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# Evaluating human factors effect in reducing helicopter accidents (Case Study: Maintenance division, IHSRC)

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## ABSTRACT

Flight safety is mostly dependent on repair and maintenance issues which if it is not done correctly, it will lead to accidents at different scales. In comparison, among multiple threats in the aviation industry, tracing a technician's faults in the repair and maintenance could be extremely difficult. Although most of the times, these errors remain unseen, uncorrected, and hidden and therefore have negative impacts on helicopter safety. Thus, analyses of these various factors which influence human performance help people to work in close collaboration with each other more effectively. In this study, we indented to identify human factors influencing repair and maintenance aviation industry and then evaluate the importance and impact degree of affecting factors on each other and helicopter accidents. In order to identify the human factors, some documents such as handbooks, standards, organizational procedures, and relevant literature in this area have been used. Given that the identified factors are not independent of each other and there is a casual relationship between them, a combined method using AHP and DEMATEL for evaluating and determining their importance was used. In this case, AHP determines the effects of factors on helicopter crash and DEMATEL method determines the effects of factors on each other. For this purpose, a questionnaire (comparison matrix) was distributed among some experts. The statistical population included all employees in technical areas, standards, design bureau, and technologies development. In this regard, a kind of survey has been performed with 15 experts in this field. After data collection and data analyses by using the proposed methods, the most important criteria in helicopter accidents was the standards of training and the less important one was related to repetitive and boring nature of these jobs. The other human factors such as fatigue, personal problems, and lack of resource including accessories and components have an equal importance. This study was an applied research adopting a correlational method and survey design.

Helicopter is a kind of aircraft which embraces too much complexity, so that its design and manufacturing made human to show his highest level of creativity (Ancel et al., 2015). Utilizing aerodynamic principles in designing helicopter parts and components alongside the mechanical and metallurgical engineering sciences has made helicopters more desirable than fixed-wing aircrafts and missiles (Billings & Reynard, 1984). Helicopter engine utilizes metallurgical thermodynamics, main and peripheral gear boxes as well as powertrain configuration to exploit mechanical and metallurgy engineering designs. These are all components which should have provided properly in order to have proper operation, interaction, and safe flight. The functions of these components must be achieved their best possible performances through interacting individually or collectively. All people involved in designing, manufacturing, utilizing, operating as well as maintaining have to precisely do their jobs, so that a helicopter can fly safely (Cacciabue, 2004). To analyze helicopter safety, responsible states and authorities always try to take special actions and seminars regarding this issue which hold around the world to provide solutions for reducing accidents occurrences (Shappell & Wiegmann, 2012). Statistically speaking and according to the results obtained from such seminars, the helicopter accident rate per flight is roughly constant. In comparison to other types of aircrafts, helicopters are able to fly straight up to some height above the earth which cause hazard threats or risks (Stanton et al., 2013). Helicopter accidents are mostly due to three main causes including improper operator usage, mechanical malfunctions, and electrical malfunctions. Each simple or complex part of a helicopter can cause an accident alone or in conjunction with other parts of the helicopter. A helicopter is a collection of integrated mechanical parts or components which seek to work together. Although high safety margins are applied to design these parts, improper functioning of each part can entail a catastrophic accident. Electrical malfunctions refer to any kind of malfunction in electrical systems and power supplies in a helicopter. This is true especially for power supply systems which provide electrical power for some crucial components like radio communication and navigation. Flight safety is mostly determined by maintenance and if it is not done correctly a range of accidents may occur. Maintenance failures consist of improper assembly of parts, missing parts during assembly, and ignoring relevant inspections and tests (Stolzer, Halford & Goglia, 2015). As International Civil Aviation Organization (ICAO) includes an individual's overall performance in an aviation system in its definition and pays attention to human factor in personnel performances, working environments, its association with machineries, equipments, tools, procedures, and above all their interrelationships. It has major targets in air transportation, safety, and effectiveness. Based on previous studies which have been done by Bell Helicopter Company (BHC) on the causes of helicopter accidents from 1982 to 2005 (Figure 1), the issue of human factor was significant despite increasing and decreasing the number of accidents. These factors allocate almost 70 to 80 percent (a constant percentage) to themselves in a year.

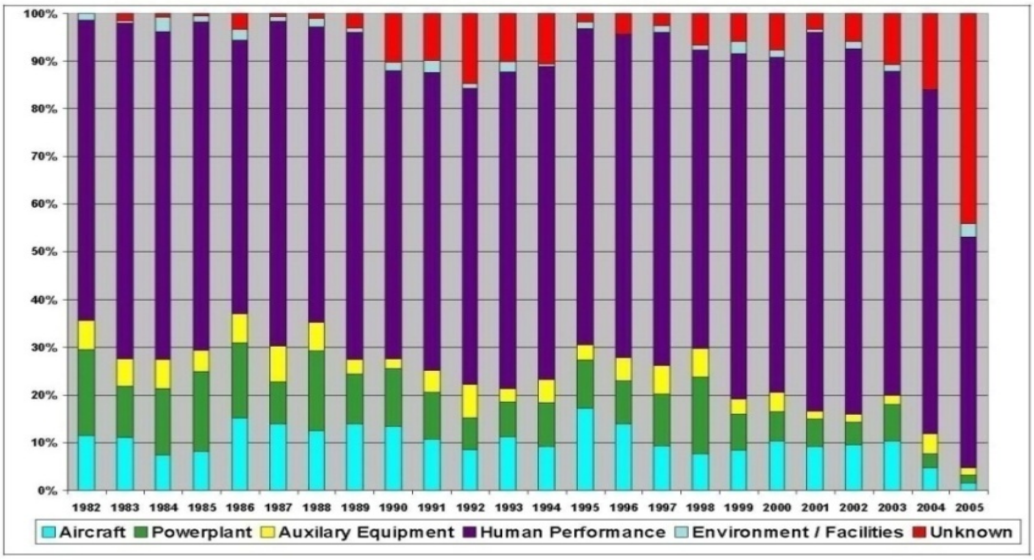


*Figure 1.* Crash causes during years 1982 to 2005

BHC is considered as one of important centers which is increasingly looking for new ways to have safe helicopter flights. It also has the largest share of the current fleet in the world. Also, it proposed a center which is called Joint Helicopter Safety Analysis Team (JHSAT) for the first time in Safety Conference in Canada which immediately approved by 30 member states. JHSAT team's objective is to organize members for practical and theoretical interventions regarding helicopter safety. This objective has reduced the number of flight accidents up to 80 per cent within 10 years. It is obvious that the main concern should be the United States which is considered as the world's number one helicopter manufacturer and operator. Figure 2 shows that more than 50 per cent of helicopters in the world are flying in this country.

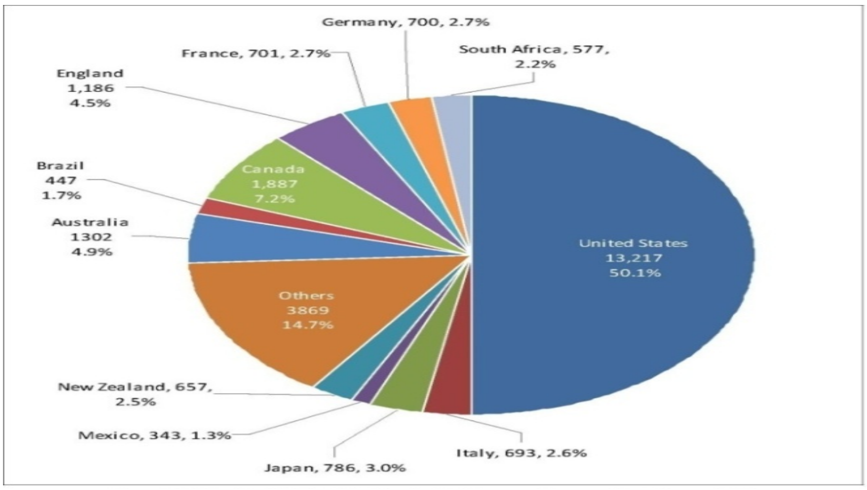


*Figure 2.* Helicopter usage percentage in countries

The term human factors have been highly focused on civil aviation industry recently which differ from mechanical malfunctions. These factors usually refer to human failures and errors. The list of human factors that influence extensively on maintenance and performance (Salas, Jentsch & Maurino, 2010). Human factors embrace a broad range of people with various competencies, strengths, weaknesses, and limitations. Some points are more serious than others, but in most cases three or four factors usually combine together in an accident. According to Figure 3 which is presented by Federal Aviation Administration's (FAA) in 2009, more than 80 per cent of flight accidents happen due to human factors.

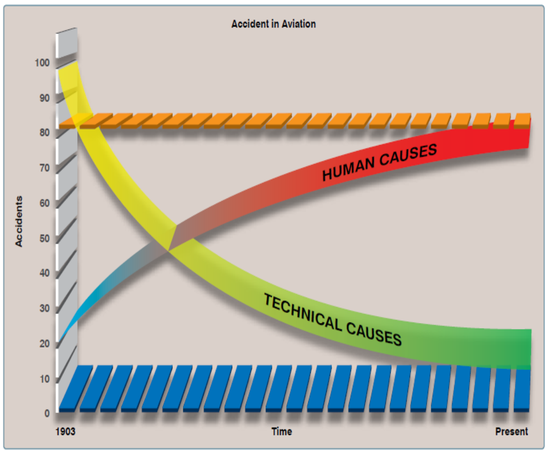


*Figure 3.* Flight crashes occurrence percentage due to human and technical factors

The importance of doing research about human factors in repair and maintenance industry necessitates finding the best solution for human performance in repair, maintenance and inspection. Studying various factors which affect human performance, we have to reach a particular point in which people could work more efficiently and effectively. Therefore, recognizing human factors can enhance the quality and safety of personnel and aircrafts (Mohaghegh, Kazemi, & Mosleh, 2008). Since most of the accidents occur due to chain of factors, it is more desirable to break a chain link rather than focusing on primary causes. It is always focused on risks when it is worked on safety because the lack of safety may result in higher rates of risk. By chain breaking of hazardous factors, the rate of relative risk will decrease to very low levels and on the contrary the safety will increase (Maurino, Reasonson, Johnstonton, & Lee, 1995). This study aimed at evaluating human factors effect in reducing helicopter accidents.

## The Literature Review

Human errors are defined as human actions with unplanned or unintended consequences. In training section, evaluation of hazardous areas and safety inspections should not be confined to efforts which prevent the errors from occurring. It also should give us the ability to detect and correct errors before they lead to catastrophic consequences. Human errors are considered as the main causes of flight accidents and crashes especially since 1989. FAA investigations office, aircraft safety center in Australia, and ICAO center in Europe have performed studies that investigate the effect of human factors on aviation maintenance. Recognizing the values and interests of maintenance personnel to improve human resources management has proved to be important (Edwards, 1972). Regarding the importance of helicopter accidents, it is necessary to review and analyze researches, theories, and views in the field of human resource related issues.

**Shell Model**

Shell model was first proposed by Edward in 1972. In 1987, the model was then altered and revised by Hawkins. The main components or shortcomings of the model are shown in Figure 4. In this model, S refers to the improper translation of the procedures and incorrect writing of menus while H stands for inadequate and improper tooling. E refers to undesirable environment or inadequate hangar space while L reflects the relationship with other people and workforce shortages.

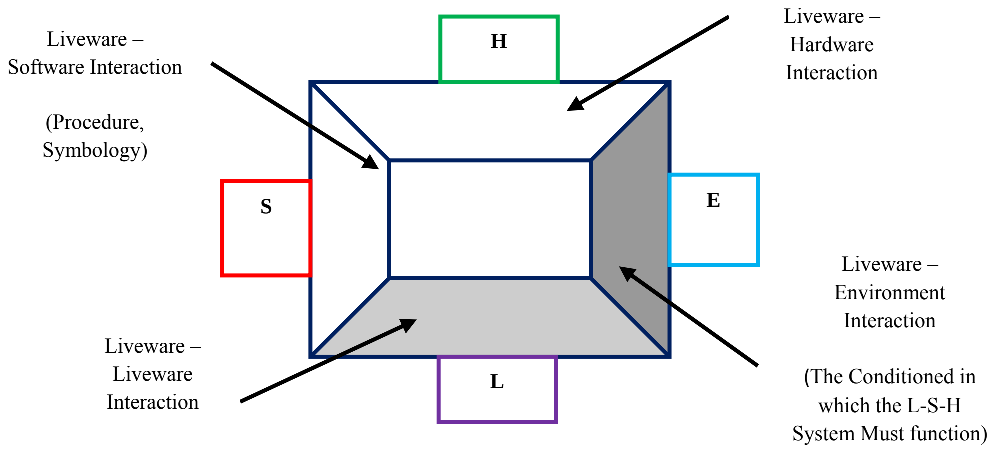


*Figure 4.* Shell model

Obviously, technical personnel play pivotal roles in this process and are located at the center of this model. Furthermore, the other involving factors and limitations should be taken into account otherwise they may result in crashes or accidents. Leonelli (2003) introduced a continuous supervision and analysis system as a means of evaluating, analyzing, and troubleshooting activities which perform during maintenance operations and considered their effectiveness. Lock and Strut (1995) identified five major factors which influence on aviation technical inspections including availability of the parts or unites being inspected, general lighting conditions in workplace, employees' motivation and general moods, and work procedure. This study determined the importance of each factor on the number or rate of errors occurred in aviation industry. Patankar and Taylor (2004) paid attention to the impact of human factors on aviation maintenance from three perspectives, namely individual, organizational, and academic. They analyzed different effects of human factors on aviation maintenance industry such as crash occurrence and similar lists. Reviewing human factors in maintenance industry by them reflected that successes usually happen in individual level while errors or failures in organizational level. They concluded that academic researchers have to determine proper principles of human factors. Many safety practices have to change because they are cultural and it is necessary to consider them both in practical and academic levels. Based on Reason (1997) argued that the personnel of helicopter industry focus on human factors could enhance efficiency, effectiveness, and helicopter safety. Sumwalt (1998) stated that human factors are actually considered as the central part of any system. The physical, physiological, and psychological factors influencing an individual's ability are used in performing specific tasks. Physical factors which include in the study are not limited to age, physical strength, technical skill, audiovisual ability, and other sensations. Physiological factors refer to general health state, diet, stress, tiredness, disability regarding specific work, and general life style. Psychological factors include mental abilities, information processes, emotions, attention, work load, personality characteristics, mental models, and knowledge levels including training, attitude, and moods. Human factors determine human abilities and limitations and afterwards system components can be adapted to them. Also human factors can affect efficiency such as time, work units, safety, error, and in some cases attitudes. In late 1980s and early 1990s, TC12 organization enumerated about 12 human factors related to safety which could lead to error and crash due to great number of aircraft accidents and maintenance fails. These 12 factors that are also known as "Dirty Dozen" are lack of communication, excessive self-confidence, lack of information and knowledge, distraction, lack of teamwork mentality, fatigue, lack of resources, tensions, workload, lack of courage and boldness, awareness shortage, and norms. Drury's studies (1991) provided a description of personal errors that are based on maintenance and inspection. He identified these human errors by separating inspection items to distinct tasks and determining different errors and failures of these tasks. These errors and defects were balanced and validated based on observations which made during the inspection and interviewing with inspectors, supervisors, and quality control people. From his point of view, a model of aviation maintenance and inspection must include four interrelated parts which are users, equipments, documentations, and tasks. It is recommended that these parts are then connected to physical, social, and organizational environments during proper time. Considering aforementioned studies and investigating top document reviews in the field such as handbooks, standards, organizational procedures, subject literature and brainstorming with participation of experts from PANHA, this research proposed eleven maintenance human factors which affecting helicopter accidents including training, fatigue, workplace environment, resource shortage consists of accessories and components, lack of courage and boldness, communication and coordination, stress, knowledge and skill, excessive self-confidence, personal issues, and repetitive and boring jobs.

## Method

Based on conceptual framework of our research (Figure 4), 11 human factors have been identified. These factors were not independent and there were cause and effect relationships between them. To find the impact of each relationship, AHP and DEMATEL methods were used. AHP method was used to find the impact of human factors on helicopter accidents and DEMATEL was used to find the interrelationships among these factors. Statistical population of this study consisted of 15 experts or specialists currently working in technical, standards, design and technology development offices of Iran Helicopter Support and Renewal Company.

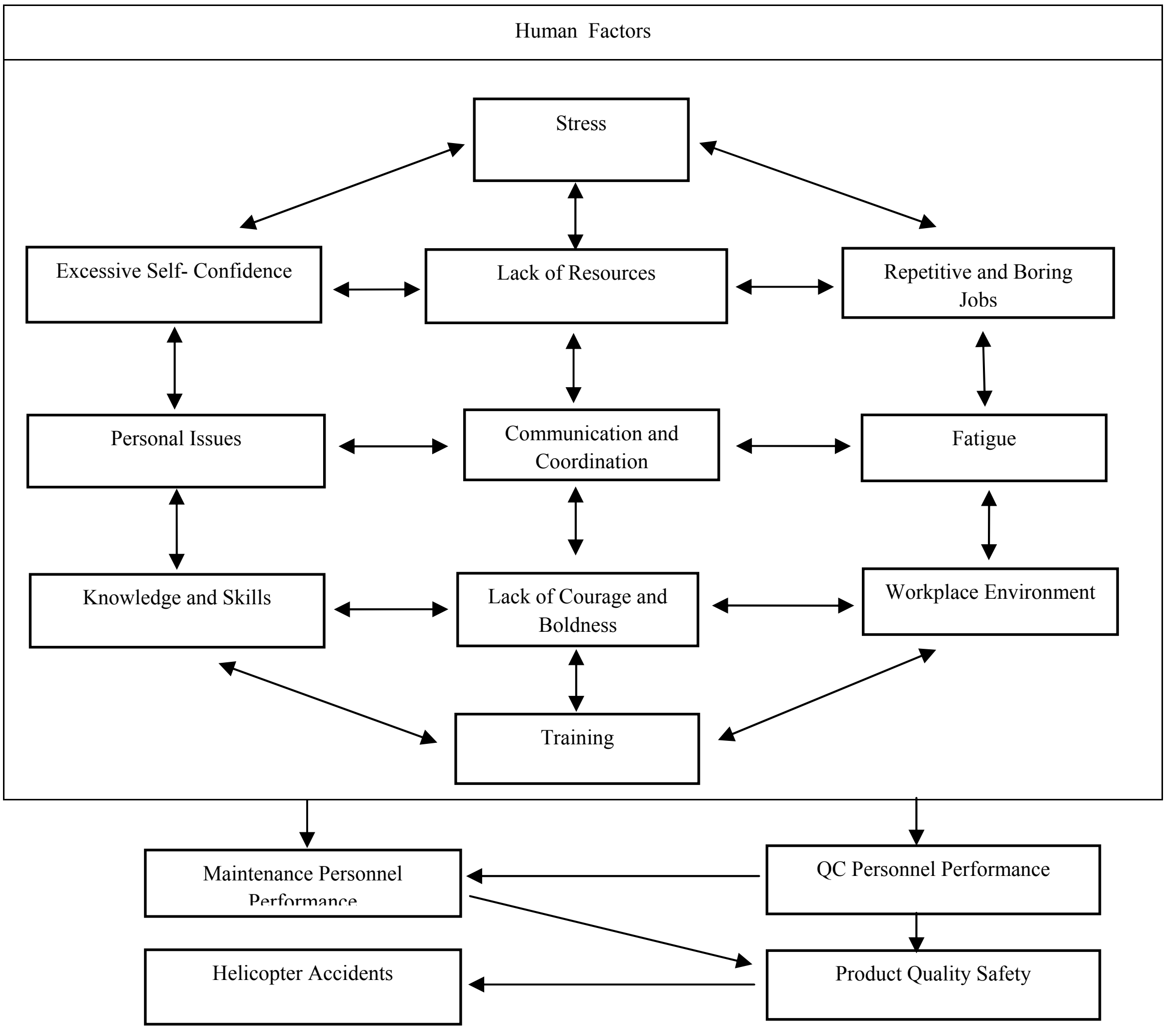


*Figure 5.* Conceptual method of research

## Analytical Hierarchy Process (AHP)

Thomas Saaty (1970) developed Analytical Hierarchy Process (AHP) as a decision-making method including four principles for analyzing the hierarchy process and establishing the applicable laws and regulations of them. Principles consists of inversion condition, homogeneity, dependence, and expectation. Inversion condition states that if A's preference to B is n, then B's preference to A is 1/n while homogeneity principle expresses that element A and element B must be homogenous and comparable. In other words, element A's superiority to element B cannot be infinity or zero. Dependence states that each hierarchical element could be dependent to the element in higher level and this dependence might continue to the uppermost level. Finally, expectations are applied to hierarchical structure. They states that the evaluation process should repeat in change cases. For running AHP, some steps should be taken into account including modeling, preference judgment, weight calculation, merging relative weights, and judgment consistency investigations. In modeling step, problem and the goal or decision making is hierarchically connected to decision elements. Decision elements include decision criteria and decision alternatives. Preference judgments or mutual comparisons are done by pair-wise comparison of decision elements and assigning numerical scores resembling preference or relative importance between two elements. Therefore, the alternative or criterion is compared to the alternative or criterion. In order to calculate the weight, geometrical average of values in each row is calculated first and then the values obtained from geometrical averages are placed in new columns and their sum is calculated. All values in this new column are divided to their sum. This average denotes the relative weight of decision elements or matrix rows. In order to rank decision alternatives, relative weight of each element is multiplied in weight of higher elements to find final weight. Therefore, each element has a final weight. Inconsistency rate shows that to what extent the obtained priorities can be trusted; for instance, if alternative A is more important than alternative B (preference value 5) and B is relatively more important than C (preference value 3), then it is expected that A is considered far more important than C (preference value 7 or more). Experience shows that the inconsistency rates less than 0.1 imply acceptable consistency and otherwise comparisons should be reevaluated. Five steps are used to find inconsistency rate. The first step refers to the calculating total weight vector; therefore, we multiply the pair-wise comparison matrix in column vector of relative weights. Resultant vector is called total weight vector. To calculate consistency vector in the second step, the elements from total weight vector are divided by relative priority vector. The obtained vector is called consistency vector. In the third step, the average of consistency vector's elements ($\lambda_{max}$) is estimated. To calculate the consistency index, formula 1 is used. In this formula *n* refers to the number of alternatives for each problem.

Formula 1:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

To calculate consistency ratio, the consistency index should be divided to random index. Consistency ratios which are smaller or equal than 0.1 show consistency in comparisons.

Formula 2:

$$CR = \frac{CI}{RI}$$

**DEMATEL Method**

Decision Making Trial and Evaluation (DEMATEL) method was introduced by Fonetla and Gabus in 1971. It is one the decision methods based on mutual comparisons which use the experts' judgments for extracting system factors and structuring them systematically in order to apply them in graph theory. This presents a hierarchical structure of the existing factors in a system along with influence interrelationships so that the effect of relationship intensity is determined by numerical value. Some steps should be taken into account to apply DEMATEL method. First of all, a building direct relation matrix which consists of number of rows and columns equal to the number of criteria is built. Then the formula 3 is used to normalize the direct relation matrix.

Formula 3:

$$N=K*M$$

In this formula $k$ is calculated as below (formula 4). First the sum of elements in all rows and columns are obtained. The reverse of the biggest value in all rows and columns is $k$. To calculate the complete relation matrix, formula 5 is used.

Formula 4:

$$k=\frac{1}{\max\sum_{j=1}^{n}a_{ij}}$$

Formula 5:

$$\mathrm{T}=\mathrm{N}*(\mathrm{I}-\mathrm{N})^{-1}$$

To create a causal diagram, the sum of elements in each row (D) for each factor is estimated to reflect the influence of that factor on other factors in the system (influence of variables). Moreover, the sum of column elements (R) for each factor shows how much it is influenced by other factors in the system. Finally, R value and D value are added and normalized.

Table 1
*Evaluating Criteria in AHP & DEMATEL*

| AHP | | DEMATEL | |
|---|---|---|---|
| Status of Comparison between ith and $J^{th}$ Criterion | Preference Value | The Extent of Influence Ogi$^{th}$ Criteria on $J^{th}$ Criteria | Preference Value |
| Equal Importance | 1 | No Influence | 0 |
| Relatively more Important | 3 | Very Low | 1 |
| More Important | 5 | Low | 2 |
| Far more Important | 7 | High | 3 |
| Absolutely more Important | 9 | Very High | 4 |

To find the final weights for each criteria, the obtained weights from DEMATEL for each criterion should be added to weight and normalize the obtained weights from AHP and finally propose a combined AHP & DEMATEL method.

## Data Analysis

In the first step, comparison matrix as a questionnaire was distributed among 15 experts from technical standards, design offices, and technology development in IHSRC. After recollecting questionnaires and analyzing the received data, it was found that 11 of them have to be omitted because the consistency rate was less than 0.1 and therefore only 4 questionnaires could be used. The averaged values were calculated for the consistent matrices. In the second step, DEMATEL questionnaires (comparison matrices) were distributed among those experts who had consistent AHP responses. At the end, final weights for criteria were obtained based on arithmetic average weights from AHP and DEMATEL methods.

### Analyzing Data from AHP Questionnaires (Comparison Matrices)

Table 2 and Chart 1 reflect the importance of training criterion relative to the whole helicopter accident criteria is 28.08 per cent which indicates this factor has about 28.08 per cent effect on an accident. According to Table 2, the importance for other criteria such as resource shortage namely accessories and components, knowledge and skills, personal issues, stress, fatigue, workplace environment, excessive self-confidence, lack of courage and boldness, communication and coordination, and repetitive and boring jobs are 13.51, 13.05 , 10.66, 8.41, 7.39, 5.43, 4.97, 3.60, 2.50, and 2.40 per cents respectively. Therefore, the highest weight or importance is related to training and the least to repetitive and boring jobs.

Table 2
*Criteria Weights in Obtained from AHP Method*

| | Human Factors | Weight (AHP) |
|---|---|---|
| A | Stress | 8.41 |
| B | Fatigue | 7.39 |
| C | Workplace Environment | 5.43 |
| D | Personal Issues | 10.66 |
| E | Training | 28.08 |
| F | Repetitive and Boring Jobs | 2.40 |
| G | Excessive Self-Confidence | 4.97 |
| H | Knowledge and Skills | 13.05 |
| I | Communication and Coordination | 2.50 |
| J | Lack of Resources | 13.51 |
| K | Lack of Courage and Boldness | 3.60 |

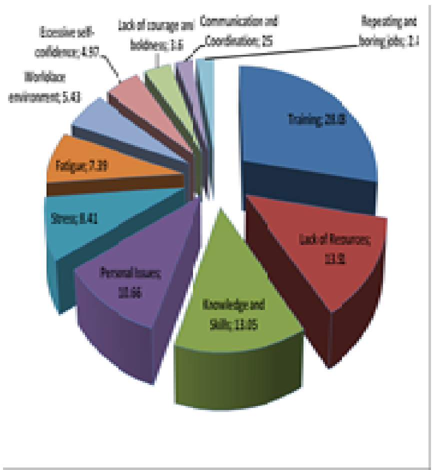


*Chart 1*. Criteria weights in obtained from AHP method

### Analyzing Data Obtained from AHP & DEMATEL

Table 3 and Chart 2 present the final weights criteria for each of 11 criteria in helicopter accidents including training (18.29), knowledge and skills (14.34), stress (10.78), fatigue (9.73), personal issues (9.41), lack of resources (9.39), communication and coordination (7.21), workplace environment (6.74), lack of courage and boldness (5.82), excessive confidence (5.03), and repetitive and boring jobs (3.28). Therefore, the highest weight allocates to training and the lowest to repetitive and boring jobs. In addition, other human factors such as fatigue, personal issues, and lack of resources gained the same importance.

Table 3
*Final Weights Obtained from Combined AHP & DEMATEL Method*

| | Human Factors | $F_1$ | $F_2$ | $F_3$ | $F_4$ | Final | Final (%) |
|---|---|---|---|---|---|---|---|
| A | Stress | 0.08 | 0.09 | 0.10 | 0.14 | 0.10 | 10.78 |
| B | Fatigue | 0.12 | 0.10 | 0.08 | 0.07 | 0.09 | 9.73 |
| C | Workplace Environment | 0.09 | 0.06 | 0.06 | 0.05 | 0.06 | 6.74 |
| D | Personal Issues | 0.14 | 0.10 | 0.04 | 0.08 | 0.09 | 9.41 |
| E | Training | 0.22 | 0.17 | 0.18 | 0.14 | 0.18 | 18.29 |
| F | Repetitive and Boring Jobs | 0.04 | 0.03 | 0.01 | 0.02 | 0.03 | 3.28 |
| G | Excessive Self-Confidence | 0.03 | 0.05 | 0.08 | 0.03 | 0.05 | 5.03 |
| H | Knowledge and Skills | 0.06 | 0.15 | 0.16 | 0.18 | 0.14 | 14.34 |
| I | Communication and Coordination | 0.05 | 0.05 | 0.07 | 0.10 | 0.07 | 7.21 |
| J | Lack of Resources | 0.05 | 0.09 | 0.13 | 0.09 | 0.09 | 9.39 |
| K | Lack of Courage and Boldness | 0.07 | 0.06 | 0.04 | 0.04 | 0.05 | 5.82 |

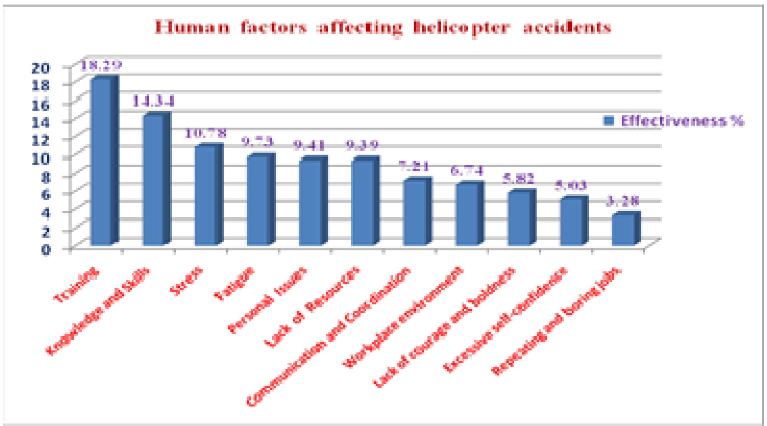


*Chart 2.* Final weights obtained from combined AHP and DEMATEL methods

## Conclusion

Pareto analysis allocated the horizontal axis to itself in Chart 3. It showed that all the criteria are considered in this study while the left vertical axis presented the obtained percentage for each criterion and the right vertical axis presents the Pareto curve for them. The slope of Pareto curve in distribution showed that the criteria such as training and knowledge and skills have the highest importance while stress, fatigue, personal issues, and lack of resources have the less importance in comparison to other ones. Other five criteria including communication and coordination, workplace environment, lack of courage and boldness, excessive self-confidence, and repetitive and boring jobs have far less importance.

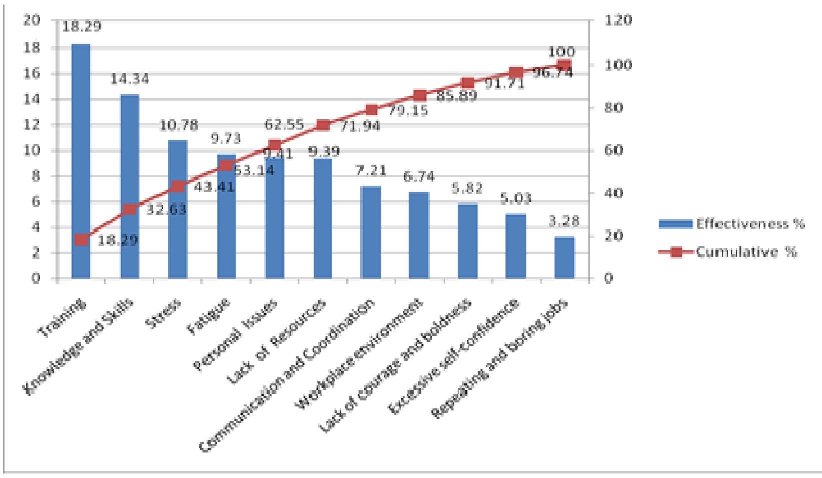


*Chart 3*. Pareto analysis

Regarding the high weight training results, the qualification of maintenance personnel should be monitored carefully to confine the effects of shortcomings within training mechanisms in advance to hinder the helicopter safety. A general supervision over training should be placed at the center of any quality assurance process or safety assurance program. A mechanism should be created to measure and monitor the status of human resources. Therefore, a scale quantitative should be developed to evaluate the plans improvement. Moreover, the safety management should implement some policies to clear the human error occurrence and present a safety system. The safety management in the company presents proper feedbacks of errors and accidents to train maintenance engineers and other relevant personnel. It is necessary that the knowledge and skills of experienced personnel in the company gather and document by the knowledge management department. Furthermore, the training books, manuals, and current training processes should be reviewed and then incorporated some new up-to-date methods of training. More research should be done about each sub-factor and its effect on human factors in order to increase the concentration on effective variables and then improve plans. Through doing research on how to measure the status of human factors in maintenance, the status of factors influencing an accident can be measured and plans for improving them devised. Finally, more research on the effect of each factor on helicopter reliability should be done. In fact, the results of this study could be validated through the use of appropriate official tools to measure the reliability of system and human factors.

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