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ORIGINAL ARTICLE

A Hybrid Approach for Analyzing Human Reliability (Case:An Industrial Sector in Tehran)

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ABSTRACT

According to recent reports, human errors may cause major systemic disasters at different levels of an organization. Therefore, human reliability assessment is an essential and systematic approach to the analysis and reduction of human errors in industries. The aim of this study is to propose a new approach for analyzing human reliability in order to minimize the defects and shortcomings of conventional methods in this field. The relevant hypotheses of the twelve-step approach indicate that all evaluations are performed at a continuous time and in a varying environment, and all variables are independent of each other. In the proposed approach, a combination of techniques (such as HTA, SHERPA, Markov, etc.) is used for identifying human errors and measuring human reliability. To measure the function of this new approach, a case study between four milling machine operators in workshops of Saipa Automobile Company for six months was considered. Finally, the results show the ease of use and enough clarity of the proposed approach for analysts' use.

KEYWORDS: *Human Error, Human Reliability Assessment, SHERPA, Markov Method*

INTRODUCTION

Over the past few decades, human activities have played the most important role in accidents with severe political, economic, social, and environmental consequences and disruption of planned performance. Several studies have indicated that more than 90 percent of all accidents in the industry have occurred due to human errors such as the Three Mile Island accident (1979), the Chernobyl disaster (1986), the Bhopal disaster (1984), the Space Shuttle Challenger disaster (1986), the Piper Alpha oilfield explosion (1988), and the Prestige oil spill (2002) [1,2]. Human resources are one of the most important assets of organizations that play a huge role in their success [3]. It is almost impossible to eliminate human error, and with the high level of uncertainty in human activities, it is very difficult to predict all the causes of human error, which may lead to inaccurate results [4].

Adverse effects of human error occurrence can be largely neutralized and mitigated by creating and stabilizing appropriate managerial programs and observing their determinants [5]. To achieve an effective program for managing human errors, probabilities of their occurrence should be measured by appropriate statistical methods [6]. In this regard, human reliability assessment is an important step that identifies, models, and quantifies important human errors and provides solutions to prevent them or reduce their adverse consequences. Thus, the reliability or

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unreliability of data related to human factors and the complexity of human behavior can be determined through human reliability assessment [7]. Additionally, human reliability should be considered as a distinct element of the reliability of technical and economic systems [8] and should be considered in the design and development of complex systems [9].

Results of human reliability assessment are often given as input to the possible risk assessment sector. Then, the reliability of an entire system is analyzed by dividing each system into its components including hardware, software, and human operators [7]. In general, human reliability assessment approaches include seven stages: problem definition, analysis of performance factors, task evaluation, human error assessment, error assessment, margin elimination, elimination strategies, and evaluation of recommendations [10].

Human reliability assessment techniques are often employed as an essential component of safety management for safety-critical systems such as nuclear facilities, military operations, and aerospace projects [11]. In this regard, various approaches have been recently developed in this context. Therefore, researchers have accurately analyzed information such as costs, ease of use, ease of analysis, data availability, reliability, and face validity to find the best approach to assess human reliability [12,13]. The evaluation of human reliability analysis methods and accreditation to their approaches and models is very important. Such validation is warranted to assess the credibility of HRA results [14].

There are different classifications of human reliability assessment methods. The most complete and contemporary classifications have divided these techniques into three groups, namely: task-based, time-based, and condition-based groups. Each model has important features according to the analysts [7].

Understanding the issues and limitations of human reliability assessment techniques is very important. Therefore, in a recent study, Park et al. (2019) have examined the remaining and emerging issues of human reliability in domestic nuclear power plants [15]. French et al. (2011) studied some methods of human reliability assessment. By arguing that there was a need for further research and development before fulfilling the needs of human reliability and risk analysis, they sought to create a way to reach a managerial society with full knowledge of implicit assumptions in human reliability analysis and its limitations. Furthermore, they concluded that these methods could give managers structures by which they can manage complex systems safely [16]. De Felice et al. (2012) reviewed the development of human reliability analysis since its creation. They identified the scope of every methodology to assess human reliability and its strengths and weaknesses [17]. Musharraf et al. (2013) pointed out that traditional approaches of human reliability analysis suffered from unrealistic assumptions about the independence of human factors and related measures [18].

Among the numerous quantitative studies that have been conducted with regard to human reliability assessment in various industries, Laumann (2018) has found and categorized various criteria by using the thematic analysis method. She also stated some ways to improve human reliability assessment by the proposed criteria [19]. Precise qualitative analysis is an important factor for predictions in the field of human reliability assessment [14].

Recently, dependence assessment that examines the relationship between human tasks as well as the effect of this dependence on the probability of human error has been extensively considered in studies on human reliability assessment [20]. For instance, Chen et al. (2017) proposed a new computational method based on the Dempster–Shafer evidence theory (DSET) and the hierarchical analysis process for controlling dependence in human reliability analysis [21]. Guo et al. (2017) also introduced a new computational model based on the Dempster–Shafer evidence theory and the Evidence Credibility Decay Model (ECDM), whose results indicate a change in dependency levels due to changes in the positions of input factors [22].

Most papers that have reported studies on human reliability assessment have presented the investigation of dangerous and critical industries, including nuclear, process, and transportation industries. In this regard, Di Pasquale et al. (2018) provided the first systematic literature review on human reliability assessment in manual assembly systems [23]. In a study titled "Assembly-specific database for predicting human reliability in assembly operations," Kern & Refflinghaus (2015) introduced a process that provided the possibility of transferring knowledge about human reliability, which was obtained from industries with safety crises, to manual assembly operations. The study aimed to systematically predict the possibility of human error in any field of industrial and manual

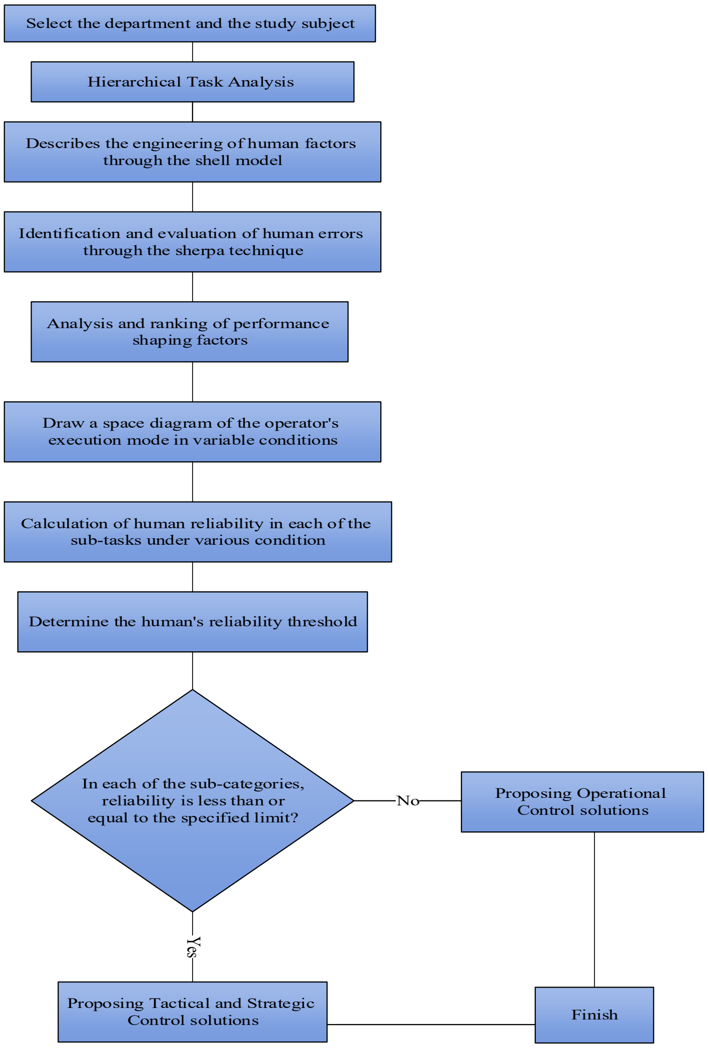

Figure 1. The new approach structure

mass production [24]. Also, in this context, Komal (2017) in his study considered the probability of error in the process of handwashing because to develop a food safety management system for healthcare, the implementation of a proper handwashing technique by humans could play a vital role [25].

Considering conditions, time, and work tasks, and the unreliability in the estimation of human errors, the present research sought to present a new approach to analyze human errors and reliability. This approach included twelve stages and its constant assumptions indicated that all evaluations were conducted at a constant or changing time and environment and all variables were independent. To offer the proposed approach in this study, a combination of error identification and evaluation techniques and human reliability was used. Finally, the study suggested controlling measures dependent on the threshold of human reliability that was different according to experts in various industries and jobs. A case study of milling machine operators working in workshops of SAIPA Automobile Company was considered to assess the performance of this approach.

According to our literature review, there is only one research on human reliability assessment in the automotive industry that utilized the analytic hierarchy process (AHP) to select an appropriate human reliability analysis technique. In this way, HRA techniques have been examined based on the criteria used in the automotive industry [26].

RESEARCH METHOD

The presented approach in this study includes a combination of different qualitative and quantitative techniques with the aim of identifying and evaluating human errors and human reliability, as shown in Fig.

1. The objectives of this approach include reducing the need for experts' judgments, conducting more accurate analyses, and ultimately making decisions based on reliability thresholds, which vary in different industries. In this section, each of the stages of this approach has been introduced in detail.

Hierarchical Task Analysis (HTA)

The Hierarchical Task Analysis includes the study and analysis of activities performed to achieve a primary goal. Numerous researchers have used this method to accurately evaluate human errors. For instance, Akyuz et al. (2018) used this method to conduct a task analysis of operating procedures of the emergency fire pump at ships [27], and Boring (2015) introduced this technique to define and build seven stages of incidents caused by human failure that is the unit of analysis in the assessment of human reliability [28]. Akyuz and Celik (2015) used this technique to assess human reliability through knowledge-based systems and reduce operational problems caused by human errors on sea ships. Additionally, they argued that the Analytic Hierarchy Process of job tasks is a need for human reliability assessment; therefore, the analysts can properly identify opportunities for the occurrence of human errors [29]. In another study, they also used the Analytic Hierarchy Process of job tasks to assess human reliability in gas oil storage and transmission processes that are complex operations in marine fleet transportation [30]. Musharraf et al. (2013) used this technique to evaluate human reliability under emergency conditions. As a result, they identified a total of 17 tasks in this scenario and put them in four steps, namely awareness, assessment, withdrawal, and recovery [18].

SHELL Model

The SHELL model stands for Software, Hardware, Environment, and Liveware. The main focus of this model is on the human factor, or the liveware, which is the most fundamental, unpredictable, and impressible component in terms of internal changes (such as hunger, fatigue, motivation, etc.) and external changes (such as temperature, light, etc.), and also the most flexible component of the system. This member should be placed alongside other components in a way that will prevent possible failure in different conditions [31]. This model can indicate and record all interactions of operators with other components of the system since it is an important and useful step in identifying human errors. Lin et al. (2014) used this model to carry out a qualitative analysis of human reliability in medical devices [32]. Pouliquen et al. (2005) studied an approach obtained from the Accident/Incident Data Reporting (ADREP) to conduct research on the validation of human factors in the SHELL Model [33].

Systematic Human Error and Reduction Prediction Approach (SHERPA)

This technique can rank errors and determine their consequences and critical values in each job task that is identified by the Analytic Hierarchy Process. The Systematic Human Error and Reduction Prediction Approach can be effectively used when changes occur in various types of activities, environmental conditions, time spent at work, and interruptions during work shifts to evaluate changes in the probability of human errors. The generality is a main benefit of this technique. In other words, this technique is comprehensively appropriate regardless of constraints of a particular environment and working conditions [34]. This method has been widely used in studies on safety and reliability in a variety of industries, including the nuclear industry, oil and gas, transmission, and distribution of electricity and petrochemicals. For instance, Jang et al. (2016) proposed a new framework for human reliability assessment and soft control of executive errors in advanced control rooms of nuclear power plants. Their study was based on the analysis of tasks through a systematic approach to identify and reduce human errors and examine features of applied techniques in human reliability analysis [35]. Moreover, Mandal et al. (2015) used this method along with a hierarchical analysis of job tasks and the Fuzzy Vikor method for more complete and better identification of human errors and prioritization of possible risks in working with air cranes [36]. Imtiaz et al. (2014) studied broad aspects of human interactions and practices and probabilities of errors in these cases among oil and gas exploration personnel through the Systematic Human Error and Reduction Prediction Approach [37].

Analyzing and Ranking Performance-shaping Factors

Human factors are influenced by a number of sub-factors that affect the creation of errors [13]. These factors are known as determinants of performance and include instructions, education, connections, supervision, employee recruitment, people accessibility to organizations, human-machine interfaces, organizational factors, stress, environmental conditions, and strategic factors such as different conflicting goals, time pressure, and limited resources [38,39]. A large number of human failure events are dynamically associated with multiple error causes in current HRA methods. In this regard, no guidance or limit is considered to determine the qualitative levels of performance shaping factors [40].

Kim et al. (2017) presented a framework for estimating the levels of Performance Shaping Factors (PSFs) on the assumption that there is sufficient human reliability data [40]. Porthin et al. (2019) also examined the effects of PSFs on the estimation of probable human error in advanced control rooms (ACRs) of nuclear power plants. The result is that digitization may change the effects of PSFs on error estimation and the method in which PSFs should be defined and measured should be changed [41].

In another study by Hetherington et al. (2006), with a review of 20 studies on seafaring, human elements related to shipping safety have been investigated. The monitoring and modification of human factors affecting shipping safety, including fatigue, pressure, health, state of consciousness, workgroup, decision-making, communication, automation and safety culture are considered necessary [42]. In this regard, Kelly & Efthymiou (2019) analyzed human factors in fifty controlled flight into terrain aviation accidents from 2007 to 2017. To do this they used the Human Factors Analysis and Classification System (HFACS) framework and interviews with five senior aviation safety experts. Eventually, the common factors involved in these accidents were decision-making and skill-related errors associated with planning, cooperation and communication issues [43]. Providing a new approach, the present study determined the performance-creating factors in each job task separately and then analyzed and ranked them through fuzzy theory. The fuzzy technique in group decisions leads to the establishment of a common understanding of experts' views. In other words, the quantification of experts' views makes it possible to fully reflect the human thought style and has more consistency with linguistic and sometimes vague human descriptions [44].

Experts' views can be gathered by a 5-7 point Likert Scale to determine the significance of these factors. Their views become a triangular fuzzy number using the fuzzy scale. The fuzzy mean can be used to aggregate views as follows:

$$A_i = \left(l_i, m_i, u_i\right) \tag{1}$$

$$A_{AVE} = \left(\frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}\right) \tag{2}$$

The following equation can be used to defuzzificate and finalize the data mean

$$\text{Definite amount} = \frac{l+m+u}{3} \tag{3}$$

Calculation of Human Reliability in each of the Sub-tasks under Variable Conditions

Human operators can make errors in normal or stressful conditions. Among techniques for analyzing and calculating human reliability, Markov's method is capable of providing a setting in which only one operator continuously performs a task in variable conditions. According to fig. 2, assumptions corresponding to this model are:

1. All errors are statically independent.
2. The operator performing the task is subject to continuous time.
3. The human error rate is constant.

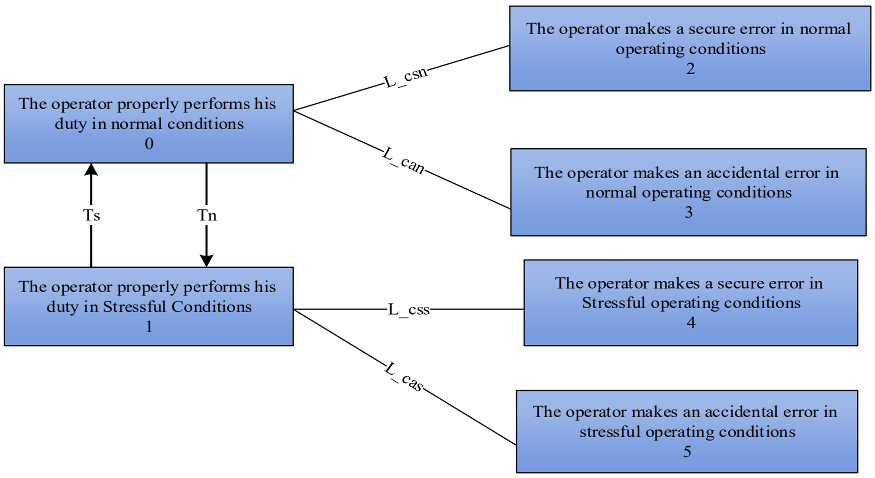

Figure 2. Space diagram of human operator implementation model

4. Environmental change from normal to abnormal and vice versa is constant [45].

Therefore, to calculate the reliability of operators in performing each of the sub-tasks in normal and stressful conditions, a mathematical model based on Markov's method with respect to the human error rate was used [46]. To use this model, the space diagram of human operators' implementation scenarios in variable conditions must be drawn first (Fig. 2) and then the error rate and transfer coefficients from one condition to another must be calculated to determine the number of errors.

$\sum t$ = The sum of total working hours
N = Number of Errors occurred
L = Error rate
T_s= Constant rate of change from normal conditions to stressful conditions
T_n= Constant rate of change from stressful conditions to normal conditions
L_{csn}= Constant error rate that operator in normal working conditions makes safely
L_{can}= Constant error rate that operator in normal working conditions makes with an incident
L_{css}= Constant error rate that operator in stressful working conditions makes safely
L_{cas}= Constant error rate that operator in stressful working conditions makes with an incident
Based on the Markov method, a system of equations corresponding to Figure 2 is as follows:

$$\frac{dp_0(t)}{dt}+(L_{csn}+L_{can}+T_s)\times p_0(t)=T_n\times p_1(t) \quad (4)$$

$$\frac{dp_1(t)}{dt}+(L_{css}+L_{can}+T_n)\times p_1(t)=T_n\times \quad p_0(t) \quad (5)$$

$$\frac{dp_2(t)}{dt}=L_{csn}\times p_0(t) \quad (6)$$

$$\frac{dp_3(t)}{dt}=L_{can}\times p_0(t) \quad (7)$$

$$\frac{dp_4(t)}{dt}=L_{css}\times p_1(t) \quad (8)$$

$$\frac{dp_5(t)}{dt}=L_{can}\times p_1(t) \quad (9)$$

$$p_0(0)=1$$

$$p_1(0)=p_2(0)=p_3(0)=p_4(0)=p_5(0)=0$$

By solving the above equations through Laplace transform, the probabilistic equations of different conditions are obtained. Therefore, human reliability at time, unreliability under normal and stressful conditions, and the mean time to human error for each of the sub-tasks can be calculated by the following formulas [46]

$$A=\exp\left(-\left(\frac{1}{2}\times(L_{csn}+L_{can}+L_{cas}+T_n+T_s+L_{css})\right)\times t\right) \quad (10)$$

$$B=\cosh\left(\frac{1}{2}\times t\times E\right) \quad (11)$$

$$C=\sinh\left(\frac{1}{2}\times t\times F\right) \quad (12)$$

$$D=1/\left(\begin{matrix}L_{csn}\times L_{css}+L_{csn}\times L_{cas}+L_{csn}\times\\ T_n+L_{can}\times L_{css}+L_{can}\times L_{cas}+\\ L_{can}\times T_n+T_s\times L_{css}+T_s\times L_{cas}\end{matrix}\right) \quad (13)$$

$$\begin{aligned}E=\mathrm{sqrt}(&L_{can}^2+(2\times(T_s+L_{csn}-L_{css}-L_{cas}-T_n))\times\\ &L_{can}+L_{cas}^2+(2\times(L_{css}-L_{csn}-T_s+T_n))\times L_{cas}+L_{csn}^2\\ &+(2\times(T_s-L_{css}-T_n))\times L_{csn}+L_{css}^2+\\ &(2\times(-T_s+T_n))\times L_{css}+(T_n+T_s)^2)\end{aligned} \quad (14)$$

$$F=\mathrm{sqrt}\left(\begin{matrix}-2\times L_{csn}\times L_{css}-2\times L_{csn}\times L_{cas}-2\times\\ L_{csn}\times T_n-2\times L_{can}\times L_{css}-2\times L_{can}\times L_{cas}-2\times L_{can}\times\\ T_n-2\times T_s\times L_{css}-2\times T_s\times L_{cas}+2\times T_s\times T_n+L_{csn}^2+\\ 2\times L_{csn}\times L_{can}+2\times L_{csn}\times T_S+L_{can}^2+2\times\\ L_{can}\times T_s+L_{cas}^2+2\times L_{cas}\times T_n+2\times L_{cas}\times\\ L_{css}+T_n^2+2\times T_n\times L_{css}+T_S^2+L_{css}^2\end{matrix}\right) \quad (15)$$

$$p_0(t)=A\times(\cosh(\frac{1}{2}\times t\times F)+c\times \frac{T_n-L_{csn}-L_{can}+L_{cas}-T_s+L_{cas}}{F}) \quad (16)$$

$$p_1(t)=2\times T_s\times A\times\frac{\sinh(\frac{1}{2}\times t\times E)}{F} \quad (17)$$

$$\begin{aligned}p_2(t)=((&L_{csn}\times L_{css}+L_{csn}\times L_{cas}+L_{csn}\times\\ &T_n+L_{can}\times L_{css}+L_{can}\times L_{cas}+L_{can}\times T_n+T_s\times L_{css}+\\ &T_s\times L_{cas}-T_s\times T_n-2\times L_{cas}\times T_n-2\times L_{cas}\times L_{css}-\\ &T_n^2-L_{cas}^2-L_{css}^2-2\times T_n\times L_{css})\times A\times C\times\frac{L_{csn}}{F}+\\ &(L_{css}-(L_{css}+L_{cas}+T_n)\times\\ &B\times A+T_n+L_{cas})\times L_{csn})\times D\end{aligned} \quad (18)$$

$$p_3(t) = ((L_{csn} \times L_{css} + L_{csn} \times L_{cas} + L_{csn} \times T_n + L_{can} \times L_{css} + L_{can} \times L_{cas} + L_{can} \times T_n + T_s \times L_{css} + T_s \times L_{cas} - T_s \times T_n - 2 \times L_{cas} \times T_n - 2 \times L_{cas} \times L_{css} - T_n^2 - L_{cas}^2 - L_{css}^2 - 2 \times T_n \times L_{css}) \times A \times C \times \frac{L_{can}}{F} + (L_{css} - (L_{css} + L_{cas} + T_n) \times B \times A + T_n + L_{cas}) \times L_{can}) \times D \quad (19)$$

$$p_4(t) = \left(\begin{array}{l} -C \times T_s \times L_{css} \times A \times \\ \frac{L_{csn} + L_{can} + L_{cas} + T_n + T_s + L_{css}}{F} + \\ (1 - B \times A) \times L_{css} \times T_s \end{array} \right) \times D \quad (20)$$

$$p_5(t) = \left(\begin{array}{l} -C \times T_s \times L_{cas} \times A \times \\ \frac{L_{csn} + L_{can} + L_{cas} + T_n + T_s + L_{css}}{F} + \\ (1 - B \times A) \times L_{cas} \times T_s \end{array} \right) \times D \quad (21)$$

Human reliability at time

$$R(t) = P_0(t) + P_1(t) \quad (22)$$

Unreliability under normal conditions

$$URN(t) = P_2(t) + P_3(t) \quad (23)$$

Unreliability under stressful conditions

$$URS(t) = P_4(t) + P_5(t) \quad (24)$$

Mean Time To Human Error $MTTHE = \int_0^{\infty} R(t)dt$ (25)

Determining Human's Reliability Threshold and Proposing Control Solutions

In the final stages of applying the proposed approach, the human reliability threshold is determined by considering the average opinions of the intended industry experts. In addition, based on the value of this threshold, control solutions will be presented. If the value of human reliability for each of the sub-tasks is less than or equal to the threshold, strategic and tactical control strategies will be proposed. Otherwise, operational control strategies (basic and sometimes instantaneous ones) will be proposed. Operational control methods (basic and sometimes instantaneous) include a lot of training, monitoring, and inspections by the operators and supervisors during work, establishing an appropriate communication system with other departments and individuals, and small changes in the environment atmosphere, which sometimes happen due to the routine nature of the tasks. However, considering strategic and tactical control methods, more basic measures and gradual evaluation of employees' feedback on the controlling solutions are needed; this is often realized through reviewing attitudes and skills of employees, development of long-term training programs, development of individual and group goals, and systems of reward and productivity. Finally, to employ strategic and tactical control strategies and limit human errors with a strong impact on reducing human reliability, a combination of performance evaluation methods and job richness techniques can be used in the long-term.

In fact, after the control solutions are provided, the risk level and human reliability are again evaluated. If positive results are evaluated, the work will be completed. Otherwise, they should be revised in providing control solutions or even previous steps.

CASE STUDY

The automotive industry is one of the key and largest industries in the country. Equally important, firms and factories constituting the automotive industry include a large number of different business units. One of these units is the triple hall. From the professions existing within this unit, the milling section was studied. The results obtained from applying the new proposed approach in this study are described in the following tables and figures.

Milling involves the following tasks:

1. Dimensional control and deburring of parts coming from the cutting unit to the machining unit.
2. Lineation, map reading, and consideration of dimensional and geometric tolerances of parts.
3. Fixing the work piece on the machine's desk.
4. Selecting the tool with respect to the machining method.
5. Selecting proper type of cooling liquid with respect to the substance.
6. Selecting the correct order of machining on the work piece.
7. Setting the machine rotation, the load applied on the work piece, the tool operation, and changing them during operation if necessary.
8. Deburring and final dimensional control of various dimensions of the work piece.
9. Putting the work tool in a special closet.
10. Cleaning the work table after finishing the milling operation.

Table 1. Checklist of human Error types in the Systematic Human Error and Reduction Prediction Approach

Error type	Error ID	Error description
Functional Errors: Individuals' failure in correct or timely performing of an act	1A	Act is performed too early or too late
	2A	The act is in a wrong time
	3A	The act is performed in the wrong direction
	4A	The act is performed less or more than necessary
	5A	The change operation is performed
	6A	Correct action is performed on the wrong operation
	7A	The wrong action is performed on the correct operation
	8A	Desired action is forgotten
	9A	Action is performed incompletely
	10A	The wrong action is performed on the wrong operation
Visit Error: Individuals' failure in timely or correct checking	1C	Checking is forgotten
	2C	Checking is performed incompletely
	3C	The correct check is performed on the wrong operation
	4C	The wrong check is performed on the correct operation
	5C	Checking is performed at inappropriate time
	6C	Wrong check is performed on the wrong option
Retrieval Errors: Possible Error occurrence in Error recovery by immediate action that is carried out after occurrence of an Error to returns the system to its original state	1R	Required information is not available
	2R	Information is presented incorrectly
	3R	Data retrieval is incomplete
Communication Error: It occurs during communication with other sectors	1I	No information is exchanged
	2I	Misinformation is exchanged
	3I	Information exchange is incomplete
Selection Error: When an operator selects the wrong option or forgets a stage in the process of controlling the system	1S	Selection will be deleted
	2S	Wrong choice is made

11. Delivering the work piece to the assembly unit.
The results obtained from implementation of SHELL model among milling machine operators are as follows:

Interaction with software: Specific instructions for performing the job in written and verbal forms are transmitted to operators through work plans and the unit supervisor. Safety instructions for handling milling machines and the chemical safety information sheets are also available to operators. Moreover, operators who work with Computer Numerical Control (CNC) and Numerical Control (NC) milling machines should also be familiar enough with coding and getting commands from devices through computers.

Interaction with hardware: Operators in performing the milling operations use blades appropriate for the work piece material, air grinder and rasps for deburring, and calipers and micrometers to control dimensions of the work piece. Various standard tools in a variety of shapes, thicknesses, and widths should be available to the operator. In the studied workshop, there were one ordinary and one manual milling machine, three NC milling machines, and one CNC milling machine.

Interaction with environment: The noise level at the work environment is 82-83 decibels, the comfort index in the cold season of the year is 5.22 CET[1], index of thermal stress is 7.21 WBGT[2], and the average brightness is 330 lux. The operator, in performing their tasks, is exposed to various chemicals such as oil, diesel, and oil-water of the cutter machine. Also, the milling operator is exposed to pollutants and noises caused by the work of other sectors such as welding and painting.

Interacting with departments and other people: Operators in performing their tasks are directly involved with individuals like the supervisor and operators of the cutting and assembly sectors, and indirectly are involved with parts designers and lab experts. Having applied the HTA and SHELL model to the milling machine operators, all human errors that exist in every job task were completely identified.

Additionally, this is done through a systematic human error and reduction prediction approach. Each of the sub-tasks may be a combination of errors, i.e., an error will result in a subsequent error. Moreover, to complete

1- Corrected Effective Temperature
2- wet bulb globe temperature

Table 2. Applying Systematic Human Error and Reduction Prediction Approach

Row	Job task	Error type	Error description	Error consequence	Risk level
1	Initial and final deburring	3A, 2C, 9A	The Operator does not make sure of complete and correct placement of work piece in clamp. Operator does not use personal protective equipment such as safety glasses and gloves in performing deburring. Operator does not respect the safety distance.	Causing damage to the operator (especially in the head and face) due to the work piece escaped from the clamp- Defectiveness of work piece and the waste of material, waste of time and sometimes rework.	3B

Table 3. Ranking the factors leading to risky operations

Factors leading to risky practices	Fuzzy average	Definite amount
Inadequate education	(0.65,0.9,1)	0.85
Lack of available time	(0.6,0.85,0.95)	0.8
Low experience	(0.5,0.75,0.95)	0.73
Lack of physical access to tools and facilities	(0.6,0.85,1)	0.82
Inappropriate quality of communication with other departments and individuals	(0.35,0.6,0.85)	0.6
Non-standard and unstable tools	(0.7,0.95,1)	0.88
Job fatigue and burnout	(0.4,0.65,0.9)	0.65
Complexity and high volume of work	(0.55,0.8,0.95)	0.77
Lack of supervision and inspection systems	(0.5,0.75,0.95)	0.73

worksheets of the systematic human error and reduction prediction approach, Table 1 is used to determine the error type [47]. According to Table 2, the risk level is also recognized through a matrix of risk probability and severity of occurrence.

The results of this step in one of the following job tasks (initial and final pilling) are shown as bellows:
After implementing the Systematic Human Error and Reduction Prediction Approach in relation to each of the job sub-tasks, effective performance factors in reducing operator reliability in each of these categories were separately identified and ranked by using the Fuzzy technique. In this regard, the opinions of 5 experts were taken into consideration. The higher the absolute mean value of each criterion became, the higher its priority was than others. Performing this stage of the proposed approach that prioritizes preventive actions is of great value. The results of this step, which are in relation to the initial and final sub-task of deburring, are shown as Table 3.

Assuming that the acceptance threshold in this step is 0.5, all factors mentioned in the table above are important to propose suggestions for the controlling strategies. In the next stage, the number of safe and unsafe errors was determined under normal and stressful conditions and during the given time, i.e., six months. The error rate was calculated for each of these conditions. Table 4 illustrates this step of the proposed approach for each of the job sub-tasks of the milling machine operators (the normal working hours and the number of hard working hours are 1440 and 360, respectively). In the studied unit, each person is allowed to have 60 hours of overtime per month. Additionally, since extra shift is rarely allowed, it is not considered in the calculations.

Table 5 illustrates the results obtained from the calculation of human error probabilities, the lack of human reliability in normal and stressful conditions, human reliability after a certain hour (12 hours), and the average time of human error for each of the job sub-tasks.

According to Table 6, the maximum and minimum unreliability in stressful conditions are related to sub-tasks eight and ten, respectively. The maximum and minimum unreliability in normal conditions are for sub-task seven and four. The results also show that the maximum and minimum reliability values after twelve hours belong to sub-tasks nine and eight, respectively. The mean time to human error and reliability after a specific hour are proportional, so the maximum and minimum values are respectively related to sub-tasks nine and eight.

The average opinion of the experts in relation to the

Table 4. Number and rate of human error in different job tasks and conditions

Job task	N_{csn}	N_{can}	N_{css}	N_{cas}	L_{csn}	L_{can}	L_{css}	L_{cas}
Initial and final deburring	0	1	3	1	0	0.0007	0.008	0.003
Initial and final control of dimensions	2	0	4	0	0.0014	0	0.01	0
lineation and map reading	1	0	3	1	0.0007	0	0.008	0.003
Fixing the work piece on the desk	1	0	3	2	0.0007	0	0.008	0.005
Choosing machining tools	1	1	3	1	0.0007	0.0007	0.008	0.003
Selecting and applying coolant	2	1	4	2	0.0014	0.0007	0.01	0.005
Choosing the right machining order	3	1	5	1	0.002	0.0007	0.014	0.003
Setting the machine, the amount of load entered into the work piece, and the tool advance	3	1	6	2	0.002	0.0007	0.016	0.005
Inserting work tools in a special wardrobe	1	0	2	1	0.0007	0	0.005	0.003
Cleaning the work desk	2	0	2	1	0.0014	0	0.005	0.003

Table 5. Occurrence probability of different scenarios

Number of Job task	$p_0(t)$ Probability of performing the right act in the normal conditions	$p_1(t)$ Probability of performing the right act in the stressful conditions	$p_2(t)$ Probability of a safe Error in the normal conditions	$p_3(t)$ Probability of a safe Error with an accident in the normal conditions	$p_4(t)$ Probability of a safe Error in the stressful conditions	$p_5(t)$ Probability of an Error with an incident in the stressful conditions
1	0.77434	0.1922	0	0.00678	0.01804	0.00586
2	0.7666	0.19112	0.016039	0	0.028415	0
3	0.77460	0.19233	0.006716	0	0.017841	0.005803
4	0.77170	0.1907511	0.006700	0	0.01775	0.011762
5	0.769235	0.191135	0.006692	0.0066927	0.017783	0.005784
6	0.755805	0.18688	0.013203	0.006639	0.023261	0.011630
7	0.74791	0.185708	0.019830	0.0066166	0.029088	0.005691
8	0.740943	0.182996	0.019751	0.0065901	0.033425	0.011489
9	0.780252	0.193943	0.006731	0	0.0118819	0.005832
10	0.777753	0.194303	0.013368	0	0.0119028	0.005814

Table 6. Reliability and Unreliability about different conditions and sub-tasks

Job task	Unreliability in stressful conditions	Unreliability in normal conditions	Reliability after passing 12 hours	Mean time to human Error
1	0.023908	0.006783	0.96654	1817.1
2	0.028415	0.016039	0.95772	1800.51
3	0.023644	0.0067165	0.96694	1817.85
4	0.029512	0.00670	0.962451	1809.41
5	0.023567	0.013385	0.960370	1805.5
6	0.034892	0.019843	0.942694	1772.26
7	0.035580	0.026447	0.933618	1755.2
8	0.044915	0.026341	0.923939	1737.01
9	0.017714	0.006731	0.974195	1831.49
10	0.017659	0.0133393	0.967665	1819.21

determination of the reliability threshold was calculated to be 0.8. For this reason, according to Table 6, one can conclude that the reliability value is not less than or equal to 0.8 in any of the job sub-tasks. Additionally, in the studied workshop, operators have a relatively high reliability in performing their tasks. Finally, training people before beginning work as well as in-service training that completes the experiences and skills of the operators must be considered. Therefore, based on prioritizing the performance factors, future controlling measures should be more focused on the following issues:

1. Performing spot inspections, reminding the operators

regularly by supervisors before, during, and after completion of the operators' work in order to prevent promotion of false norms among them with the goal of better development of the organizational culture, and helping them make accurate and timely decisions.

2. Providing milling operators with appropriate and calibrated tools before beginning work.

3. Completion and correction of existing guidelines to perform a safe and error-free operation by the operators (detailed description of items stated in instructions during work by supervisors is also effective in operators' instantaneous decisions and is considered a kind of educational program. Thus, the operator can be informed about the consequences of possible errors they might make).

4. Establishing an appropriate communication system with other relevant departments to have a quick response and resolve problems during work to reduce irreparable consequences of human error that has its origins in communication.

5. Proposing more efficient ways for operators to do their jobs by supervisors, giving safety and ergonomics advice to operators through continuous and occasional visits, and preventing them from successive overtime (that is out of their capability since increasing work dimensions and complexity gradually results in fatigue, job burnout, and finally operator's cognitive and operational failures).

6. Taking measures to avoid quick performance of tasks by operators that results from their misconceptions of available time and leads to changes in executive standards. To use this approach, it is necessary to precisely and constantly monitor how operators do their work. Additionally, the importance of teamwork in carrying out tasks has been mentioned.

DISCUSSION

Human resources are considered infallible elements in most systems. Hence, it is essential to consider human factors in order to increase the safety level of various systems. To increase reliability and ensure the quality of correct and flawless operation of people in situations where there is the possibility of making an error, various approaches can be used. In this regard, the first step is identification and then evaluation of errors and human reliability; implementing this step in any organization and industry is a significant help for decision-makers and managers. Based on the results of the analyses, they can prioritize actions to improve status and reduce the severity of human errors or even prevent them from occurring. The proposed approach in this study is a small step towards these objectives.

To present the proposed approach in this research, the following issues were considered: minimizing expertise judgments, better assessment of operators' cognitive actions, e.g., the possibility of making several decisions through evaluation of their performance in the form of data collection in order to evaluate human reliability, quantifying and prioritizing factors shaping operators' risky performance, working conditions, tasks, and especially time.

Carrying out research on the case study and presenting the proposed model, it was concluded that most of our objectives in assessment of errors and human reliability were achieved by this model. Additionally, the new approach has enough ease and clarity for use and it convincingly satisfies analysts' information needs to provide appropriate control strategies that prevent and reduce human error. This model can be used in different industries, and only if the sub-tasks are increased, will the corresponding calculations be complex and time-consuming.

CONFLICT OF INTEREST

All authors have no conflicts of interest to declare.

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