An Analysis of Occupational Incidents, Prioritization of Factors Causing These by Using Multi Criteria Decision Making Methods and Identification of Ways for Reducing These: Case Study in Oil and Gas Fields

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Abstract

The aim of the Occupational Health and Safety studies conducted in the oil and gas sector is; to protect workers and to ensure occupational safety in works performed on drilling fields. The aforementioned studies of the companies operating in this field in Turkey are inadequate and are not given due importance to. In such companies, occupational incidents become inevitable for that reason. A vast number of studies have been conducted in many other countries around the world to reduce the number of occupational incidents, and those have led to a substantial reduction in those incidents. In Turkey, it is necessary to take measures to reduce the number of occupational incidents in the oil and gas sector. In this study, occupational incidents occurred in the company investigated as a case study and the other occupational incidents occurred in similar companies and the measures taken to reduce them have been discussed in detail. This study aims to explain what occupational incidents occur in the sector, what the root causes of them are and how to reduce the occupational incidents by taking measures.

Keywords: Multi Criteria Decision Making, Occupational Health and Safety, Occupational Incident, Petroleum and Natural Gas Drilling.

Introduction

It is difficult, costly and dangerous work to extract various mines by drilling. However, there is a great energy deficit increased with technology and progress in the world. For this reason, countries are resorting to a variety of ways to extract oil and similar products to meet this energy deficit. In many countries having underground resources, there are fields for land and deepwater drilling in order to extract resources such as oil or natural gas for obtaining energy.

Those drilling works, as significant element of the energy sector, bear the risk of occupational incidents. Because natural or legal entities with exploration licenses, who would like to conduct drilling work which is highly expensive, prefer to hire small companies that are not the experts in that field, in order to get their drilling works done in a more economical way.

In drilling works, as one of the most hazardous sectors of activity alongside with mining, lots of occupational incidents and occupational injuries and deaths occur where the occupational health and safety regulations are not applied.

In the literature, there are various reports and studies conducted by various institutions that address the various aspects of occupational incidents in oil and gas sector concentrated in extractive works. For example, in the study of Hill (2012), it has been identified that the rate of occupational incidents occurred in USA's oil and gas extraction sector between 2003 and 2009 was seven times higher than the occupational incidents occurred in all other sectors. According to the statistics of U.S. Department of Labor's Bureau of Labor Statistics (US BLS), 823 people working in extractive activity in the oil and gas sector lost their lives between 2003 and 2010. This figure is seven times higher than the rate of occupational incidents in all other industries of USA. Mulloy (2014) stated that the oil and gas extraction sector is growing rapidly and occupational diseases, injuries and deaths will bring along with them. In the last five years since 2007, this sector has grown by 40%, and it has been surprisingly found that the most common occupational incidents occurred are occupational motor vehicle accidents and the most dangerous hazards in terms of occupational diseases are caused by the exposure to silica dust. According to a report of the Centers for Disease Control and Prevention (CDC), work-related mortality rates in the oil and gas extraction sector have increased by 27.6% between 2003 and 2013. The report International Labor Organization (ILO) published in 2016 indicates that the hard labor of oil and gas extraction sector shows itself in the form of occupational incidents. According to the reports of Occupational Safety and Health Administration (OSHA), the leading cause of fatalities from occupational incidents is occupational vehicle accidents. The long journeys to the area of work, transport of staff from and to there, transport of heavy loads, the weather conditions, prolonged accumulation of acute fatigue caused by working for a long time can result in occupational motor vehicle incidents. Another cause of accidents is identified as crashing-shearing-trapping. According to OSHA, 3 of every 5 casualties caused as a result of crashing-shearing-trapping.

American federal statistics of US BLS show that fire accidents are more common in this sector than in other sectors. There are standards published by NFPA and API to prevent fire and explosion. In Turkey, the available standards are Regulations of the Ministry of Labour and Social Security of June 2013 on Emergency Situations in the

Workplace, which is published on Official Gazette No. 28681 dated on 18 June 2013; and Regulation on Fire Protection of Buildings Issued by the Council of Ministers No. 12937 on 27 November 2007.

According to Canadian Center for Occupational Health and Safety (CCOHS), another kind of occupational incident is fall accidents. According to statistics of US BLS related to fall accidents, in 2014 247,120 non-fatal cases involving slips and falls and around 800 fatalities were reported. According to the data of CCOHS, more than 42,000 people are injured at work due to fall accidents.

According to a report published in Industrial Safety and Hygiene News, working in enclosed working areas also pose a danger to the workers in oil and gas sector. Drilling workers often work in enclosed sheds. For example; enclosed working areas in drilling fields such as petroleum and other storage tanks, mud-pit pits, sand storage tanks, etc.

In this study, what kind of occupational incidents occur in oil and gas sector in Turkey and what the root causes of them are will be identified by using TOPSIS method. On the other hand, a statistical comparison between the occupational incidents occurred in the firms at other countries within the same sector and occupational incidents in Turkey will be presented. This study aims to contribute the occupational health and safety studies of Turkey in oil and gas sector; to provide a guideline document that explains what occupational incidents occur in the sector, what the root causes of these incidents are and how to reduce these incidents by taking measures for the companies operating in petroleum, natural gas, geothermal drilling sector in Turkey in order for them can benefit from.

Statistics of Occupational Incidents

The statistical comparison between Turkey and other countries regarding the occupational incidents occurred in Oil, Geothermal, Gas Drilling Sector, has been made by using the incident analysis provided in International Association of Drilling Contractors (IADC) Incident Statistics Program.

IADC is an organization, which is working actively worldwide since 1940. Among the IADC studies, the Incident Statistics Program (ISS) was created to monitor the occupational safety and occupational incident data for the drilling industry. The aim of using the IADC data in this study is to benefit from this organization, which provides a comprehensive study by using the data of many different firms operating worldwide.

There are many methods for calculating incidence rate described in the literature in order to make comparisons between occupational incidents statistics. These methods for calculating incidence rate have been developed to be able to make comparison independently of the size and structure of a firm. For example, there is a difference between the probability of 1 worker per 100 full-time workers involved in a recordable occupational incident in 1 year within an establishment with 100 employees and the probability of 1 worker per 50 full-time workers involved in a recordable occupational incident in 1 year within an establishment with 50 employees. In order to be able to compare the probability of occupational incidents between the two firms, various "incident rate" calculations have to be used. For the comparisons between the data of IADC member countries and the data of Turkey, the incident rate calculation formulas, examples of which are provided in Table 1, are used.

More detailed information can be found on the website regarding the incident rate calculation data published by OSHA, which is provided below in the References.

The formulas given in Table 1 are used to find the number of incidents per 1,000,000 or 200,000 labor hours. Incidence Rate represents the formula using the 1,000,000 ratio, and frequency rate represents the formula using the 200,000 ratio. Depending on the type of the occupational accident, various incidence rate or frequency rate calculations can be made. For example, incidence rate and frequency rate calculations can be made for lost time incidence rate. Making such calculations allow making comparison with the situation at other countries, as described above.

Figure 1 shows the comparison of lost time incident rate between Turkey and Europe and lost time incident rate of the firm from Turkey, which is chosen as an example case for this study. These calculations are made by using the formulas regarding lost time incident rate provided in Table 1.

Table 1 *Incident Rate Calculations Formula*

Incident Rate Criteria	Formula
Accident Frequency Rate[1]	Total Accidents X 1,000,000[2]/ MAN-HOURS
Accident Severity Rate[1]	Total Lost Work Days X 1,000/ MAN-HOURS
Accident Incidence Rate[1]	Total Accidents X 100,000/ MAN
Medical Treatment Incidence Rate[3]	Medical Treatment Incidences X 200,000 / MAN-HOURS
Medical Treatment Frequency Rate	Medical Treatment Incidences X 1,000,000 / MAN-HOURS
Lost Time Incidence Rate	Lost Time Cases X 200,000 / MAN-HOURS
Lost Time Frequency Rate	Lost Time Cases X 1,000,000 / MAN-HOURS
Recordable Incidence Rate	Total Incidents X 200,000 / MAN-HOURS
Recordable Frequency Rate	Total Incidents X 200,000 / MAN-HOURS

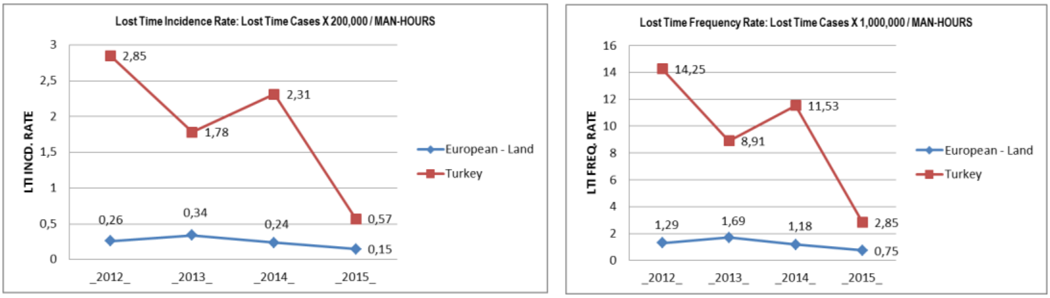

Figure 1. Comparison between lost time incident rates of Europe and Turkey, 2015. The European average data was adopted from the *2015 report* by IADC, retrieved from http://www.iadc.org/wp-content/uploads/2017/08/2016-Annual-Report-for-Industry-Totals.pdf

As can be observed here, there is a significant difference between lost time incident rate occurred in oil and gas sector in Europe and Turkey average. Lost time incident rate occurred in Europe between 2012 and 2015 is 248, whereas lost time incident rate occurred in Turkey between 2012 and 2015 is 74. The data received in Turkey's case indicates the need for more effective implementation of occupational health and safety management systems. Lost time incident rates occurred in other years also provide similar results. The analysis of lost time incident rates occurred is provided in Appendix-1. The analysis provided in Appendix-1 are dividing lost time incident rates occurred between 2012 and 2015 according to the criteria of Equipment, Time of Day, Operation Type, Occupation, Body Part, Age, Time in Service For Company, Month, Injury Cause Type and Location and provide the comparisons between Turkey and Europe in that regard. Criteria were selected by taking root cause analysis following an incident into account. At the same time, the data in the figures were selected according to the reasons with the highest frequency. The results of TOPSIS analysis, which will be explained in the next section, will show which of these criteria are effective in the occurrence of lost time incidents and which of these criteria influence lost time incidents more.

Multi Criteria Decision Making Methods

Decision making problems are a process of finding the best option from all available alternatives. The comparison of the alternatives by considering many criteria in the problems has become quite widespread. After the objectives, criteria and alternatives are identified, various methods can be used. Some of the problem solving methods can be listed as SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ELECTRE (Elimination and Choice Translating Reality), Bayesian Network Based Framework, AHP (The Analytic Hierarchy Process), SMART (The Simple Multi Attribute Rating Technique), ANP (Analytic Network Process).

One of the multi criteria decision making methods, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was presented with reference to the study of Hwang and Yoon (1981). The basic idea of this method is to select the alternative closest to the positive ideal solution while maximizing benefit criteria of the solution whereas minimizing its cost criteria. In the same way, the aim is to obtain the solutions, which are selecting the criteria having farthest distance from the negative ideal solution while maximizing the cost criteria whereas minimize the benefit criteria.

The application of the TOPSIS method consists of 6 steps. These steps can be listed respectively as constructing decision matrix, constructing standard decision matrix, calculating weighted decision matrix, determining ideal and negative ideal solutions, calculating the separation measures and calculating the relative closeness to the positive ideal solution.

Topsis Method

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); which was developed by Hwang and Yoon in 1981 as a method to sort alternatives by calculating their proximity to the ideal and negative ideal solutions. The application steps of the TOPSIS method tailored for this study are presented below (Iç et al., 2015):

Step 1:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \qquad (1)$$

Step 2: *Obtaining the normalized decision matrix (R):* The normalized decision matrix (eq'n (3)) is determined by using eq'n (2):

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{n} a_{ij}^2}} \qquad (2)$$

and

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (3)$$

Step 3: *Obtaining the weighted normalized decision matrix (V):* In this step, firstly, the weights (importance values) of the ten criteria (w_j; $j=1,\ldots,m$) are assigned. The weighted decision matrix *V* is formed by multiplying elements in each column in the normalized decision matrix (r_{ij}, $i=1,\ldots,n$) and its corresponding criterion weight (w_j, $j=1,\ldots,m$):

$$V = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_m r_{1m} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_m r_{2m} \\ \dots & \dots & \dots & \dots \\ w_1 r_{n1} & w_2 r_{n2} & \dots & w_m r_{nm} \end{bmatrix} \qquad (4)$$

Step 4: *Identification of ideal and negative ideal solutions:* In order to obtain an ideal *(A^*)* solution, Eq. (5) is used to determine the highest value for each column of the matrix V (the lowest value if the relevant criterion has the minimization direction) and to obtain the negative ideal *(A^-)* solution, Eq. (6) is used to determine the lowest values for each column of the matrix V (the highest value if the corresponding criterion has the minimization direction).

$$A^* = \left\{ (\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J^{'} \right\} \rightarrow A^* = \{v_1{}^*, v_2{}^*, \dots, v_m{}^*\} \qquad (5)$$

$$A^- = \left\{ (\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J^{'} \right\} \rightarrow \quad A^- = \{v_1{}^-, v_2{}^-, \dots, v_m{}^-\} \qquad (6)$$

Step 5: Calculation of distance to the ideal solution (S_i^*), distance to the negative ideal solution (S_i^-) and performance score (C_i^*) for each year

Distances to the ideal solution and negative ideal solution and performance scores are obtained according to Eq. (7), Eq. (8), and Eq. (9) respectively. C_i^* gets a value between 0 and 1 ($0 \leq C_i^* \leq 1$).

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2} \qquad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2} \qquad (8)$$

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \qquad (9)$$

Here C_i^* gets a value between $0 \leq C_i^* \leq 1$.

Values in table indicate that nearest distance to '1' shows that the influence of the causes of accidents on the related solution is high (absolute), that nearest distance to '0' shows that the influence is low (ineffective when it has the value of 0).

The factors that caused the accidents in this study are selected as follows:

- Number of accidents that occurred during night shift
- The place of the accident (location / Derrick / Mast)

- The profile of the employee experiencing the occupational accidents mostly (the number of rig workers)
- Accident type (caught between, struck by)
- Rig type drilling where the occupational accidents seen mostly
- Age average of employees experienced the occupational accident
- Number of inexperienced employees (less than 1 year) experienced the occupational accidents
- Number according to the most injured body part (finger)
- Number of the occupational accident related to equipment (car / truck, bus, casing, pipe, tubular, drill collar)
- Number of the occupational accident related to operation (material handling - forklift, installation, maintenance, drilling routine)

There is a need for the use of multi criteria decision making (MCDM) methods in the joint evaluation of ten selected measurement criteria.

In this study, factors that lead to lost time incidents occurred in a real firm operating in Turkey are analyzed by using TOPSIS method

Table 2. *Decision Matrix Constructed Regarding Lost Time Incidents Occurred Between 2012 and 2015*

Criteria	Equ	Opr	Tim	Loc	Ocp	Ict	Mon	Age	Tis	Bod
Equ	21	23	37	27,5	33,5	31	25	28	26,5	22,5
Opr	23	25	39	29,5	35,5	33	27	30	28,5	24,5
Tim	37	39	53	43,5	49,5	47	41	44	42,5	38,5
Loc	27,5	29,5	43,5	34	40	37,5	31,5	34,5	33	29
Ocp	33,5	35,5	49,5	40	46	43,5	37,5	40,5	39	35
Ict	31	33	47	37,5	43,5	41	35	38	36,5	32,5
Mon	25	27	41	31,5	37,5	35	29	32	30,5	26,5
Age	28	30	44	34,5	40,5	38	32	35	33,5	29,5

Tis	26,5	28,5	42,5	33	39	36,5	30,5	33,5	32	28
Bod	22,5	24,5	38,5	29	35	32,5	26,5	29,5	28	24

Note. Criteria = Incidents Root Cause. LTI = Lost time incidence Equ= LTI's by Equipment (car/truck, bus, Casing ve Drill Collar). Opr = LTI's by Operation (Rig/Equip. Repairs/Maint., Routine Drilling Operations.) Tim = LTI's by Time Of Day (Morning/Day Shift) Loc. = LTI's by Location (Rig Floor/Derrick/Mast) Ocp. = LTI's by Occupation (Floorman, Roustabout). Ict =. LTI's by Injury Cause Type (caught between, struck by) Mon = LTIs by Months (January, February, June) Age= LTI's by Average of Age. Tis= LTIs by Time in Service For Company (>1 yr. < 5 yrs.) Bod= LTI's by Body Part (fingers).

Table 3. *Weighted Normalized Decision Matrix*

Criteria	Equ	Opr	Tim	Loc	Ocp	Ict	Mon	Age	Tis	Bod
Equ	0,02378	0,02433	0,02673	0,02532	0,02629	0,02593	0,02481	0,02542	0,02513	0,02420
Opr	0,02605	0,02645	0,02818	0,02716	0,02786	0,02760	0,02679	0,02723	0,02702	0,02635
Tim	0,04190	0,04126	0,03829	0,04006	0,03885	0,03931	0,04068	0,03994	0,04030	0,04141
Loc	0,03115	0,03121	0,03143	0,03131	0,03139	0,03136	0,03126	0,03132	0,03129	0,03119
Ocp	0,03794	0,03755	0,03576	0,03683	0,03610	0,03638	0,03721	0,03676	0,03698	0,03765
Ict	0,03511	0,03491	0,03396	0,03453	0,03414	0,03429	0,03473	0,03449	0,03461	0,03496
Mon	0,02831	0,02856	0,02962	0,02901	0,02943	0,02927	0,02878	0,02905	0,02892	0,02850
Age	0,03171	0,03174	0,03179	0,03177	0,03179	0,03178	0,03175	0,03177	0,03176	0,03173
Tis	0,03001	0,03015	0,03071	0,03039	0,03061	0,03053	0,03026	0,03041	0,03034	0,03012
Bod	0,02548	0,02592	0,02782	0,02670	0,02747	0,02718	0,02630	0,02678	0,02655	0,02581

Note. Criteria = Incidents Root Cause. LTI = Lost time incidence Equ= LTI's by Equipment (car/truck, bus, Casing ve Drill Collar). Opr = LTI's by Operation (Rig/Equip. Repairs/Maint., Routine Drilling Operations.) Tim = LTI's by Time Of Day (Morning/Day Shift) Loc. = LTI's by Location (Rig Floor/Derrick/Mast) Ocp. = LTI's by Occupation (Floorman, Roustabout). Ict =. LTI's by Injury Cause Type (caught between, struck by) Mon = LTIs by Months (January, February, June) Age= LTI's by Average of Age. Tis= LTIs by Time in Service For Company (>1 yr. < 5 yrs.) Bod= LTI's by Body Part (fingers).The decision matrix, which is the first step of the TOPSIS method, is constructed by using Table 2 and the normalized decision matrix is obtained by normalizing the numerical values by using Eq. (2) in the first step of the method. For the criteria provided in Table 1, average number of the accidents occurred has been considered. On the other hand, in order to identify the weights of the each mentioned criterion, three experts of the firm were asked to evaluate each criterion with a score from 1 to 10 (1 refers to the least important; 10 refers to the most important) and then the criteria weights were identified by considering the averages of the expert evaluations by rounding them up to nearest whole numbers. Then, the table of normalized criteria weights was obtained (Table 3). Then, weighted normalized matrix was obtained as a result of multiplying normalized decision matrix by the normalized criteria weights identified for each criterion. At the last step, by using Eq.(5-8) in the in the implementation steps of TOPSIS method the distances to the ideal and negative ideal solutions; by using Eq.(9), the influence of the causes of occupational accidents on lost time incidents, TOPSIS ranking scores were obtained.

Conclusion

As a result of the analysis, the causes of the accident are mathematically expressed by ranking the causes of the accidents according to the accident results.

In Figure 2, ranking scores can be seen clearly. Values in table indicate that nearest distance to '1' shows that the influence of the causes of accidents on the related solution is high (absolute), that nearest distance to '0' shows that the influence is low (ineffective when it has the value of 0).

As observed from these calculation results, as the factors determined as the cause of the accidents, Equipment (Pipes/Collars/Tubulars/Csg., Material, Engine/Pump, Machinery), Operation *(Rig/Equip. Repairs / Maint., Routine Drilling Operations.)*, Body Part (fingers) shines out as the highest scores in the results of total lost time incidents.

There three causes are followed by Month, Time in Service for the Company, Location, Age, Incident cause type, Occupation, Time in Service respectively. In the analysis provided in the appendix, most seen ones are Pipe, tubular, casing tubing in equipment-related accidents. At the same time, the finger injuries are within the first three ranks in TOPSIS analysis in analysis provided in appendix. These results show that engineering measures are required to reduce occupational accidents in oil drilling. It is thought that it would be beneficial to make the drilling works by using the machines, that is to say, by transition to new technology; rather than by using hands. In the risk analysis to be applied to the oil and gas drilling fields, addressing the high risk areas mentioned here will reduce the occupational accidents.

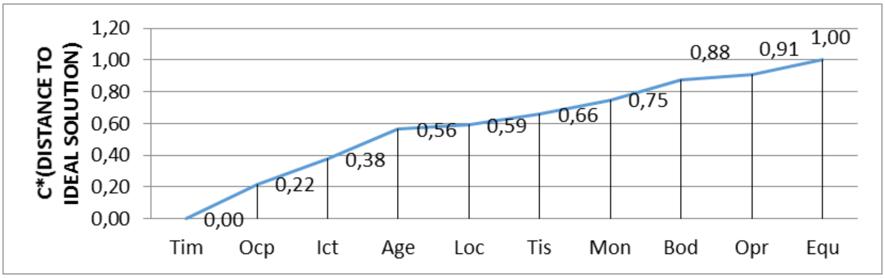

Figure 2. TOPSIS Ranking Scores of Criteria of Occupational Accidents (C^*)

Note. Criteria = Incidents Root Cause. LTI = Lost time incidence Equ= LTI's by Equipment (Pipes/Collars/Tubulars/Csg., Material, Engine/Pump, Machinery). Opr = LTI's by Operation (Rig/Equip. Repairs/Maint., Routine Drilling Operations.) Tim = LTI's by Time Of Day (Morning/Day Shift) Loc. = LTI's by Location (Rig Floor/Derrick/Mast) Ocp. = LTI's by Occupation (Floorman, Roustabout). Ict =. LTI's by Injury Cause Type (caught between, struck by) Mon = LTIs by Months (January, February, June) Age= LTI's by Average of Age. Tis= LTIs by Time in Service For Company (>1 yr. < 5 yrs.) Bod= LTI's by Body Part (fingers).

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Footnotes

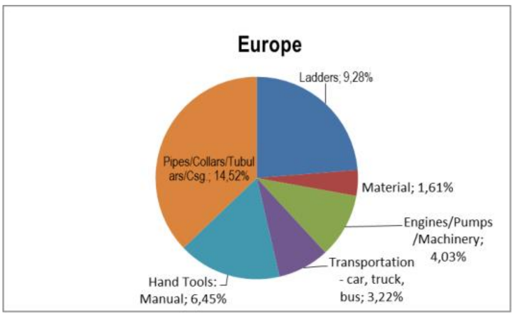
[1] It has been decided in 16th International Conference of Labour Statisticians in Geneva in 1998.

[2] It is used to find the lost time due to occupational accidents in 1,000,000 labor hours.

[3] It is provided as described by The Bureau of Labor Statistics (BLS).

Appendix

Appendix-1



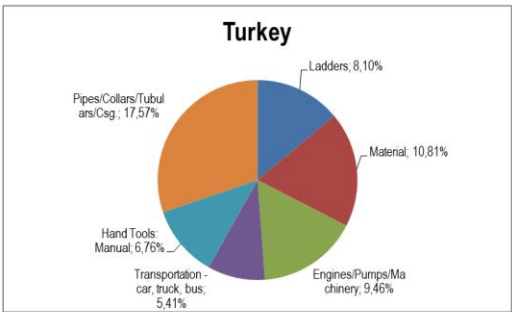


Figure 3. LTI's by Equipment in Turkey and Europe

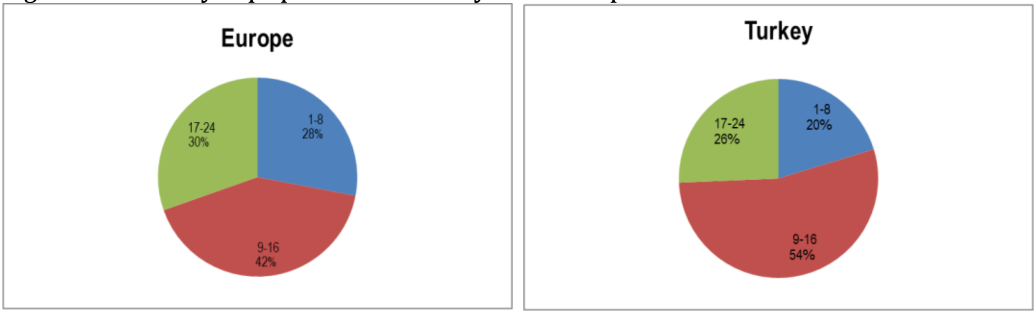


Figure 4. Comparison of Lost Time Incidents by Time of Day in Turkey and Europe

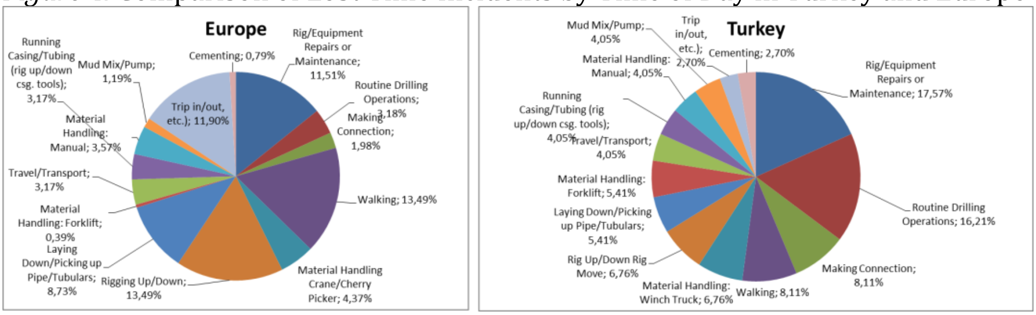


Figure 5. Comparison of Lost Time Incidents by Operation Type in Turkey and Europe

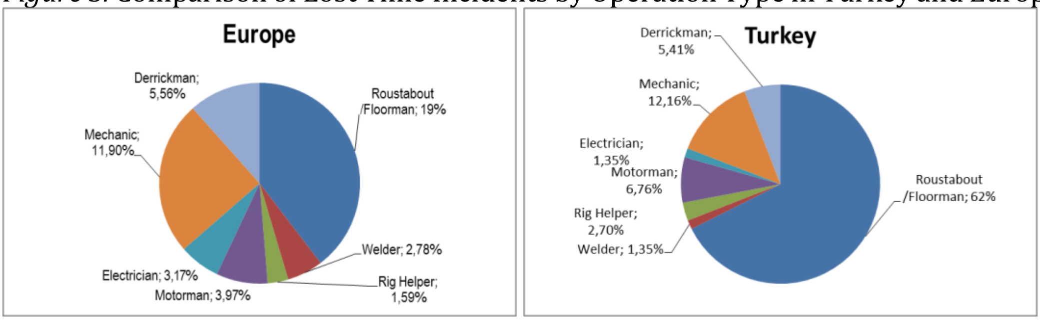


Figure 6. Comparison of Lost Time Incidents by Occupation in Turkey and Europe

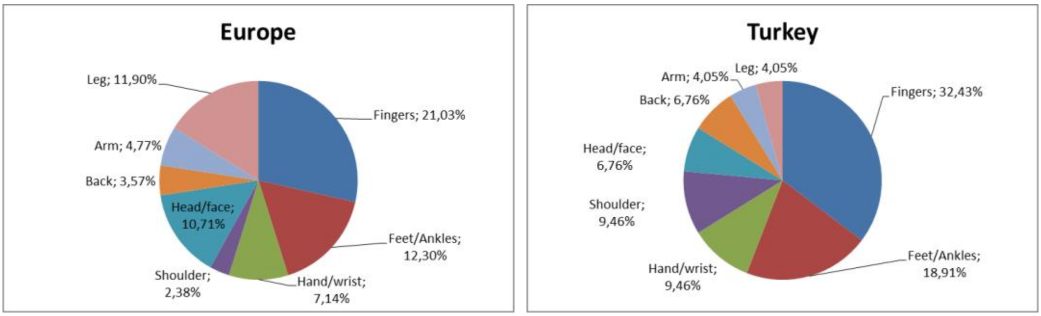


Figure 7. Comparison of Lost Time Incidents by Body Part in Turkey and Europe

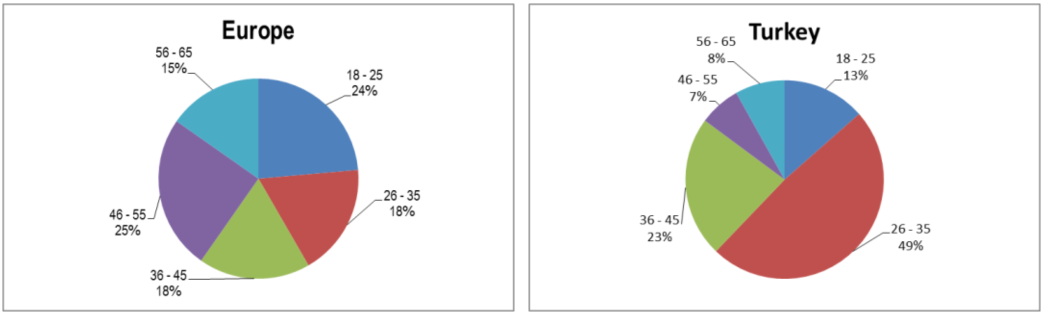


Figure 8. Comparison of Lost Time Incidents by Age in Turkey and Europe
Note. Data of Europe has only been analyzed based on 2014-2015 data. No data on age of staff before 2014 is available.

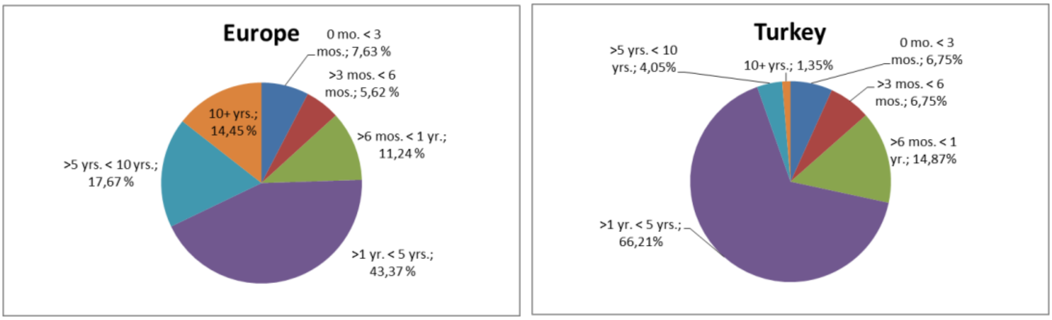


Figure 9. Comparison of Lost Time Incidents by Time in Service For Company in Turkey and Europe

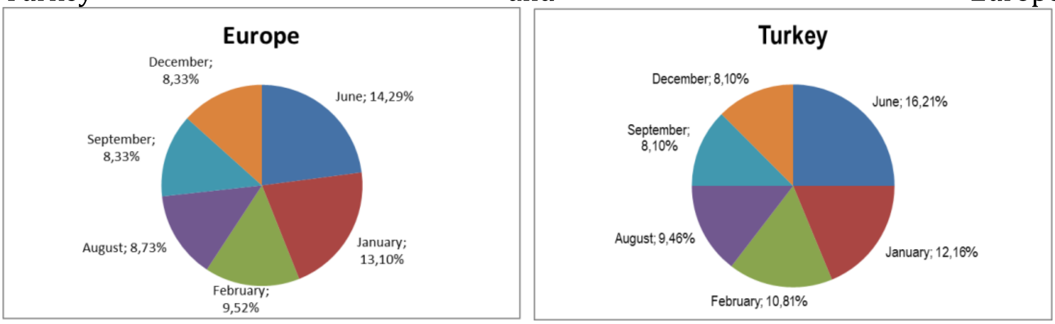


Figure 10. Comparison of Lost Time Incidents by Month in Turkey and Europe

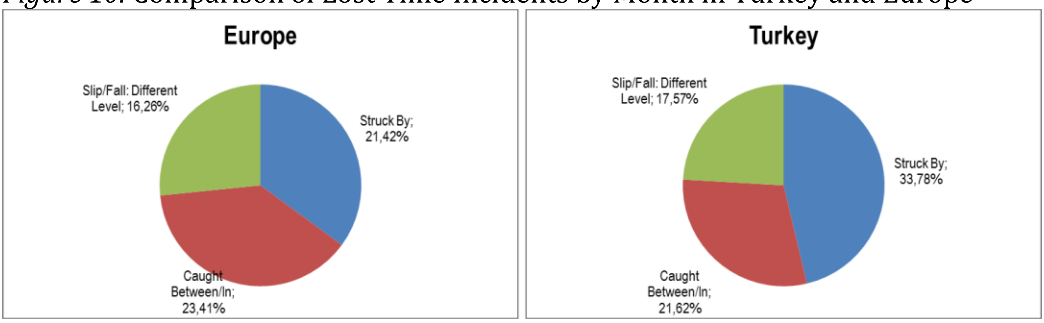


Figure 11. Comparison of Lost Time Incidents by Injury Cause Type in Turkey and Europe

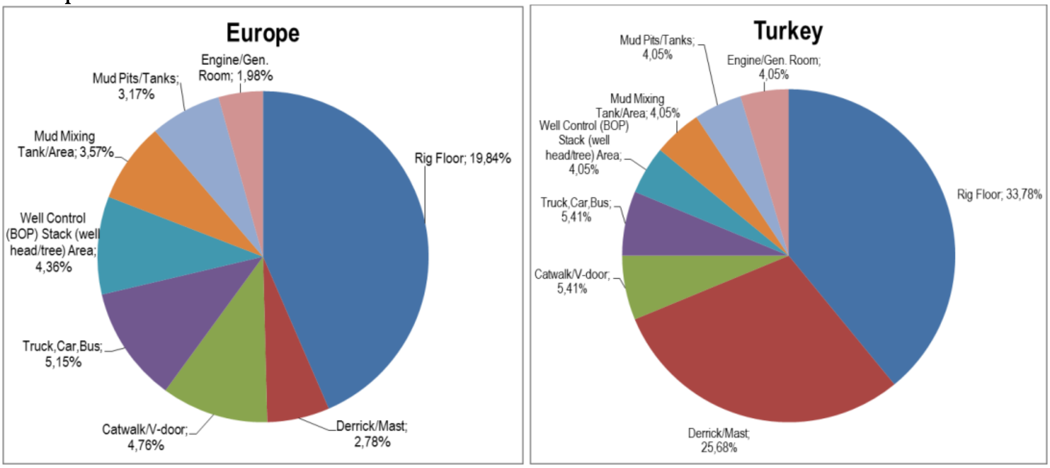


Figure 12. Comparison of Lost Time Incidents by Location in Turkey and Europe