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# AN INVESTIGATION ON THE CAUSES OF WORK-RELATED ACCIDENTS IN ELECTRICITY DISTRIBUTION CENTERS IN IRAN

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**Abstract**

Every year, work-related accidents cause death and injury to thousands of people in the world. In addition to human losses, these accidents also cause huge economic losses to companies and organizations. Likewise, based on reports from Iranian organizations in charge, namely the Ministry of Labor and the Ministry of Health, a significant number of the staff of companies and organizations in the country are injured or dead each year as a result of work-related accidents. Among these companies and organizations are electricity distribution companies which due to the nature of their work, are particularly faced with work-related accidents and suffer large human losses. This research tries to identify the factors causing work-related accidents, and if possible, provide ways to reduce the probability of such accidents. The method used is causal and field studies have been carried out. Study of existing documentation on past events suggests safety equipment defects, inadequate training, lack of proper supervision and lack of coordination among executive units as the main factors causing work-related accidents in electricity distribution centers. As obtaining the expert's opinion on those factors could help us determine the relation between them through a holistic approach, as opposed to collecting the documentation about the causes of accidents, which was a component-oriented approach, we obtained expert views using a questionnaire and interpreted them using the Interpretive Structural Modeling (ISM) mathematical technique to determine those relations. Based on the results from this method, inadequate training has been the main cause of work-related accidents in the electricity distribution centers in Iran. This paper provides strategies with regard to reducing the impact of the factors, prioritizes those strategies and points out the most important strategies.

**Keywords:** Work-Related Accidents, Electricity Distribution Personnel, Training, ISM technique, Safety

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## Introduction

Human societies need to perform numerous activities in order to survive. Supplying food, clothing and means of transportation is not easily possible, as there are many physical and financial hazards on the way. Part of these hazards is associated with work time. Human has put a great amount of thought and effort to minimize such hazards.

**Historical background:**

With the industrial revolution and the emergence of heavy machinery with gigantic gears, presses, chains, blades and special transportation devices, industrial hazards were increased. Since the earliest days, scientists like Dr. Alexis Carrel have warned that uncontrolled industrial advancements will lead to the annihilation of human life, should humans not be concerned about their own lives and protect them during those advancements. The increasing trend of these hazards lasted until after World War II, when statistics showed such huge rises in industrial accidents that the issue of industrial protection and safety systems started to be considered of great importance. [Rajabzadeh, 1386]

Until the late eighteenth century, industrial hazards were not involved in human life as they are now, and the issue of preserving capitals and human resources and creating a healthy, safe and secure work environment was not much considered. [Kazemi, 1382]

A work-related accident is an accident which occurs while at work, and as a consequence of it [Nahri, 1387] and is classified variously based on:

- Type of the accident
- Type of the tools involved
- Type of the damage incurred
- Location of the accident

Based on occupational diseases, work-related accidents are divided into five categories:

1. Caused by physical factors
2. Caused by mechanical factors
3. Caused by biological factors
4. Caused by chemical factors
5. Caused by mental factors [Kazemi]

Tens of millions of workers each year fall victim to accidents which cause death or disability to a large number of them. Based on the statistics published in the developed countries, one out of every ten workers is fallen victim annually, and as a result of such accidents, five percent of the national work days are lost. On the one hand, work-related accidents cause discomfort to the victims and/or their families, and on the other hand they cause loss of resources and weakening of economic foundations of the society. For those reasons, such accidents are of great consequence. [Afsharzadeh, 1382]

This research addresses the issue of work-related accidents –especially its new form in the modern life– using the scientific method. The introduction of electric power industry and the utilization of such great achievement also brought into existence the problem of electrical injuries and related accidents. A large part of such accidents occur at power distribution facilities. An attempt to identify the causes, and decrease the number, of work-related accidents in those facilities will have an undeniable impact on the figures of work-related accidents throughout the country.

## Statement of Problem

Electricity distribution centers are responsible for utilizing electricity networks, as well as performing maintenance and modifications on those networks. Another responsibility of distribution centers is to sell new electricity connections to the applicants and to collect electricity tariffs from subscribers. While performing these tasks, personnel of distribution companies are exposed to a variety of accidents which may cause damage and injury to the victims or even death of them. There are 40 distribution companies active in Iran and operate under the supervision of Tavanir Co., which is one of the main companies of the Ministry of Energy.

The Distribution Safety Bureau of Tavanir Co. has recorded and classified the accidents occurred in the distribution centers as the various groups presented in *Table 1*:

*Table 1*

**Types of work-related accidents occurred in distribution companies**

1. Low-voltage electric shock above the ground
2. Low-voltage electric shock on the ground
3. Low-voltage electric shock above the ground and falling
4. Medium-voltage electric shock above the ground
5. Medium-voltage electric shock on the ground
6. Medium-voltage electric shock above the ground and falling
7. Burns caused by arc flash
8. Burns caused by fire
9. Falling from the pylon
10. Falling together with the pylon
11. Falling from ladder

12. Falling from tree/wall/roof
13. Pylon falling on people
14. Collision with equipment or tools
15. Motorcycle accidents
16. Road accidents
17. Urban accidents
18. Falling from lift/crane/pallet
19. Objects falling on
20. Pylon falling on people
21. Other cases

Study of the accident records documented in distribution companies shows that these accidents can be summarized in three main groups:

1. Accidents directly caused by electric shock
2. Accidents indirectly caused by electric shock
3. Accidents not associated with electric shock

The classification is resulted by taking into consideration that most of accidents associated with the operations of distribution centers are linked to the fact that the activities of those companies are indeed associated with electricity networks, which by their nature pose potential dangers to life and property. These dangers include burns and fractures caused by contacting power lines and getting thrown by them. Some accidents, however, appear to have no connection with power grid operations but occur as they could also occur in any other workplace regardless of the nature of the operations. Among them are car accidents, objects falling on people, which cause physical injuries. According to reports archived in Tavanir Co., accidents caused directly by electric shock include medium-voltage electric shock above the ground and on the ground, low-voltage electric shock above the ground and on the ground, and also different types of burns. The reports mention falling from electricity pylon, falling together with pylons, falling from ladders, falling from above, pylons falling on people as the accidents indirectly caused by electric shock. Accidents not related to electric grids including road accidents, collisions with equipment and tools and other cases not caused by electric shocks fall under the last category. Frequencies of the types of accidents

according to the aforementioned classification are presented in *Table 2*:

| Type of Accident | Year | | | | | Sum |
|---|---|---|---|---|---|---|
| | 84 | 85 | 86 | 87 | 88 | |
| Caused directly by electric shock | 76 | 108 | 85 | 82 | 40 | **391** |
| Caused indirectly by electric shock | 40 | 25 | 33 | 35 | 26 | **159** |
| Not associated with electric shock | 34 | 27 | 28 | 22 | 13 | **124** |
| **Total Sum** | **150** | **160** | **146** | **139** | **79** | **674** |

*Table 2: Accidents in Iranian distribution centers*
*(source: The Distribution Safety Bureau of Tavanir Co.)*

Figures presented in *Table 2* indicate that accidents occur frequently in distribution companies, of which 58 percent are caused directly by electric shock, 24 percent caused indirectly by electric shock, and 18 percent not associated with any electric shock. Understanding the factors involved in accidents occurred in distribution centers is a matter of importance, and can be a significant 'first step' to preventing damages to life and property. The researchers attempt to identify those effective factors by posing the following questions:

1. Is *inadequate training* among the main factors causing work-related accidents in distribution companies?
2. Is *lack of proper supervision* among the main factors causing work-related accidents in distribution companies?
3. Is *lack of coordination among executive units* among the main factors causing work-related accidents in distribution companies?
4. Is *safety equipment defects* among the main factors causing work-related accidents in distribution companies?
5. What is the relation between the main factors causing work-related accidents in distribution companies?

6. How can strategies effective in restraining work-related accidents in distribution companies be prioritized?

## Methodology

In terms of purpose, the current research falls under the applied research category, and in terms of method, under the descriptive-causal research category. The dependent variable here is work-related accidents, and there are four independent variables: inadequate training, lack of supervision, lack of coordination, safety equipment defects. In the first phase of this research, existence of a relation between the dependent variable and each of the independent variables was investigated. In the second phase, a mathematical technique called Interpretive Structural Modeling (ISM) was utilized to determine the relation between the independent variables. In the third phase, the strategies effective in restraining work-related accidents in distribution companies were prioritized.

Two types of data are used in this research:

1. Data extracted from the documents made available by the Distribution Safety Bureau of Tavanir Co. and the Office of Inspections of the Ministry of Labor.
2. Data obtained from safety experts in the power industry. These data were needed for structural analysis and paired comparisons and were collected through a questionnaire for constructing a graph, and another questionnaire for prioritizing the strategies.

The spatial domain of this research includes the electricity distribution companies throughout the country and the temporal domain includes all of the accidents occurred between 1384 and 1388[1] Jalali years.

There were 15 experts involved in the research who were qualified against our criteria.

## Data Analysis

Descriptive statistics were employed to determine the frequencies of the data collected from documents and to identify the main factors. In order to structure the variables, the Interpretive Structural Modeling (ISM) was used. This method is among the methods utilizing the expert's opinion, and the process of employing it to determine the relation between the variables is as follows:

Stage 1. List the parameters or the elements of a given system. Each element will form a node in the digraph to be drawn.

Stage 2. Determine the existing relation between the vertices (nodes) of the digraph.

Stage 3. Determine the group decision making rule for the existing relations between each pair of nodes.

Stage 4. Obtain the expert's opinion for each paired comparison test performed on a pair of elements.

1 2006 – 2010 in the Gregorian Calendar

Stage 5. Determine the consensus on a possible relation between each pair of elements and connect the corresponding nodes with a directed arc.

Stage 6. Draw the corresponding digraph. Determine the corresponding adjacency matrix.

Stage 7. Determine the reachability matrix based on the adjacency matrix.

Stage 8. Identify the possible level partitions from the reachability matrix. (Asgharpoor, 1382, p.120)

## Findings

Study of the documents found in the Distribution Safety Bureau of Tavanir Co. and the records of the accidents occurred between 1384 and 1388, shows the frequencies of the three groups of accidents which are described in *Table 3*:

| Factors | Caused directly by electric shock | | Caused indirectly by electric shock | | Not associated with electric shock | |
|---|---|---|---|---|---|---|
| | Primary Factor | Secondary Factor | Primary Factor | Secondary Factor | Primary Factor | Secondary Factor |
| Safety equipment defects | 88 | 29 | 21 | 11 | 1 | 0 |
| Inadequate training | 33 | 25 | 14 | 5 | 2 | 0 |
| Lack of supervision | 13 | 32 | 2 | 5 | 2 | 0 |
| Lack of coordination among units | 21 | 4 | 0 | 1 | 0 | 0 |
| **All accidents** *(including unknown factors)* | **189** | | **39** | | **14** | |

*Table 3: Frequencies of the effective factors in each of the three groups of accidents*

According to those figures, the most frequent factor associated with accidents caused directly by electric shock is indeed *safety equipment defects*, which has been mentioned in 88 cases as the primary factor and in 29 cases as the secondary factor, totaling 117 times. These comprise 46 percent of the total cases directly involving electric shock.

In the same group, *inadequate training* has been mentioned 33 times as the primary factor and 25 times as the secondary factor. These collectively represent 17 percent of the total cases which make inadequate training the second most important factor.

*Lack of coordination among units* has been mentioned 21 times as the primary factor and 4 times as the secondary factor, and is the third most important factor with a total of 11 percent of all cases.

As the least important factor in the first group, *lack of supervision* has been mentioned 13 times as the primary factor and 32 times as the secondary factor, comprising 6 percent of the total cases directly involving electric shock.

Of the total 39 cases indirectly involving electric shock, that is, the second group, *safety equipment defects* has been mentioned in 21 cases as the primary factor and in 11 cases as the secondary factor, making it the most important factor in this group with a total of 54 percent of all cases indirectly involving electric shock.

*Inadequate training* has been mentioned 14 times as the primary factor and 5 times as the secondary factor, making it the second most important factor in the same group with a total of 32 percent of all cases.

*Lack of supervision* has been mentioned 2 times as the primary factor and 5 times as the secondary factor, totaling 11 percent of all cases which makes it the third most important factor in the second group.

*Lack of coordination* has been mentioned in 1 case as the secondary factor, and as the least important factor, it comprises 1 percent of all cases in the second group.

Of the 14 cases in the third group, which includes accidents not associated with electric shock, *inadequate training* and *lack of supervision*, each mentioned 2 times, and *safety equipment defects*, mentioned only 1 time have been reported as the factors effective in accidents not associated with electric shock.

In order to study the existing relation between the factors and form those factors into a proper hierarchical structure using the ISM method, we distributed a questionnaire among 15 experts from distribution companies and asked them to give their opinion about the relation between the mentioned factors regarding whether each one of them can be the cause of another or not, by filling out the questionnaire using paired comparisons. This procedure was based on the majority rule, and resulted in the initial graph illustrated below:

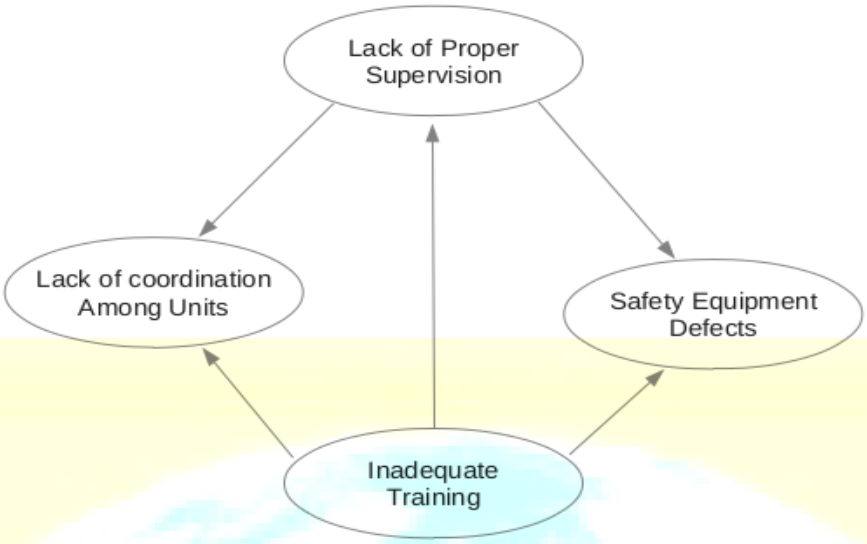


*Figure 1: The initial digraph of the factors*

First, we formed the adjacency matrix based on the graph.

Matrix ***D***:

| | Safety equipment defects | Inadequate training | Lack of proper supervision | Lack of coordination among units |
|---|---|---|---|---|
| Safety equipment defects | 0 | 0 | 0 | 0 |
| Inadequate training | 1 | 0 | 1 | 1 |
| Lack of proper supervision | 1 | 0 | 0 | 1 |
| Lack of coordination among units | 0 | 0 | 0 | 0 |

We had Matrix $\boldsymbol{D^2}=\boldsymbol{D}.\boldsymbol{D}$ as:

| | Safety equipment defects | Inadequate training | Lack of proper supervision | Lack of coordination among units |
|---|---|---|---|---|
| Safety equipment defects | 0 | 0 | 0 | 0 |
| Inadequate training | 1 | 0 | 0 | 1 |
| Lack of proper supervision | 0 | 0 | 0 | 0 |
| Lack of coordination among units | 0 | 0 | 0 | 0 |

Then we had Matrix $\boldsymbol{D^3}=\boldsymbol{D.D.D}$ as:

| | Safety equipment defects | Inadequate training | Lack of proper supervision | Lack of coordination among units |
|---|---|---|---|---|
| Safety equipment defects | 0 | 0 | 0 | 0 |
| Inadequate training | 0 | 0 | 0 | 0 |
| Lack of proper supervision | 0 | 0 | 0 | 0 |
| Lack of coordination among units | 0 | 0 | 0 | 0 |

We calculated the reachability matrix, $\boldsymbol{T}$, as:

$$\boldsymbol{T} = \boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D^2} + \boldsymbol{D^3}$$ ($\boldsymbol{I}$ is the *identity matrix*)

| | Safety equipment defects | Inadequate training | Lack of proper supervision | Lack of coordination among units |
|---|---|---|---|---|
| Safety equipment defects | 1 | 1 | 0 | 0 |
| Inadequate training | 0 | 1 | 0 | 0 |
| Lack of proper supervision | 0 | 0 | 1 | 0 |
| Lack of coordination among units | 1 | 1 | 1 | 1 |

Then we identified the level partitions from the reachability matrix, as:

| ***Ni*** **Element** | ***R(Ni)*** **Reachability Set** | ***A(Ni)*** **Antecedent Set** | ***R(Ni) ∩A(Ni)*** **Intersection** | ***R(Ni)*** |
|---|---|---|---|---|
| 1 | 1&2 | 1&4 | 1 | |
| 2 | 2 | 1&2&4 | 2 | 2 |
| 3 | 3 | 3&4 | 3 | 2 |
| 4 | 1&2&3&4 | 4 | 4 | |
| 1 | 1 | 1&4 | 1 | 1 |
| 4 | 1&4 | 4 | 4 | 4 |
| 4 | 4 | 4 | 4 | |

Inadequate training and safety equipment defects are level 1, lack of proper supervision is level 2 and lack of coordination among executive units is level 3.

The resulting final graph is illustrated in *Figure 2*:

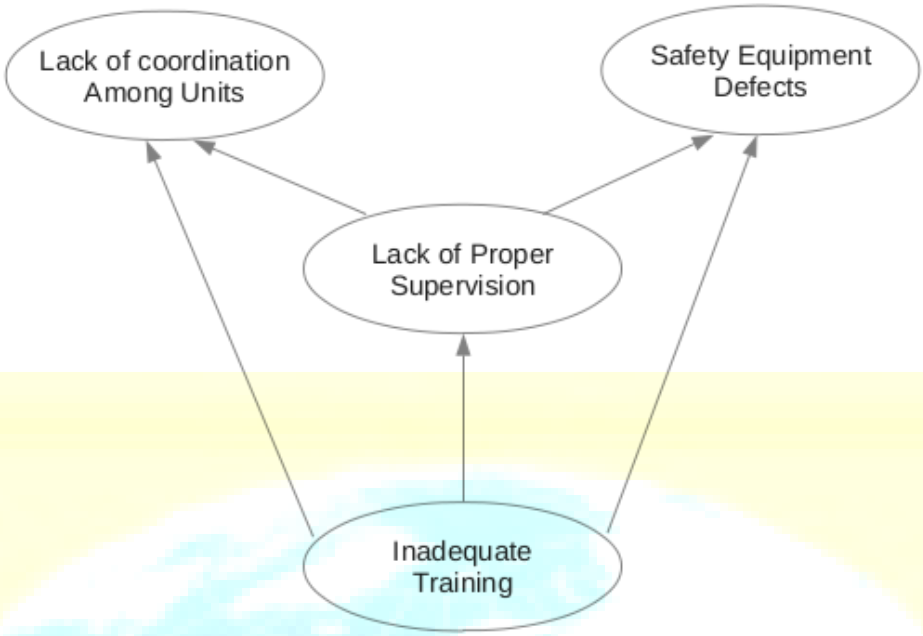


*Figure 2: The final digraph*

According to the final digraph, *inadequate training* of the distribution personnel has been the main effective factor in work-related accidents occurred in distribution centers, and in a sense, it is the factor causing other factors. On the next level, we have *lack of proper supervision* as the cause for *lack of required coordination* and *safety equipment defects*. In other words, inadequate training of the distribution personnel in distribution companies causes the improper use of safety equipment by those personnel, it causes the executive units not to work in coordination or not to acknowledge its significance, and last but not least, it causes lack of proper supervision of personnel operations. In short, inadequate training causes work-related accidents which in turn, cause burns, injuries or death to the personnel.

Strategies were proposed so as to reduce the probability of work-related accidents in electricity distribution centers, and were presented to fifteen power industry experts in form of questionnaire in order to determine the relative value of those strategies in decreasing the number of accidents caused by electric shock. The evaluation has been based on Likert scale.

The results obtained from the questionnaire and the prioritization of the strategies for preventing work-related accidents in distribution centers are as follows:

1. Provide personal safety equipment and deliver that equipment to operational teams or individuals.
2. Perform proper supervision and prevent the personnel from working separately.
3. Provide collective safety equipment and deliver that equipment to operational teams or individuals.
4. Provide training appropriate to the assigned positions during the service.
5. Assign operational positions on the condition that the corresponding training courses had

been spent.

6. Instruct the personnel to use personal and collective safety equipment.
7. Perform periodical supervision by safety officers.
8. Provide communication facilities between units.
9. Run training courses as soon as the employment begins.
10. Have operational instructions available for the purpose of coordination.
11. Apply reward and punishment based on the observations in supervision.

As can be seen from the above, provision of personal safety equipment and delivery of that equipment to the operational personnel is the first priority in the list of strategies. However, the second strategy, with the same numerical value, is about proper supervision and prevention of the personnel from working separately. As can be seen in the reports, a large portion of accidents occur to employees lacking safety equipment or working separately. Provision of collective safety equipment and delivery of that equipment to operational personnel, along with provision of training appropriate to the assigned positions during the service is the second priority.

Use of reward and punishment method was listed as the last priority, due to the fact that the method, which is currently employed in distribution companies, has not been proven effective in preventing accidents. There have been accidents with victims who had been previously rewarded or punished.

## Conclusion

According to the safety specialists from distribution companies throughout Iran, *safety equipment defects* is the factor causing approximately 46 percent of accidents directly involving electric shock, and about 54 percent of accidents indirectly involving electric shock occurred in distribution centers. On the other hand, according to the opinions collected from experts in distribution companies, *safety equipment defects* is the most important factor in the first and second groups of accidents. Therefore, it is considered to be a main factor causing accidents associated with electric shock. Despite the fact that *safety equipment defects* is not a main factor in accidents not associated with electric shock, it can be considered a main factor in general since the mentioned category covers a small percentage of total accidents (roughly 6 percent). Therefore, the question regarding whether *safety equipment defects* is among the main factors causing work-related accidents in distribution companies is answered affirmatively.

*Inadequate training* is the factor causing 23 percent of accidents directly involving electric shock, and 17 percent of accidents indirectly involving electric shock, hence another important factor causing work-related accidents occurred in electricity distribution centers in Iran. In addition, concerning the expert's opinion, *inadequate training* is considered to be the third most important factor causing accidents directly involving electric shock, the second most important factor causing accidents indirectly involving electric shock, and the second most important factor in accidents not associated with electric shock. Therefore, the question regarding whether *inadequate training* is among the main factors causing work-related accidents in distribution centers is also answered affirmatively.

*Lack of proper supervision* is the factor causing 6 percent percent of accidents directly involving electric shock, and 11 percent of accidents indirectly involving electric shock. Not being of as much consequence as the other factors, yet it is considered by experts to be the second important factor causing accidents associated with electric shock. Consequently, the question regarding whether *lack of proper supervision* is among the main factors causing work-related accidents in distribution companies is answered affirmatively.

*Lack of coordination among the executive units* is the factor causing 11 percent of accidents directly involving electric shock, and only 1 percent of accidents indirectly involving electric shock. As a result, the question regarding whether *lack of coordination among the executive units* is among the main factors causing work-related accidents in distribution centers is answered affirmatively only with regard to accidents caused directly by electric shock. The question is however answered negatively concerning accidents caused indirectly by electric shock as well as accidents not involving electric shock.

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