EFFECTS OF SIX SIGMA IMPLEMENTATION ON OCCUPATIONAL HEALTH AND SAFETY IN INDUSTRIAL DIESEL ENGINE PRODUCTION AND MAINTENANCE PROCESSES

by

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This study researched the results of implementing the Six Sigma approach to occupational health and safety in the Diesel engine industry in Europe. Six Sigma is a robust philosophy used in manufacturing industries to improve production processes, reduce risks, and enhance quality. It also aims to prevent work accidents and create a safer working environment by eliminating process faults. Employers must prioritize employee protection and a healthy working environment, and the Six Sigma methodology offers opportunities to achieve this. The study focused on the accident and injury types and amounts of one of the industrial Diesel engine production and maintenance companies operating worldwide. Occupational accident statistics were used between 2019-2022 as data. The path taken in occupational health and safety with Six Sigma in these three years was examined. In order to be able to decide on changes in health and safety conditions, the company's analysis of air-flows and heat transfer using the exhaust gas temperature in a project aimed at optimizing workplace temperature control is exemplified.

Key words: *temperature transfer, Six Sigma, occupational health and safety, industrial Diesel engines, exhaust gasses, ergonomy*

Introduction

Technological advancements bring both benefits and risks to the workplace. The increasing incidence of work accidents and occupational diseases highlights the critical importance of worker health, safety, and conducive working conditions. Industrialization and mechanization in the 20th century resulted in higher rates of limb loss, fatalities, and occupational hazards due to chemical exposures. Every new tool, machine, equipment, and utensil, and every new substance that participates in the production process is a phenomenon that poses a threat to human health, environmental safety, and health, as well as workplace safety. In other words, the bill of increasing prosperity today is to humanity, environmental pollution, work accidents, and occupational diseases [1-3].

The progress of industrialization day by day depending on technology has led to the emergence of undesirable situations as well as its positive contributions to working life [4, 5]. In particular, new production processes and techniques have an important role in the rapid increase in occupational diseases and work accidents [6-10]. Raw materials, equipment, and machinery that have just joined the production process have caused work accidents as well as

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numerous occupational diseases. Thousands of people in working life are exposed to work accidents every day and either die or become disabled, while hundreds of employees are faced with work-related occupational diseases [11-15].

Health and safety are both necessary and fundamental human rights for people. The health and safety of people are constantly affected by some external factors [16, 17]. Injury or loss of life of employees due to occupational accidents brings with it many invisible losses, as well as labour losses and financial losses in the workplaces, and the country's economy and social order are adversely affected. Therefore, we can say that the phenomenon of occupational health and safety has become a global problem [8, 18, 19].

The establishment of a healthy and safe working environment or facilities by the owners of the business, the protection of the employees from both work accidents and occupational diseases, taking the necessary precautions and implementing the measures taken are the indispensable priority of the working life and the common obligation of the relevant social parties [16, 17, 20-23]. Today, countries with a low rate of occupational diseases and accidents, or at least successful in this regard, are seen as safe and soundly structured countries that can provide perfect working conditions and have reached a level of modernity in line with their targets.

Providing healthy and safe workplaces for employees will positively contribute to the country economy and the employer and the employees working more efficiently, willingly, happily and effectively. The level of development of the countries, the stability and success in the economy, the technological breakthroughs, the quality of education and the value it puts for the health of its citizens can increase even more [24-27]. The measures to be taken or foreseen to be taken regarding occupational health and safety should not be seen as a financial burden by employers. Investment for the future should be seen as a priority to ensure productivity and continuity of production [28-31].

With this purpose, many companies aim to improve their employees' occupational health and safety conditions by taking various measures and focusing on eliminating workplace risks and hazards using many different methods. One of these methods is the Six Sigma methodology, used in many industrial improvement activities.

This study examines accidents and injuries in an industrial Diesel engine production company in Europe. It analyzes the impact of implementing the Six Sigma improvement methodology. The data covers 2019-2021, with the company adopting Six Sigma in 2020. The study aims to assess the improvements achieved through Six Sigma in reducing accidents and injuries.

Subject

Hazard and risk are often used interchangeably, but there is a difference. While the term hazard includes all kinds of undesirable events, both natural and man-made, the concept of risk also includes efforts to reduce the number and severity of undesirable events [32].

The Six Sigma methodology has gained prominence in industry due to its effectiveness in identifying risks, measuring performance, and improving processes. Companies use Six Sigma to achieve international standards, incorporate leading technologies, and continuously enhance their manufacturing processes. By eliminating waste and implementing impactful solutions with minimal effort, Six Sigma aims to achieve well-controlled processes and reduce problems effectively. In addition, Six Sigma works towards integration. It includes processes that use the five-step cycle of define, measure, analyzes, improve and check (DMAIC) and robust statistical methods. Supporting organizational leaders, involving organizational members, sharing measurable performance measures, and applying powerful statistical techniques are some of them [33].

The Six Sigma method has gained popularity recently as a comprehensive approach to improving the quality and safety of manufacturing processes, logistics, and technical maintenance.

In the company that is the subject of this article, various safety improvement studies have been carried out to reduce and prevent the occurrence of similar accidents with the establishment of Six Sigma teams that analyze the data on the accidents that occurred between the years 2019-2022.

Calculating potential temperature change in a workplace project is one of the example of these studies. Study has focused to analyze hourly temprature chances in Diesel engine test cell to get action for air temperature related ergonomical problems. Within the project, Diesel engine manufacturer's data sheets were used for the calculations and the results below have been found.

The ventilation air-flow is 0.399 m^3/s, and the exhaust gas-flow is 0.945 m^3/s. The exhaust gas temperature is 443 °C, and the initial temperature of the workplace air is 24 °C. The workplace volume is 400 m^3, and the specific heat capacity of the gas is 1005 J/kgK.

Step 1: Convert temperatures to Kelvin:

$$T_2 = 443 + 273.15 = 716.15 \text{ K}$$

$$T_1 = 24 + 273.15 = 297.15 \text{ K}$$

Step 2: Calculate the exhaust gas mass-flow rate:

$$\text{Mass-flow rate} = \text{Exhaust gas-flow rate} - \text{Ventilation air-flow rate}$$

$$\text{Mass-flow rate} = 0.945 - 0.399 = 0.546 \text{ kg/s}$$

Step 3: Calculate the heat transfer rate:

$$\text{Heat transfer rate, } Q = \text{Mass-flow rate} \cdot Cp(T_2 - T_1)$$

$$Q = 0.546 \cdot 1005 \cdot (716.15 - 297.15) = 240507.72 \text{ J/s}$$

Step 4: Convert the heat transfer rate to an hourly basis:

$$\text{Energy transfer} = Q \cdot 3600 \text{ seconds} = 240507.72 \text{ J/s} \cdot 3600 \text{ s} = 866428992 \text{ J}$$

Step 5: Calculate the temperature change:

$$\text{Temperature change} = \text{Energy transfer}/(Cp \cdot \text{mass-flow rate} \cdot \text{workplace volume})$$

$$\text{Temperature change} \approx 866428992 \text{ J}/(1005 \text{ J/kgK} \cdot 0.546 \text{ kg/s} \cdot 400 \text{ m}^3) \approx 4.67 \text{ K}$$

Step 6: Convert the temperature change to Celsius:

$$\text{Temperature change} \approx 4.67 \text{ °C/h}$$

Material and method

This study focuses on analyzing accidents in the industrial Diesel engine production and maintenance sector, specifically in relation to the application of the Six Sigma DIMAC method. The research examines data from the years 2019, 2020, and 2021, comparing the accident data before and after implementing Six Sigma. Descriptive statistics and the Wilcoxon

Signed Rank Test are utilized for analysis. The study aims to determine statistically significant differences and identify the least and most advanced accident classes and injury types. Based on the findings, safety measures will be proposed for areas with the least development. The study evaluates the decrease in the number of accidents following the implementation of the Six Sigma method during the years 2019-2021.

Methods and techniques used in the analysis

The Wilcoxon signed-rank test is a non-parametric statistical test used in research and academic fields. It compares the results of two dependent samples without assuming a specific data distribution. The test ranks the absolute differences between the samples and is sensitive to changes in magnitude, but not direction. It is suitable for situations where data may not follow a normal distribution or when the sample size is small. The test assesses the null hypothesis of no difference between the samples and calculates a test statistic for comparison with a critical value. The variance of the test statistic depends on the number of tied ranks and observations in each group. According to Cimen, when the data are normally distributed in the examination of engineering data, Single sample T-Test. Otherwise, Wilcoxon Single Sample Sign Ranking Test should be preferred. For this reason, Wilcoxon Signed Rank Test was used in this study [34, 35].

The Wilcoxon signed-rank test is a widely used non-parametric statistical test in research and academic fields. It is suitable for analyzing data that may not follow a normal distribution or when the sample size is small. This test compares two dependent samples and involves calculating a test statistic that is compared to a critical value to make decisions about the null hypothesis.

Data

The data used in the study belong to an enterprise operating in the industrial Diesel engine production and maintenance and repair services sector.

Table 1 shows the changes in the accident quantity as number and in percentage. The Six Sigma method started to be implemented in the mentioned business in 2020. The data in 2019 consists of the accidents and their types and statistics before the implementation. In the analysis, the data for 2020, the first year of the application, and 2021, the second year, were compared based on this year.

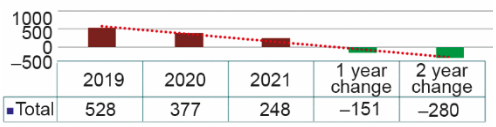

Figure 1. Change in the total number of accidents by years

According to fig. 1 significant decrease in accidents was observed when analyzing data from 2019-2021. The implementation of the Six Sigma method led to a reduction in accidents, particularly in the *ergonomics* category, which decreased from 113 to 47. The number of accidents classified under *other* also decreased from 96 to 12. Accidents related to *industrial vehicles* remained relatively stable, with a slight decrease from 7 to 5. Overall, there was a substantial decrease in the annual number of accidents, declining from 528 in 2019 to 377 in 2020, representing a reduction of more than half.

Table 1. Accident quantity and change in percentage by years

	2019	2020	2021	2020	2021
Ergonomics	113	91	47	–19%	–19%
Other	96	71	12	–26%	–26%
Hand safety – hand tools	88	38	52	–57%	–57%
Slip stuck fall	87	73	48	–16%	–16%
Hand safety – handling	64	52	40	–19%	–19%
Driving safety	25	8	1	–68%	–68%
Elevator and crane	11	7	3	–37%	–37%
Machine guard	11	15	3	36%	36%
Chemical safety	11		1	–100%	–100%
Industrial vehicles	7	7	5	0%	0%
Electrical safety	6	1	1	–83%	–83%
Working at height	3	3	2	0%	0%
Industrial hygiene	2	2		0%	0%
LOTO	2	1		–50%	–50%
Test cell safety	1	5	1	400%	400%
Contractor safety	1			–100%	–100%
Working environment			10	0%	0%
Handling/warehouse			7	0%	0%
Equipment safety			7	0%	0%
Eye safety			3	0%	0%
Animal/insect bite		3	1	300%	300%
DoT incident			1	0%	0%
Facility safety			1	0%	0%
Gas line safety			1	0%	0%
Health and safety			1	0%	0%
Total	528	377	248	–29%	–29%

According to tab. 2, 11 of them decreased, 3 increased, and 11 remained the same between 2019-2020 and 15 of them decreased, 9 increased, and one remained the same between 2019-2021.

Table 3 shows that the Wilcoxon signed-rank test revealed a significant difference between the measurements in both comparisons. In the 2019-2020 comparison, $p = 0.009 < 0.05$, indicating significance at the 99% level. In the 2019-2021 comparison, a lower p-value of $p = 0.001 < 0.05$ was obtained, indicating a highly significant difference at the 99.9% level.

Table 2. Wilcoxon test rank table for accident

		N	Average rank	Rank
2020-2019	Negative	11a	7.55	83.00
	Pozitive	3b	4.00	8.00
	Equal	11c		
	Total	16		
2021-2019	Negative	15d	8.00	120.00
	Pozitive	9e	0.00	0.00
	Equal	1f		
	Total	25		

a. 2020 < 2019 **b**. 2020 > 2019 **c**. 2020 = 2019 **d**. 2021 < 2019 **e**. 2021 > 2019 **f**. 2021 = 2019

Table 3. Wilcoxon test results for accident classes

	2020-2019	2021-2019
Z	–2.625b	–3.413b
Asymp. P value (double-tailed)	0.009	0.001

a. Wilcoxon signed-row test, **b.** created in positive order.

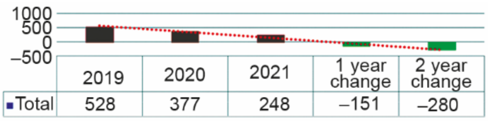

Figure 2. Change in the total number of injuries by years

Table 4 and fig. 2 show that 2019 to 2021 reveals a general decrease in injurys. Incision were the most common type of injury, with 126 accidents in 2019. After implementing the Six Sigma method, this number dramatically dropped to 70 in 2020, with a slight decrease in 2021. Sprains were the second most common type, with 83 accidents in 2019, 63 in 2020, and 38 in 2021. Both types of injuries saw significant decreases after implementing the 6 Sigma method. However, crush injuries increased from 4 in 2019 to 22 in 2020, though it decreased to 10 in 2021. The *other* category showed an increase from 14 injuries in 2019 to 23 in 2020, with a decrease to 16 in 2021, but still higher than in 2019.

According to tab. 5, it can be seen that 14 of the injuries decreased (a), 5 decreased (b), and 4 remained the same (c) between 2019-2020. When compared to 2019-2021, 18 of the injuries decreased (d), 3 increased (e), and 2 remained the same (f).

Table 6 shows that revealed a significant difference between the analysis revealed significant differences in the number of injury types after implementing the Six Sigma method. In the one-year comparison (2019-2020), there was a significant difference with a *p*-value of 0.031 at the 95% level. In the two-year comparison (2019-2021), the difference was highly significant with a *p*-value of 0.0001 at the 99.9% level.

Table 4. Injury number and change in percentage by years

	2019	2020	2021	2020	2021
Incision	126	70	65	–44%	–48.4%
Sprain	83	63	38	–24%	–54.2%
Broken	70	38	31	–46%	–55.7%
Pain-pain	51	60	34	18%	–33.3%
Other	14	23	16	64%	14.3%
Wear and scratch	36	26	12	–28%	–66.7%
Impact injury	19	7	8	–63%	–57.9%
Foreign body injury	10	8	8	–20%	–20.0%
Crush	4	22	10	450%	150.0%
Musculoskeletal system	31	19	5	–39%	–83.9%
Shoulder left pain			3	0%	300.0%
Burn	10	7	2	–30%	–80.0%
Shake	12	3	3	–75%	–75.0%
Hernia	2	3	2	100%	0.0%
Water pickup	1	1	1	0%	0.0%
Detachment	17	5	7	–71%	–58.8%
Bite	3	3	1	0%	–66.7%
Fragment break	4	3	2	–25%	–50.0%
Dislocation	3	3		0%	–100.0%
Amputation	10	3		–70%	–100.0%
Puncture	3	7		133%	–100.0%
Ergonomic	17	3		–82%	–100.0%
Electric shock	2			–100%	–100.0%
Total	526	377	248	–28%	–53%

Table 5. Wilcoxon test rank table for injuries

		N	Ortalama Sıra	Sıralamaların Ortalaması
2020-2019	Negative	14a	10.61	148.50
	Positive	5b	8.30	41.50
	Equal	4c		
	Total	23		
2021-2019	Negative	18d	11.06	199.00
	Positive	3e	5.50	11.00
	Equal	2f		
	Total	23		

a. 2020 < 2019 **b**. 2020 > 2019 **c**. 2020 = 2019 **d**. 2021 < 2019 **e**. 2021 > 2019 **f**. 2021 = 2019

Table 6. Wilcoxon test results for injury types

	2020-2019	2021-2019
Z	–2.155b	–3.516b
Asymp. P value (double-tailed)	0.031	0.000

a. Wilcoxon signed-row test, **b.** created in positive order

Results

The reliability level for the annual accident numbers for the 2019-2021 period in the accident classes was determined as 90% because the number of measurements was only 3. It is seen that 15 of the 25 accident classes included in the analysis decreased within the determined confidence interval. Only the number of accidents in the test cell safety class stayed the same in 2019 and 2021, so it remained outside these classes.

The annual number of accidents in injury types for the 2019-2021 period was determined as 90% because the number of measurements was only 3. It is seen that 19 of the 23 injury types analyzed decreased within the determined confidence interval. Others were excluded from this group, as there was an increase in crush types and no change in the number of hernia and blister types injuries.

Relationship between injury types and accident classes

The relationship between the types and classifications of accidents that occur in the workplace is given in tab. 7.

When tab. 7 is examined, it can be seen that hand accident classes are particularly associated with a higher number of accident types. The numerical expression of the relationship between them is given in tab. 8.

According to tab. 8, although the proportional decrease in *Hand safety – hand tools* and *Hand safety – handling* accidents remains average, they still have the highest number of injuries compared to other classes. After two years, these accident types accounted for a total of 92 accidents, indicating their dominance in the accident list.

Figure 3 shows that the pareto analysis revealed that the majority of injuries are concentrated in the general injury cluster, including incision, abrasions, scratches, crushes, and blisters.

Similarly, as in fig 4. the pareto analysis showed that the highest number of accidents occurred in the *Hand safety – handling* and *Hand safety – hand tools* categories within the overall accident types. Regression analysis indicated a downward trend in average accident data since the implementation of Six Sigma DMAIC method in 2020, suggesting improvements in reducing casualties.

Figure 5 shows the regression analysis of the number of accidents and injuries. It was observed that the average accident data covering three years showed a downward trend when considering the number of accidents since 2020 when the improvements were started with the Six Sigma DMAIC method. Similarly, the regression analysis determined that the number of accidents and the types of injuries were positively related.

As a result of the regression analysis, the correlation coefficient r: 0.7, which shows whether there is a linear relationship between the two variables, confirms this relationship.

Table 7. Relationship between injury types and accident classes

Injury types	Accident group
Incision	Hand safety- hand tool, machine guard
Sprain	Slip, trip, fall
Broken	Slip, trip, fall, working at height, industrial vehicles, driving safety
Pain	Ergonomy, hand safety-hand tool, hand safety-handling, driving safety
Scratch	Hand safety, hand tool, slip, trip, fall
Musculoskeletal system	Ergonomy, hand safety-handling
Impact injury	Industrial vehicles, driving safety, elevator and crane
Ergonomy	Ergonomy, hand safety-handling
Shake	Industrial vehicles, driving safety
Foregein body injury	Other
Burn	Other, chemical safety/SDS, test cell safety
Amputation	Machine guard hand safety-hand tool
Crush	LOTO, hand safety-hand tool
Fragment break	Machine guard
Bite	Diger
Dislocation	Slip, trip, fall
Detachment	Hand safety-hand tool
Electrical shock	Electrical shock
Hernia	Ergonomy, hand safety-handling
Water pickup	Hand safety-hand tool

Table 8. Number of injury types associated with accident classes

Accident classes	Number of types of injury associated with	Accident classes	Number of types of injury associated with
Hand_safety – hand tools	8	Elevator and crane	1
Slip stuck fall	5	Working at height	1
Ergonomics	4	Chemical safety or SDS	1
Hand safety – handling	4	Electrical safety	1
Other	3	Test cell security	1
Industrial vehicles	3	Industrial hygiene	1
Machine guard	3	LOTO	1
Driving safety	3		

Conclusion and recommendations

The study found a significant decrease in accidents and injuries after implementing the Six Sigma method in the industrial Diesel engine production sector. Specific accident clas-

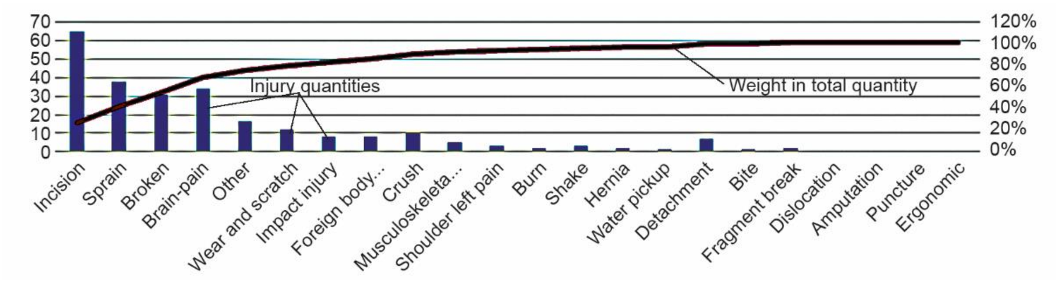

Figure 3. Pareto analysis of injury number

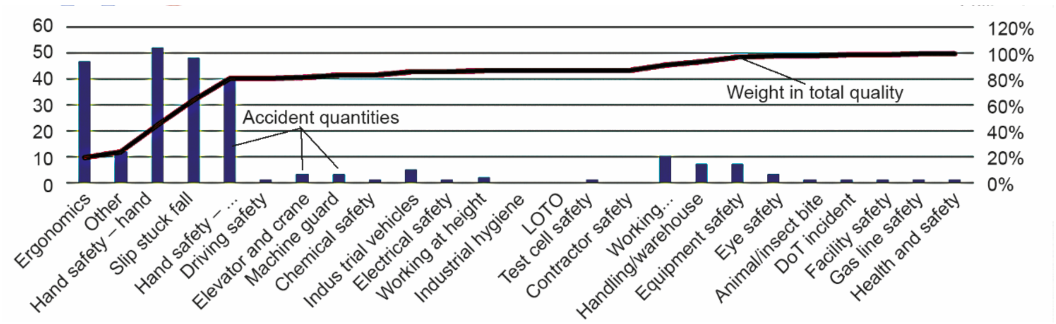

Figure 4. Pareto analysis of accident number

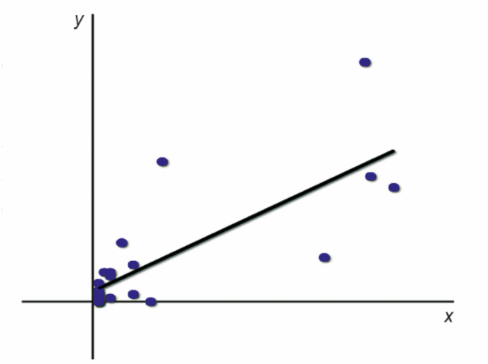

Figure 5. Regression analysis of accident numbers and injury numbers; *x* – injury number and *y* – accident number of accident classes

ses and injury types were identified, and safety measures were proposed. The number of accidents and injuries decreased by more than half during the study period. Incision and sprains showed significant decreases, while crush injuries and injuries classified as *other* increased. Regression analysis showed a downward trend in accidents since implementing Six Sigma. Hand safety accidents with hand tools were the highest in frequency, suggesting the need for better personal protective equipment, such as gloves. The study concludes that implementing Six Sigma can significantly reduce occupational accidents and injuries, and recommends its application in all companies for occupational health and safety.

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