA) [48], HFMEA and Systems Theoretic Accident Model and Process (STAMP) [46].

III.3. REPRESENTATION

The first type of dependence, referred as type-1 or direct dependence, deals with the direct relationship between two actions. This type of dependence can be managed explicitly in two ways: first, through the use of a formal dependence model, and second, by applying conditional probabilities. The second type of dependence addresses relationships at a more complex level, beyond the simple 'sub-task error dependencies' [15]. Some dependence method used in HRA are : Fault Tree Analysis (FTA), Event Tree Analysis (ETA), THERP, Cognitive Reliability and Error Analysis Method (CREAM), and Standardize Plant Analysis Risk Human Reliability Analysis (SPAR-H).

III.3.1. FTA

FTA used to map the process of cardiopulmonary resuscitation (CPR) (such as chest compression rates and ventilation) based on the American Heart Association (AHA) roles. This study was conducted over three months during daytime shifts in the emergency department's CPR section at Imam Reza Hospital in Mashhad, Iran describe the risks in five steps: CPR quality, medication therapy, CPR team, defibrillator, and rhythm diagnosis [52].

III.3.2. THERP

THERP is one of the most widely used dependence assessment methods in HRA. Valid dependence results were obtained in the blood transfusion process by advancements in dependence assessment employing techniques based on Linguistic Hesitant Fuzzy Sets (LHFSs) and THERP between successive human acts [53].

III.3.3. SPAR-H

SPAR-H acknowledges that certain PSF have both positive and negative effects on health. The majority PSFs are assumed to have positive effects by SPAR-H, which should be taken into consideration while estimating the HEP. Additionally, SPAR-H makes the assumption that these positive effects frequently reflect the significance of the PSF's negative effects on performance [54]. Dependency based SPAR-H has been used in clinical and pathology laboratories [55], hospitals [56], Radiology [57], Neonatal ICU [44], surgical settings [58].

III.4. HUMAN ERROR QUANTIFICATION

Human error quantification is the most challenging part of human reliability analysis, as all methods of determining human error involve quantifying human error probability (HEP) or human reliability values. Human error quantification refers to the process of determining the probability of human failure or measuring human reliability in performing a task using various methods.. The first generation of HRA was developed based on the assumption that a decline in condition would prevent humans from completing a task, similar to the reliability concept applied to machines or equipment. First-generation methods include THERP, Human Error Assessment and Reduction Technique (HEART), and SHERPA. The second generation of HRA introduces the concept that context is the most important factor influencing operator performance, emphasizing the connection between context and HEP. Second-generation methods include CREAM and SPAR-H [59]. These methods are based on specific databases and therefore, the results derived from these methods have relatively lower uncertainties such as: NARA [60].

III.4.1. Observational Clinical Human Reliability Analysis (OCHRA)

OCHRA is a method developed based on the culture of operating systems/surgery, which emphasizes the determination of error types (procedural/execution) and the underlying mechanisms (external error modes [33], [61]. OCHRA method is combined with several other methods to enhance the analysis and accuracy of human reliability determination, including Objective Structured Clinical Examination (OSCE) for laparoscopic operations [34]; Non-Technical Skills (NOTECHS) for laparoscopic cholecystectomy surgery [62]; Objective Structured Assessment of Technical Skills (OSATS) [63] and Lichtenstein Open Inguinal Hernia Repair (LOIHR) for open inguinal hernia repair procedures [64].

III.4.2. Heart

HEART method used to quantify Human Error Probability (HEP) based on a function of three variables: General Task Types (GTTs), Error Producing Conditions (EPCs), and the relative importance of each selected EPC as determined by expert judgment [65]. This method has been applied [66], [67] or combined with the Graphic Rating Scale for weighting in the radiotherapy treatment process [68], Fuzzy logic [69], Fuzzy Stepwise Weight Assessment Ratio Analysis (SWARA-PCA) in nursing [70], Macro Cognitive- Bayesian Analysis [71], Fuzzy- Software, Hardware, Environment, Liveware (SHELL) - The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS [72].

III.4.3. Success Likelihood Index Methodology (SLIM)

SLIM is a decision- analytic approach with fundamental rationale is that the success likelihood of a task depends on the combined effects of a set of PSFs [15]. Fuzzy Analytical Hierarchical Process (FAHP) were used, for study in an emergency department in Iran. Writing medications information in the patient's Kardex based on the information recorded in the PRF", had the highest HEP (2.06 E-2) [73]. Fuzzy Analytical Network Process (FANP) combined with SLIM used to investigate human reliability in 54 hospital emergency departments in 15 provinces of Iran. From matrix of paired comparisons in nine emergency tasks using SLIM, checking test results and diagnosis task had the highest probability of error for referring patients to intensive care or discharge. [74].

III.4.4. SPAR-H

SPAR-H determines the Human Error Probability (HEP) based on the contributions of cognitive types, PSF (Performance Shaping Factors), and dependency factors such as crew, time, location, and cues. There are eight PSFs as: Available time, Stressors, Complexity, Experience/Training, Procedures, Ergonomics/HMI, Fitness for duty, and Work processes [54]. SPAR-H has been combined with other methods in some area, including HTA in pathology laboratories [55], and cross- sectional hospitals unit [56], FMEA in Radiology [57], HTA-SHERPA in Neonatal ICU [44], SWARA [75] and Ratio Magnitude Estimation (RME) in surgical setting [58].

III.4.5. CREAM

CREAM method based on the concept of Contextual Control Modes with determining HEP based on the values of Error Modes, Cognitive Performance Conditions (CPC), and Cognitive Function Failure (CFF). [76]. This method used to determine the probability of errors made by nurses in the emergency department and found that range error probabilities was 0.00966 – 0.02108 with giving oral medications as minimum and setting tasks and using DC shocks in urgent cases as maximum task. [77]. In the pharmacy area, recommended HRA assessment approach based on the pharmacy framework combined with Probabilistic Model Checking, called the Systems Analysis for Formal Pharmaceutical Human Reliability (SAFPHR) [78]. The use of existing HRA methods can generate more practical HEP values; however, the development of HRA methods, particularly specific Influence Factors (IF), will allow for better characterization of risks, greater contributions, and identification and evaluation of targeted improvements for processes [52]. This is the basis for the development of methods based on system characteristics by modifying IF, including in surgery [58], [79], and radiotherapy [71].

III.5. IMPACT ASSESSMENT

This stage aims to determine individual human error, PSF/IF/CPC in relation to the overall human error identified in the previous stages. Impact analyzing has been used in some areas in healthcare [44], [58], [68], [74], [80]. The determination of the influence of EPCs in human errors made using percentages (Percentage Contribution to Unreliability (%CU)) according to the HEART method used in the radiotherapy treatment process [68] and surgery [80]. Chadwick and Fallon (2012) identified the EPCs that most contribute to HEP in the radiotherapy treatment process are : shortage of time available for error detection & correction (49%), no obvious means of reversing an unintended action (31%), little or no independent checking or testing of output (14%), and task pacing caused by the intervention of others (6%) [81]. Onofrio and Trucco (2020) used Monte Carlo simulations to assess the influence of IFs (Influencing Factors) in critical tasks during open robotic surgery based on expert input. The simulation was conducted with scenarios based on the Clavien-Dindo grading system for patient outcomes [82].

III.6. ERROR REDUCTION

Error reduction goals are identify steps for error reduction through recommendations for error recovery strategies and system redesign recommendations [83], [84]. Recommendation strategy based on HRA concepts has been applied in some various areas in healthcare [17], [25], [44], [46], [74], [80]. SHERPA method analyzed human errors based on the type of error, the consequences of the error, control measures, and error prevention strategies [25]. Ashour et al (2022) stated the remedial strategies in pharmacy in stronger actions: architectural/physical plant changes, new devices with usability testing, engineering control (forcing function), process simplification, standardization of equipment or processes, and tangible involvement by leadership [17]. In the emergency unit, demonstrated that it can be used to provide remedial strategies, concluding that the remedial strategy should include hand hygiene, good infection control techniques, and the use of checklists to standardize practice for 115 sub-goals in three critical care [25]. In the Bronchoscope Assisted Percutaneous Dilational Tracheostomy (BPDT) surgical process, recommended both individual and organizational level interventions, such as improving the safety of BPDT beyond simulation-based education (SBE), pre-setting appropriate alarm limits, regular auditing of checklist compliance, and ensuring procedural adherence and communication[23]. For patient transfer to a hospital ward in nursing some recommendation are: strengthening communication around medication-related information, formal structured handovers by medical and nursing staff when a critical care patient transfers to a hospital ward and formal medication plan [85].

Table 1: Human Reliability Analysis Methods and Applications in Healthcare.

Authors	Units	Methods	TA	HEI	Representation	HEQ		Impact Analysis	Error Reduction Strategy	Main Findings
Bickely & Torgler [27]	Public Healthcare System	HFACS	√	√	-	-	-	√		Proposed the new framework of HFACS-PH to determine dependence between different levels and sub- categories.
Jalali et al [29]	Public Healthcare System	HFACS	√	√	-	-	-			Introduce a new and applicable framework for the causation of MAEs based on the original HFACS.
Yiasemidou et al[40]	Laparoscopic cholecystectomies	EEM, OCHRA CAT	-	√	-	√	-	√		Compared different case-specific, preoperative mental rehearsal methods before minimally invasive rectal cancer surgery to measured surgical performance using two validated scores, Competency Assessment Tool (CAT) and OCHRA.
Muthukuaramy et al [41]	Laparoscopic cholecystectomies	EEM, OCHRA	√	√	-	√	-	√		Develop a surgical error reduction system (SERS) for laparoscopic appendectomy by OCHRA model and impact analysis on patient's outcome.
Tang et al [86]	Sleeve gastrectomy	EEM, OCHRA , OSCE	√	√	-	√	-	√		A new approach that combines Objective Structured Clinical Examination (OSCE) and OCHRA was developed and used to assess trainees' operative and cognitive skills during laparoscopic training courses.
Khaleghi et al [43]	Emergency unit	SHERPA, MIL-	√	√	-	-	-	√		Identify human errors type and risk error analysis

		STD-88213							committed by emergency department (ED).
Pouya et al [87]	Neonatal ICU	SHERP A, SPAR-H	√	√	√	√	√	√	Determining the type of nursing task errors, the risk level, and assessing the probability of human error in the duties of the nurse.
Ashour et al [17]	Pharmacy	SHERP A	√	√	-	-	-	√	Used a prospective error analysis method to examine the process of dispensing medication, and identify remedial solutions to avoid potential errors, categorizing them as strong, intermediate, or weak based on an established patient safety action hierarchy tool
Corbett et al [20]	Surgery	SHERP A	√	√	-	-	-	√	Developed a hierarchical task listing of steps required to perform successful Functional Endoscopic Sinus Surgery (FESS), identification of errors, risk analysis, and reduction through remediation.
Lavelle et al [88]	Surgery	SHERP A	√	√	-	-	-	√	Used SHERPA to identify the steps and the risk associated with each of these steps required to complete a BPD
Aliabadi et al [89]	Chemotherapy	SHERP A, HFMEA	√	√	-	-	-	√	Identification and assessment of physician and nurse 'errors during chemotherapy process, corresponding risk and safety principles in cross-sectional descriptive study.
Faiella et al [90]	Home care settings	HTA, SHERP A, HFMEA, STAMP-STPA	√	√	-	-	-	√	This combination of Healthcare Failure Mode and Effect Analysis (HFMEA), SHERPA and STAMP-STPA was effective in identifying corrective actions to address human errors and detecting failures of the constraints necessary to maintain safety
Poulsen et al [91]	Manag. Drug shortages	SHERP A, HFMEA, STAMP	√	√	-	-	-	√	Used prospective risk assessment to identify patient safety risks in hospitals associated with the management of DSs among actors at national, regional and local level in Denmark.
Lucey et al [45]	Open carpal tunnel decompression	SHERP A	√	√	-	-	-	√	Used HRA techniques to identify critical steps that are prone to error, potential human errors at each subgoal, the level of risk associated with each task and how these potential errors could be prevented.
Motie et al [49]	Nursing	SHERP A	√	√	-	-	-	√	Identify and evaluate human errors among nurses working at an Iranian Hospital.
Mohammadfam I et al [51]	Nursing	CREAM		√	-	√	-	√	Identify and evaluate the nature and reasons of human errors in the medication process in a hospital.
Zhang et al [92]	Blood transfusion	LHFs, THERP	√		√		-	-	Develop a new method based on linguistic hesitant fuzzy sets and the THERP technique

									to manage the dependence in HRA
Amir Farzam et al[55]	Pathology lab.	SPAR-H			√	√	-	√	Identify human error using SPAR-H in clinical and pathology laboratories in hospitals.
Sands et al[93]	Radiology	SPAR-H, FMEA	√		√	√	-	-	Proposed methodology which combined SHERPA and FMEA to identified error modes with potential affects to the safe delivery of treatment and risk analysis in radiotherapy.
Chenani et al [94]	Surgery	SPAR-H, RME	√		√	√	√	√	Adapt SPAR-H technique for application in surgical settings through suggesting more context-specific definitions for performance shaping factors (PSFs), designing precise levels and elicitation of multipliers through a domain expert judgment approach.
Mishra et al[62]	Laparoscopic cholecystectomies	OCHRA, NOTEC HS	√	√	-	√	-	√	The relationship between non-technical teamwork skills and technical errors was studied using a behavioral marker system validated in aviation and adapted for use in surgery
Nazari & Simons[95]	Laparoscopic cholecystectomies	OCHRA, OSATS	√	√	-	√	-	√	Use if the step-by-step frameworks to construct an accurate Lichtenstein open inguinal hernia repair (LOIHR) stepwise description and the OCHRA-checklist based on this stepwise description for surgical training and assessment
Aceves-Gonzalez et al[66]	General	HEART	√	√	-	√	-	√	Use HEART to evaluate a medication administration task within a simulated scenario of NICU and estimate the impact of a human-centered design (HCD) label in medication administration compared to a look-alike (LA) label.
Beirouti et al[67]	Intensive Care Unit	HEART, AHP	√	√	√	√	√	√	Predicted, revealed and assessed of medication errors nurses in one of the public hospitals.
Chadwick & Fallon[81]	Radiotherapy	HEART, Graphic Rating Scale	-	-	-	√	√	√	Analyze critical nursing tasks within modern radiotherapy using modified version of the proactive HRA method.
Castiglia et al [69]	Radiotherapy	HEART, Fuzzy Logic, THERP	√	√	√	√		√	Proposed method to investigate accident scenarios that involve operator errors during high-dose-rate (HDR) treatment by modified on the basis of fuzzy set concept with the aim of prioritizing an exhaustive list of erroneous tasks that can lead to patient radiological overexposures.

Kaseoglu et al [70]	Nursing	HEART , Fuzzy SWAR A-PCA (FSPC)	√	√	√	√	√	√	Proposes the effect of the subjective judgments of the decision-makers on the objectively obtained HEP with FSPC-HEART method to calculate HEP for each task, combined with the effect of physical and mental workload factors for each employee.
Ghasemi et al [96]	Emergency	SLIM, FAHP	√	-	-	√	-	√	Developing a new and comprehensive method for estimating the probability of medication errors in hospitals by identifying factors affecting medication errors based on healthcare framework, weighting and rating of factors, the Fuzzy multiple attributive group decision making methodology and Fuzzy Analytical Hierarchical Process (FAHP) and SLIM to calculate the probability of medication errors.
Sefidkouhi et al [74]	Emergency unit	SLIM, FANP	√	-	-	√	√	√	Identify the factors contributing to human error in hospital emergency departments using Fuzzy Analytical Network Process (FANP) and SLIM to investigate human reliability in cross sectional emergency departments.
Chenani et al [97]	Surgery	SPAR-H, SWAR A	√	-	√	√	-	√	Adapt SPAR-H technique through Stepwise weight assessment ratio analysis (SWARA) and eleven-digit numerical scale to quantify weight and negative influence rate of the PSFs during surgical processes
Zheng et al., [98]	Pharmacy	CREAM, PMC	√	√	√	√	√	√	Develop a new HRA called the Systems Analysis for Formal Pharmaceutical Human Reliability (SAFPHR) by combining concepts from CREAM with Probabilistic Model Checking (PMC), a computational tool for automatically proving properties about complex, stochastic systems.
Deeter et al., [99]	General	CREAM	-	√	-	v	-	v	Human error modes identification, and causal factor associated with error modes for 58 sentinel events.
Rantanen et al., [100]	Oncology department	GEMS, CREAM	√	√	-	√	-	√	Employed HTA, Generic Error Modeling System (GEMS, both qualitative and quantitative prospective CREAM, risk mitigation and made recommendations for further improvement of safety of the pharmacy operation.
Onofrio & Trucco[82]	Robotic surgery	HEART , Monte Carlo	√		-	√	√	√	Propose methodology for performing mesoergonomics analysis and simulated using

									Monte Carlo for Grade 0 to 3 patients outcome.
Bourne et al., [101]	Critical cares	HTA, SHERP A	√	√	-	-	-	√	Identify the task steps involved in intensive care patients transferring to a hospital ward and their potential for human errors, and to prioritize areas to improve medication safety.
Pandya et al., [102]	Radiotherapy	HEART, Macro Cognitive, BA, CARA, THERP	√	√	√	√	√	√	Develops the quantification framework of a new HRA method, for the radiotherapy domain. The method's reference data is obtained via expert judgment, due to the lack of domain-specific data, elicited on a qualitative scale. The values are combined via an expert aggregation method, developed specifically for HRA. The paper also includes an attempt to validate the elicitation against applicable HEP values from existing HRA methods (THERP, CARA).
Wang et al., [103]	Robot assisted rehabilitation process	HTA, HEART, SHELL, TOPSIS	√	√	√	√		√	Develop extended HEART method which integrates the HEART, SHELL model, HTA. Specifically, the weight assignment of the expert group is determined using the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and Trapezoidal fuzzy number to handle the vague and uncertain information of expert opinions.

Source: Authors, (2026).

HRA has been widely applied in human error analysis in healthcare to identify errors and improve worker reliability. Healthcare is a very complex domain, requiring interactions between components to ensure the success of the system. It is specific and thus requires a high tolerance for uncertainty [4]. Future healthcare faces significant challenges, including complex care needs of highly high-risk populations (elderly, immune system disorder, comorbidities), staff shortages, burnout, and global crises (such as the COVID-19 pandemic), where identifying, controlling, and predicting hazards that lead to care errors will impact patients and system users [83]. This does not mean that HRA techniques cannot be applied in healthcare, but it shows that applying this method in healthcare is not easy [71]. In general, several activities differ from the original HRA domain (nuclear), such as differences in organization, equipment design, culture, methods, and techniques. Thus, the application of methods from other domains must be carefully adapted and applied appropriately [82]. The aim goals, theoretical analysis, and limitations of a technique in its original context must be understood in detail before it is applied in healthcare [62]. Because failure to apply HRA, in addition to reducing the benefits gained from its application, also contributes to increased risks for patients [82]. The characteristics of activities in healthcare are not only different from the nuclear industry (the basis of HRA) but also among units within healthcare.

For example, surgery has characteristics such as time limitations, patient comorbidities, risk levels, high uncertainty, and high technology understanding, which are different from inpatient care and require long-term communication and collaboration with lower risk levels and uncertainty. These characteristics must be understood and serve as the basis for developing HRA methods in healthcare. Some proposed HRA methods in healthcare have been done such as SAFPHR (Systems Analysis for Formal Pharmaceutical Human Reliability) based on CREAM to analyze human error factors in the common community pharmacy dispensing procedure [98], [104] and OCHRA based on the concept of EEM [105] but the HRA method adaptation for the different unit in healthcare remains open. The dependence approach such as characterization and identification of dependencies, as in the overall HRA method is the weakest part of HRA analysis because there is no consistency in terminology and the application of basic HRA. There are two issues related to inconsistency: dependency and interrelationship between subtasks. These two issues should be viewed separately from different perspectives, as they are critical points in the accuracy of HEP calculations. Paglioni and Groth [106] redefined the concept of dependency as the relationship between two HRA variables when there is a direct/indirect connection that will affect the conditional probability of a variable.

The concept of dependency as the interrelationship of all variables used in HRA analysis aligns with previous research [107], [108] where the weighting of IFs was shown to significantly impact HEP results. Some weightings in healthcare have been conducted, including using the Graphic Rating Scale [109] and Fuzzy AHP [110], but the application of other MADM methods or interrelationship methods between tasks or factors still available, including Preference Ranking Organization Method For Enrichment Evaluation (PROMETHEE), Elimination et Choix Traduisant la Realité (ELECTRE), Bayesian Network, and Bayes Bayesian Network. Error reduction strategies for improving worker reliability in healthcare have been made using expert analysis, SHERPA, Markov Monte Carlo on several existing factors. Analysis of the influence of factors on reliability is needed to ensure that the improvement strategy becomes more targeted, focused, and systematic. Sensitivity analysis [65], [111] or Percentage Contribution to Unreliability (% CU) by the HEART method can be used to analyze influencing factors, making improvement recommendations more quantifiable and significant for enhancing human reliability.

V. CONCLUSIONS

The scope of the HRA method's used in healthcare, its application domains, and the combination of approaches employed are examined in this review of the literature. A number of nuclear-based HRA techniques, such as SHERPA, THERP, HEART, SLIM, CREAM, and SPAR-H, have been widely applied in the medical field. In the fields of surgery and radiotherapy, IFs have been developed and adjusted in accordance with the culture of the healthcare system, however, additional adaptation are still required in other areas if the activity characteristics differ from those of the basic HRA technique or from current advances. Similar changes have been implemented in surgery (OCHRA) and pharmacy (SAFPHR) to determine human reliability in healthcare, but other sectors still need improvement. The same applies to the description, examine, depiction of interrelationships among activities or IFs in healthcare. This literature review is expected to serve as a source or initial step for researchers in determining the techniques and developments to pursue in healthcare.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Tutik Farihah, Jamasri and Rini Dharmastiti.

Methodology: Tutik Farihah and Jamasri.

Investigation: Tutik Farihah and Rini Dharmastiti.

Discussion of results: Tutik Farihah, Jamasri and Rini Dharmastiti.

Writing – Original Draft: Tutik Farihah.

Writing – Review and Editing: Tutik Farihah, Jamasri and Rini Dharmastiti.

Resources: Tutik Farihah.

Supervision: Jamasri and Rini Dharmastiti.

Approval of the final text: Tutik Farihah, Jamasri and Rini Dharmastiti.

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