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Research article

Identifying and preventing human error in the sugar production process: A multi-stage approach using HTA, HEC and PHEA techniques

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ABSTRACT

This article discusses the importance of identifying and preventing human error in industrial environments, specifically in the sugar production process. The article emphasizes the importance of choosing the right technique for risk assessment studies resulting from human errors. A cross-sectional study was conducted using a multi-stage approach – Hierarchical Task Analysis (HTA), Human Error Calculator (HEC), and Predictive Human Error Analysis (PHEA) – to identify potential human errors in the sugar production process. The HTA, HEC, and PHEA techniques were employed to evaluate each stage of the process for potential human errors. The results of the HTA technique identified 35 tasks and 83 sub-tasks in 14 units of the sugar production process. According to HEC technique 4 tasks with 80 % probability of human error and 2 tasks with 50 % probability of human error had the highest calculated error probabilities. The factors of individual skill, task repetition and importance were the most important factors of human error in the present study. The analysis of PHEA worksheets showed that the number of human errors identified in the tasks with highest probability were 8 errors, of which 50 % were action errors, 25 % checking errors, 13 % selection errors, and 12 % retrieval errors. To mitigate the consequences of human error, it was recommended training courses, raising operator awareness of error consequences, and installing instructions in the sugar production process. Based on the findings, the article concludes that the HEC and PHEA techniques are applicable and effective in identifying and analyzing human errors in process and food industries.

1. Introduction

Error is inevitable and an aspect of being human and it can occur even when the best plans are set [1]. In many work environments, human resources are considered the most important and critical element of work systems. They collect and process a huge amount of information every moment and make decisions based on it. Therefore, the occurrence of human error while performing tasks is likely in many jobs and this is a serious issue at all organizational levels. Obviously, even the slightest human error in many industrial environments can lead to catastrophic accidents and debilitating injuries [2,3]. On the one hand, accidents cause concern to the personnel

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and on the other hand, they cause concern to the employer. They result in disability of personnel, loss of work, capital loss and negatively impact the economy of society. Therefore, it is essential to identify human error, determine its root causes and prevent recurrence [4,5].

Focusing on human error in the field of industrial accidents has shown that it is a combination of various factors such as (i) poor direct safety management and supervision; (ii) unsafe workplace conditions; (iii) worker's perceptions, skills and training; and (iv) broader organizational factors [6].

Romli and Rosidi stated that sugar is one of the strategic food products that must be available at any time [7]. The major producers of sugar in the world are Brazil, India, China, Thailand, and the United States, among which Brazil and India together produce about 40 % of the world's sugar [8]. In Iran, after the textile industry, the sugar industry is the second oldest industry [9]. Research was conducted on the one sugar industry in Iran to study the human error on the operational activities. In this study the primary products of the factory include white sugar in 50 kg bags, dried sugar beet pulp and molasses. The number of factory personnel is 350 in the operating season and 130 in the rest of the year. During the exploitation season, workers work in two 10-h shifts. Due to the large amount of work, especially in the exploitation season, the occurrence of human error in this manufacturing industry can lead to huge accidents and even reduce the quality of sugar produced.

In order to produce sugar, beets are harvested and transported to the industry. The sugar content of the beets is determined by weighing them. In the production process, the beets are first washed and sliced into thin strips. The raw juice is extracted from slices, and the beet pulps are used for animal feed. The raw juice is purified to obtain thin juice. To increase the sugar content from 15 % to 70 %, the thin juice undergoes a boiling process. The resulting syrup then goes through a six-step evaporation process to further increase its concentration. The next step is a four-stage crystallization process, where the syrup is heated and sugar powder is added to form crystals once the mixture reaches a saturated state. In the centrifuge stage, the sugar crystals are separated from the effluent due to the high speed. The resulting liquid at this stage is molasses. The sugar crystal is wet and needs to be dried to obtain the final product. Finally, the produced sugar is stored in a warehouse.

Everingham et al. mentioned sugar industry have high sensitivity and due to the nature of its raw materials such as seasonal, perishable, bulky, and diverse quality, face additional errors [10]. Therefore, the human errors can occur in the sugar production process in any activity. Such they cause performance loss and also financial, psychological, social and time losses [11]. The cost of human errors in the food industry can be very high. Most of the time, affected industry discover real causes associated with a wide range of human factors, such as workload and inadequate supervision, design of the task, inadequate procedures, lack of competence due to ineffective training, and so on [12].

Morais et al. cited factors such as inadequate skills, insufficient information, long working hours, poor quality control, inadequate communication, design problems, management issues, social pressures, and unfair task allocation have associated with human error [13]. Also there are several types of human errors, that can occur in the sugar production process [7].

For this purpose, this study was designed and implemented with the aim of identifying possible human errors and determining the resulting consequences in the sugar industry. Choosing the right technique is the first and basic step in risk assessment studies resulting from human errors [14].

Task analysis is a very general term with a wide variety of techniques. The particular type of task analysis is Hierarchical Task Analysis (HTA) [15]. This study utilized Hierarchical Task Analysis (HTA) to identify the sugar industry tasks and subtasks. As regards, Embrey emphasized that it has been applied extensively in a number of safety critical industries [15].

Human Error Calculator (HEC) selected to calculate the probability of human error in each identified task by HTA. The basic aim of using Human Error Calculator (HEC) technique is to quantify the probability of errors for tasks. The HEC technique is one of the quantitative assessment techniques [5]. The study results of the Shirali et al. showed that the HEC technique is easy, simple and useful technique to calculate the probability of human error. In addition, they confirmed HEC is a practical, effective, beneficial, quantitative and understandable technique for managers [5].

Since the sugar industry is a sensitive and strategic product [10], the prediction of errors may be a trump card before the error occurs and has negative consequences [15]. Therefore, in the following, the Predictive Human Error Analysis (PHEA) technique was chosen to predict human error, consequences and error reduction strategies. This technique comprises an error checklist and is a most recent variant of the Systematic Human Error Reduction and Prediction Approach (SHERPA) technique developed by Embery [16]. Kirwan categories PHEA as useable, available, practicable and appropriate tools [17].

A review of the research literature shows that although many studies have been conducted on human error [12,18–20], but there are the limited number in the field of sugar industry. Generally, they are about risk assessment and not human error. Therefore, the importance of investigating human error is clearly defining and this study tries to fill existing research gap.

One of the notable features of this study is the use of a multi-stage approach to identify and analyze human errors. Therefore, this study aims to: a) corrective measures to improve activities, b) provide control strategies, c) eliminate or minimize the possibility of errors, and d) enhance safety in sugar industry.

2. Method

This cross-sectional study utilized a multi-stage approach within one of the sugar industries in Iran. Initially, a team consisting of two occupational health and safety engineers, a production manager, and a supervisor of the production unit was assembled.

The duration of the study was 4 months that it was sufficient time to gather data and conduct a thorough analysis. The participants involved in our study were carefully selected to ensure a diverse representation of individuals with expertise and experience in the sugar production industry. This included workers and supervisors who were directly involved in the production process.

This study followed three steps to gain a comprehensive understanding of the sugar production process, calculate quantitatively the probability of human errors and analyze tasks with a human error probability higher than 50 %.

These details were elaborated upon in Section 2.1, where the techniques utilized in the study were explicitly outlined. Additionally, Section 2.2 provided a comprehensive description of the research procedure, giving readers a clear understanding of the methodology employed.

2.1. Techniques used in the research

2.1.1. Hierarchical task analysis (HTA) method

HTA was introduced by Annett and Duncan in 1967 [21]. It provided a comprehensive method of hierarchy within a system. In fact, Kirwan and Ainsworth referred to it as the "best-known task analysis technique" [22]. Annett has considered HTA as a framework for task analysis, which can be represented through hierarchical diagrams, hierarchical lists, and tabular formats [23].

For this study, a hierarchical diagrams framework, described in Stanton's study, was followed to conduct HTA [24]. This framework offered a useful and standardized procedure for breaking down tasks into a sub-task hierarchy. The analysis team gathered information on tasks, sub-tasks, their relationships, and the necessary conditions using the following methods:

- Direct observation of sugar production activities.
- Interviews with 24 workers and supervisors involved in the production process.
- Reviewing procedures and documents.
- Investigating past accidents/incidents.
- Examining safety instructions.

Then, a numerical hierarchy system specified for HTA were arranged. The hierarchical number scheme for HTA required that every task was uniquely numbered with an integer in sequence and each sub-task was identified by stating its goal and its position under that task.

2.1.2. Human Error Calculator (HEC) technique

Human errors were evaluated in the sugar production using the Human Error Calculator (HEC) technique. This quantitative approach was employed to gain insights into the possibility of human error. The HEC technique was developed by the Risk Map Company [5] and involves determining the probability of human error based on five factors that affect its occurrence: urgency, complexity, importance, level of individual skill, and repetition of the task. HEC is specifically designed to calculate the percentage of human error associated with each task level description in HTA. In fact, HEC utilizes the output of the task analysis stage as input for the human error analysis. A step-by-step implementation of the HEC technique is given below.

Step1. Interviews with operators and supervisors are conducted to determine the level of urgency (ranging from "There is no urgency" to "Infinitely urgent"), the level of complexity (ranging from "Simple task" to "Infinitely complex task"), and the level of importance (ranging from "Not important" to "Extremely important"). The score of urgency, complexity and importance are assigned according to Table 1.

Step 2. Based on the values provided of Urgency-Complexity-Importance, UCI number is assigned for each task in appendix A.

Step3. The level of individual skill and task repetition is assessed for each task, and a corresponding score is assigned based on the values provided in Table 2.

Step4. The probability of human error is calculated as a percentage for each task by considering the UCI number obtained in the previous step, in addition to the scores associated with individual skill and task repetition. The calculation of the probability of human error is performed using the table provided in appendix B.

Step5. Based on HEC technique is observed that the complexity, importance, and urgency of the task, that referred to as the UCI, played a significant role in the occurrence of human errors. As the UCI factors increase, the possibility of errors also tends to increase.

Table 1
Determine the score for Urgency, Importance and Complexity.

Importance	Complexity	Urgency	score
Not important	Simple task	No urgency	1
			2
Relatively important	Relatively complex	Relatively urgent	3
			4
Quite important	Quite complex	Quite urgent	5
			6
Very important	Very complex	Very urgent	7
			8
Infinitely important	Infinitely task	Infinitely urgent	9

Table 2
Determine the score for task repetition and individual skill.

Task Repetition	Individual Skill	score
Once or twice in a lifetime	He has no skills for the task	1
Several times in a lifetime		2
Several times in one season	He is relatively skilled for the task	3
Once or twice in a month		4
Several times in a month	He is quite skilled for the task	5
Once or twice a week		6
Several times a week	He is very skilled for the task	7
Once or twice a day		8
Several times in a day	Infinitely skilled for the task	9

This suggests that tasks with higher levels of complexity, importance, and urgency are more susceptible to errors.

Furthermore, the number of repetitions performed in a task has an impact on the error rate. A higher repetition indicates reduced accuracy and concentration, thereby increasing the occurrence of human errors. Therefore, tasks with more repetitions are associated with a higher chance of errors occurring.

Another important aspect is individual skill. As individual skill increases, the chance of errors decreases. This implies that individuals with higher skill levels are less prone to errors compared to those with lower skill levels.

By the integration of these factors and analyzing the relationships between scores of the urgency, complexity, repetition, individual skill, and repetition was calculating the probability of human errors as a percentage. Finally, the obtained percentage was interpreted using Table 3.

2.1.3. Predictive Human Error Analysis (PHEA) technique

This technique was initially developed by Embrey [16] and has now gained widespread usage across various industries including nuclear, oil and gas, power transmission and distribution, petrochemical, and medicine [25–27]. The primary advantage of the PHEA technique is its systematic approach to identify human errors [28]. Additionally, PHEA suggests error reduction strategies [29]. By utilizing the PHEA technique, a deeper understanding of the factors contributing to human error in high-risk tasks can be obtained. This, in turn, enables the development of more effective strategies to prevent errors and enhance the safety and efficiency of the sugar production process. According to Baber and Stanton, PHEA consists of five main stages [28].

1 Problem definition: In this stage, tasks with a potential for human error are identified. In this study, the identified problems were tasks with a human error probability higher than 50 %, as determined by the HEC technique.
2 Task analysis: The inputs of task analysis stage are derived from HTA method.
3 Human error analysis: This stage utilizes the error classification checklist presented in Table 4.
4 Consequences analysis: This stage, the analyst team determines the consequences of the human errors for system.
5 Error reduction strategies: The final stage involves suggesting error reduction strategies that aim to prevent or mitigate the consequences of errors.

All the findings from these stages were recorded in the PHEA worksheets (Table 5).

2.2. Research procedure

Fig. 1 provides an overview of the research procedure flowchart. The study consisted of three key steps:

1. Identifying the tasks involved in the sugar production process from beets with a breakdown the process into task/subtask levels.
2. Calculating of the probability of human errors for each task based on five factors: urgency, complexity, importance, level of individual skill, and repetition of the task.

Table 3
Interpretation of human error.

interpretation	level	Row
The probability of human error is very low and negligible risk	$\leq$ %10	1
The probability of human error is low and change may be needed	$\leq$ %25	2
The probability of human error is moderate and change implement soon	$\leq$ %50	3
The probability of human error is high and change implement very soon	$\leq$ %75	4
The probability of human error is very high and change implement immediately	$\leq$ %90	5
The probability of human error is infinite and the job must be changed or stopped	Up to %90	6

Table 4
Error classification in PHEA technique.

Error classification	
Planning errors	
P1	Plan preconditions ignored
P2	Incorrect plan executed
P3	correct but inappropriate plan executed
P4	Correct plan executed but too soon/too late
P5	Correct plan executed in wrong order
Action errors	
A1	Operation too long/too short
A2	Operation mistimed
A3	Operation in wrong direction
A4	Operation too little/too much
A5	Misalign
A6	Right operation on wrong object
A7	Wrong operation on right object
A8	Operation omitted
A9	Operation incomplete
Checking errors	
C1	Check omitted
C2	Check incomplete
C3	Right check on wrong object
C4	Wrong check on right object
C5	Check mistimed
Retrieval errors	
R1	Information not communicated
R2	Wrong information communicated
R3	Information communication
Selection errors	
S1	Selection omitted
S2	Wrong selection made

Table 5
PHEA worksheet.

Task	Error Mode	Description	Consequence	Reduction Solutions

3. Prediction and analysis of human errors in selected tasks where the probability of human error was higher than 50 %. Each selected task was analyzed step-by-step for error mode identification, consequences analysis, error reduction strategies, and the proposal of suitable solutions.

Initially, data was collected for the HTA method from various sources, including walking through survey, semi-structured interviews with workers and supervisors, procedure reviews, document analysis, investigation of past accidents/incidents, and safety instructions. In the second step of the present study, the probability of human error was estimated for all of the tasks within the sugar production process, following the step-by-step guidelines of the HEC technique (refer to section 2.1.2). Finally, for tasks with a probability of human error higher than 50 %, the PHEA technique was used to gain more in-depth information about error mode, error description, consequence and reduction solutions.

In this study, the problem definition and task analysis were conducted for two Stages of the PHEA technique, using both the HEC technique and HTA method. Then, the selected tasks were categorized with human errors mode using error classification checklist (refer to Table 4). The tasks were classified into five categories: Planning, Action, Checking, Retrieval, Selection. This categorization facilitates the identification of potential errors associated with each task. Furthermore, the consequences of each error were assessed on the system and a full description of the identified errors consequences was provided. The final step of the PHEA process involved proposing error reduction solutions aimed at modifying the work system to prevent the occurrence of errors.

3. Result

Each shift in the production unit had 24 workers who worked 10-h shifts. The production unit was divided into fourteen sections. The job tasks were identified through direct observation of sugar production activities, interviews with operators and the head of the production unit, review of procedures and documents, investigation of past accidents/incidents, and review of safety instructions.

The HTA method determined 35 tasks and 83 subtasks in the sugar production process. The Numerical HTA diagram was drawn to determine hierarchy of the tasks and sub tasks. The result of the HTA is presented in Fig. 2.

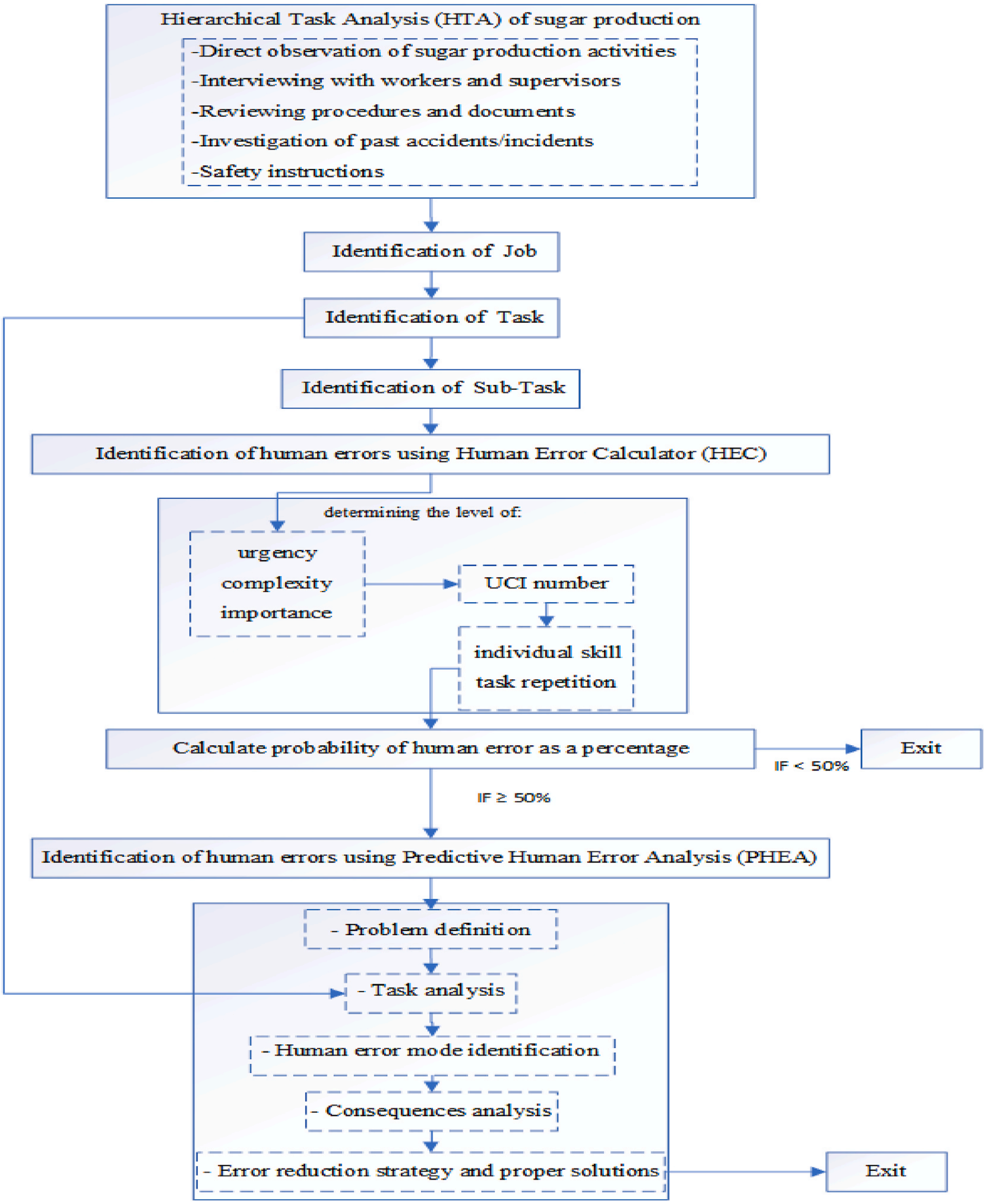

Fig. 1. Overview of the research procedure flowchart.

Next, in the HEC technique, five factors of importance, complexity, urgency, individual skill and task repetition were calculated for each task identified by HTA in an exhaustive manner. UCI number and the percentage of probability of human error was determined for each task. Table 6 presents the results obtained from the analysis of the Human Error Calculator technique.

The result of this study showed, probability of the human error was 80 % for four tasks. According to Table 3, this means that the possibility of human error is very high. These tasks need a strategy that can be implemented immediately. Human error was 50 % for two tasks and 30 % for nine tasks, that means probability of the human error is moderate and changes implement soon. The probability of human error was 20 % for nine tasks and 15 % for 2 tasks, where the possibility of human error is low and changes may be needed. The probability of human error was calculated to be 10 % for six tasks and 7 % for three tasks, indicating a very low and negligible risk of human error. The results obtained from the implementation of the Human Error Calculator technique revealed that the four tasks with the highest error probability of 80 % were: "Controlling the size of the slice," "Adjusting the diffusion time," "Monitoring the size of sugar crystals during cooking," and "Cutting off vacuum and steam to stop cooking." Additionally, tasks such as "Monitoring PH" and

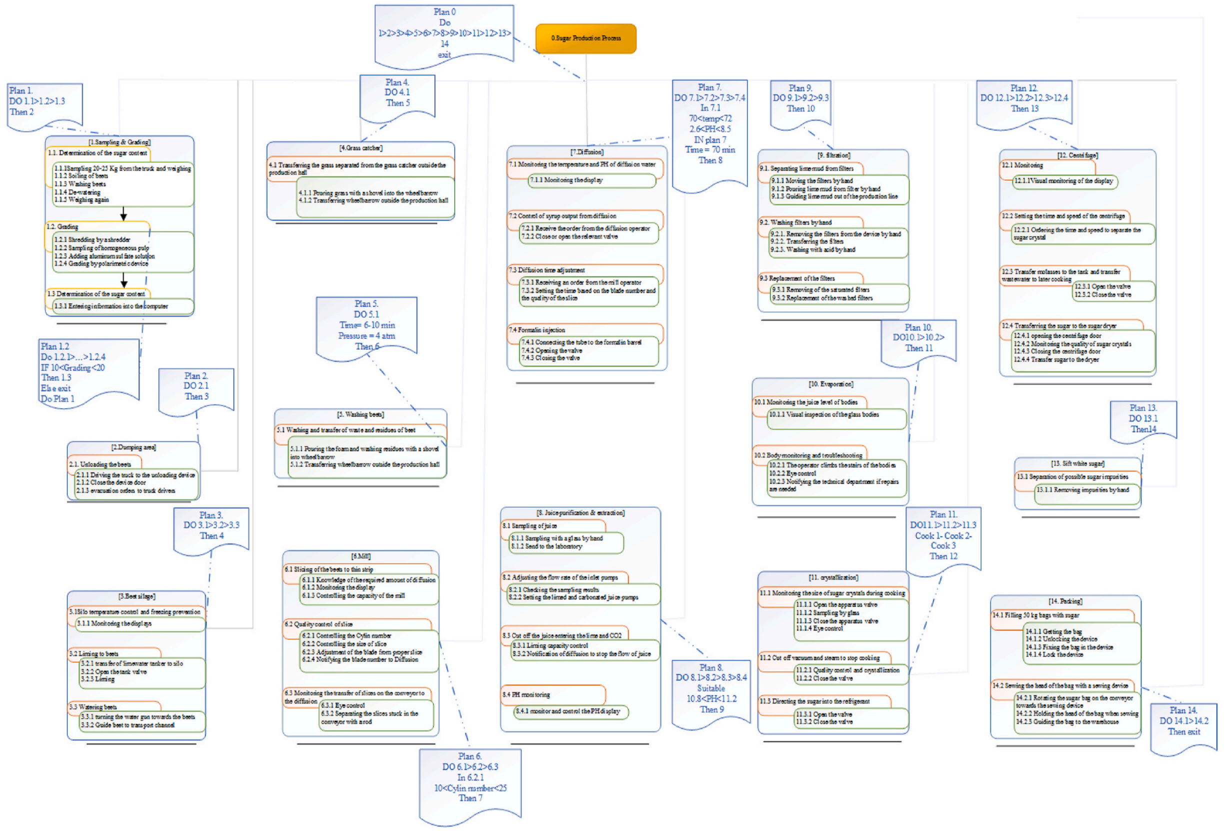

Fig. 2. HTA of sugar production process.

"Injecting formalin" were associated with error probability of 50 %.

Chart 1 presents a summary of the aforementioned information. As evident, the error probability frequency is within the range of 20 %–30 %, which in according to Table 3, corresponds to the categories of moderate and low error probabilities.

Chart 2 presents the frequency of the five factors in the HEC technique. By examining the frequency of each factor based on the highest score (score = 9), it becomes evident that the most significant factors are individual skill, task repetition, and importance.

As stated earlier, in this study, the PHEA technique was used for tasks with a probability of human error higher than 50 % (six tasks). The PHEA technique was utilized to comprehensively predict the error modes, error descriptions, error consequences, and reduction solutions for all six tasks identified through HTA. Table 7 present the PHEA worksheet specifically performed for these tasks.

Based on the error classification checklist (refer to Table 4) in the PHEA technique, a total of eight predicted errors were identified. Among these errors, four were action errors, two were checking errors, one was a selection error, and one was a retrieval error. The frequency distribution of error classification in the PHEA for this study is illustrated in pie chart 3.

The investigations conducted revealed that action errors (50 %) and checking errors (25 %) constituted a substantial portion of the predicted errors.

4. Discussion

Human error, with its potential for significant consequences, necessitates the identification of causes and the development of prevention and mitigation strategies. However, despite its importance, there is a notable gap in research concerning human error within the food industry. This gap is particularly concerning given the vital role of the sugar industry in the economic development of numerous countries.

An examination of the factors contributing to the probability of human error revealed that individual skill, task repetition, and task importance played significant roles. In essence, human errors were observed to occur due to repetitive tasks, inadequate skill levels, and a failure to recognize the importance of tasks. These errors were influenced by various factors, including fatigue, inappropriate personnel selection, unfamiliarity with the consequences of errors, job dissatisfaction, and erroneous decision-making by operators based on incorrect information. Additionally, a lack of skills, experience, or knowledge resulting from inadequate training or ineffective training programs were also linked to these errors.

To address these issues, it is crucial to implement measures that enhance skill development, reduce task repetition, and emphasize the significance of tasks. Additionally, addressing factors such as fatigue management, proper personnel selection, improving

Table 6
Determining of importance, complexity, urgency, individual skill, task repetition for tasks.

Unit	Task	Subtask	Urgency	Complexity	Importance	UCI number	Task Repetition	Individual Skill	probability of human error
1. Grading	1.1. Determination of the sugar content	1.1.1. Sampling 20–25 Kg from the truck and weighing 1.1.2. Soiling of beets 1.1.3. Washing beets 1.1.4. De-watering 1.1.5 Weighing again	1	1	3	2	9	7	%30
	1.2. Grading	1.2.1. Shredding by a shredder 1.2.2. Sampling of pulp 1.2.3. Adding aluminum sulfate solution 1.2.4. Grading by polarimetric device	1	5	9	5	9	9	%30
	1.3. Record the results of sugar content and grading	1.3.1. Entering information into the computer	3	3	9	5	9	9	%30
2. Dumping area	2.1. Unloading the beets	2.1.1. Driving the truck to the unloading device 2.1.2. Close the device door 2.1.3. Evacuation orders to truck drivers	1	1	2	1	9	9	%7
3. Beet silage	3.1. Silo temperature control and Prevent freezing	3.1.1. Monitoring the displays	1	2	3	2	8	9	%10
	3.2. Liming to beets	3.2.1. Transfer of limewater tanker to silo 3.2.2. Open the tank valve 3.2.3. Liming	5	1	9	5	9	9	%30
	3.3. Watering beets	3.3.1. Turning the water gun towards the beets 3.3.2. Guide beet to transport channel	1	2	9	4	8	9	%15
4.Grass catcher	4.1. Transferring the grass separated from the grass catcher outside the production hall	4.1.1. Pouring grass with a shovel into the wheelbarrow 4.1.2. Transferring wheelbarrow outside the production hall	1	1	2	1	9	9	%7
5.Washing beets	5.1. Washing and transfer of waste and residues of beet	5.1.1. Pouring the foam and washing residues with a shovel into wheelbarrow 5.1.2. Transferring wheelbarrow outside the production hall	1	1	2	1	9	9	%7
6. Mill	6.1. Slicing of the beets to thin strip	6.1.1. Knowledge of the required amount of diffusion 6.1.2. Monitoring the display 6.1.3. Controlling the capacity of the mill	1	5	9	5	9	9	%30
	6.2. Quality control of slice	6.2.1. Controlling the Cylin number 6.2.2. Controlling the size of slice 6.2.3. Adjustment of the blade from proper slice 6.2.4. Notifying the blade number to Diffusion	1	9	9	6	9	7	%80

(*continued on next page*)

Table 6 (*continued*)

Unit	Task	Subtask	Urgency	Complexity	Importance	UCI number	Task Repetition	Individual Skill	probability of human error
	6.3. Monitoring the transfer of slices on the conveyor to the diffusion	6.3.1. Eye control 6.3.2. Separating the slices stuck in the conveyor with a rod	1	1	5	2	9	9	%10
7. Diffusion	7.1. Monitoring the temperature and PH of diffusion water	7.1.1. Monitoring the display	1	3	9	4	9	9	%20
	7.2. Control of syrup output from diffusion	7.2.1. Receive the order from the diffusion operator 7.2.2. Close or open the relevant valve	1	1	5	2	9	9	%10
	7.3. Diffusion time adjustment	7.3.1. Receiving an order from the mill operator 7.3.2. Setting the time based on the blade number and the quality of the slice	1	6	9	5	9	7	%80
	7.4. Formalin injection	7.4.1. Connecting the tube to the formalin barrel 7.4.2. Opening the valve 7.4.3. Closing the valve	1	3	3	2	8	5	%50
8.Juice purification & extraction	8.1. Sampling of juice	8.1.1. Sampling with a glass by hand 8.1.2. Send to the laboratory	1	2	2	2	8	9	%10
	8.2. Adjusting the flow rate of the inlet pumps	8.2.1. Checking the sampling results 8.2.2. Setting the limed and carbonated juice pumps	1	5	9	5	8	9	%20
	8.3. Cut off the juice entering the lime and CO2	8.3.1. Liming capacity control 8.3.2. Notification of diffusion to stop the flow of juice	1	3	5	3	9	9	%20
	8.4. PH monitoring	8.4.1. monitor and control the PH display	1	3	5	3	9	7	%50
9. filtration	9.1. Separating lime mud from filters	9.1.1. Moving the filters by hand 9.1.2. Pouring lime mud from filter by hand 9.1.3. Guiding lime mud out of the production line	3	1	3	2	8	9	%10
	9.2. Washing filters by hand	9.2.1. Removing the filters from the device by hand 9.2.2. Transferring the filters 9.2.3. Washing with acid by hand	1	3	5	3	7	7	%30
	9.3. Replacement of the filters	9.3.1. Removing of the saturated filters 9.3.2. Replacement of the washed filters	1	3	9	4	7	9	%15
10. Evaporation	10.1. Monitoring the juice level of bodies	10.1.1. Visual inspection of the glass bodies	1	1	7	3	9	9	%20
	10.2. Body monitoring and troubleshooting	10.2.1. The operator climbs the stairs of the bodies 10.2.2. Eye control 10.2.3. Notifying the technical department if repairs are needed	1	5	9	5	4	7	%30
11. Crystallization	11.1. Monitoring the size of sugar crystals during cooking	11.1.1. Open the apparatus valve 11.1.2. Sampling by glass	3	7	9	6	9	7	%80

(*continued on next page*)

Table 6 (*continued*)

Unit	Task	Subtask	Urgency	Complexity	Importance	UCI number	Task Repetition	Individual Skill	probability of human error
		11.1.3. Close the apparatus valve 11.1.4. Eye control							
	11.2. Cut off vacuum and steam to stop cooking	11.2.1. Quality control and crystallization 11.2.2. Close the valve	3	7	9	6	9	7	%80
	11.3. Directing the sugar into the refrigerant	11.3.1. Open the valve 11.3.2. Close the valve	1	3	7	4	9	9	%20
12. Centrifuge	12.1. Monitoring	12.1.1. Visual monitoring of the display	3	7	9	6	9	9	%30
	12.2. Setting the time and speed of the centrifuge	12.2.1 Ordering the time and speed to separate the sugar crystal	3	7	9	6	9	9	%30
	12.3. Transfer molasses to the tank and transfer wastewater to later cooking	12.3.1. Open the valve 12.3.2. Close the valve	1	1	5	2	9	9	%10
	12.4. Transferring the sugar to the sugar dryer	12.4.1. Opening the centrifuge door 12.4.2. Monitoring the quality of sugar crystals 12.4.3. Closing the centrifuge door 12.4.4. Transfer sugar to the dryer	1	3	5	3	9	9	%20
13. Sift white sugar	13.1. Separation of possible sugar impurities	13.1.1. Removing impurities by hand	3	1	9	4	9	9	%20
14. packing	14.1. Filling 50 kg bags with sugar	14.1.1. Getting the bag 14.1.2. Unlocking the device 14.1.3. Fixing the bag in the device 14.1.4. Lock the device	5	1	3	3	9	9	%20
	14.2. Sewing the head of the bag with a sewing device	14.2.1. Rotating the sugar bag on the conveyor towards the sewing 14.2.2. Holding the head of the bag when sewing 14.2.3. Guiding the bag to the warehouse	5	1	3	3	9	9	%20

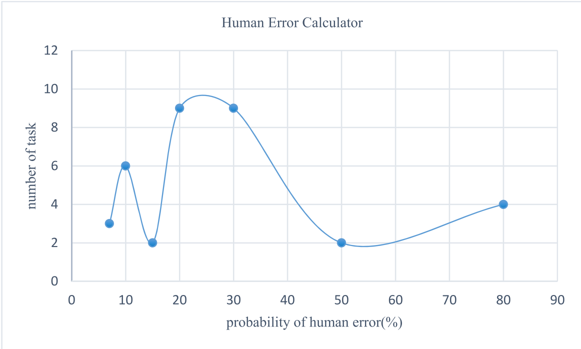

Chart 1. Frequency of tasks for the probability of human error.

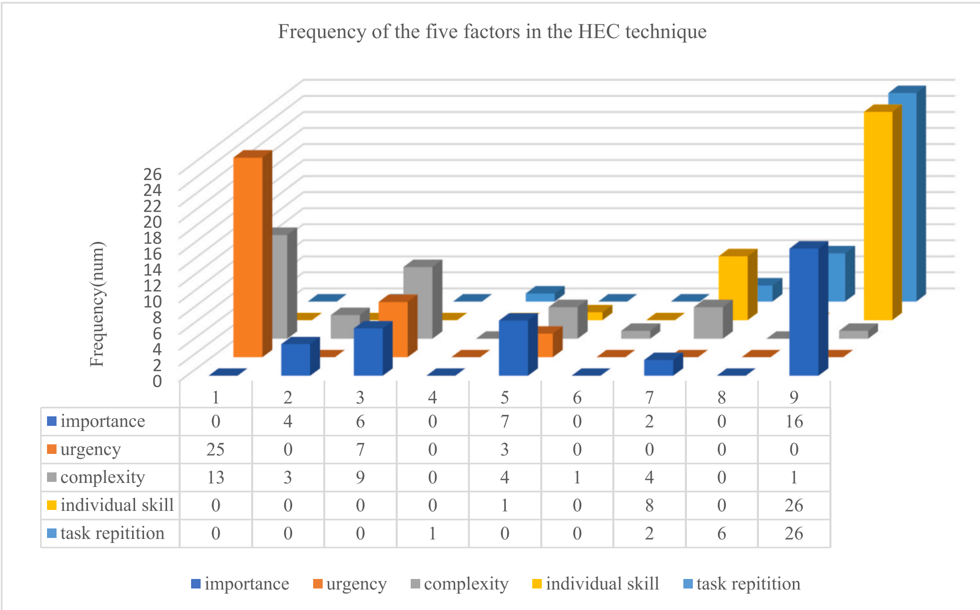

Chart 2. Frequency of the five factors in the HEC technique.

awareness of error consequences, job satisfaction, and promoting accurate decision-making through reliable information can contribute to minimizing human errors. Furthermore, investing in comprehensive training programs that effectively equip individuals with the necessary skills, experience, and knowledge is essential to mitigate the occurrence of errors in the food industry.

Multiple reports have highlighted that skill-based errors exert the most significant influence in error occurrence. In a study conducted by Shirali et al. within the epoxy control room of a pipe-making company, three crucial factors contributing to human error in the industry were identified: task repetition, individual skill, and task importance [5]. These findings are consistent with the results of the present study. Shirali et al. examined 158 accident reports in the steel industry and found that skill-based errors were the primary cause of accidents [4]. Similarly, Ting and Dai reported that skill-based errors accounted for 45 % of all accidents [30]. Celik and Cebi also investigated the causes of accidents in the industry and found that skill-based errors had the greatest impact [31].

The study revealed that during the sugar production process, six tasks were found to have errors with a probability of over 50 %. Among the errors classified using the PHEA technique, action errors emerged as the most prevalent type (50 %), while retrieval errors were the least frequent (12 %). Similar findings have been reported in other studies utilizing this technique to investigate human errors. For instance, Jahangiri conducted a study in the Isomax Unit of an Oil Refinery [29], and Orosi examined paper machine workers at Pars paper mills [32] found similar results. In a separate investigation by Pourimani, a total of 337 errors were identified using PHEA, that were 246 action errors, 13 checking errors, 28 retrieval errors, 33 selection errors, and 17 planning errors [27].

The study results indicated, action errors (notably A1, A2, A4, A8, and A9 codes) had higher frequency. These findings emphasis the significance of levels of skill, maintaining adequate concentration, and accuracy, as these factors significantly contribute in action errors. Importantly, these findings further confirm the importance, individual skill, and execution of repetitive operations as three key factors emphasized in the HEC technique within the context of the present study. Furthermore, Mortazavi et al. conducted the HEIST technique and reported that the most frequent errors were associated with improper task performance [33]. This supports the

Table 7
PHEA worksheet for sugar production.

probability of human error with HEC technique	Task		Description	Consequence	Reduction Solutions
%80	6.2. Quality control of slice	S_2	- Unfamiliarity with the type of blades -inappropriate choice of blades with beet	-Increasing the percentage of thin sugar beet slices -Improper thickness of slices -Undesirable extraction -Increase of non-sugar substances in the syrup coming out of diffusion -Softness slices accumulation in diffusion -Disruption of syrup passage inside the diffusion -Reducing the degree of syrup purity	-Examining job duties to ensure that the duties match the operator's capabilities -Use of skilled operator -Installation of instructions in front of the operator's view -Periodic visit of the production manager -Using of the checklist for the preparation and installation of the blade
		R_4	-Inappropriate and wrong interpretation of the Cylin number received from the laboratory	-Using the wrong blade -Increasing the percentage of thin sugar beet slices -Improper thickness of slices	-Paying attention to human limitations (for example, memory limitations to recall information) -Installation of instructions and detailed explanation of instructions to the operator
%80	7.3. Diffusion time adjustment	A_9	-Defining and determining the time required for extraction of beet slices	-As the stop time in diffusion increases, more non-sugar substance enters the syrup -Creating a serious problem for filters if pectin is present - Preventing crystallization and reducing the quality of produced sugar	-Use of skilled and experienced operator -Training and awareness of the operator regarding the size of the slice and the time required for extraction from types of slices
%50	7.4. Formalin injection	A_8	-The process of connecting the pipe to the formalin barrel is not done correctly -It is possible to pour formalin on the operator	-Severe burns of the operator -Severe irritation of the nose, throat and respiratory tract	-Use of locking fasteners -Recheck the connection before transferring formalin -Using of breathing mask, gloves, glasses, clothes and shoes resistant to chemicals -Training in the use of personal protective equipment -Installation of formalin MSDS on the barrel -First aid training for operators in cases of exposure to formalin
%50	8.4. PH monitoring (Suitable PH 10.8–11.2)	C_4	-Viewing on the screen is incomplete.	-Lower PH, non-sugar substances are not completely separated. -Higher PH causes re-dissolution of coagulated materials and affects the quality and purification of the syrup.	-Operator training to read the screen correctly -Recording Suitable PH (10.8–11.2) near the screen
%80	11.1. Monitoring the size of sugar crystals during cooking	C_1	-Inspection of sugar crystals are delayed	-Improper crystallization of sugar and poor quality of produced sugar	-Holding a training program at the beginning of the operation season by an experienced person -Using visual alarms -nstallation of high-quality sugar cooking instructions
		A_4	-The desired action is performed very quickly	-Due to the high temperature of the cooking apparatus and the small sampling device, there is a possibility of burning the operator's hand with the syrup -A quick inspection of the target sample leads to wrong decisions about the crystallization mode	-Operator awareness of error consequences -Use appropriate gloves when sampling -Using a larger sampling tool that has a plastic handle
%80	11.2. Cut off vacuum and steam to stop cooking	A_1 & A_2	-The desired action is performed too soon or too late	-Complete cooking is not done and it will not have the right syrup for the centrifuge unit -The size of the crystals becomes inappropriate and the quality of the product decreases	-Operator training -Placing a high-quality baking sample in the sampling location

identified action errors in the PHEA technique and confirms the notion that action errors during task execution can have an impact on overall performance. These findings highlight the critical role of skill, concentration, and accuracy in minimizing the occurrence of action errors, emphasizing the need for targeted interventions and training programs to enhance these factors and mitigate potential

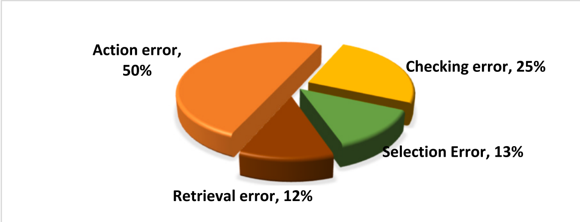

Chart 3. Frequency of error classification in PHEA technique.

risks in various operational settings.

The present study showed that checking errors are the second type of error and make up about 25 % of all errors. Among the identified checking error, C1 (Check omitted) and C4 (Wrong check on right object) codes observed during operations. Various factors, including lack of concentration, inaccuracy, negligence, overconfidence, and inexperience, can contribute to the occurrence of checking errors.

Some studies have examined the impact of training on mitigating human error. Hamzeian et al. investigated the quality of training, emphasizing the importance of appropriate instructions to enhance reliability and reduce human error [34]. In the survey conducted within this industry, it was observed that written and planned training was not provided to the employees. Consequently, to address this issue, the study proposes coherent, effective, and continuous training as a control solution. Specifically, the proposed control solutions implement in tasks such as "Diffusion time adjustment," "PH monitoring," "Monitoring the size of sugar crystals during cooking," and "Cutting off vacuum and steam to halt cooking".

The results of this study showed that human errors arise from individuals relying on personal preferences or experiencing confusion due to the absence of clear instructions and a lack of work step checklists. Therefore, it is recommended to revise job descriptions, develop task performance checklists, and create comprehensive work instructions. These measures can significantly contribute to the prevention of checking errors (25 %), retrieval errors (12 %), and selection errors (13 %)

The limitations in our study are attributed to various factors within the study factory, which include the following: absence of recorded information, lack of accurate statistics and data, inadequate documentation, absence of documented task descriptions, incorrect information recording, and lack of cooperation from workers, which may hide true information when responding to questions regarding errors. It is important to acknowledge these limitations as they may have influenced the depth and comprehensiveness of our study findings and conclusions.

Despite these limitations, the strength of this study is successfully shifting the focus of human error studies from control rooms, particularly in industries such as oil, gas, petrochemicals, and even surgery, to the vital and sensitive food industry, specifically the sugar industry.

The present study contributes to researchers' understanding of the broader aspects of human error management. Additionally, it opens up potential opportunities for researchers to address the gaps in human error studies within the food industry.

5. Conclusion

The occurrence of human errors in the sugar industry can lead to huge accidents and reduce the quality of the produced sugar. The objective of this study was to identify and evaluate the risks associated with human errors and propose solutions to reduce these errors. The research findings have identified a total of 35 tasks and 83 subtasks involved in the sugar production process. According to the HEC technique, individual skill, task repetition, and importance were identified as influential factors contributing to human errors in this industry. Among the identified tasks, probability of the human error was 80 % for four tasks and 50 % for two tasks. Using the PHEA technique, it was determined that "Action errors" were the most prevalent cause of human errors in these tasks. Errors reduction solutions were suggested such as operator training, raising operator awareness of error consequences, employing skilled and experienced operators, and changing many other various factors.

CRediT authorship contribution statement

Fatemeh Musavi: Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Conceptualization. **Reza Hekmatshoar:** Supervision, Project administration, Methodology, Conceptualization. **Majid Fallahi:** Writing – review & editing, Supervision, Funding acquisition. **Atefeh Moradi:** Writing – original draft, Data curation. **Mohsen Yazdani-Aval:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Calculate the UCI number using the score of urgency, complexity and importance

Urgency	Complexity	Importance								
		1	2	3	4	5	6	7	8	9
1	1	1	1	2	2	2	3	3	3	4
	2	1	2	2	2	3	3	3	4	4
	3	2	2	2	3	3	3	4	4	4
	4	2	2	3	3	3	4	4	4	5
	5	2	3	3	3	4	4	4	5	5
	6	3	3	3	4	4	4	5	5	5
	7	3	3	4	4	4	5	5	5	6
	8	3	4	4	4	5	5	5	6	6
	9	4	4	4	5	5	5	5	6	6
2	1	1	2	2	2	3	3	3	4	4
	2	2	2	2	3	3	3	4	4	4
	3	2	2	3	3	3	4	4	4	5
	4	2	3	3	3	4	4	4	5	5
	5	3	3	3	4	4	4	5	5	5
	6	3	3	4	4	4	5	5	5	6
	7	3	4	4	4	5	5	5	6	6
	8	4	4	4	5	5	5	6	6	6
	9	4	4	5	5	5	6	6	6	7
3	1	2	2	2	3	3	3	4	4	4
	2	2	2	3	3	3	4	4	4	5
	3	2	3	3	3	4	4	4	5	5
	4	3	3	3	4	4	4	5	5	5
	5	3	3	4	4	4	5	5	5	6
	6	3	4	4	4	5	5	5	6	6
	7	4	4	4	5	5	5	6	6	6
	8	4	4	5	5	5	6	6	6	7
	9	4	5	5	5	6	6	6	7	7
4	1	2	2	3	3	3	4	4	4	5
	2	2	3	3	3	4	4	4	5	5
	3	3	3	3	4	4	4	5	5	5
	4	3	3	4	4	4	5	5	5	6
	5	3	4	4	4	5	5	5	6	6
	6	4	4	4	5	5	5	6	6	6
	7	4	4	5	5	5	6	6	6	7
	8	4	5	5	5	6	6	6	7	7
	9	5	5	5	6	6	6	7	7	7
5	1	2	3	3	3	4	4	4	5	5
	2	3	3	3	4	4	4	5	5	5
	3	3	3	4	4	4	5	5	5	6
	4	3	4	4	4	5	5	5	6	6
	5	4	4	4	5	5	5	6	6	6
	6	4	4	5	5	5	6	6	6	7
	7	4	5	5	5	6	6	6	7	7
	8	5	5	5	6	6	6	7	7	7
	9	5	5	6	6	6	7	7	7	8
6	1	3	3	3	4	4	4	5	5	5
	2	3	3	4	4	4	5	5	5	6
	3	3	4	4	4	5	5	5	6	6
	4	4	4	4	5	5	5	6	6	6
	5	4	4	5	5	5	6	6	6	7
	6	4	5	5	5	6	6	6	7	7
	7	5	5	5	6	6	6	7	7	7
	8	5	5	6	6	6	7	7	7	8
	9	5	6	6	6	7	7	7	8	8
7	1	3	3	4	4	4	5	5	5	6
	2	3	4	4	4	5	5	5	6	6
	3	4	4	4	5	5	5	6	6	6
	4	4	4	5	5	5	6	6	6	7

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(*continued*)

Urgency	Complexity	Importance								
		1	2	3	4	5	6	7	8	9
	5	4	5	5	5	6	6	6	7	7
	6	5	5	5	6	6	6	7	7	7
	7	5	5	6	6	6	7	7	7	8
	8	5	6	6	6	7	7	7	8	8
	9	6	6	6	7	7	7	8	8	8
8	1	3	4	4	4	5	5	5	6	6
	2	4	4	4	5	5	5	6	6	6
	3	4	4	5	5	5	6	6	6	7
	4	4	5	5	5	6	6	6	7	7
	5	5	5	5	6	6	6	7	7	7
	6	5	5	6	6	6	7	7	7	8
	7	5	6	6	6	7	7	7	8	8
	8	6	6	6	7	7	7	8	8	8
	9	6	6	7	7	7	8	8	8	9
9	1	4	4	4	5	5	5	6	6	6
	2	4	4	5	5	5	6	6	6	7
	3	4	5	5	5	6	6	6	7	7
	4	5	5	5	6	6	6	7	7	7
	5	5	5	6	6	6	7	7	7	8
	6	5	6	6	6	7	7	7	8	8
	7	6	6	6	7	7	7	8	8	8
	8	6	6	7	7	7	8	8	8	9
	9	6	7	7	7	8	8	8	9	9

Appendix B. Calculate the probability of human error

UCI	Individual Skill	Task Repetition								
		1	2	3	4	5	6	7	8	9
1	1	10	15	15	20	20	20	30	50	50
	2	10	10	15	15	20	20	30	40	50
	3	10	10	10	15	15	20	20	30	40
	4	10	10	10	10	15	15	20	20	40
	5	8	9	9	10	10	15	15	20	30
	6	7	8	9	9	10	10	15	15	20
	7	6	7	7	8	8	9	10	15	15
	8	2	4	4	6	7	7	8	9	10
	9	1	1	1	1	2	2	4	6	7
2	1	20	30	30	40	50	50	60	70	80
	2	20	20	30	30	40	50	50	70	80
	3	20	20	20	30	30	50	50	60	70
	4	15	20	20	20	30	40	50	50	70
	5	15	15	15	20	20	30	40	50	60
	6	10	10	15	15	20	20	30	40	50
	7	9	10	10	10	15	15	20	20	30
	8	7	8	9	9	10	10	15	20	20
	9	2	4	4	6	7	8	9	10	10
3	1	40	40	50	60	60	70	80	91	92
	2	40	40	50	50	50	70	70	80	91
	3	30	40	40	50	50	60	70	80	91
	4	20	30	30	40	50	50	60	70	80
	5	20	20	20	30	40	50	50	60	70
	6	15	20	20	20	30	40	50	50	60
	7	10	15	15	20	20	20	30	50	50
	8	9	10	10	15	15	15	20	20	40
	9	6	7	8	8	9	9	10	15	20
4	1	50	60	70	70	80	80	91	92	93
	2	50	50	50	70	80	80	80	91	92
	3	50	50	50	60	70	80	80	91	92
	4	40	40	50	50	60	70	70	80	91
	5	30	40	40	50	50	60	70	80	91
	6	20	20	30	40	50	50	60	70	80
	7	15	20	20	20	30	40	50	50	70
	8	10	10	15	15	20	20	30	40	50
	9	7	8	9	9	10	10	15	15	20

(*continued on next page*)

(*continued*)

UCI	Individual Skill	Task Repetition								
		1	2	3	4	5	6	7	8	9
5	1	60	70	80	80	80	80	91	92	93
	2	50	60	60	70	80	91	92	92	94
	3	50	50	60	70	80	80	91	92	93
	4	50	50	50	60	70	80	80	91	92
	5	40	50	50	50	60	70	80	80	92
	6	30	40	40	50	50	60	70	80	91
	7	20	20	30	30	40	50	50	70	80
	8	15	15	15	20	20	30	40	50	60
	9	8	9	9	10	10	15	20	20	30
6	1	70	80	80	91	91	92	93	94	95
	2	70	70	80	80	91	91	92	93	94
	3	60	70	70	80	80	91	92	92	94
	4	50	60	70	70	80	80	91	92	93
	5	50	50	60	60	70	80	80	91	92
	6	40	40	50	50	60	70	80	80	91
	7	20	30	40	40	50	50	60	70	80
	8	15	20	20	20	30	40	50	60	70
	9	9	9	10	10	15	15	20	20	30
7	1	80	80	91	92	92	93	94	95	96
	2	70	80	80	91	92	92	93	94	95
	3	70	70	80	80	91	92	92	94	94
	4	60	60	70	70	80	91	92	92	94
	5	50	50	60	70	80	80	91	92	93
	6	40	50	50	50	60	70	80	91	92
	7	30	40	40	50	50	60	70	80	91
	8	15	20	20	30	30	50	50	60	70
	9	9	10	10	15	15	20	20	30	40
8	1	80	80	91	92	92	93	94	95	96
	2	80	80	91	91	92	93	94	95	96
	3	70	80	80	91	92	92	93	94	95
	4	70	70	80	80	91	91	92	93	94
	5	60	60	70	70	80	91	91	92	93
	6	50	50	60	60	70	80	91	91	92
	7	30	40	50	50	60	70	80	80	91
	8	20	20	30	40	50	50	60	70	80
	9	10	10	15	15	20	20	30	40	50
9	1	91	91	92	92	93	94	95	96	97
	2	80	91	91	92	93	94	94	95	96
	3	80	80	91	91	92	93	94	95	96
	4	70	80	80	91	91	92	93	94	95
	5	60	70	80	80	91	91	92	93	94
	6	50	60	70	70	80	80	91	92	94
	7	40	50	50	60	70	70	80	91	92
	8	20	30	30	40	50	60	70	80	91
	9	10	15	15	20	20	20	30	40	50

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