ANALYSIS OF PHYSIOLOGICAL RISK FACTORS FOR OCCUPATIONAL ACCIDENTS IN CONSTRUCTION INDUSTRY

by

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ABSTRACT

ANALYSIS OF PHYSIOLOGICAL RISK FACTORS FOR OCCUPATIONAL ACCIDENTS IN CONSTRUCTION INDUSTRY

It is a well-known fact that construction tasks require intensive physical performance and continuous attention. These factors sometimes have adverse impacts on workers and stimulate construction accidents. Since it is commonly emphasized that there is a significant relationship between accidents and physiological parameters, this research aims to observe the relationship between accident times and the physiological measurements collected from construction workers. For this purpose, eight different hypotheses were developed between the physiological variables and construction accidents. To test these hypotheses the real-time Heart Rate (HR), Skin Temperature (ST), Electrodermal Activity (EDA), and Blood Sugar Levels (BSL) of the construction workers were collected during winter and summer time. The real-time physiological variables were collected from a total of 21 workers at two different seasons in the construction site. The information about construction accidents that occurred in Turkey between 2010 and 2018 years was received from Social Security Insurance (SSI). The hourly and seasonal correlation analysis between the accidents and real-time monitored physiological variables (EDA, HR, BSL, and ST) were performed in this study. Spearman's Correlation analysis, a non-parametric correlation method, was performed between construction accidents and physiological measurements. The results of this study show that construction accidents are significantly inverse correlated with BSL of the workers in the morning hours (before lunch). On the other hand, there is a significant seasonal correlation between the other physiological variables (i.e. HR, EDA, ST) and construction accidents. To overcome adverse impacts of the physiological factors on the workers, efficient can be arranged and more short breaks should be given.

ÖZET

İNŞAAT SEKTÖRÜNDE MEYDANA GELEN İŞ KAZALARI İÇİN FİZYOLOJİK RİSK FAKTÖRLERİNİN ANALİZİ

İnşaat alanında gerçekleştirilen işler, yoğun ve sürekli dikkat gerektiren bir yapıya sahip olduğu için, yorgunluk, dikkat eksikliği, motivasyon düşüklüğü ve özellikle fizyolojik değerlerdeki ani değişimler, ağır iş kazalarının meydana gelmesine neden olmaktadır. Toplanan bu fizyolojik verilerin kazalar üzerinde ciddi etkisi olabileceği düşünülmektedir. Fakat şimdiye kadar ölçülen fizyolojik değerlerle kaza istatistikleri arasındaki ilişkiyi inceleyen bir çalışma bulunmamaktadır. Bu nedenle, bu araştırmanın asıl amacı inşaat sahasında meydana gelmiş iş kazaları ile inşaat işçilerinden toplanan gerçek zamanlı fizyolojik ölçümler arasındaki ilişkiyi incelemektir. Bu amaçla fizyolojik değişkenler ile inşaat kazaları arasında mevsimsel ve günlük çalışma saatlerine göre sekiz farklı hipotez geliştirilmiştir. İnşaat işçilerinin gerçek zamanlı Kalp Atımı (KA), Deri Sıcaklığı (DS), Elektrodermal Aktivitesi (EDA) ve Kan Şekeri Seviyelerinin (KŞS) toplanmasına karar verilmiştir. Gerçek zamanlı fizyolojik değişkenler, şantiyede iki farklı mevsimde toplam 21 işçiden toplanmıştır. 2010-2018 yılları arasında meydana gelen inşaat kazaları ile ilgili bilgiler Türkiye'de kurulan Sosyal Güvenlik Sigortası'ndan (SGK) alınmıştır. Kazalar ile gerçek zamanlı dört fizyolojik değişken arasındaki korelasyon analizi gerçekleştirilmiştir. Bu çalışmanın sonuçları, inşaat kazalarının sabah saatlerinde (öğle yemeğinden önce) işçilerin kan şekeri değerleriyle anlamlı derecede ters ilişkili olduğunu göstermektedir. Öte yandan, fizyolojik değişkenler (HR, EDA, ST) ve inşaat kazaları arasında önemli bir mevsimsel ilişki olduğu sonucuna varılmıştır. Fizyolojik faktörlerin işçiler üzerindeki olumsuz etkilerini azaltmak için verimli çalışma programları düzenlenmeli, gerçek zamanlı veri izleme sistemleri geliştirilmeli ve işçilere kısa molalar verilmelidir.

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LIST OF SYMBOLS

Hz	Hertz
μS	Microsiemens

LIST OF ACRONYMS/ABBREVIATIONS

BLS	Bureau of Labor Statistics
BMI	Body Mass Index
BP	Blood Pressure
BVP	Blood Volume Pressure
BR	Breathing Rate
BSL	Blood Sugar Level
CGM	Continuous Glucose Measurement
EDA	Electrodermal Activity
EEG	Electroencephalography
EMG	Electromyogram
ESAW	European countries on Statistic Accidents at Workplaces
FDA	Food and Drug Administration
GSR	Galvanic Skin Response
HR	Heart Rate
HSE	Health and Safety Executive
MW	Mental Workload
LED	Light-Based Detection
ILO	International Labour Organization
OSHA	Occupational Safety and Health Administration
SSI	Social Security Insurance
ST	Skin Temperature
VR	Virtual Reality

1. INTRODUCTION

1.1. Motivation of the Research

The construction industry provides significant labor force and includes various tasks such as building, dam, and high way construction, engineering, demolition of all types of structures, renovation, and maintenance. Since such construction works are typically unique, complex, and very hazardous, there have been increasing concerns about construction safety and health conditions all over the world. It is a well-known fact that the number of accidents in the construction industry is higher than in other sectors in many countries (ILO 2019). For instance, 971 occupational injuries occurred in the US construction sector in 2017, which consists of approximately 20% of the total occupational accidents in all industries (BLS 2018). Similarly, 21% of the total occupational fatalities belong to the construction sector in the European countries (Eurostat 2018). The fatality rate of construction activities in the UK is three times higher with respect to all other industries (HSE 2019). Labor-intensive tasks in the construction field that they inevitably cause disruption, fatigue, and lack of motivation, mental stress lead to several accidents. Besides, most of the construction accidents happened due to unsafe human behaviors (Haslam et al. 2006; Abdelhamid and Everett, 2002). Hence, the health conditions of the construction workers while working are major factors that play a role in the accidents. For this reason, this research study has focused on the physiological parameters of the construction workers to understand the biological causes of occupational accidents. Therefore, it is attempted to achieve more reliable conclusions to understand the impact of the physiological factors on construction accidents. In addition, the physiological risk factors were aimed to be identified empirically.

1.2. Background of the Research

It is a well-known fact that the construction tasks demand intensive physical performance in harsh workplaces. Therefore, such physical demands of the construction works can cause a number of accidents due to fatigue, poor quality attention, physical or physiological strains in the construction industry (Abdelhamid and Everett, 2002; Cheng *et al.* 2013). For this reason, most of the studies have focused on the physical, mental and physiological parameters of the construction workers to understand the biomedical causes of the occupational accidents (Gatti *et al.* 2014; Lee *et al.* 2017; Lee and Migliaccio, 2016; Jebelli *et al.* 2019a; Jebelli *et al.* 2019b).These studies showed that if the workers are not able to meet the physical and physiological standards to work in the construction sites, they could show irregular and unbalanced reactions during working times (Gatti and Migliaccio, 2012; Lee and Migliaccio, 2016; Shen *et al.* 2017). These reactions are called as the stress or biometric indicators of the human body. Such responses of the human body to any situation were precisely monitored by using remote wearable devices or biometric sensors (Cheng *et al.*, 2013; Min *et al.* 2012; Shen *et al.*, 2017). With advancing remote sensing technology, the stress indicators such as Heart Rate (HR), Blood Pressure (BP), Mental Workload (MW) or Fatigue, Breathing Rate (BR), Galvanic Skin Responses (GSR) or Electrodermal Activity (EDA) and Skin Temperatures (ST) can be monitored and evaluated precisely in construction sites (Aryal *et al.* 2017; Gatti *et al.* 2014; Sungjoo *et al.* 2016; Hwang and Lee, 2017). According to such previous research, it is widely emphasized that there is a significant relationship between the accidents and physiological parameters of the construction workers. However,a study does not exist that quantitatively examines the relationship between such physiological values and occupational accident times in the construction industry so far, to the best of the jury's knowledge.

1.3. Statement of the Research

Because the majority of the construction accidents are of human-based, the studies conducted in recent years have focused on the examination of the physical and physiological variables of the workers (Gatti *et al.* 2014; Hwang and Lee, 2017; Shen *et al.* 2017; Jebelli *et al.* 2019a). In particular, real-time physiological values such as heart rate, skin temperature, blood pressure, respiratory, electrodermal activity were precisely collected from the workers via biometric sensors. In previous studies, it was attempted to observe the changes in the physiological variables during working time by considering diverse factors such as age, work type, etc.. According to the results, physiological measurements of the workers are significantly reliable indicators of mental stress and physical fatigue. Thus, it is necessary to understand how the physiological values of the workers play a role in construction accidents. Exploring and finding the relationship between physiological values and construction accidents provides valuable information to reduce or prevent such incident cases.

1.4. Aims and Objectives of the Research

In previous studies (Gatti *et al.* 2014; Hwang and Lee, 2017; Shen *et al.* 2017; Jebelli *et al.* 2019a), it is highlighted that changes in the physiological parameters of the workers could play a major role in construction accidents. Thus, this thesis aims to examine the correlation between physiological risk factors and occupational accidents in the construction industry empirically. In other words, it is attempted to understand the role of the physiological variables on construction accidents. Different objectives are defined to achieve the aim of this research. The objectives of this study are;

(i) examining the correlation between the physiological variables and construction accidents,
(ii) developing a new analysis model to be performed between countable accident and time-series data
(iii) identifying effects of the physiological factors on the accidents based on the hourly and seasonally analysis
(iv) providing a number of suggestions for the construction industry, especially for the Turkish construction industry.

1.5. Research Methodology

The research methodology of this study consist of five main parts. Firstly, eight different hypotheses were developed between physiological factors and construction accidents (hourly and seasonal). It was decided to collect the real-time Heart Rate (HR), Skin Temperature (ST), Electrodermal Activity (EDA), and Blood Sugar Levels

(BSL) of the construction workers. The wristband (E4 Empetica) selected for this study includes HR, EDA, and ST sensors. Another device (Dexcom) was used in monitoring real-time BSL of the workers. Also, the Power Analysis was performed to estimate the required minimum sample size for this study. According to the Power Analysis, at least 8 workers were required for one season in this research. The real-time physiological variables were collected from a total of 21 workers at two different seasons in the construction site. The physiological variables were collected during a week (from Monday to Sunday; 6 days) from each worker. The information about construction accidents that occurred between 2010 and 2018 years was received from Social Security Insurance (SSI) established in Turkey. A total of 26 million points of physiological values and 199.817 construction accidents were collected and included the analysis process. The hourly and seasonal correlation analysis between the accidents and real-time monitored four physiological variables (EDA, HR, BSL, and ST) were performed in this study. Before performing the analysis, physiological values were cleaned. In order to perform analysis between construction accidents and physiological variables, they have to be in the same domain. Therefore, all datasets were converted to categorical variables. Then, the linear interpolation method was applied to achieve the same data length to conduct a correlation analysis. Besides, the normality of all datasets was tested. According to normality test results, the datasets did not fit the normal distribution. Therefore, Spearman's Correlation analysis (non-parametric correlation method) was performed between construction accidents and physiological measurements. A survey was also conducted with medical doctors and occupational health and safety managers to get feedback on the results achieved in this study.

1.6. Scope and Limitations

The scope of this research is to assess the relationship between physiological risk factors and construction accidents. The result of this study is expected to make contributions to the construction safety area. With the crucial contributions of this study, there are also a few limitations that exist. The datasets (construction accidents and physiological measurements) in this research were only collected from the Turkish construction industry. Therefore, the results achieved in this research may not be generalized. The obtained findings and suggested recommendations might be different in different countries. Besides, the physiological values can be collected from more workers carrying out diverse construction activities. Another limitation of this study is that psychological conditions and daily habits of the workers (e.g., sleeping and working time, tobacco usage, experience, age, etc.) could be considered in the analysis.

1.7. Structure of the Research

This thesis research consists of six main chapters (Figure 1.1). The motivation, background, statement, aims and objectives, research methodology, scope, and limitations of the research are briefly presented in the first chapter. The detailed background of this study such as occupational accidents in construction sites, biometric factors of the human body, and these parameters used in different fields and construction safety area is explained in the second chapter.The third chapter under the research methodology title includes hypotheses development, power analysis, sensor selection, data collection process, and data analysis. The result section is composed of the normality test and correlation analysis results. Discussion of the correlation analysis, recommendations, difficulties encountered during data collection, the impact and unique aspect of this study, limitations, and potential future research are stated in the fifth chapter. The last chapter involves a detailed summary and conclusion of this research. Besides, three appendixes (survey conducted with a construction worker, the illustrations of the measured physiological values from each worker, and a survey conducted with the occupational health managers and medical doctors) were included at the end of the thesis research.

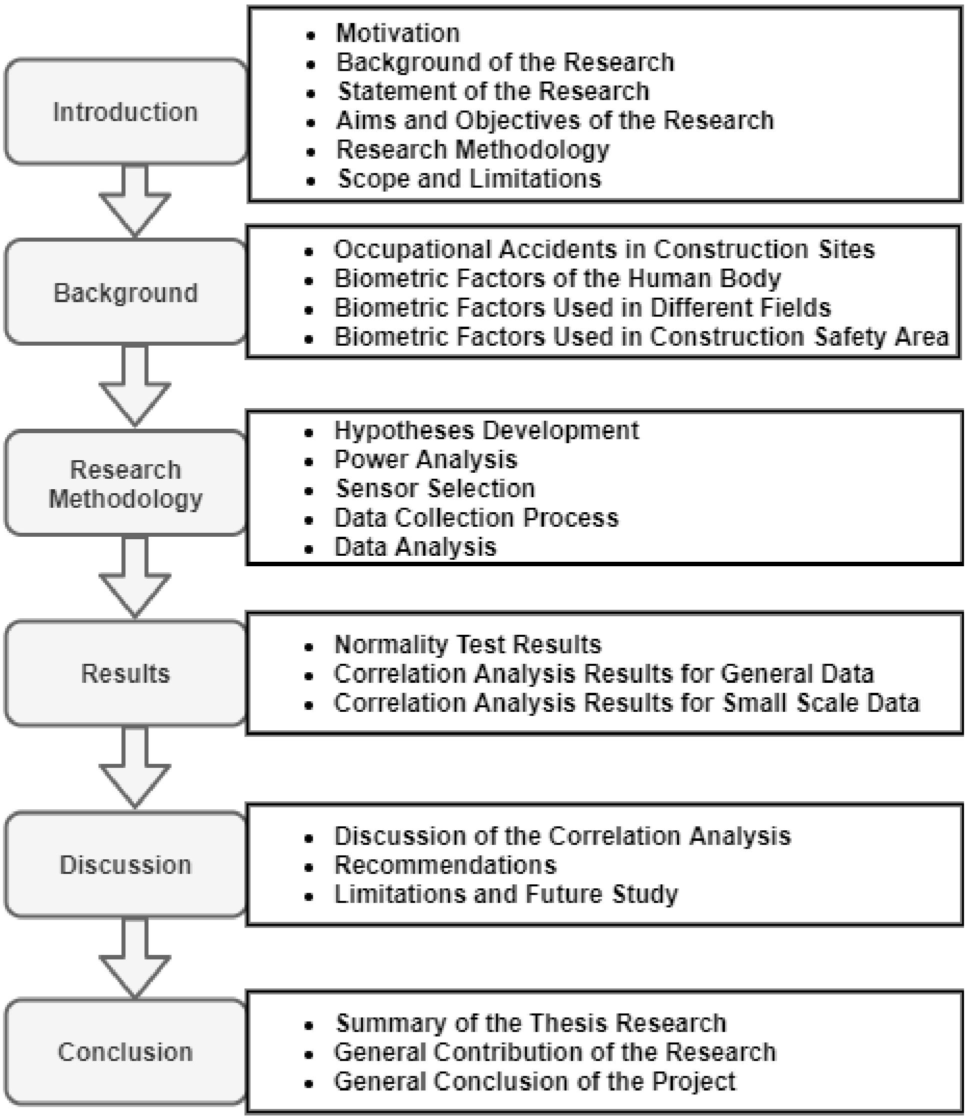


Figure 1.1. Organization of the Thesis Research.

2. BACKGROUND

2.1. Occupational Accidents in Construction Sites

The construction industry has the most hazardous workplaces compared to other sectors. In Turkey, for example, 591 fatal accidents happened during construction works in 2018, which constitutes 38% of the total fatal accidents in all sectors (Social Security Institution, 2018).In other countries, for instance, the U.S., 1003 of the 5250 fatal occupational injuries were taken place in the construction industry in 2016 (BLS, 2018). Moreover, construction works have the highest fatality rates (%20) in the European Countries (Eurostat, 2019). As can be understood from these statistical results, the activities in construction are thought to be the most dangerous and require more attention in the sense of occupational safety and health. Construction workers are usually under risk because of dynamic work conditions and difficult environmental factors.Therefore, much concern about the occupational health and safety issues for the construction sites exist. As a consequence, the statistical analysis of accidents has gained more attention owing to representing a real big picture of the occupational health and safety conditions. Most of the governmental institutions such as Occupational Safety and Health Organization (OSHA), Social Security Institution of Turkey (SSI), Bureau of Labor Statistics (BLS), European Commission Statistics (Eurostat) and non-governmental organizations such as International Labor Organization (ILO) and National Safety Council (NSC) collect and share the detail occupational accident statistics on their official web sites.

Apart from the official and non-official organizations, a number of studies were conducted to identify main causes of the accidents and provide solutions to occupational safety problems in the construction industry (Lopez *et al.* 2008; Gürcanli and Müngen, 2013; Jeong, 1998; Lopez *et al.* 2011; Amiri *et al.* 2016).To understand reasons for the occupational deaths and injuries, the accident data was collected and analyzed with respect to different factors such as age, accident type, experience, size of the company, the location of the accident, time of the accident, etc. While some of the statistical analysis on the incident cases have been grounded on the data taken from official organizations such as OSHA, BLS, and ILO (Huang and Hinze, 2003; López Arquillos *et al.* 2012), the others were based on the expert witness assessment reports (Gürcanli and Müngen, 2013) and some review papers utilized the historical accident data (Rozenfeld *et al.* 2010). Such studies can be reviewed and divided into four variables with respect to their focus points; i) accident types, ii) age and experience of the workers iii) time of occupational accidents.

Since the fatalities and injuries have constantly increased for each year in the construction sector, the studies have focused on understanding the accident reasons in a detailed way. By defining the main characteristics of construction accidents, it could be easy to suggest efficient solutions for achieving safety construction workplaces. In different studies, the accidents were analyzed and categorized with respect to the construction activity types (Gürcanli and Müngen, 2013; Huang and Hinze, 2003; Jeong, 1998). Consequently, the common accident types were identified and given more attention to such accidents specifically to suggest permanent safety solutions.

Gürcanlı and Müngen (2013) analyzed 1,117 expert witness reports on accidents between 1972 and 2008 years in the Turkish construction industry. The authors classified the reports according to the outcome of the accident (death or injury), the emergence time of the incident (hour, day, and date-time), the accident types (fall, collapse or equipment accident), and the activity type at the accident time. The results obtained from this study show that the accident type falling from height is the most prominent one, which consists of 54.1 of total incident cases. Also, the severity of fall accidents is higher than in other cases such as electrocutions, structural collapse, and falling objects. Thus, the fatal accidents commonly happen during working at height, for example, scaffolds, ladders, or roofs.

Another research was conducted to examine the fall accidents that occurred between 1990 and 2001 years in the U.S. by using the OSHA database (Huang and Hinze, 2003). The authors were interested in identifying the main patterns of the fall accidents seen in construction sites. The collected 7,543 accident data were analyzed and 2.741

cases happened due to falls, which accounts for 36% of the total accidents. According to the result, while the ratio of fall accidents increased dramatically, the number of other accident types like caught in, struck by equipment, electrocution decreased slightly from 1990 to 2001. As one can understand from this result, the falling from height is a prevalent accident type seen in the past as well as now.

Jeong (1997) studied the patterns of the fatalities and injuries in the construction industry of South Korea between 1991 and 1994. The data extracted from the annual accident statistics of the Ministry of Labor was analyzed in views of work experience, the age of worker, size of the company, injury type, and accident type in detail. The findings from this study show that the fall from height constitutes 42% of the total fatal accidents and was responsible for 19% of all the injury cases in construction sites. Consequently, it is widely agreed that the fall from a height as an accident type leads to catastrophic results and carries excessive risks for construction workers.

Along with identifying dangerous accident types in construction works, some of the studies also have analyzed the age and experience of the workers encountering a serious accident (Huang and Hinze, 2003; López *et al.*, 2012). Since a number of variables are needed to be considered to understand the occupational death and injuries, Arquillos and his colleagues, (2012) aimed to classify the patterns of the accidents. Different variables that may have an impact on construction accidents were considered in this study. Thus, the authors took into account the size of the company, days of absence, the location of the accident, the age of the workers taking place in the accidents. Statistical analysis was performed on the historical accident data collected between 2003 and 2008 in Spain to assess the impact of each selected variable. The findings obtained from this study demonstrate that about 30% of the workers having a severe accident experience are ranging from 30 and 39 age, which is a higher rate compared to other age groups. Also, it is concluded that older workers are more open to the serious consequences of work accidents.

Jeong (1998) analyzed the past accidents occurred in construction sites over the period 1991-1994 in South Korea.The historical data was taken from the annual accident reports published by the Ministry of Labor. The objective of this research to assess the main characteristics of the occupational injured accidents resulted in deaths or injuries. For this reason, the collected accident data was evaluated in the aspect of the size of the company, the age of workers, the experience of workers, and injury type. The results indicate that the injured workers between 30 and 40 age constitute approximately 40% of the total injuries in South Korea. The distributions of injured and death workers classified according to the work experience show us that over 90% of the workers have 1 year or less experience in construction works.

Previous research conducted by Lopez and his colleagues (2008) focused on the accidents in the construction industry. This study aimed to analyze the serious impact of accidents on workers. The statistical analysis of the historical data points out that roughly 28% of the total workers involving in fatal or injured accidents are between 30 and 39 years old in construction workplaces. Also, the consequence of the work accidents could be more severe for older worker groups ranging in age 40 and 49. The fatality ratio for workers constituting 26.4% of total occupational deaths is higher than other age groups.

The accidents and its serious effects could show significant differences with respect to age distribution and work experience in construction sites. Given information about the age of the workers in catastrophic cases is believed to be useful for occupational health strategies and safety training programs. For example, the tasks requiring intensive physical activities can be arranged according to workers? age distributions. The age groups between 40 and 50 should be given more attention in terms of occupational safety and health in construction (Marsza-ek *et al.* 2005). Since the older workers have a high fatal risk when they encounter an accident, construction activities requiring intensive physical demand should not be conducted by these elder workers.

Apart from the age and experience of the workers, the occurrence time of the occupational accidents is another major parameter in construction sites. The result of some previous studies proved that significant correlation is found between the accidents and occurrence time of the accidents such as days of the week, hours of the day and seasons of the years (Amiri *et al.* 2014; López *et al.*, 2008; Dumrak *et al.* 2013; Gürcanli and Müngen, 2013; Lopez *et al.* 2011).

Amiri and his colleagues (2014) carried out a study to investigate the patterns of construction accidents in terms of occurrence frequency and severity.They used historical occupational accident data obtained from The Iranian Social Security Organization (ISSO) including 21,864 cases that occurred from 2007 to 2011 in the construction industry of Iran. The purpose of this study is to analyze the accident data in the point of age of workers, day of the week, an hour of the day, type of accidents and seasonal analysis, etc. According to the result, the accidents show a tendency in increasing between 10:00 am and 11:00 am. The increased rate of accidents in those times also continues between 11:00 am and 12:00 am until lunch break. After a lunch break, the occurrence frequency of the accidents is higher between 15:00 and 17:00 compared to other working hours. Another result of the accident analysis shows that the accident rates climbed on Saturday and Sunday which days are the beginning of the week for the Iranian work calendar. From the perspective of the seasonal analysis, more occupational accidents happen in June than other months in construction sites. However, it is concluded that the consequence of the accidents could be more catastrophic in colder months of the year, especially in March.

Another similar work was conducted by Gürcanlı and Müngen (2013) for the Turkish construction industry. This study was based on expert reports released for accidents that occurred between 1972 and 2008 in Turkey. Along with the accident types, the time of the incident cases was analyzed in this research deeply. The analysis results of the expert reports demonstrate that the accidents have a higher occurrence probability between 10:00 and noon times (22.6%) and between 3:00 and 5:00 pm times (18.7%). Also, 9.9% of the total accidents were happened at just after lunchtime time between 13:00 and 14:00. It can be concluded that about half of total accidents could happen at the end of the morning times from 10:00 to 12:00 am, just after lunch break time between 13:00 and 14:00.

Previous research (Dumrak *et al.*, 2013) examined the construction accidents with respect to individual properties of the workers such as age, experience, gender, and evaluated other site factors such as the size of the company, time of the accident, season and location, etc. The authors studied 24,764 cases reported between 2002 and 2011 years in South Australia. The results of the statistical analysis present that the higher proportion of accident times occurred between 10:00 and 12:00 am, which constitutes 27.2% of total accidents.Also, it was proved that the accidents slightly more were seen on Monday (19.5%) and Tuesday (20.1%) compared to other days of the week.

Lopez and his colleagues (2008) represented a result of the study related to accident times such as hours of the day and days of the week. The construction accidents happened in Spain between 1990-2000 years involving 1,630,452 cases that were evaluated. It was concluded that there was an accumulation of the accidents between 10:00 and 11:00 am in Spain. Also, after just lunchtime between 14:00 and 15:00 in Spain, there is a higher emergence probability in accidents. In addition to this information, more accidents happened on Monday (24.2%) in the Spanish construction industry. This situation is called as a "Monday Effect" in different studies(Campolieti and Hyatt, 2006; Card and McCall, 1996).

Another study conducted by Huang and Hinze (2003) assessed the distribution of fall accidents (between 1990 and 2001 in the U.S.) with respect to the month of the year and day of the week. The obtained results show that the accident types, falling from a height, increased in summer months from June (9.1%) to August (10.3%) and declined in winter months between December (7.6%) and February (6.6%). The examined accident data from the perspective of the hours demonstrate that most of the accidents happened between 10:00 and 11:00 and show increases from 13:00 and 14:00 just after break time in construction sites.

Lopez *et al.* (2011) also studied the impact of the lunch break on construction accidents. According to the results, the authors emphasized that the accidents dramatically increase before and after lunch break in construction sites, which is why called "lunch effect".

As one can conclude that the occupational accidents might show differences in terms of time such as an hour, day, and month in the construction industry. However, the construction accidents have been commonly occurred on Monday or at the beginning of the weeks, between 10:00 and 12:00 and between 13:00 to 15:00, and especially in summer months. In addition, some of the accident types such as falling from a height and electrocutions cause more severe consequences on the construction workers. Particularly, working at height has more risk of accidents for construction workers. It is also confirmed that the severity results of accidents have been commonly seen in the age group older than 45 in construction workplaces.

To decrease the construction accidents happening due to diverse reasons, various applications such as safety training programs, law regulations, and technological innovations have been implemented so far. One of them is related to monitoring human body reactions (physical and physiological measurements or body biometric indicators) during construction activities via wearable bio-sensors that have gained more attention for last year.

2.2. Biometric Factors of the Human Body

Along with different approaches, innovative digital applications have been introduced to manage occupational safety issues in construction sites. Most of the construction accidents are thought to happen due to unsafe human behaviors (Hinze, 2003). As the human body factors are thought to be a crucial parameter in occupational health and workers? safety, biometric devices started to be used as a novel technology for recent years. To evaluate the human physiological and behavioral changes during actual working time, a number of biometric variables have been monitored in different ways.

First of all, the common properties of the biometric measurement sources (Heart Rate, Electrodermal Activity (EDA), Skin Temperature (ST), Blood Pressure (BP), Brain Activity, Blood Sugar Level (BSL) and Ergonomic values) will be explained separately in the following sections. Then, how these human body indicators used in different scientific fields such as construction safety, health, sport, industry, driving, and medical will be given in detail. After that, a number of studies conducted in real construction sites to monitor the physical and physiological factors will be explained with their aims, methodologies, and results (Figure 2.1).As a consequence, the general usage perspective of biometric indicators and sensors in different fields with construction could be systematically understood in a precise way.

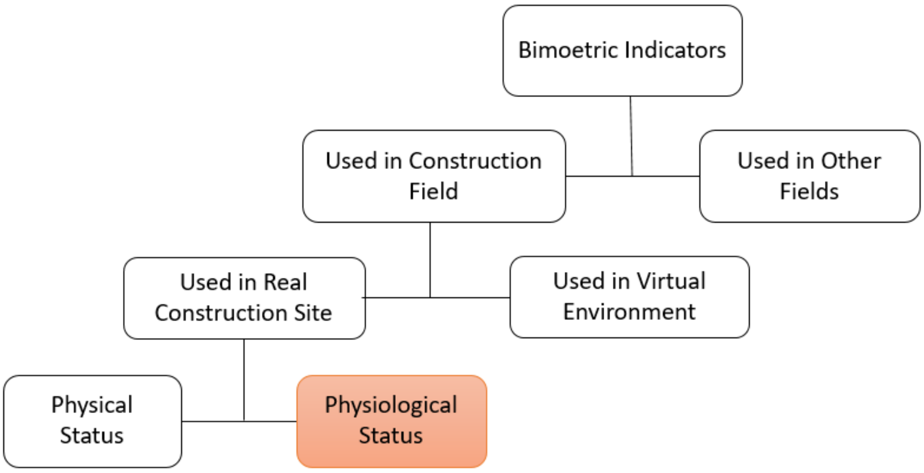


Figure 2.1. Usage Purposes of the Biometric Indicators.

2.2.1. Heart Rate

Heart Rate (HR) is a major indicator to demonstrate the physiological reactions of the human body during tasks, activities, and exercises. HR is measured by counting a number of heart pulses per minute (Sharma and Gedeon, 2012). Various body monitoring systems have developed to monitor and understand cardiovascular changes under specific conditions. A human body's heart show reactions to the emotions, environmental conditions, stressors, physical and physiological changes sensitively (Hwang *et al.* 2016). To measure HR, the sensors electrocardiogram (ECG) and photoplethysmography (PPG) have been commonly used in different studies (Gatti, *et al.* 2011; Hwang *et al.* 2016; Shen *et al.* 2017; Jebelli *et al.* 2019a). ECG sensor is set up close to the heart located on the body and measures electrical signals produced from the continuous heart waveforms. On the other hand, a PPG sensor measures HR variability by using light-based technology (LED), which is named as a photodetector. The LED detects the blood transmission underbody skin pumped by the heart. PPG sensors are placed in a wristband and can monitor HR variability in a sensitive way (Figure 2.2) (Hwang *et al.* 2016). Therefore, such sensors provide opportunities to collect real-time biometric data from worksites in a precise way.

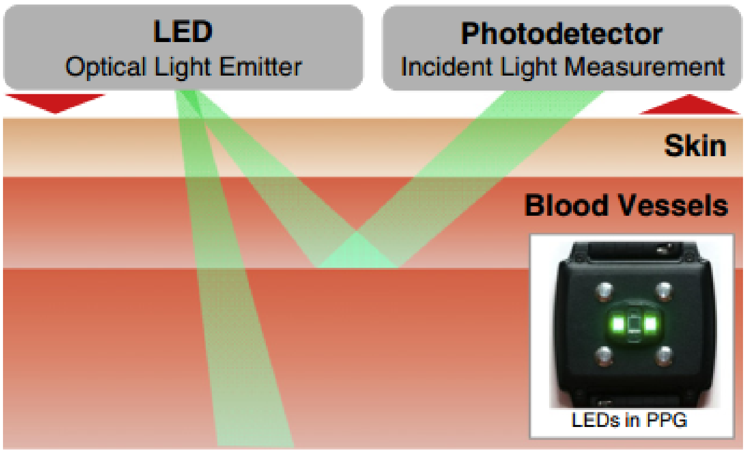


Figure 2.2. PPG Sensor Working Process.

2.2.2. Electrodermal Activity

Galvanic Skin Response (GSR) also known as Electrodermal Activity (EDA) response is another reliable biometric parameter to observe body internal reactions under different conditions (Sharma and Gedeon, 2012). Skin conductivity or EDA accepted as a valuable stress indicator can be measured by electricity flow intensity under the skin (Figure 2.3) (Jebelli et al 2019b).

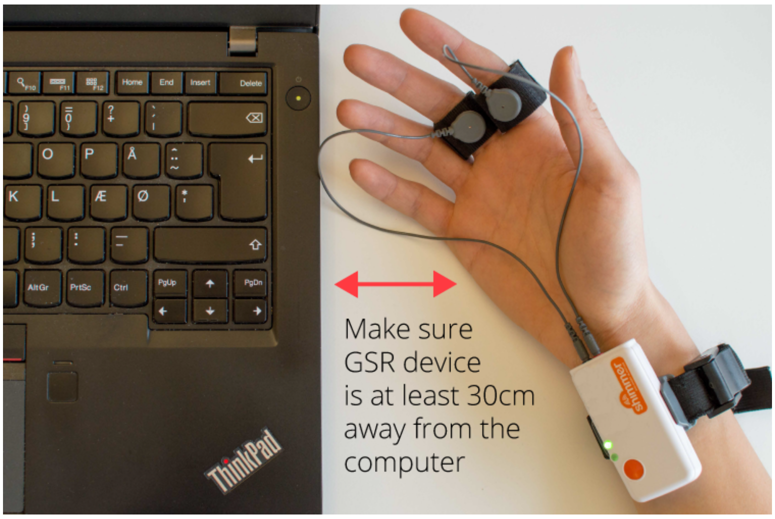


Figure 2.3. EDA or GSR Device.

The moisture level of the skin might decrease or increase producing the electrical signals when a body shows internal reactions to the specific conditions (Sharma and Gedeon, 2012). Electrodermal activity responses can be monitored by using electrodes fixed on the hand fingers or using sensors embedded into the wristband devices (Ergun, 2015). The wristbands provide numerous advantages in monitoring physical or physiological factors at real working places because of portable, uninterruptible, and low-cost properties.

2.2.3. Body and Skin Temperature

There is a relationship found between the Body or Skin Temperature (ST) level and physical demand of the works (Hwang and Lee, 2017; Aryal *et al.* 2017). Besides, skin temperature and stress levels have a significant correlation, which makes body temperature as another biometric indicator to observe the internal human body reactions. The skin temperature variable is available to track via simple sensors included in the commercial wristbands. The ST is especially important to show the heat stress of a human body working under high temperature.

2.2.4. Blood Pressure

Blood Pressure (BP) is created by the pressure of the blood circulation on the wall of a blood vessel (Pickering *et al.* 1996). Blood Volume Pulse (BVP) which is produced by BP is continuously monitored by PPG sensors detecting the amount of the light reflected from under the skin surface (Sharma and Gedeon, 2012). BP or BVP is believed to be a sensitive biometric indicator in observing human body reactions under stress or pressure.

2.2.5. Brain Activity or EEG

Brain activities are the most reliable parameters to detect and comprehend the mental status of a human according to the outside and inside conditions. Especially, mental workload occurred due to intensive tasks that can be analyzed by using electroencephalography (EEG) sensors (Aryal *et al.*, 2017; Chen and Song, 2016; Chen *et al.* 2016).The neural activity occurred in the brain leads to electrical signals which can be monitored through EEG devices (Figure 2.4). Also, it is a well-known fact that there is a significant positive correlation between mental workload and brain neural activities (Chen and Song, 2016). The neural activities are a reliable indicator in demonstrating human mental stress. EEG also has many advantages in implementing working places easily due to being non-intrusive, portable, and providing high-resolution data.

Figure 2.4. EEG Devices.

2.2.6. Blood Sugar Level

Another human internal body parameter is Blood Sugar Level (BSL) captured by the Continuous Glucose Monitoring (CGM) system. The glucose level could change during day and night times. The glucose measurement system is used for diabetes; however, it could be also applied to any person to observe blood sugar level changes at any time. So far, the glucose levels or BSL have been measured by extracting a blood sample from a fingertip. (Figure 2.5a). Then, a device can calculate BSL just for that time. Recently, there is non-intrusive sensor technology called as CGM system that has been introduced and used to monitor glucose levels without any piercing a finger (Figure 2.5b) (Dexcom, 2017; FreeStyle Libre, 2018).These new digital commercial devices confirmed by U.S. Food and Drug Administration (FDA) enable continuous or real-time glucose reading during daytime and nighttime without any interruptions for users.

Figure 2.5. a) Old Style for BSL, b) New Style for BSL.

2.2.7. Ergonomic Variables

To improve the health and safety level of the construction workers at construction sites, some of the studies considered the ergonomic factors such as breathing rate, fatigue, energy or oxygen expenditure, and body activities (Hsu *et al.* 2008; Kim *et al.* 2016). Since the construction tasks require intensive and repetitive physical activities, musculoskeletal disorders, and over fatigue are inevitable among the construction workers. Taking the ergonomic indicators into account, it is believed that the body health, safety performance, and productivity of the workers on the construction sites increase efficiently. Also, some of the labor-intensive construction tasks such as lifting, material handling, equipment operations, ironworks, and bricklaying have been classified as risky activities by monitoring body ergonomic responses. (Cheng *et al.*, 2013; Nath *et al.* 2017). In addition to ergonomic measurements, physical activities such as thoracic posture, body acceleration, and body speed are other crucial indicators for body health and safety performance of the workers in construction works (Shen *et al.*, 2017).

All of the stated biometric indicators, which are physical and physiological factors are used in different scientific areas from sport to health for various purposes. The following section is attempted to explain the usage field of such biometric indicators.

2.3. Biometric Factors Used in Different Fields

Various biometric values have been monitored in different fields such as industry (Melin *et al.* 1999), health (Apiletti *et al.* 2009), psychology (Healey and Picard, 2005; Maaoui and Pruski, 2010) and sport (Coyle *et al.* 2009; Ermes *et al.* 2008).

Melin and his colleagues (1999) examined physiological stress responses of the assembly workers working at a car engine factory. The purpose of this study is to show stress response changes in two types of work organization; i)more traditional assembly line requiring short repetitive activities and ii) efficient and flexible activity types providing diverse work activities. The physiological factors urinary in epinephrine, heart rate, and systolic blood pressure levels of the workers were recorded at different three times during working and non-working periods. The findings from this study show that the measured physiological values of the workers increased in both work organizations form compared to work-free periods as expected. Also, the tiredness based on the cardiac activity and blood volume pressure of the subjects working on the traditional assembly line was higher than others in the flexible work organization.

Another study utilized physiological signals to form a novel framework for monitoring the health conditions of the patients in a hospital environment (Apiletti *et al.* 2009). The selected physiological parameters such as heart rate, arterial blood volume, oxygen uptake, galvanic skin response, and skin temperature were monitored by using different sensors from 64 patients. According to the result of this study, the real health conditions of the patients can be monitored and quantified via biometric indicators precisely.

The physiological data also were collected and analyzed to quantify the stress levels of the drivers in a psychology study (Healey and Picard, 2005). Four biometric sensors Electrocardiogram (ECG), Electrodermal Activity (EDA), Electromyogram (EMG), and respiration were utilized to observe stress levels of the car drivers under two different situations; the highway as an open road and heavy traffic at city streets. The findings from this research demonstrated that the drivers have higher stress levels in heavy traffic conditions with respect to driving times on open roads. Also, it is concluded that physiological factors such as heart rate, skin conductance, and respiration are reliable indicators for defining the emotion levels of a human body.

Coyle and his friends (2009) developed and implemented a textile-based wearable device including physiological sensors to observe sports performance accurately. They integrated sweat pH, breathing rate, and joint flexion sensors into the wearable device. The real-time data were collected from participants wearing textile-based sensors during indoor cycling. The authors revealed that the developed low-cost physiological monitoring system, wearable sensor technology embedded the biometric sensors, is effective and reliable to evaluate sports performances during exercises.

A previous thesis study by Gomke (1996) was conducted to assess the correlation between the blood sugar levels of the workers and occupational accidents in the surface mining industry. The historical accident data was collected from the different surface mining industry and the blood sugar level of the workers was measured per hour from 8 am to 5 pm. The statistical analysis showed that low blood sugar level is significantly correlated with accidents especially before lunch break.

It can be concluded from these previous studies in diverse fields that the biometric parameters are accurate, feasible, and reliable to observe and comprehend the human body reactions under different real conditions.

2.4. Biometric Factors Used in Construction Safety Area

Although the physiological and physical sensors have been widely utilized in different areas, they are also commonly applied in construction safety areas for theoretical and practical aims. This part can be divided into two main sections according to utilization purposes of the biometric factors; i) used in virtual environments, and ii) used in real construction activities.

Since the Virtual Reality (VR) technology provides efficient and reliable training opportunities, it has gained importance for recent years in construction safety training. A number of studies conducted to develop VR based safety training environments for the construction workers (Guo *et al.* 2012; Li *et al.* 2012; Park and Kim, 2013; Zhao and Lucas, 2015; Pedro *et al.* 2015). However, the reality of such virtual training tools has been discussed intensively. To measure the reliability of these simulation training tools, the biometric factors showing real body reactions are used in various studies (Hsiao *et al.*, 2005; Saeidi *et al.* 2017; Lowe *et al.* 2017).

One study examined the feasibility of the game based safety training tool by observing the human biometric responses in different virtual environment systems (Hsiao *et al.*, 2005). The authors added real and virtual planks in different heights (0, 6 m, and 12 m) and two scaffolding platforms at two width conditions (0.3, 0.6 m) into the augmented virtual scaffolding models. Patterns of the participants who walked on real and virtual planks (0, 6, 12 m height and 30, 60 cm) embedded in the virtual environment were assessed by measuring physical and physiological parameters.According to the result, significant differences were found between the cardiovascular reactivity of the participants who walked on the virtual and real planks. It is concluded that the effectiveness of such training tools could be increased by embedding real construction materials into the VR environment.

Ergun (2015) conducted a thesis study to test the reliability of a virtual environment whether it provides real emotion or not like a real construction site for participants. She collected skin conductivity, blood volume pressure, and skin temperature data from 12 participants taking part in the virtual environment tests. The experiments were carried out in two virtual environment phases; the first one was just discovering a simulated construction site as a baseline test and the second one was experiencing four accident scenarios in the virtual site. The physiological stress levels galvanic skin response and blood volume pressure of the participants increased during accident scenarios in the virtual environment according to baseline tests.

As one can understand that the biometric factors have significant potential to represent the feasibility of the VR technology and provide reliable results to monitor human body reactions under virtual environment conditions.

Apart from a virtual environment, the biometric variables have been also measured in construction sites to assess the real-time physical and physiological reactions of the workers during actual working times. Such parameters are widely monitored in construction sites because of providing detailed information about human body reactions to intensive and repetitive tasks. The relevant studies on the physiological and physical measurements of the workers in real construction workplaces are presented in the following two chapters in detail.

2.4.1. Physical Status of the Workers in Real Construction Sites

Some of the studies have considered the ergonomic variables such as gait, balance, energy expenditure or fatigue, physical activities and oxygen uptake to observe unsafe behaviors that occurred throughout construction tasks (Cheng *et al.*, 2013; Hwang *et al.*, 2016; Ryu *et al.* 2016). In addition to defining unsafe or dangerous patterns, the previous studies highlighted that the productivity of workers can be optimized by using bodily response factors (Kim *et al.*, 2016; Nath *et al.* 2017).

For example, a novel technology was introduced to identify ergonomically safe and unsafe behaviors of the construction workers in one study (Cheng *et al.* 2013). It is a well-known fact that the repetitive activities in a long time cause musculoskeletal injuries among the workers.The authors developed a continuous remote monitoring system including physical activity recognition sensors, which was applied in masonry works established in a lab environment. Two participants took place in diverse test scenarios. Only heavy load lifting activities done in masonry works were taken into account specifically. The developed physical status monitoring system was used to track two participants during heavy load lifting activities in different positions. Therefore, the healthiest and safest lifting position was identified with respect to ergonomic data gathered from the participants. According to the test results, the upright body posture angle should be less than 250 during handling a material, which is accepted as a safe behavior.

Nath and his colleagues (2017) aimed to quantify the productivity of the construction workers with respect to the ergonomic data through mobile sensors. The productivity of workers is a crucial point in construction projects, which have to be finished in planned time and budget. Therefore, the authors aimed to evaluate the physical activities in terms of productivity and fatigue in general ergonomic variables in this study. They introduced a remote sensor system to collect real-time location and ergonomic information from the workers at a real construction site. Particularly, lifting, loading, pushing, and pulling activities were found the main reasons for the overexertion in real construction sites. The results show that participant 1 demonstrated more productive actions than other participants according to the ergonomic data during all activities. In addition, the workers are under high ergonomic risks because of repetitive pushing and pulling activities. Some physical activities exceed the limit of the human body during construction tasks that lead the musculoskeletal disorders among the workers.

The conducted studies demonstrate that reliable and precise results can be achieved from the real-time ergonomic variables during construction works by using non-intrusive sensors. Along with the physical responses of the human body, the physiological responses also can be monitored and assessed in different ways accurately.

2.4.2. Physiological Status of the Workers in Real Construction Sites

As mentioned before, the physiological parameters have great importance especially in health (Apiletti *et al.* 2009) and sport (Coyle *et al.* 2009) searches. Along with the sport and health studies, physiological indicators have been taken part in safety research fields such as mining (Nie *et al.* 2016) and driving (Gao *et al.* 2014; Healey and Picard, 2005). Apart from these studies, the construction-related ones are more prevalent for last years (Gatti *et al.* 2014; Hwang and Lee, 2017; Min *et al.*, 2012; Shen *et al.*, 2017; Jebelli *et al.* 2019a; Jebelli *et al.* 2019b).

Min and his colleagues (2012) studied the cardiovascular stress and postural stability of four inexperienced and four expert construction workers at two height positions (1.7 m and 3.3 m) with and without safety handrails. The human body balance and stress level during working are major factors in the construction safety area. Hence, this study aims to observe the physiological and physical responses of the participants for different working scenarios. A commercial sensor embedded in the chest-belt was used to monitor the heart rate of the participants during all the experiment phases. The results achieved from this study demonstrated that there is a significant difference in heart rate measures of the workers found between two height working positions (1.7 m and 3.3 m). Also, working with handrails has a crucial potential in decreasing cardiovascular stress and has a positive impact on body balance. The most stressful and dangerous position was identified as working at height without using safety handrails with respect to the physiological measurements.

Another study (Gatti *et al.* 2014) was carried out to present and validate a Physiological Monitoring System (PMS) for construction workers. The authors considered two physiological factors; i) Heart Rate (HR) and ii) Breathing Rate (BR). The reliability of continuous remote sensing technology is an important aspect of construction safety to achieve reliable information. Hence, the main target of this research is to investigate the feasibility of two remote physiological monitoring sensors by comparison with a standard laboratory instrument as a control test (used medical equipment). Ten subjects participated in the test processes. The breathing and heart rate measures were received during dynamic activities such as arm lifting, batting, weight moving, walking, and body thoracic rotation which are the main construction work actions.According to the experiment outcomes, one of the commercial physiological sensors was highly precise in monitoring heart rate values during dynamic physical activities. On the other hand, the breathing rate levels of the participants could not be monitored accurately for all times via remote commercial sensors during physical actions.

To enhance the capacity of physiological monitoring systems and provide more information about body health conditions, different bio-inspired sensors embedded into a wearable device were utilized in one study (Gatti *et al.* 2012). Four biometric factors such as HR, BR, body accelerations, and Skin Temperature (ST) were taken into account to monitor and evaluate well beings of the workers. The emotion and stress levels of workers during tasks are crucial indicators of well-being which is a vital subject as well as safety in the construction industry. In this study, a test protocol involving a series of tasks from static to dynamic patterns and requiring 40 minutes was designed for biometric measurements. The findings received from this study present that heart rate measurements show accuracy in demonstrating the health conditions of the workers and reflect each activity with the right information at real construction sites.

A wristband-type health device including different physiological sensors was used and validated in various studies (Hwang and Lee, 2017; Muaremi *et al.* 2014; Pandian *et al.*, 2008). Hwang and Lee (2017) utilized wristband technology to monitor real-time physiological responses of the construction workers.In the case study, the HR data was collected from a total of 19 construction workers at two different construction sites. Among the construction activities, removing heavy materials, and installing the doors considerably increased the heart pulses of the workers, which cause high energy expenditure and distraction. The analysis of physical activities based on the collected HR data by using wristband type devices was conducted and validated in a precise way in this study.

To give another example for monitoring biometric variables at a real construction site, a study carried out by Shen and his friends (2017) assessed physiological measures of the construction equipment operators could be taken into account. Two equipment operators participated in the test process; one of them was a dozer operator and the other was an excavator operator.The physical and physiological measurements such as heart rate, breathing rate, upper body posture angle, and body acceleration were received from operators for a 5-day duration and analyzed statistically. According to the result of the experiment, the heart rate data of the two operators showed significant differences due to their special tasks during operation times.

3. RESEARCH METHODOLOGY

The research methodology of this study is constructed on five main parts to achieve reliable and efficient results (Figure 3.1). To begin, the hypotheses related to study objectives were developed and will be stated clearly in the following section. Then, the power analysis especially used in biomedical research was performed to calculate the sample size for this research. The Power Analysis process will be explained in the next part. The sample size refers to the number of workers that are required to collect physiological data in this study.

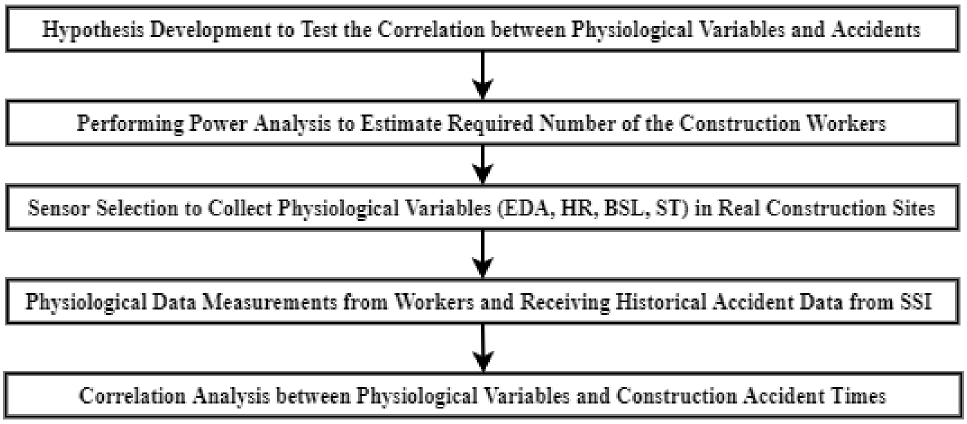


Figure 3.1. Processes of the Research Methodology.

After the calculation of the sample size or number of the construction workers, the selected wearable physiological sensors will be presented with their selection reasons. Also, the data collection process to measure the physiological variables will be explained in detail. At the end of the research methodology part, it will be also presented how the collected data was analyzed according to the hypotheses.

3.1. Hypotheses Development

The main purpose of this research is to evaluate whether the construction accidents are correlated with the physiological values of the workers based on the time. To perform the correlation analysis between the physiological risk factors and time of the occupational accidents in the construction industry, it is required to develop hypotheses for each variable. A previous study conducted by Gomke (1996) assessed the relationship between low blood sugar levels and accident hours. For this purpose, Gomke (1996) developed a hypothesis that there is a correlation between the low blood sugar level and occupational accidents in the mining surface industry.The accident data and blood sugar levels of the workers were collected from the surface mining industry. According to the results, a significant relationship was found between the accidents and blood sugar level before the lunch break. Almigbal *et al.* (2018) explored the impact of being diabetes (owing to high blood sugar level) on driving safety. The authors concluded that such diabetes plays a major role in motor vehicle collisions due to not considering their health conditions.

Based on these conclusions, the first hypothesis (H_{1-1}) suggests that there is a significant correlation between the blood sugar levels of the workers and construction accidents during a working day. On the other hand, most of the studies (Jebelli *et al.* 2019a; Jebelli *et al.* 2019b; Choi *et al.* 2019; Aryal *et al.* 2017; Hwang and Lee, 2016) point out that physiological variables which are Skin Temperature (ST), Heart Rate (HR) and Electrodermal Activity (EDA) are good indicators to understand the mental stress and physical fatigue of the construction workers while carrying out tasks. It is commonly emphasized that these human body reactions (mental stress and physical fatigue) have crucial roles in construction accidents. Especially, HR values provide information about the fatigue level of the workers while carrying out construction activities (Jebelli *et al.* 2019a). It would be expected hourly correlation between the physical fatigue of the workers based on HR values and construction accident time. Also, ST and EDA are other crucial parameters to understand body strains of the workers with respect to the accident time.Therefore, it is necessary to evaluate the hourly relationship between accidents and these physiological variables (EDA, HR, ST). For this purpose, three different hypotheses (H_{1-2}, H_{1-3}, H_{1-4}) that there is an hourly significant relationship between the construction accidents and these physiological variables (EDA, HR, ST) were separately developed (Figure 3.2).

The seasonal impact of these physiological variables on the construction accident is also emphasized in different studies (Perez-Alonso, 2011; Waters *et al.* 1979; Montazer *et al.* 2013; Tawatsupa *et al.* 2010). Particularly, heat stress has been observed among the construction workers due to working under high temperature. Heat stress deteriorates the human body physiology and increases physical fatigue and mental stress significantly together while underworking at high and humid workplaces. In this sense, it is highly required to understand the influences of such physiological variables on the construction accident seasonally. In this sense, the second hypotheses (H_{2-1}, H_{2-2}, H_{2-3}, H_{2-4})were develop to evaluate whether there is a seasonal correlation between the physiological variables (BSL, EDA, HR, ST) and the construction accidents (Figure 3.2).

According to the literature review and interview conducted with the occupational health managers, the Heart Rate (HR), Skin Temperature (ST), Blood Sugar Level (BSL), and Electrodermal Activity (EDA) were selected as physiological parameters to measure in this research.The changes in such physiological values were attempted to observe with respect to time (hourly and seasonally). The developed hypotheses between the physiological variables and the construction accident times can be seen in the below relation diagram clearly (Figure 3.2).

According to Figure 3.2, a total of 8 different hypotheses were tested in this research. The explanation of each hypothesis is elaborately given below.

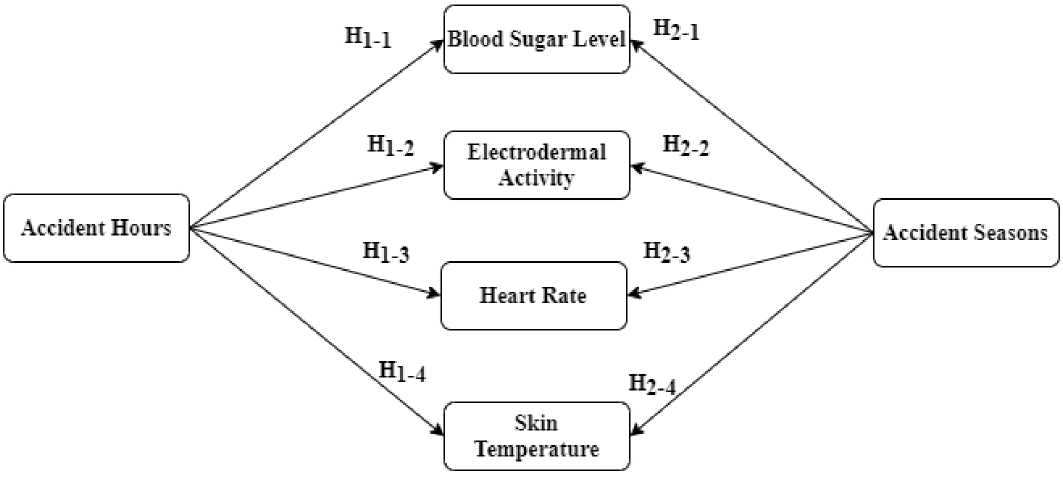


Figure 3.2. Hypotheses of the Research.

(i) Between Construction Accidents and Physiological Variables Hourly (4Hypotheses)

- H_{1-1}:There is a significant hourly relationship between the construction accident and blood sugar level of the workers
- H_{1-2}:There is a significant hourly relationship between the construction accident and electrodermal activity of the workers
- H_{1-3}:There is a significant hourly relationship between the construction accident and heart rate measures of the workers
- H_{1-4}:There is a significant hourly relationship between the construction accident and skin temperature of the workers

(ii) Between Construction Accident andPhysiological Variables Seasonally (4 Hypotheses)

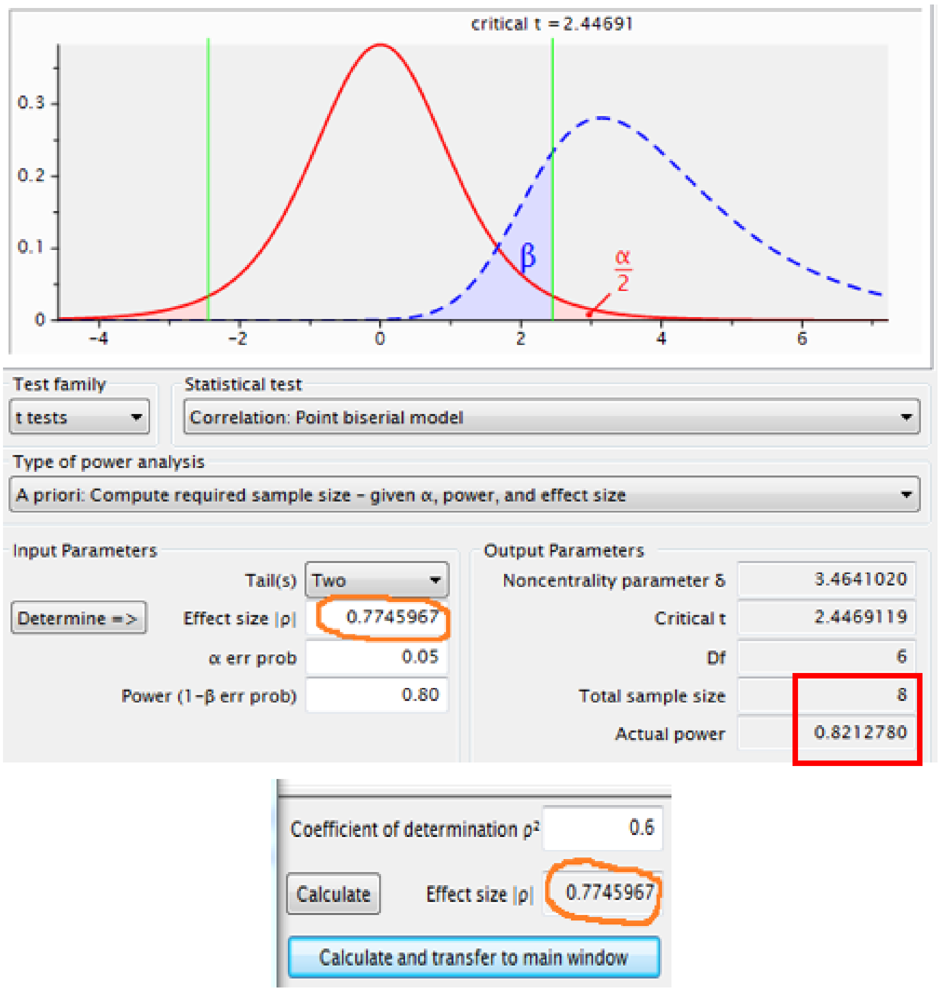
- H_{2-1}:There is a significant seasonally relationship between the construction accident and blood sugar level of the workers
- H_{2-2}:There is a significant seasonally relationship between the construction accident and electrodermal activity of the workers
- H_{2-3}:There is a significant seasonally relationship between the construction accident and heart rate measures of the workers
- H_{2-4}:There is a significant seasonally relationship between the construction accident and skin temperature of the workers

3.2. Power Analysis

The Power Analysis is a crucial procedure used to determine if the tests have enough power to make a reliable conclusion. In other words, Power Analysis test the hypothesis that the result of the study is significant. In all statistical analyses, there are two result options; i) the null hypothesis provides a reasonable conclusion or ii) the sample size is not sufficient to either accept or reject the null hypothesis, which requires more or fewer samples. On the other hand, researchers sometimes study with a large and redundant sample size that consumes considerable time. Therefore, the sample size should be calculated in an optimal way to avoid wasting time and unreliable statistical results. In the Power Analysis, the effect size, alpha and beta values, and coefficient determination have to be defined. Effect size means the minimum deviations required in the null hypothesis test. While the Alpha value represents the significance level of the test, the Beta value shows the probability of accepting the hypothesis. Power Analysis results show the power of the test according to the defined sample size. Therefore, sample size found in power analysis can be reliable to achieve statistically significant hypothesis results. The power of a study should be at least 0.8 and ideally could be 0.9. This is also used for the sensitivity factor that shows the significance level of the statistical analysis.The power analysis is used especially in natural, behavioral, and biomedical sciences for these reasons to identify the optimum number of a sample size before starting research (e.g., Cohen, 1992; Faul *et al.* 2007; Steidl *et al.* 1997).

There are various open-source, free, and online power analysis tools such as PASS and G*Power providing statistical power analysis. However, G*Power is the most commonly used in scientific studies (e.g., Erdfelder *et al.* 2009; Nosek and Smyth, 2007; Tsujimoto *et al.* 2007). G*Powersupports different statistical tests such as F, t, zero, binomial, and Chi-square. G*Power tool calculates the required sample size according to required statistical power (1-β), and significance level. The tool also supports the graphical representation of the power analysis results.In addition, different design options such as distribution and design-oriented approaches are provided by G*Power. To calculate the statistical power of a study, α, β, and effect size have to be identified during the analysis process. In G*Power 3, five different analysis methods such as a priori, compromise, criterion, sensitivity, and post hoc analyses are included. For this study, the G*Power statistical tool was utilized in this research to calculate the sample size before the experiments. As stated before, the sample size is calculated to find the required number of the workers at least.

The sample size was calculated based on the t-test Correlation-point bi-serial model which shows the relationship between a continuous variable X and a discrete variable Y, the latter of which takes on values 0 and 1 (Erdfelder *et al.*, 2009). As dependent variables time (Y - discrete variable) and independent variables physiological values (X - continuous variables) were used in the developed hypotheses, the t-test Correlation-point bi-serial statistical method was applied in the power analysis (Figure 3.3).



Test family: t tests
Statistical test: Correlation: Point biserial model
Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

Input Parameters
Tail(s): Two
Effect size |ρ|: 0.7745967
α err prob: 0.05
Power (1-β err prob): 0.80

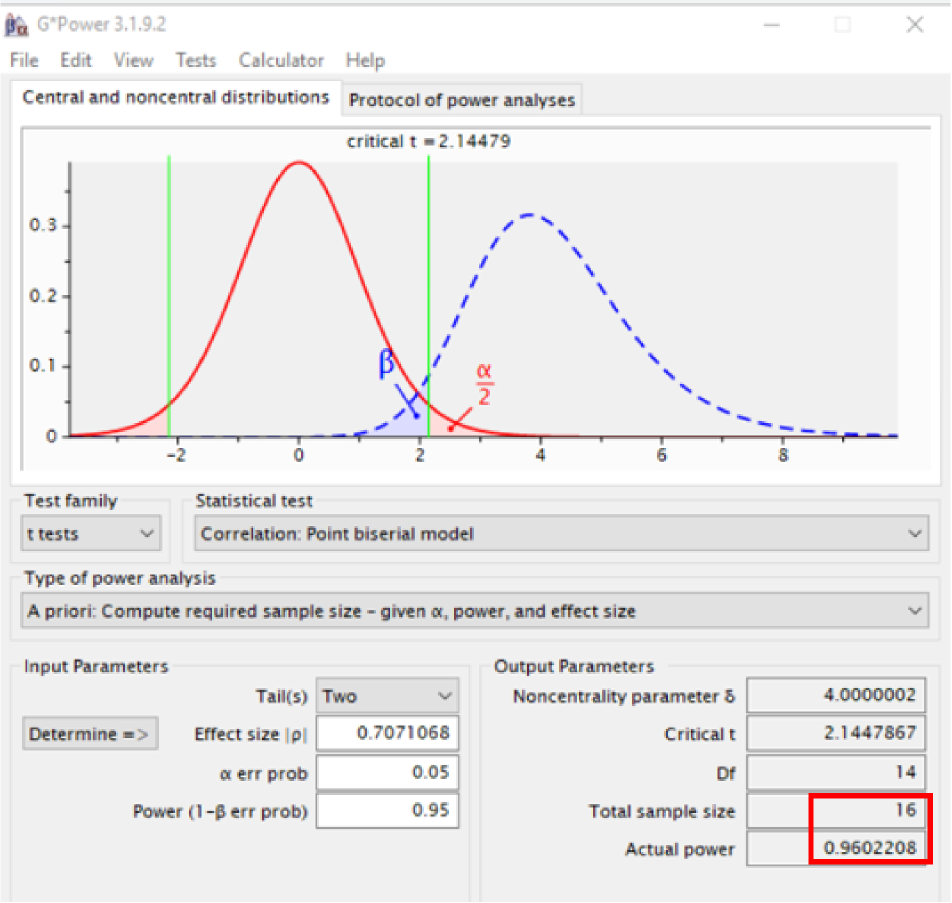
Output Parameters
Noncentrality parameter δ: 3.4641020
Critical t: 2.4469119
Df: 6
Total sample size: 8
Actual power: 0.8212780

Coefficient of determination ρ²: 0.6
Effect size |ρ|: 0.7745967

Figure 3.3. Calculation of the Sample Size for One Season.

During the power analysis process, the coefficient of determination needed for the percentage variation in Y explained by X-variables should be defined and entered. Since the coefficient of determination should be at least 0.5, 0.6 was selected to stay on the safe side statistically. Then, the effect size was calculated as 0.77 according to the coefficient of determination used as 0.6. The effect size demonstrates the strength of the correlation between dependent and independent variables in an empirical way. By using calculated effect size (0.77), the error probability (p-value defined for the null hypothesis; 0.05) and required the least power of a test value (0.8), the total sample size for one season was defined as eight (8) at least and the actual power will be 0.82 for our tests.

Accordingly, the sample size is to be at least 16 workers in all the data collection process. The calculated new total sample size within all values is shown below (Figure 3.4). Therefore, the actual power of this study will be 0.96.



Test family: t tests

Statistical test: Correlation: Point biserial model

Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

Input Parameters

Tail(s): Two
Effect size |ρ|: 0.7071068
α err prob: 0.05
Power (1-β err prob): 0.95

Output Parameters

Noncentrality parameter δ: 4.0000002
Critical t: 2.1447867
Df: 14
Total sample size: 16
Actual power: 0.9602208

Figure 3.4. Calculation of the Sample Size in Total.

3.3. Sensor Selection

Different wearable biometric sensors such as Shimmer3 ECG, Polar H10, Microsoft Band, and MetaHealth for the scientific and practice purposes are available.Among the commercial and wearable biometric sensors, the E4 Empetica was selected for collecting physiological data including heart rate, electrodermal activity, and skin temperature. “The E4 wristband is a wearable research device that offers real-time physiological data acquisition and software for in-depth analysis and visualization” (Empetica, 2017). The main advantage of the E4 device is to provide an unobtrusive and real-time physiological data monitoring. In addition, the collected real-time raw data can be easily extracted from a cloud-based platform. The wristband device E4 also has been used in different studies and its reliability and efficiency were proved scientifically (Garbarino *et al.* 2015; McCarthy *et al.* 2016; Shoval *et al.* 2018; Jebelli *et al.* 2019a).

The main properties of the E4 wristband biometric device are given below (Figure 3.5).

Figure 3.5. Empetica E4 Wristband (Empetica, 2017).

The device includes a PPG sensor that measures HR by 1 Hz and EDA sensors providing respiratory rate changes of the skin by 4 Hz. Also, it has an infrared thermopile sensor to read peripheral skin temperature by 4 Hz. To transfer the collected raw data, USB technology is used. In addition, Flash memory of E4 can collect data until 60 hours for each user (Figure 3.6).

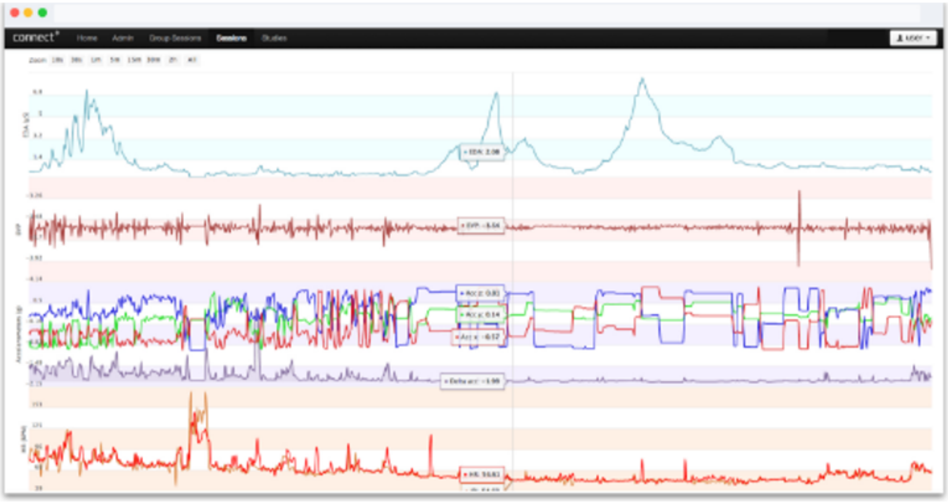


Figure 3.6. Collected Raw Data (HR, BVP, EDA, ST) Vision.

The physiological measurements can be viewed on the secure cloud platform, E4 connect (Figure 3.6). The raw data can be extracted in diverse formats to perform analysis. The E4 wristband provides various sensors which are Electrodermal Activity (EDA), Acceleration, Heart Rate (HR), Blood Volume Pulse (BVP), and Skin Temperature (ST) to collect raw data.

Another wearable device Dexcom was used to monitor Blood Sugar Levels of the workers. The Dexcom defined as Continuous Glucose Monitoring (CGM) system is a small wearable device that tracks glucose levels throughout the day and night. Most of the users of Dexcom consist of diabetes. The main advantage of Dexcom is being approved clinically by the FDA (U.S. Food and Drug Administration) and used in different scientific research (Basu *et al.*, 2017; Levitt *et al.* 2018).

Dexcom2s CGM consists of three main parts (Figure 3.7):

(i) A sensor is embedded under the skin to monitor real-time Blood Sugar Levels (BSL) up to seven days. It can be placed on the abdominal or arm region to collect data. It can be used for just one person.

(ii) A transmitter delivers the collected BSL value to the receiver. It is located on the BSL sensor.

(iii) A receiver that shows the captured each BSL value on a screen and the collected data can be extracted from the receiver to different digital platforms such as PC in Excel Spreadsheet format (Dexcom, 2018).

Figure 3.7. Parts of Dexcom or CGM (Sensor, Receiver, and Transmitter) (Dexcom, 2018).

3.4. Data Collection Process

After the selection of the biometric sensors, Empetica E4 and Dexcom, and the calculation of sample size, the data collection process was designed in two different sections; i) physiological data collection (HR, EDA, ST, BSL) and ii) historical accident data collection in this study.

3.4.1. Physiological Data Collection

Before starting the physiological data collection process, the worker target group was defined with respect to construction activity type (Figure 3.8). It was stated in the background section that falling from a height is the most dangerous and frequent accident type in construction sites. Working at height is a good example of a construction task that needs high physical demand and body balance. Therefore, the physiological parameters of the participants working at height were attempted to collect as possible. Another important aspect is that the physiological data had to be collected from healthy workers to achieve more reliable results. To start the data collection in construction sites, it was contacted with the Project Managers of the construction project and construction site was identified. The construction project where the physiological data was collected includes shopping malls, residential units, and commercial buildings. The project was conducted by a consortium company, which has huge construction projects in different countries.

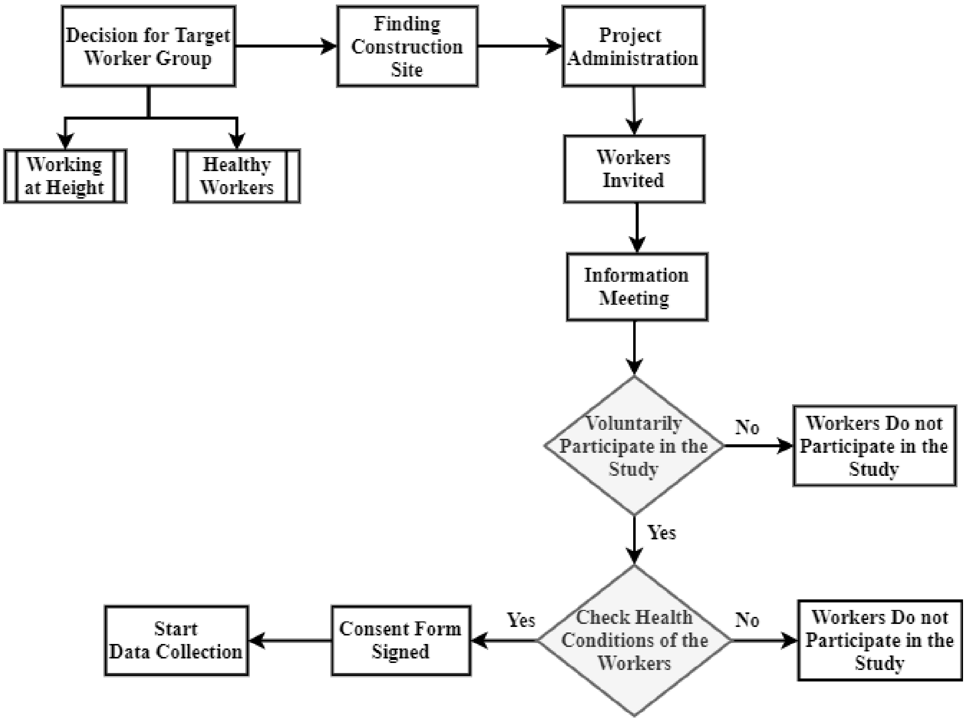


Figure 3.8. Organization of the Physiological Data Collection Process.

The thesis research was presented and explained with its aims related to occupational health and safety in detail, then the project managers accepted to help for the data collection process in the construction site. For this process, project managers appointed a planning engineer to help during the data collection process in the construction site. The planning engineer organized the informal meetings with the workers before the data collection starts. Then, the workers were invited to information meetings (Figure 3.9a and Figure 3.9b).Firstly, detailed information about the project and the data collection process was explained to the workers. Especially, the information about sensors and their usage purposes were clarified. Then, they were asked whether they could voluntarily participate in such a study or not.When they accepted to participate in this study, they signed a consent form and fill out the survey (see Appendix I). The survey questions are related to demographic information of the workers to calculate BMI. Also, their general daily habits such as sleeping and working time, tobacco usage, and sports activities were asked in the questionnaire. Other questions are about whether they have acrophobia or they are in a hurry in case of having limited time to finish a task.

Figure 3.9. a) An Information Meeting, b) An Information Meeting.

After the information meetings and when the workers voluntarily agreed to take place in the study, the process of physiological variable measurements started on Mondays at the beginning of working hours at 8 am (Figure 3.10). At the end of each day, the collected data was saved in the Excel files. The wristband data was uploaded in the cloud-based platform created by Empetica and can only be retrieved from there. However, BSL values can be directly downloaded from the receiver. After that, all data has been saved, these data in the sensor memory are automatically deleted. Thus, the data to be collected in the next day will not be overlapped with the previously collected data. Therefore, all collected data were recorded daily. Although the wristband is simple to use, the process of collecting the BSL was somewhat more complicated. The workers were asked whether they want to participate in the study voluntarily. When a worker accepted to participate, BMI information was taken from the construction company upon their permission.

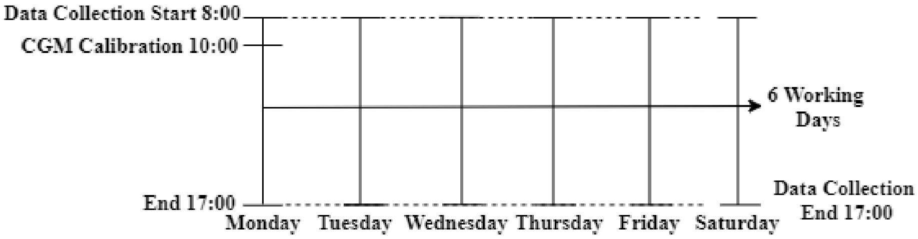


Figure 3.10. Data Collection Process for Each Worker.

BSL and HR values of the workers that were given at rest time before were obtained from the occupational health specialist of the construction company. These values are important to observe differences between working and rest times. In addition, the work types that workers carried out were also recorded. Thus, by examining the health values of the workers, the process of collecting data from the healthy workers targeted within the scope of the project was checked based on the BMI. The initial health conditions of the workers were also considered according to the Body Mass Index (BMI) (Awolusi *et al.* 2016). BMI is a measuring technique to calculate the ratio of body height and weight of a person. There is a range generated for healthy and unhealthy persons by the Centers for Disease Control and Prevention (CDC 2015) with respect to BMI. One of the main objectives of this study is to collect physiological data from healthy workers based on BMI. Also, a healthy person of BSL values should be between 72 and 99 mg/dl immediately after eating a meal (fasting blood sugar level) and up to 140 mg/dl two hours after a meal (National Institute for Health and Care Excellence, 2019). On the other hand, HR value should be less than 100 blood pulse per minute (bpm) (Palatini, 1999). After these steps, the physiological data collection process was started on the construction site.

The data collection process started on 15 July 2019. It is available to check the data via mobile API developed by Empetica (ST, HR, EDA) (Figure 3.11) and receiver (BSL) whether it is being collected or not. One of the wristbands was working well and the other one failed to collect EDA data, which indicated that the problem was not related to the working environment.

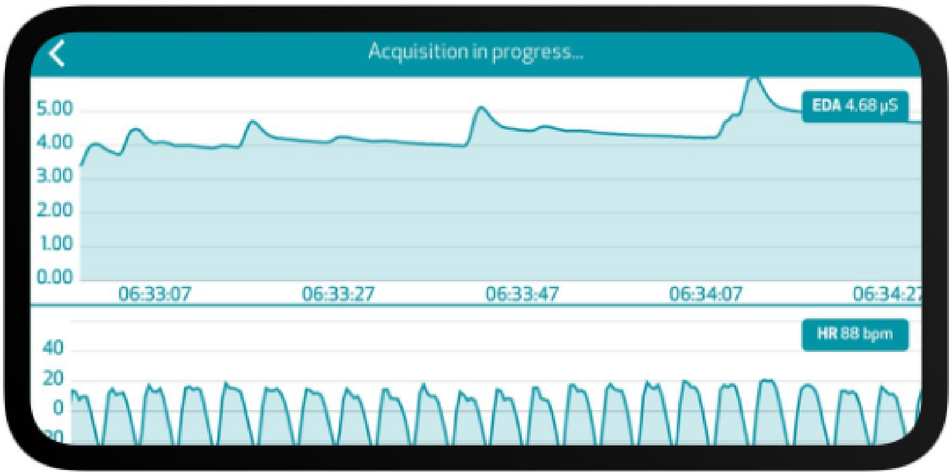


Figure 3.11. Mobile API for Wristband.

It was aimed to collect the physiological data from at least 8 workers for summer and from 8 workers for winter with respect to the Power Analysis that is stated in the previous Section 3.2.

After the collection of the summer data, the physiological data that should be also collected in the winter season were collected from the workers in the same construction project. As in the summer season, construction company site chiefs provided workers to us to attend the information meeting one week before the start of the measurements.

Similar to the working procedure in the summer season, the applications of devices were carried out before working time on Monday morning. According to the collected data during a week, physiological measurements for one worker continued until Friday or Saturday. In the winter season, physiological data was collected via one wristband and two BSL measurement devices. The data collection process was started at the beginning of January to reach the required minimum number of workers (8) whose data should be measured in winter days. Two months before the end of the winter, the measurements were started and the measurements were completed without any interruption by attaching wristbands to eight workers within 8 weeks. Apart from these participants, some workers have voluntarily measured their BSL values during the week during the winter season. Thus, the number of workers that allowed to measure his BSL was eleven, while the number of workers whose physiological data was measured via wristband was eight (Figure 3.12, Figure 3.13, Figure 3.14 and Figure 3.15). Only three workers voluntarily participated in measuring BSL values without wearing a wristband.

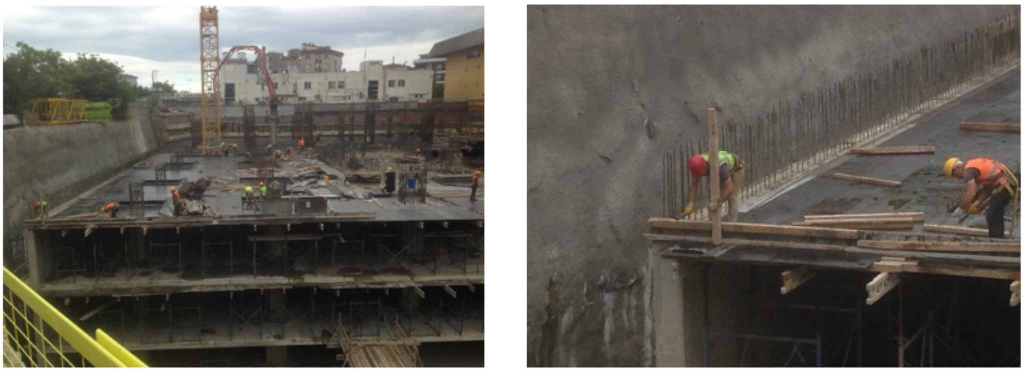


Figure 3.12. Construction Workers During Data Collection.

Figure 3.13. Construction Workers during Data Collection.

Figure 3.14. Construction Workers During Data Collection.

Figure 3.15. Construction Workers During Data Collection.

3.4.1.1. Data Collection of the BSL. While the application of the wristband is easy, the BSL measurement device requires some additional implementation to collect the data. To collect physiological data, the BSL measurement device was initially applied to the workers (Figure 3.16). The working principle of the BSL measurement device (Dexcom) is more complicated according to the wristband (Empetica E4). To activate the GCM system, a sensor measuring the blood sugar is first injected into the body, for example in the back of the arm or on the abdominal region. Once the injected sensor is firmly attached to the body through stickers, the transmitter sensor is activated automatically. The sensor measures per 5 minutes and sends the measured data to the receiver via the transmitter (Figure 3.17).

Figure 3.16. Blood Sugar Sensor Implementation on Two Different Body Region.

Figure 3.17. Parts of the BSL Measurement Device.

Initially, the BSL sensor is placed under the body skin and the sensor is activated. Then, the BSL sensor needs to be calibrated after approximately 2 hours to start the data collection (Figure 3.10). During that time, BSL value cannot be collected and available on the receiver screen. After 2 hours, two blood glucose values taken from two fingertips must be entered into the transmitter to calibrate the sensor (Figure 3.18). After entering the values, the blood glucose sensor is calibrated and starts to measure the blood glucose values per 5 minutes. The values can be read on the receiver screen (Figure 3.19). However, during the first 2 hours, they carried out their activities on the construction site.In some cases, the blood sugar sensor removed from the body during that time. In this case, a new sensor has to be attached to the body and the process returns to the beginning. On the other hand, the wristband collects real-time physiological data from the beginning of working hours at 8 am.The application of the wristband is very easy and does not interrupt the workers during construction tasks. All these implementation processes take 10 or 15 minutes. Therefore, the data collection process does not influence the working schedule of the workers and progress in the construction site.

Figure 3.18. Taking Blood Sample for Calibration.

Figure 3.19. Reading Glucose Values on Receiver.

3.4.2. Historical Accident Data Collection Process

Collection of the historical accident time information is another crucial leg of this research. The time information of the construction accidents was received from The Social Security Institution (SSI). The SSI records all the occupational accident time information such as the hour of the day, the day of the week, and month of the year with respect to the European countries on Statistic Accidents at Workplaces (ESAW) methodology. ESAW is a compulsory data collection procedure for all EU or candidate countries.For this reason, among the accident records, SSI has the most reliable and confidential information according to other governmental and non-governmental institutions in Turkey. The construction accident data is not available publicly and this accident information was received via official permission from SSI.In the construction accident data, the time information (year, day, and hour) of all accidents (fatalities and injuries) that occurred from 2010 to the end of 2018 was included in the Excel format file. Also, age information of the workers encountering an accident and information on the construction activity type (NACE code) in which the accident occurred was provided. In summary, time information 268,635 accidents that happened in the Turkish construction industry were received from SSI.

3.5. Data Analysis

Before data analysis, collected physiological data EDA, ST, and HR data have to be filtered and cleaned to carry out reliable statistical analysis. All data cleaning and analysis processes were done by using the Python programming language. Two strong open-source programming languages exist; Python and R. While R has been just developed for data analysis purposes, Python has various functions apart from data analysis. Python programming language has been also used widely for Data Science. Besides, the learning process and writing syntaxes of Python is easier than R. Python can also be used in different project platform such as developing websites, game, artificial intelligence, etc. Python is also very useful in visualizing data by using the matplotlib library. To conduct the data analysis process, Python has strong libraries such as Pandas, NumPy, and SciPy. Especially, Pandas has been developed for big data analysis purposes. Since correlation analysis was performed to test the developed hypotheses, it was preferred to use the Pandas module that has diverse functions to make the pairwise comparison between two or more columns in data frames.Python also has a HeartPy library to filter HR data included Hampel filtering (Figure 3.20). The HeartPy library provides cleaning noisy HR data. Some syntaxes have been written for cleaning PPG data collected from the wristband. All data preparation, modeling, and analysis process are explained in the following part.

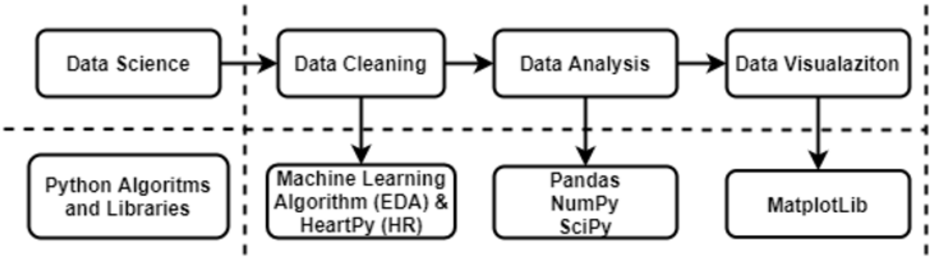


Figure 3.20. Data Analysis Process via Python.

3.5.1. Data Preparation

After receiving historical accident time information from SSI and measuring physiological data (EDA, HR, ST, BSL), such two variables had to be prepared for data analysis. First of all, construction accidents that occurred between 8 am and 5 pm during normal working hours were extracted from all accident data. The collected physiological data corresponding to the same time interval between 8 am and 5 pm was also extracted. Accordingly, more accurate and significant data analysis can be done since the same time interval is considered for construction accidents and collected physiological data. However, any accident and the measured physiological value between 12-13 hours, lunch or break time in construction sites, were not taken into account for the data analysis process. Besides, the accidents that occurred on Sundays were removed and not considered in the analysis. Thus, 199.817 of 268.635 construction accidents were just taken into account for the data analysis process. After extracting both accidents and physiological data for certain periods, two different variables were obtained; one of them is countable construction accident data, the other one is physiological values based on time series (Figure 3.21). Construction accident data was analyzed with respect to hourly, daily, and seasonally, which was a descriptive analysis of historical accidents. Therefore, it could be observed how accidents behave during the time of the day and seasons.

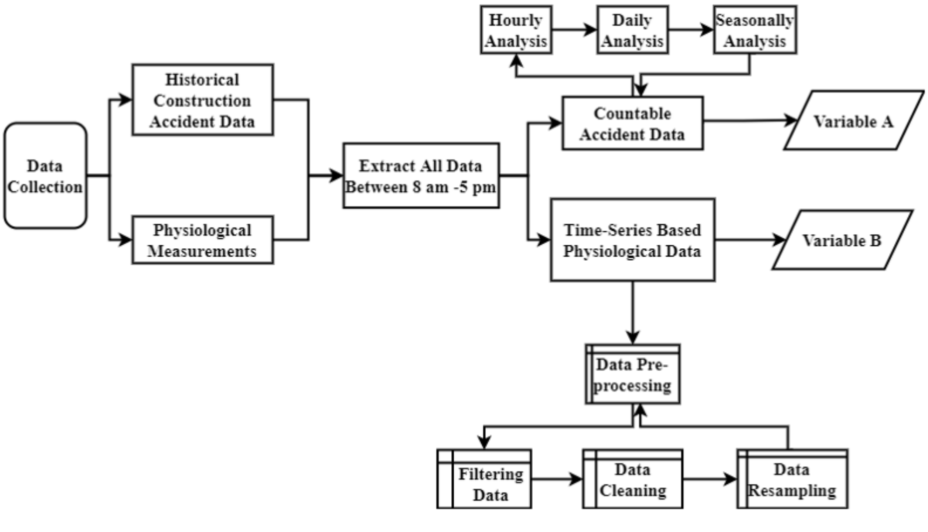


Figure 3.21. Data Preparation Framework.

According to descriptive analysis, the accidents have a significantly distinct pattern with respect to the hour of the day (Figure 3.25) and the month of the year (Figure 3.23). The number of accidents significantly increases during summer months according to seasonal analysis (Figure 3.23). In addition, the hourly analysis result of the construction accidents shows that the accidents climb toward the lunch break. Accordingly, more accidents happen immediately before the lunch break with respect to other working hours (Figure 3.25). On the other hand, there is no significant difference observed in the daily distribution of construction accidents (Figure 3.24). As can be seen in Figure 3.22, the number of accidents recorded before 2013 is extremely less than accidents recorded after 2013. The main reason for these differences is related to the usage of the ESAW recording system. As stated before, SSI has recorded each occupational accident via the ESAW system since 2013. Therefore, the accidents recorded after that time have been more reliable with respect to previous years. Accordingly, the accidents that occurred since 2013 were taken into account for the analysis process in this study.

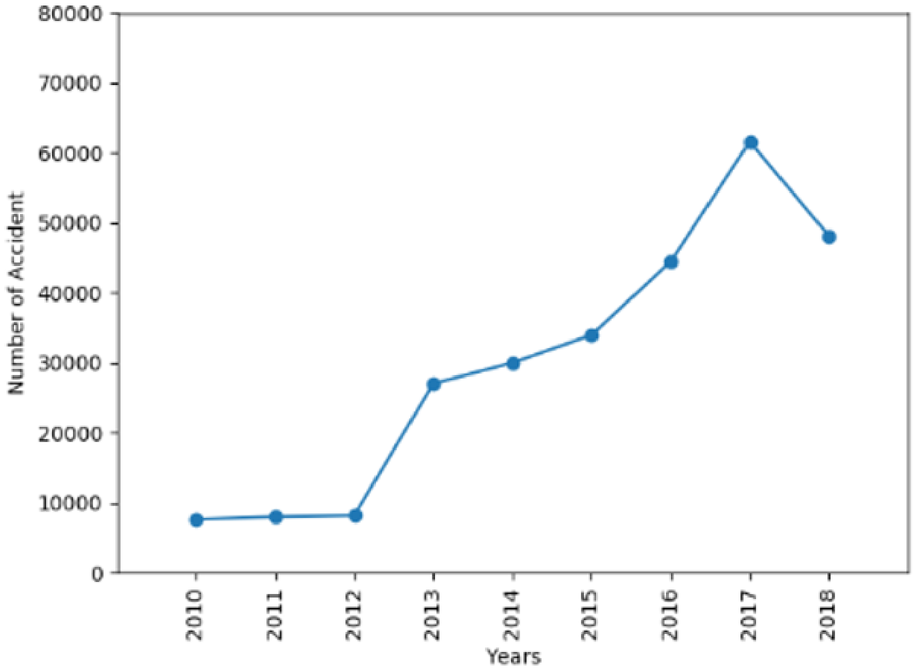


Figure 3.22. Yearly Distribution of the Accidents.

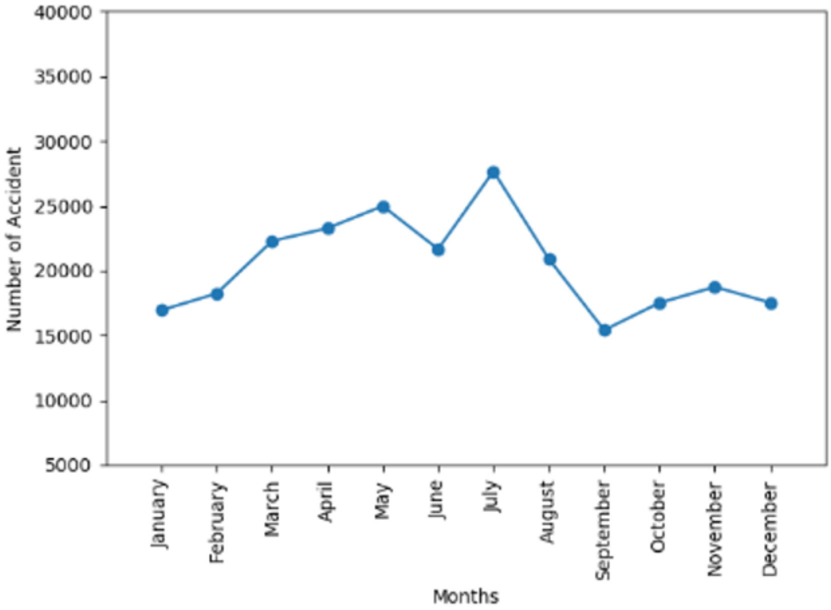


Figure 3.23. Monthly Distribution of the Accidents.

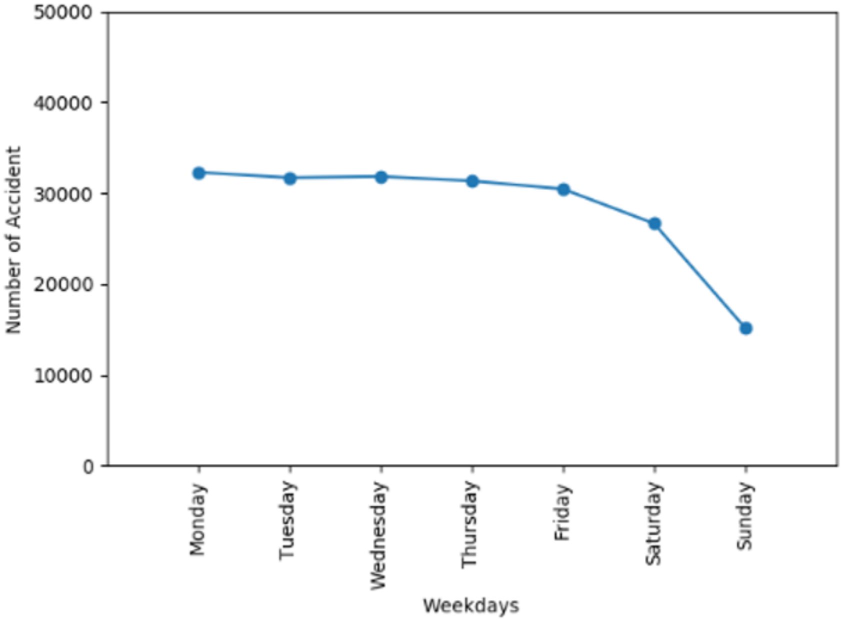


Figure 3.24. Daily Distribution of the Accidents.

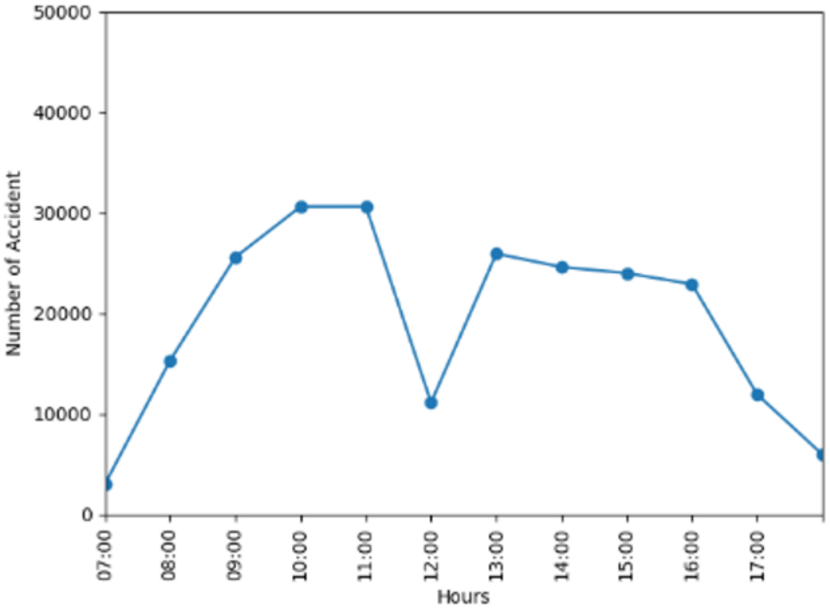


Figure 3.25. Hourly Distribution of the Accidents.

After identifying which accidents will be considered in the data analysis process according to descriptive time series analysis, physiological data has to be also prepared for the same purpose. Before analyzing the collected physiological data, it is necessary to remove noise or unexpected signals (Choi *et al.* 2019, Hwang and Lee, 2017, Hwang *et al.* 2016). Most of the wristband especially off-the-shelf wearable ones capture unwanted signals during physiological data measurement. Because the data collected from a construction site that has dynamic conditions (e.g., body movements, environmental factors, sensor movements, and sweating) could be noisy, they have to be removed or cleaned from the real measurements. Noisy data causes unreliable data analysis processes and evaluations.

Since the working principle of each physiological sensor is different and physiological values were measured in different frequencies, diverse filter methods were applied to each physiological factor during the data cleaning process. To perform the data cleaning process for EDA signals, a machine-learning algorithm was implemented by using the Python programming language developed by Sara *et al.* (2015). The algorithm works with 3-axis Accelerometer and skin temperature data to detect the artifacts in EDA signals. Subscripts of the algorithm are provided at the GitHub code-sharing platform. The low-pass filter was used in the algorithm. The same filtering method was also utilized in other studies (Jebelli *et al.* 2019a, Jebelli *et al.* 2019b) related to physiological variables collected in the construction sites. The low-pass filter blocks and limits the signals which are higher than the cut-off frequency. For this study, the cut-off frequency is defined as 1 Hz to filter EDA artifacts (Sara *et al.* 2015). After filtering EDA data, artifact signals still exist in the collected data and were cleaned by using the binary selection method developed on the Support Vector Machine algorithm (Sara *et al.* 2015) (Figure 3.26). Along with the filtering and cleaning EDA data, collected Skin Temperature (ST) responses also needed to be cleaned. For this purpose, the high-pass filter method was applied, which was also implemented in the previous studies (Aryal *et al.* 2017, Jebelli *et al.* 2019a). The high-pass filter passes signals which are higher than the defined cut-off frequency, thus unwanted or noise signals under the cut-off frequency can be eliminated (Figure 3.26). For this study, the cut-off frequency is defined as 0.05 Hz based on the previous studies (Jebelli *et al.* 2019a, Jebelli *et al.* 2019b). To filter HR data, rolling and Hampel filter methods were applied and collected data were smoothed by using HeartPy Python library (Figure 3.26). After all this process, the collected physiological values (EDA, HR, ST) were resampled to one minute. A previous study conducted by Jebelli *et al.* (2019b) shows that 60 seconds interval of a physiological variable reflects about 90% of the real properties of the collected data if the data is cleaned properly. This is the reason why the collected data was resampled to one minute.Accordingly, it is easy to study such big data by using cleaned and smoothed values. All of this process is called as pre-processing in the data science field.

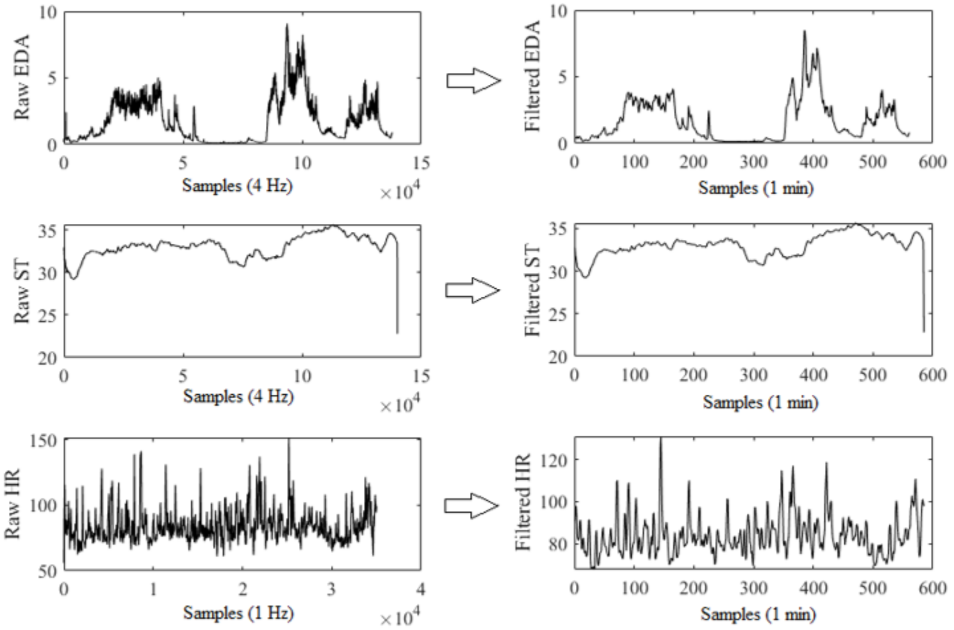


Figure 3.26. Raw and Filtered Physiological Signals.

All these data pre-processing steps were implemented to physiological measurements of each construction worker separately. Accordingly, all the physiological data collected were available for data analysis. The countable accident data were labeled as Variable A and physiological data based on time series were coded as Variable B at the end of the data preparation process (Figure 3.21).

3.5.2. Data Modelling and Analysis

For this study, it was planned to perform correlation analysis between construction accidents and collected physiological variables in a different time domain. However, it is not easy to conduct correlation analysis between variables; one of which is countable construction accidents and the other one is time-series based physiological data. Also, since the information on construction accidents occurred in the past (between 2010 and 2018) and the physiological data were collected after these accidents, it is not possible to match two variables in the same time domain. Meanwhile, correlation analysis requires the same length dataset for both variables. None of these required conditions could be met since one variable is countable and other variable includes time-series based physiological values. The length of the two variable datasets also was not the same. Because of such reasons, the countable accident and physiological variable datasets were converted to categorical variables (Figure 3.27). This process was based on a previous study (Tu and Soman, 2014). The authors (Tu and Soman, 2014) categorized the time of the events to understand consumer behaviors from different perspectives.Therefore, the accidents that occurred between 8 am and 9 am were categorized as 8 in this thesis research. Besides, the physiological values collected between 8 am and 9 am were grouped as 8 similarly. All of the physiological variables and construction accidents between 8 am and 5 pm were grouped similarly.Before the categorization of the construction accidents, a weight number was calculated for each incident case. Each accident has a severity value with respect to its emerging time. First of all, an accident rate was determined according to the occurrence month of the accident. Therefore, the number of cumulative construction accidents was not taken into account. The ratio was calculated by dividing the total number of construction accidents at the relevant month to the total number of construction workers in the same month (Equation 3.1). The information of total construction workers for each month was gathered from the official website of SSI (SSI, 2019).

$$(Accident\ Severity)_m(\%) = \frac{\Sigma(\#Accident)_m}{\Sigma(\#Worker)_m} \tag{3.1}$$

Along with assigning accident severity for accidents based on occurrence month, the new severity weight was also assigned for accidents between two hours. The accident severity rate between any two hours (i.e. between 8 am and 9 am) is calculated by dividing the total number of accidents between any two hours by the total number of accidents between the same two hours in the month.Then, the obtained severity weight was multiplied by the accident severity ratio previously calculated in Eq.1to include monthly accident severity weight on each accident for the relevant month (Equation 3.2).

$$(Accident\ Severity)_h(\%) = \frac{\Sigma(\#Accident)_h}{\Sigma(\#Accident)_{m*h}} \times (Accident\ Severity)_m(\%) \qquad (3.2)$$

Accordingly, each countable accident data was assigned a unique ratio value. Thus, the seasonal impact (e.g., more construction accidents occur in summer months due to intensive worker requirements in these months) on the construction accident was eliminated. After assigning ratios, the values were standardized by using the pre-processing approach which was applied for physiological variables before. By categorizing and assigning ratio values, the countable accident dataset was converted to the same domain with the physiological variables. While hourly categorization was done between 8 am and 5 pm (e.g., 8-9-10-11-13-14-15-16) for each hourly interval without including datasets between 12 and 1, the seasonal categorization was established as 0 and 1 like the binary label (i.e.., "0" represents winter and "1" represents summer). Since there are not any significant differences found between the number of daily accidents (Figure 3.24), the effect of physiological variables on construction accidents was not evaluated on weekdays. After the categorization of construction accidents and physiological variables, these two datasets were still of different lengths. To overcome this issue, the linear interpolation method was applied to the construction accident values which are lengthier than physiological variables. The linear interpolation is a common method especially applied for machine learning projects related to construction accidents (Ho and Yu, 2015), traffic accidents (Rodriuez *et al.* 2020), and seismic data collection (Jia and Ma, 2017). The linear interpolation in these studies aims to generate new datasets according to existing datasets. Accordingly, the datasets can be extended or narrowed with respect to existing variables. This method also is applied to fill missing values or predict new values.

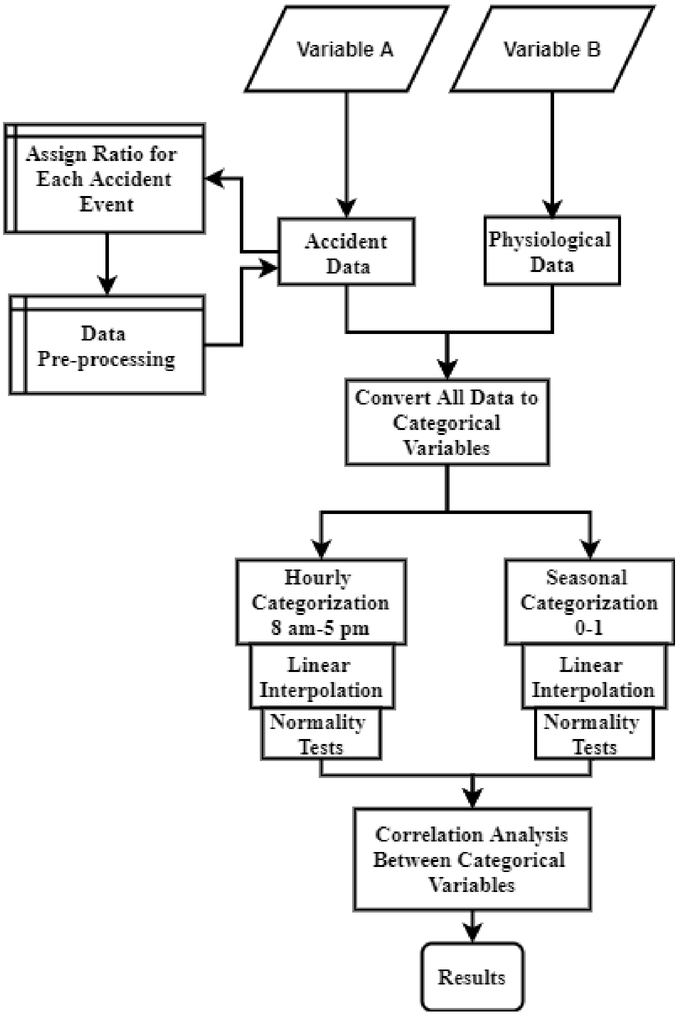


Figure 3.27. Data Modelling and Analysis Framework.

In this study, the construction accidents were narrowed due to including more row data as stated before, which was also applied in a previous study (Wu and Hilliard, 2005) similarly. For instance, 15309 accidents occurred between 8 am and 9 am, however just 5038 HR values were measured between the same interval. Therefore, a number of accidents were interpolated from 15309 to 5038 without deterring its distribution. This process was implemented for each time interval or category in four different physiological variables separately (e.g., 8-9-10-11-13-14-15-16). Accordingly, it was assigned a corresponding standardaziedaccident severity ratio to each measured physiological value. At the same time, the physiological variables were also standardized. To decide on the correlation analysis method, the normality of two datasets had to be tested. The association between two datasets are measured by three common correlation analysis such as Pearson, Kendall tau, and Spearman's Correlation analyses. While the Pearson correlation analysis is performed between parametric datasets, Kendall, and Spearman Correlation analysis techniques are generally used for non-parametric data. On the other hand, Spearman's Correlation analysis is preferred for large and continuous data rather than Kendall's tau (Chok, 2010). For this reason, the normality test was initially applied to assess the normal distributions of each dataset. To check the normality of the datasets, the Shapiro Wilk test was implemented since it was introduced for large and continuous data samples by Shapiro and Wilks (1965). The Shapiro-Wilk test is used to test the null hypothesis that the dataset shows the normal distribution, which is also used for time series data in a previous study (Bai and Ng, 2005). If the p-value is less than 0.05 (95% confidence), the null hypothesis is rejected and it is concluded that the data does not fit the normal distribution According to the normality test results, the correlation analysis between the construction accidents and four physiological variables, it was decided to conduct Spearman's Correlation analysis. Spearman correlation analysis is used to calculate the correlation coefficient (R) a measure monotonically rank correlation between two non-parametric datasets (Artusi *et al.* 2002). For instance, a previous study (Nyborg and Jensen, 200) was carried out to find a correlation between the psychometric measurements of the black and white American males who are soldiers under the U.S army. The R reflection of the correlation coefficient is calculated via Spearman's Correlation analysis. The correlation coefficient R shows the strength of the relationship between two variable sets (e.g., construction accident ratios and physiological variables in this research). If R-value is found between 1.00 and 0.00, it can be concluded that there is a positive relationship between the dependent and independent variables. When the R-value increases up from 0 to 1, the correlation between datasets becomes stronger. On the other hand, the correlation coefficient between 0.00 and -1.00 represents the inverse relation for datasets. If the R-value is found as zero, it can be concluded that there is no relationship found between two datasets. Along with the R-value, the p-value in the correlation analysis also is calculated to show signs of the achieved results. If the p-value is less than 0.05, it can be concluded that the achieved correlation coefficient is significantly reliable to evaluate the results.One study conducted by Jacon and Ganesan (2013) could be a good example of a correlation analysis applied between two datasets. In this study, the correlation between physiological variables (Rectal Temperature, Respiration Rate, and Heart Rate) and physical variables (Age and Species) of small ruminants was tested by using correlation analysis.According to the results, the correlation between Age and Respiratory Rate (-0.88), Age, and Heart Rate (-0.86) are strongly negative. Also, while the physical variable is explained highly by Age (0.98), the physiological variables are determined significantly by HR (-0.44) and RR (-0.59). The HR (-0.87) and RR (-0.89) have a strong negative relationship with Age with respect to cross-loading values of the correlation test. This study proves that the developed hypotheses could be tested by using correlation analysis in a precise way.

The correlation analysis was conducted for two different scales; large and small scales. All the collected physiological measurements and construction accident data were included in the large scale correlation analysis. On the other hand, small scale analysis represents the correlation between the collected physiological variables and the construction accidents occurring at the same time interval with the collected data. In other words, construction accidents only occurred in summer, and winter days were considered and included in the small scale analysis process. Therefore, the hourly correlation analysis was only conducted between physiological variables collected on summer days and construction accidents happened in the summer season. The same approach was also applied between two datasets for the winter season. The small scale analysis was performed to assess the validation of the large scale analysis results.

Lunch break could inevitably change internal human body factors especially physiological variables, which is called as “lunch effect” (Lopez *et al.* 2011). Therefore, the hourly correlation analyses were performed for three different time intervals. the hourly correlation analysis between construction accidents and physiological variables was conducted for the morning, afternoon, and whole working hours separately.

Besides, a survey was conducted with occupational health managers and medical doctors on all the Spearman’s correlation analysis results (Appendix III). Thus, the opinions and suggestions of these experts were taken on the obtained findings and were discussed.

4. RESULTS

4.1. Collected Data Information

Since an oxidation issue in a wristband occurred, apart from eight workers, the physiological data were collected from two more workers in summer. Thus, it was aimed to complete the missing EDA data. In general, all physiological data from different 10 workers to the end of August were collected (Table 4.1).

Also, the weather temperature data was taken from the General Directorate of Meteorology (GDM, 2020) for summer days when the real-time physiological values of the workers were collected (Table 4.2). As can be seen in Table 4.5, the average weather temperature on summer days when the physiological data was collected was approximately 31^oC . While the minimum weather temperature was 27^oC, the maximum weather temperature was 35^oC during the data collection process on summer days.

According to collected data of the workers given at rest time (HR and BSL values), it is observed that the physiological values of the workers are almost in the range that they should be. At the same time, information about the construction activities of the workers at the construction site is given in Table 4.3. Among the workers whose data collected on summer days, two of them carried out formwork construction, four were doing drywall, and others were on welding tasks (Table 4.3). Besides, the height and weight information of the workers were used to calculate Body Mass Index (BMI) of the workers, which is an important indicator of the health condition of a human body. BMI value should be lower than 30 kg/m^2, which is the limit value for obesity. If BMI value is calculated between 25 and 30 kg/m^2 shows that a person is overweight, BMI between 20 and 25 kg/m^2 corresponds to the normal weight for a human body (Nutfall *et al.* 2015). Although only one worker who participated in this study in the summer season was identified as obese, BMI of most workers demonstrates that these workers are healthy and eligible to conduct heavy construction tasks.

Table 4.1. Collected Data Information at Summer Season.

Date	Workers	EDA (4 Hz) (29 Days)						HR (1 Hz) (47 Days)						Temp (4 Hz) (47 Days)						BSL (5 min) (35 Days)					
		Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat
15-19 July	Worker 1	x	x	x				x	x	x				x	x	x					x	x	x	x	
15-19 July	Worker 2	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	
22-27 July	Worker 3	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
22-27 July	Worker 4	x			x	x		x	x	x	x	x	x	x	x	x	x	x	x						
29 July - 3 Augst	Worker 5				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
30 July - 3 Augst	Worker 6	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
5-10 Augst	Worker 7	x		x				x		x	x			x		x	x			x	x	x	x		
5-10 Augst	Worker 8		x		x			x	x	x	x			x	x	x	x			x	x	x	x		
26-29 Augst	Worker 9							x	x	x	x			x	x	x	x			x	x	x	x		
26-29 Augst	Worker 10	x	x	x	x			x	x	x	x			x	x	x	x								

Table 4.2. Temperature Data on Summer Days.

Time	Temperature	Time	Temperature	Time	Temperature
15 July	(33^{o}C)	29 July	(29^{o}C)	26 August	(31^{o}C)
16 July	(31^{o}C)	30 July	(32^{o}C)	27 August	(34^{o}C)
17 July	(28^{o}C)	31 July	(30^{o}C)	28 August	(33^{o}C)
18 July	(29^{o}C)	1 August	(27^{o}C)	29 August	(28^{o}C)
19 July	(30^{o}C)	2 August	(31^{o}C)	30 August	(29^{o}C)
20 July	(33^{o}C)	3 August	(33^{o}C)	31 August	(30^{o}C)
22 July	(35^{o}C)	5 August	(36^{o}C)	2 Sep	(28^{o}C)
23 July	(34^{o}C)	6 August	(35^{o}C)	3 Sep	(29^{o}C)
24 July	(32^{o}C)	7 August	(34^{o}C)	4 Sep	(33^{o}C)
25 July	(30^{o}C)	8 August	(34^{o}C)	5 Sep	(30^{o}C)
26 July	(34^{o}C)	9 August	(31^{o}C)	6 Sep	(28^{o}C)
27 July	(33^{o}C)	10 August	(28^{o}C)	7 Sep	(29^{o}C)

Table 4.3. Worker Information Participated in Summer

Participants	Age	Work Type	BSL (mg/dl)	BSL Range (mg/dl)	HR (bpm)	HR Range (bpm)	Height (cm)	Weight (kg)	BMI (kg/m^2)	BMI Range (kg/m^2)	Working at Height
Worker 1	45	Formwork	118	60-140	67	60-100	172	84	28.73	25-30	Yes
Worker 2	22	Formwork	82	60-140	71	60-100	173	64	21.4	20-25	Yes
Worker 3	29	Drywall	100	60-140	75	60-100	173	60	20.05	20-25	Yes
Worker 4	24	Drywall	111	60-140	80	60-100	174	78	25.76	25-30	Yes
Worker 5	28	Drywall	111	60-140	85	60-100	178	82	25.9	25-30	Yes
Worker 6	21	Drywall	84	60-140	84	60-100	174	65	21.5	20-25	No
Worker 7	32	Welding	93	60-140	81	60-100	184	78	23	20-25	Yes
Worker 8	45	Welding	96	60-140	80	60-100	174	77	25.4	25-30	Yes
Worker 9	47	Welding	131	60-140	98	60-100	171	89	30.24	¿30	No
Worker 10	20	Welding	124	60-140	82	60-100	174	63	20.8	20-25	Yes

Approximately 130.000 data were collected ST and EDA data, and 32.000 HR data was measured just for one day during eight working hours. Also, 110 BSL values were recorded for one day. In total, 47-day raw data were collected for HR (Figure 4.2) and ST (Figure 4.3), while 26-day raw data were collected for EDA data (Figure 4.4). A total of 35 days of data were collected for BSL (Figure 4.4). In total, approximately 11 million point values were collected on summer days for this study. To present examples from the collected raw data, four different physiological data collected from a worker in one day are shown in the time-series graphs as below (Figure 4.1 - Figure 4.2 - Figure 4.3 - Figure 4.4). All values provided in the figures are raw data and they are not subjected to any pre-processing (filtering, cleaning, or normalizing processes). Besides, all the collected physiological values of each worker are presented in Appendix II.

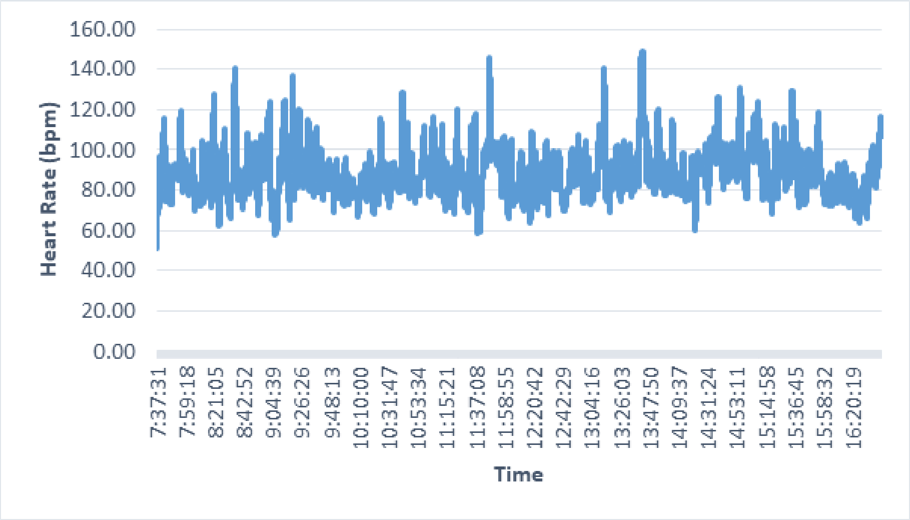


Figure 4.1. Collected Raw Data Sample for HR.

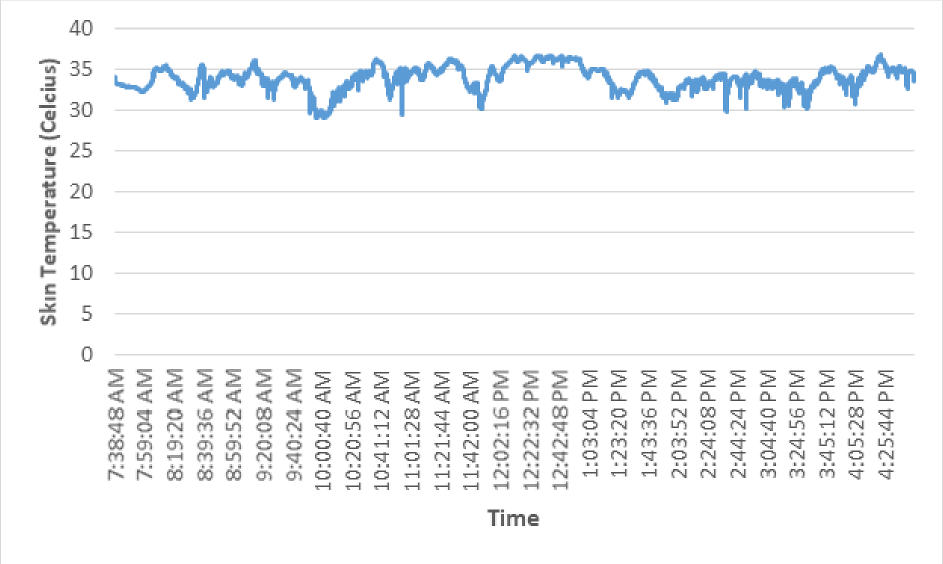


Figure 4.2. Collected Raw Data Sample for ST.

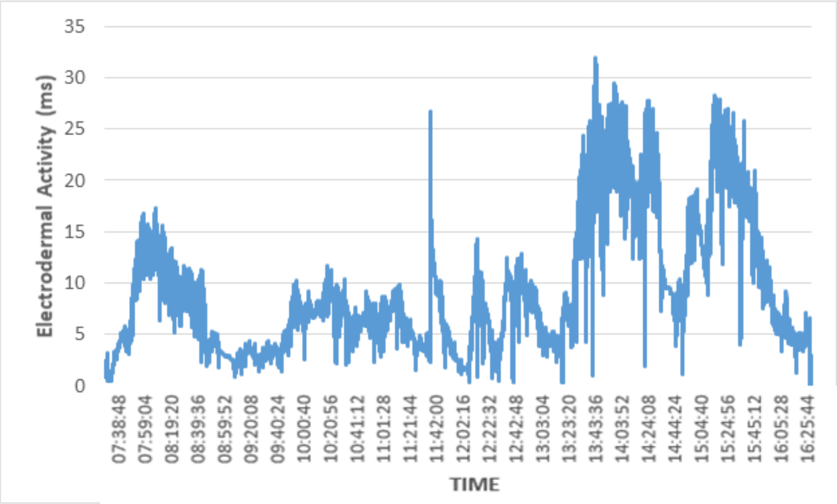


Figure 4.3. Collected Raw Data Sample for EDA.

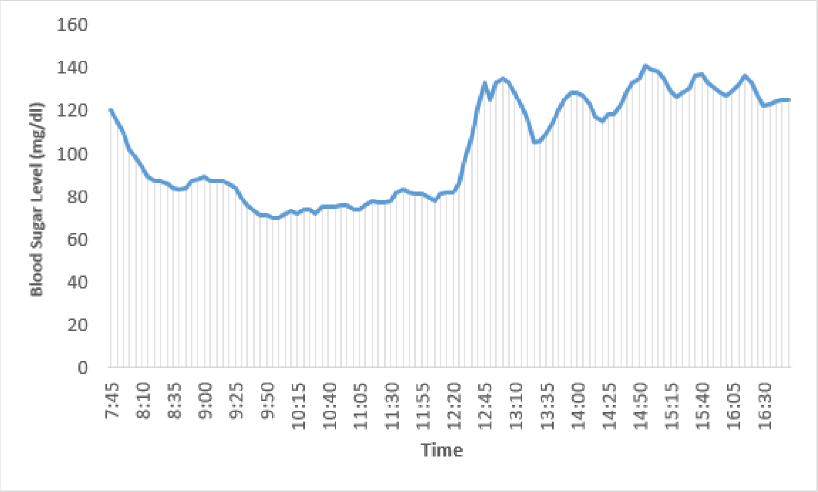


Figure 4.4. Collected Data Sample for BSL.

A total of 44 days EDA data were collected for the winter season (6 January - 29 February 2020). In the winter season, 44 days of HR and ST data were collected via the wristband. In addition, BSL was measured for 56 days. Each of the data was recorded at different frequencies. While HR and ST were recorded with 1 Hz, EDA was recorded with 4 Hz frequency (Table 4.4). The number of collected data in winter days is higher than the collected data on summer days due to the starting time of the data collection process. The Eid al-Adha was in the middle of August was another reason to collect fewer data during the summer season.

Table 4.4. Collected Data Information in Winter Season.

Date	Workers	EDA (4 Hz) (44 Days)						HR (1 Hz) (44 Days)						Temp (4 Hz) (44 Days)						BSL (5 min) (56 Days)					
		Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat	Mon	Tues	Wed	Thur	Fri	Sat
06 Jan - 11 Jan	Worker 1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
13 Jan - 18 Jan	Worker 2	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x		
20 Jan - 25 Jan	Worker 3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
27 Jan - 1 Feb	Worker 4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
3 Feb - 8 Feb	Worker 5	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x
10 Feb - 15 Feb	Worker 6	x	x	x		x		x	x	x		x		x	x	x		x		x	x	x		x	
11 Feb - 15 Feb	Worker 7																			x	x	x	x	x	x
17 Feb - 22 Feb	Worker 8																			x		x	x	x	x
18 Feb - 22 Feb	Worker 9		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
25 Feb - 29 Feb	Worker 10	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	
2 Mar - 6 Mar	Worker 11																			x	x	x	x	x	

Also, the weather temperature data was taken from the General Directorate of Meteorology (GDM, 2020) for winter days when the physiological measurements of the workers were collected (Table 4.5). As can be seen in Table 4.5, the average weather temperature on winter days when the physiological data was collected was approximately 3^{o}C.While the minimum weather temperature was -3^{o}C, the maximum weather temperature was 6^{o}C during the data collection process on winter days.

Table 4.5. Temperature Data on Winter Days.

Time	Temperature	Time	Temperature	Time	Temperature
6 January	(5^{o}C)	27 January	(-3^{o}C)	17 February	(-1^{o}C)
7 January	(6^{o}C)	28 January	(-1^{o}C)	18 February	(-2^{o}C)
8 January	(4^{o}C)	29 January	(0^{o}C)	19 February	(-2^{o}C)
9 January	(4^{o}C)	30 January	(-1^{o}C)	20 February	(2^{o}C)
10 January	(1^{o}C)	31 January	(-4^{o}C)	21 February	(4^{o}C)
11 January	(3^{o}C)	1 February	(-3^{o}C)	22 February	(0^{o}C)
13 January	(-1^{o}C)	3 February	(-1^{o}C)	23 February	(2^{o}C)
14 January	(1^{o}C)	4 February	(2^{o}C)	25 February	(4°C)
15 January	(-1^{o}C)	5 February	(6^{o}C)	26 February	(2^{o}C)
16 January	(-2^{o}C)	6 February	(4^{o}C)	27 February	(2^{o}C)
17 January	(0^{o}C)	7 February	(3^{o}C)	28 February	(3°C)
18 January	(2^{o}C)	8 February	(1^{o}C)	29 February	(-1^{o}C)
20 January	(3^{o}C)	10 February	(0^{o}C)	2 March	(2^{o}C)
21 January	(1^{o}C)	11 February	(0^{o}C)	3 March	(4^{o}C)
22 January	(2^{o}C)	12 February	(3^{o}C)	4 March	(3^{o}C)
23 January	(4^{o}C)	13 February	(1^{o}C)	5 March	(5^{o}C)
24 January	(3^{o}C)	14 February	(4^{o}C)	6 March	(3^{o}C)
25 January	(6^{o}C)	15 February	(1^{o}C)		

The initial BSL and HR values of the workers given before starting work were received from the occupational health specialist of the construction company. According to these data, it is observed that the physiological values of the workers are almost in the range that they should be. At the same time, information about the construction activities of the workers at the construction site is given in Table 4.6. In addition, the height and weight information were used to calculate Body Mass Index (BMI) of the workers, which is an important indicator of the health condition of a human body. As stated before, the BMI value should be lower than 30 kg/m^2, which is a limit value for obesity. While BMI value between 25 and 30 kg/m^2 shows that a person is overweight, between 20 and 25 kg/m^2 corresponds to the normal weight for a person (Nutfall *et al.* 2015). Although a few numbers of workers who participated in this study in the winter season were defined as overweight, BMI of most workers shows that these workers are healthy and eligible to conduct heavy construction tasks.Accordingly, the physiological data were collected from healthy workers whose BMI values between 20 and 30 kg/m^2 in this study.

Table 4.6. Worker Information Participated in Winter.

Participants	Age	Work Type	BSL (mg/dl)	BSL Range (mg/dl)	HR (bpm)	HR Range (bpm)	Height (cm)	Weight (kg)	BMI (kg/m^2)	BMI Range (kg/m^2)	Working at Height
Worker 1	22	Drywall	87	60-140	78	60-100	178	77	24.3	20-25	Yes
Worker 2	23	Drywall	108	60-140	82	60-100	178	74	23.3	20-25	Yes
Worker 3	38	Welding	102	60-140	89	60-100	183	81	24.2	20-25	Yes
Worker 4	33	Welding	98	60-140	78	60-100	170	80	27.7	25-30	Yes
Worker 5	21	Welding	117	60-140	80	60-100	185	94	28.4	25-30	Yes
Worker 6	36	Mason	92	60-140	90	60-100	168	68	24.1	20-25	Yes
Worker 7	42	Elevator	122	60-140	84	60-100	168	74	26.2	25-30	No
Worker 8	46	Elevator	107	60-140	80	60-100	173	86	28.7	25-30	No
Worker 9	53	Welding	111	60-140	75	60-100	168	67	23.7	20-25	Yes
Worker 10	51	Drywall	93	60-140	85	60-100	179	72	22.5	20-25	Yes
Worker 11	45	Plasterer	85	60-140	84	60-100	170	81	28	25-30	Yes

4.2. Analysis Results

In this study, the normality test (Shapiro Wilk test) results of two datasets show that neither construction accidents nor four physiological datasets have normal distributions for both hourly and seasonally since all p-value is less than 0.05 (Table 4.7). Accordingly, the Spearman's Correlation analysis (non-parametric test) was performed between two datasets in this study

Table 4.7. Shapiro Wilk Test Results.

	Hourly	Seasonally
BSL	0.001	0.001
EDA	0.001	0.001
HR	0.001	0.001
ST	0.001	0.001
Accident	0.001	0.001

It was developed four null hypotheses to test the correlation between physiological variables (BSL, EDA, HR, and ST) and construction accidents. Initially, the correlation analysis between construction accidents and physiological variables was conducted on large scale data (Table 4.8). The first hypothesis tests whether there is an hourly significant relationship between the construction accidents and BSL of the workers. According to the correlation analysis between the BSL and construction accidents, a significant relationship was not found (R = -0.32), which provides to reject the first test hypothesis (H_{1-1}). On the other hand, the correlation coefficient is found -0.81 between the BSL and construction accidents for morning working times, which shows the significant inverse relationship between the BSL and construction accidents. However, a similar result is not found between the BSL and accidents in the afternoon (R=0.27). The correlation coefficient between Electrodermal Activity and construction accident is -0.23 with respect to daily working hours.According to the results, since the correlation coefficient is found -0.03, the second hypothesis is rejected (Rejected Hypothesis; H_{1-2}). Thus, it can be concluded that there is not any hourly significant correlation between EDA and construction accident times. Although there is a slight inverse correlation found between EDA and construction accidents at afternoon working times (R=-0.45), this hypothesis can be also rejected for morning working times (R =-0.09). In addition, it can be concluded that the heart rate measurements of the workers do not have any significant relationship with the construction accidents for all working hours (Rejected Hypothesis; H_{1-3}). Similar results were found before and after lunch break in the third hypothesis (H_{1-3}). In the fourth hypothesis, it was aimed to test whether there is a significant hourly correlation between the skin temperatures of the workers and construction accidents. According to the results, since the correlation coefficient is -0.21, it can be evaluated that there is not any hourly significant relationship between the skin temperatures of the workers and construction accidents (Rejected Hypothesis; H_{1-4}). Besides, similar results on skin temperature also were found for morning and afternoon working hours. All the correlation results are significantly reliable because the p-values are less than 0.05.

Table 4.8. Correlation Analysis Results on Large Scale.

		Hourly			Seasonally
		Spearman			Spearman
		AM	PM	ALL	ALL
BSL	Corr. (R)	-0.81	0.27	-0.32	0.02
	p-value	0.001	0.001	0.001	0.13
EDA	Corr. (R)	-0.09	-0.45	-0.23	0.74
	p-value	0.001	0.001	0.001	0.001
HR	Corr. (R)	-0.06	0.02	-0.03	0.57
	p-value	0.001	0.001	0.001	0.001
ST	Corr. (R)	-0.18	-0.32	-0.21	0.78
	p-value	0.001	0.001	0.001	0.001

Along with the correlation analysis between four physiological variables and construction accidents according to working hours, the seasonal impact of such variables on the construction accidents was also evaluated. For this purpose, four different hypotheses were tested separately by using categorical variables 0 and 1. The results show that there are not any significant changes in the BSL values of the workers with respect to the seasons (R = 0.02). Thus, the BSL values of the workers may not have an impact on the construction accidents seasonally and the fifth hypothesis (H_{2-1}) can be rejected.

A significant correlation found between the EDA and construction accidents in terms of seasonally (R = 0.74), which allows accepting hypothesis (H_{2-2}).A similar result was also achieved between the ST variable and accidents with respect to the seasonal correlation analysis (R = 0.78). Also, the correlation between HR values and construction accidents was found significant (R = 0.57). All these findings allow us to accept the hypotheses (H_{2-2}, H_{2-3}, H_{2-4}) that propose a significant relationship between the physiological variables (HR, ST, and EDA) and construction accidents seasonally (Table 4.8). The correlation coefficients found in these analyses performed for seasonally were significant and reliable (p-value < 0.05).

The correlation analysis results on a small scale are almost entirely consistent with the previously stated results achieved from the large scale analysis (Table 4.9). The BSL values of the workers decrease toward lunch break and the number of construction accident increase in the same period. Therefore, the construction accidents are significantly inverse correlated with BSL before lunch break. Also, there is not any hourly correlation found between the physiological variables (EDA, HR, and ST) and the construction accidents at two different seasons.

Table 4.9. Correlation Analysis Results on Small Scale.

		Winter			Summer		
		Hourly			Hourly		
		AM	PM	ALL	AM	PM	ALL
BSL	Corr.	-0.78	0.33	-0.29	-0.75	0.21	-0.34
	p-value	0.001	0.001	0.001	0.001	0.001	0.001
EDA	Corr.	-0.11	-0.25	-0.28	-0.12	-0.35	-0.22
	p-value	0.001	0.001	0.001	0.001	0.001	0.001
HR	Corr.	-0.11	0.09	-0.14	-0.09	0.07	-0.06
	p-value	0.001	0.001	0.001	0.001	0.001	0.001
ST	Corr.	-0.21	-0.18	-0.27	-0.32	-0.11	-0.24
	p-value	0.001	0.001	0.001	0.001	0.001	0.001

5. DISCUSSION

5.1. Discussion of Hypothesis 1 (Hourly Analysis)

In this study, the hourly correlation analysis between the physiological variables and accident times was evaluated before and after lunch break separately. The main reason for this approach is the lunch effect which is emphasized by Lopez *et al.* (2011). Beal and his colleagues (2005) also provided a model to quantify the performance of the employees in a working day. In this model, the lunch break is highlighted since the emotions or behavior of the employees could be significantly different before and after lunch.A few studies (e.g., Kines, 2002; Lopez *et al.* 2011) considered the impact of lunch breaks on construction accidents. Therefore, the hourly correlation analysis between the construction accidents and the physiological variables was performed by considering the lunch effect in this study. According to the findings obtained in this study, there is a significant inverse correlation found between the BSL and construction accidents before lunch break (R = -0.81), and the first hypothesis (H1-1) is accepted for working hour before lunch break. While the number of accidents increases toward noontime, the BSL values of the workers decrease dramatically. At the beginning of the working time, the average BSL values of the workers start above 110 mg/dl due to breakfast. However, these values sometimes decrease under 70 mg/dl toward lunch break, which is the threshold bottom level for BSL in general. Such physiological significant changes are called hypoglycemia that the body sometimes cannot use sugar effectively, which causes burning more sugar than the required level. During hypoglycemia, the sugar level of the body decrease under 70 mg/dl in general (Palatini, 1999). A worker who under hypoglycemia conditions may become fatigued, having low energy levels and attention (Gomke, 1996). The hypoglycemia is significantly related to individual body conditions. When BSL value reduces, the nervous and muscular systems suffer from oxygen deficiency and cannot fully control the human body balance (Cryer *et al.* 1994). A previous study by Almigbal *et al.* (2010) also pointed out that low blood sugar level is one of the three major factors that cause unsafe human behavior during a car driving and results in motor vehicle collisions. Another study on a meta-analysis of BSL effect on human decision making by Orquin and Kurzban (2016) shows that a person who has low BSL is not willing to work and their decisions mostly rely on their intuitive rather than deliberate decision-making process.Garbarino and Magnavita (2015) emphasized that low blood glucose level is also a major indicator for high occupational stress. The obtained correlation analysis results in this study between BSL and construction accident times are consistent with a previous study carried out by Gomke (1996). In that study (Gomke, 1996), the hourly relationship between the BSL and occupational accidents in the surface mining industry was found significant, especially before the lunch break. According to an hourly accident analysis in this study, the pattern of accidents in the Turkish construction industry has similarities with incidents in the construction industry of Spain (Lopez *et al.* 2011) and Iran (Dumrak *et al.* 2013). Huang and Hinze (2003) found the same pattern in the construction accidents which are mostly occurred before and after the lunch break. A previous study result (Gürcanlı and Müngen, 2013) on the accident hours in the Turkish construction industry also consists of the findings of time series analysis results of the construction accidents in this study..On the other hand, the results show that there is not any significant correlation between BSL and construction accidents for all working day, which allows rejecting the null hypothesis H_{1-1}. Such results prove that the lunchtime effect is needed to be considered to evaluate construction accidents. According to hourly analysis, there is not any significant correlation between physiological variables EDA (R =-0.23), HR (R= -0.03), ST (R = -0.21), and accident times before and after the lunch break, and for all working day (Figure 5.1). Such results allow us to reject hypotheses (H_{1-2}- H_{1-3}- H_{1-4}). It is a well-known fact that these physiological variables (EDA, ST, HR) not only depend on the internal body factors but also more related to external conditions such as work type and especially environmental conditions (outdoor or indoor working environment). The weather conditions have more impact on the workers with respect to seasons and the evaluation of its effects may not be observed during a working day. In addition, work type carried out for a long time is another factor that should be considered to understand the impacts of such physiological variables (EDA, HR, and ST). Therefore, the changes in these variables may not be evaluated for hourly distribution on a working day.

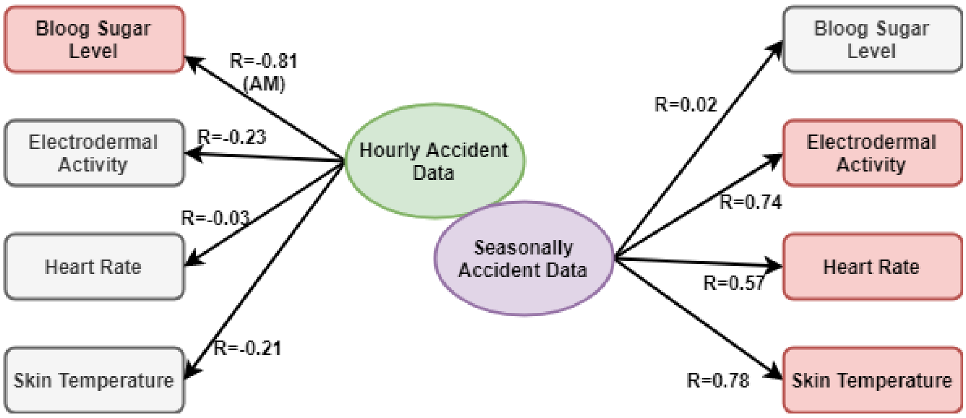


Figure 5.1. Correlation Analysis Results.

5.2. Discussion of Hypothesis 2 (Seasonally Analysis)

According to the seasonal correlation analysis results, the hypothesis H_{2-1} can be rejected since there is not any seasonally significant relationship found between the BSL and construction accidents (R = 0.02). As expected, the BSL values of the workers do not change with respect to the seasons although the number of accidents increases in summer and decreases in winter seasons. The main reason for this situation is that the BSL is highly related to internal body factors rather than external conditions. On the other hand, the physiological variables such as EDA, ST, HR depending on both internal and external factors are significantly correlated with the construction accidents according to the seasonal analysis (Accepting the last three Hypotheses H_{2-2}, H_{2-3}, H_{2-4}) (Figure 5.1). Particularly, EDA (R = 0.74) and ST (R = 0.78) have strong relationship with the construction accidents seasonally. In addition, the HR values of the workers increase on summer days (R = 0.57), which shows a significant correlation between HR and seasonal accident data. Accordingly, it can be concluded that heat stress has a major impact on construction accidents. Heat stress is related to skin temperature, heart rate, sweating, and electrodermal activity of a human body (Yi *et al.* 2016) Thus, all physiological and psychological conditions of a human body are discomforted due to the heat stress during the working time. At summer seasons, as known that the construction projects are fastened due to utilizing better weather conditions. In addition, rough works of construction projects are conducted particularly on summer days, which means that workers are more open to the impact of heat stress.

Several previous studies (Lucas *et al.* 2014; Yi and Chan 2015) also emphasized that working under high temperature causes a high-risk accident for workers in construction sites.It is a well-known fact that the construction workers are under higher heat strain risks than other workers in different industries because of the weather conditions. For this reason, more construction accidents inevitably occur in summer seasons.

In addition to heat stress, performing intensive tasks in construction projects is another crucial factor that causes a high number of occupational accidents. Along with the high-temperature effects, construction tasks require high physical demand and excessive energy expenditure. A previous study (Jebelli *et al.* 2019a) concluded that physiological variables HR and ST are good indicators to understand the physical fatigue of the workers in construction sites. According to the results obtained in this thesis research, there is a high correlation between HR and ST variables and construction accidents seasonally. When all these aspects are taken into consideration, the correlation analysis results show that the physical fatigue of the construction workers also increases on summer days with respect to the winter seasons due to heavy workload. Along with the physical fatigue, the mental stress which can be measured by EDA physiological signals (Choi *et al.* 2019) increases with high temperature and intensive tasks on summer days. Gerett *et al.* (2013) proved that electrodermal activities are increased because of high-level stress, which deteriorates the metabolic system of the body. In addition, cardiac activities also are a better predictor for the emotional stress of the workers according to a previous study (Jebelli *et al.* 2019a). When all such conclusions from previous studies taken into account, high-level stress measured by HR, ST, and EDA signals in this study could be a crucial reason for the high number of accidents in construction sites, especially on summer days. Such seasonal factors on construction accidents were also found in the number of previous studies (Yi and Chan, 2013; Lin and Chan 2009; Varghese *et al.* 2018). In summary, working under high temperature, humid environment, and carrying out intensive construction tasks that require high physical demand, and mental stress come together on summer days and have major effects on construction accidents. In other words, both internal body parameters and external environmental conditions could play a crucial role in construction accidents especially occurring at summers.

5.3. Recommendations

The correlation analysis results show that construction sites have complex and difficult working conditions for workers in terms of physiological and physical factors. Individual (physiological and psychological variables) and environmental factors (weather conditions, intensive tasks) are related to each other and lead to construction accidents together. However, it is possible to prevent or reduce such incident cases by providing basic preventive measures. One of the main contributions of this study is to suggest such preventive strategies to be implemented in construction sites.

(i) Efficient Work-Rest Cycle and Refreshment: According to hourly correlation analysis between BSL and construction accidents, the BSL could have a major role in the accidents occurring before lunch break. In addition, a result of the survey conducted with workers in a previous study (Lopez *et al.* 2011) shows that workers feel more tired themselves after immediately lunch break. All these conditions could be related to low blood sugar levels (hypoglycemia) before the lunch break and high blood sugar levels after the lunch break. To weaken such effects of BSL on the workers, a 15 minutes rest can be arranged for workers at 9:30 am refreshments that can be provided to keep the blood sugar level stable. Also, after lunch break 30 minutes can be given only for a rest to weaken the feeling of tiredness due to high BSL. According to previous study results (Quintiliani *et al.* 2010), the supplement of refreshment at construction workplaces are effective to regulate their dietary patterns, blood sugar levels and increase the safety performances of the workers. Therefore, refreshments can be provided instead of heavy desserts at meals and short breaks. Another important crucial factor is breakfast. Diet patterns of the workers especially before performing construction activities in morning times should be regulated by providing healthy breakfast meals. In that way, hypoglycemia influences on the workers can be weakened especially between 10 am and 12 am before lunch break. Also, the glucose level of the workers can be sustained in a range that should be in the same time interval. In that point, providing protein-based nutrition is important. This diet should be regulated by dieticians since meals containing protein, carbohydrates, and sugar that have to be in balance (Quintiliani *et al.* 2010),. Besides, while construction workers take a short break at the mid-morning time in the Spanish (Lopez *et al.* 2011) and US construction sectors (Jebelli et al 2019b), workers in the Turkish construction sector do not have such a rest. Such short breaks are also necessary to reduce the influences of physical fatigue and mental stress (Figure 5.2a). A previous study (Yi and Chan, 2013) concluded that the optimal rest is 15 minutes after working 120 minutes in construction sites. Therefore, approximately 80% of the human body regenerates or recovers itself (Yi and Chan, 2013). Also, this kind of short rest, 15 minutes, can be mandatory at afternoon working time around 3 pm for construction workers (Figure 5.2b).

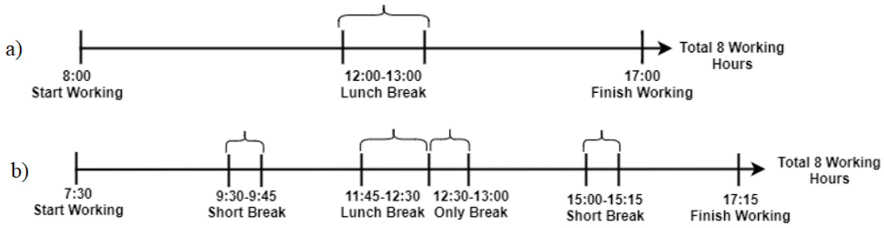


Figure 5.2. a) Usual Daily Work Shift in the Turkish Construction Industry, b) Suggested Daily Work Shift for the Turkish Construction Industry.

Accordingly, the physical workload can be also distributed to all working hours and reduce its effects on the human body. This type of work-rest cycle application is especially necessary for summer days to weaken the effects of heat stress on the workers. Therefore, all the physiological risks for workers (BSL, EDA, HR, and ST) can be eliminated by providing short breaks, which has considerable potential to reduce construction accidents.

These recommendations on short breaks were also asked to the administration of the project company to get their opinions and comments. The comments on the short break are that such breaks influence the progress of the construction activities considerably. In addition, it could be difficult for workers to return and focus on construction activities after periodical short breaks. Especially, these returns from breaks could arise new issues between laborers and site managers. Providing more short breaks influences the project process in terms of time and cost-efficiency. Refreshments bring additional costs for the project budget. In addition, extending working hours due to short breaks could have an impact on the project schedules. Also, the time of the construction activities should be planned according to short break times. This kind of arrangement on the project schedules could make it difficult or complicate the time planning of the projects. Therefore, periodical short breaks could bring new cost and project management issues in terms of time and cost during the construction phases. On the other hand, the productivity of the workers will be increased and the physical fatigue due to heavy workload can be declined via short breaks and refreshments, which are important for the project management field. In addition, the workers could be satisfied with these breaks, which have the potential to increase the motivation and productivity of the workers in construction sites. The main target of providing short breaks is to decrease construction accidents. Accordingly, the direct and indirect costs and time overruns because of construction accidents could be crucially decreased. In addition, conflicts between laborers and construction companies can be eliminated These advantages rather than the cost burden of the short breaks should be considered in the design and planning phases of the construction projects by the administrations.

In addition, providing refreshments and short breaks should be discussed with all parties in the Turkish construction industr and government. Potential advantages and disadvantages should be negotiated between parties to provide optimum solutions for these recommendations. Agreement between parties such as labor unions, company atives representatives , NGOs, and governments will make it easy to implementations of these suggestions in the construction industry.

(ii) Heat Stress Management: Along with the efficient work-rest schedule, different solutions can be provided to manage the heat stress of the workers. In a previous study (Montezar *et al.* 2013), it is emphasized that dehydration issues of the workers have to be considered while they are working under high temperature (Figure 5.3). To cope with the dehydration problems, it is highly recommended provision of cool drinking water, air ventilation at different local points, and indoor places for rests in construction sites (Morioka *et al.* 2006).In addition, the construction tasks demanding heavy workloads such as ironwork, carpenter works, brickwork, plastering, and concrete pouring can be scheduled in the morning or mid-afternoon times, when the weather is mild.Therefore, the adverse heat stress impacts can be decreased and the workers carry out the heavy tasks in safer working conditions on summer days.

Another way to overcome the heat stress effects, the older workers should be given more attention in the construction sites. According to the results of a previous study (Marsza-ek *et al.* 2005), since older people have a low resistance to high temperatures, older workers are under more heat stress risks than younger during summer seasons. With heat stress, various morbidities such as hypertension, excessive physical fatigue, and high blood volume pressure are inevitable among elder workers. For this reason, the work shift of the older workers has to be scheduled with respect to their physical and physiological conditions, especially during summer seasons in construction sites. Also, the health measurements of such elder workers have to be done more detail and periodically.

(iii) Early Warning System: To provide a novel preventive solution on the physiological risks, the early warning system can be developed for construction workers and used in construction sites (Figure 5.3). For this purpose, Yi *et al.* (2016) introduced an early warning system for the construction workers to prevent them from heat stress. The authors (Yi *et al.* 2016) stated that such a tracking system provides opportunities for protective interventions when the health alert message is received before the occurrence of construction accidents.By using a smart wristband, position tracking sensors, and smartphone application, real-time physiological variables (BSL, EDA, HR, and ST) of the workers could be easily monitored by safety and occupational health managers in construction workplaces. Developing and using such real-time monitoring systems on physiological variables enable more safety construction workplaces and have a crucial potential to reduce construction accidents.

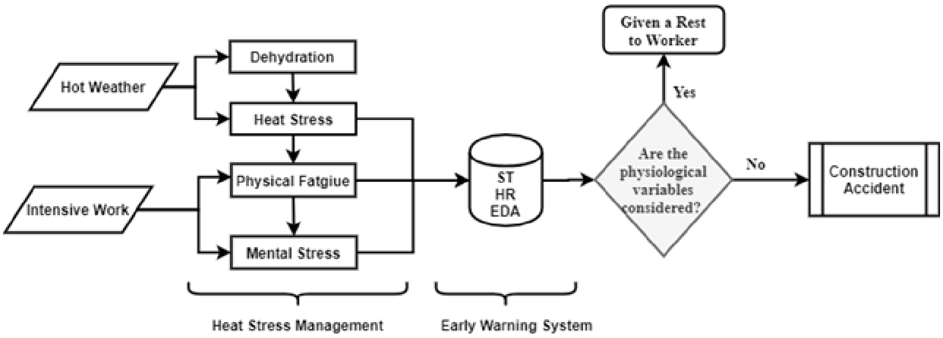


Figure 5.3. Accident Cause-Effect Relations at Summer Season.

(iv) Lean Construction: In order to increase the quality of project management organizations during the construction project, lean thinking was introduced to the AEC industry in the early 1990s (Senaratne and Wijesiri, 2008). The introduction of lean thinking to the construction industry was defined as Lean Construction. The lean construction is identified as a manufacturing management system adopted for unique construction projects to improve the efficiency of the construction process (Salem et al 2006). The main objective of implementing the lean construction method is to decrease cost and time overruns and increase profit within quality works. Recently, the lean construction methods have been suggested in different studies (Li *et al.* 2011; Thomassen *et al.* 2003; Ogunbiyi *et al.* 2014) since such a novel approach provides various advantages such as cost and time efficiency, and moreproductive process during constructionactivities.Therefore, the lean construction method including prefabricated construction components minimizes the outdoor activities in construction sites, and so the impact of outdoor conditions especially hot or cold weather can be reduced significantly.Accordingly, the workers could be less influenced by environmental conditions. It is also emphasized that the lean construction methods decrease heavy workload and prevent physical fatigue of the workers effectively (Thomassen *et al.* 2003). Li *et al.* (2011) point out that lean construction methods have major potentials to increase safety, cost, and time efficiency of the construction projects.Especially, the productivity and motivation of the workers could increase by reducing heavy workload due to implementing lean construction methods. Also, Ogunbiyi *et al.* (2014) stated that lean construction methods provide more sustainable construction workplaces in terms of occupational safety and health. In general, lean construction aims to improve the process of construction activities for different perspectives, which has diverse contributions to the construction safety area.

(v) BIM technologies: In addition to the lean construction approach, Building Information Management (BIM) technology is another solution to reduce construction accidents. BIM is an information technology-based model that provides all details of the project process such as architecture, engineering, and construction implementations during the lifecycle of the projects. BIM enables project administration to achieve more efficient schedules, design, construct, and manage construction projects. Planning of the tasks and conducting activities inefficient organization are main advantages of the BIM technologies A number of studies (Zhang *et al.* 2015; Zhang *et al.* 2013; Kiviniemi *et al.* 2011) introduced BIM-based safety management tools and proved that such tools have major contributions to site occupational safety. With the usage of BIM, construction tasks can be planned and carried out effectively. BIM plays a crucial role in the application of the construction works effectively. Scheduling construction activities requiring intensive performance is crucial to decrease the complexity of the construction process and decline heavy workloads on the construction workers. The most important point is that the usage of BIM has major potentials to decrease physical workloads on the construction workers due to providing organized workplaces and planning complex activities in a precise way. Therefore, the construction accidents that occurred due to the physical fatigue of the workers can be reduced significantly.Also, hazard identification modules and preventive measures by using 4D technologies can be integrated into the BIM. For instance, an automated hazard safety platform on fall protection was developed and integrated into commercial BIM tools by Zhang *et al.* (2015). The authors (Zhang *et al.* 2015) highlighted that early hazard detection systems have crucial potentials to warn construction workers and prevent accidents. According to the report of Kiviniemi et al (2011), BIM technologies have been also considered for site safety planning with the scheduling of the construction activities by the global construction companies. Therefore, safety site planning components should be significantly considered by all construction players.All these factors could have considerable potential to reduce the site dangers and physical demands of the workers.

According to the results of the survey conducted with medical and on-site doctors, they indicated that a short break in the middle of morning times should be given. During these breaks, refreshments can be provided to the workers. Therefore, the effects of hypoglycemia on the workers can be reduced. Also, the medical doctors emphasized that such short breaks are necessary to decrease the heat stress impacts on the workers, especially on summer days. These recommendations are consistent with previous studies and given suggestions in this study.

5.4. Real-Time Data Collection Difficulties in Construction Sites

Due to the dynamic conditions of the construction sites, it was not easy to collect real-time physiological data in this study. Firstly, the construction working environments are highly open the outdoor weather conditions. Besides, most of the construction workers carry out an intensive task and under heat stress on summer days. All of these conditions cause diverse difficulties in data collection. Based on these conditions, one of the wristbands was oxidized at the beginning of the data collection process. The EDA data could not be collected by the failed wristband. Also, the collected physiological data was significantly noisy and had to be cleaned accurately. Therefore, different filtering and cleaning methods were implemented. The sensors used to collect BSL of the workers sometimes were detached due to sweating. In that time, the injection process of a new sensor has to be started from the beginning, which caused the sensor and time-wasting considerably. Another problem encountered during data collection was the absence of the workers at the construction site. The data could not be collected efficiently all day of the week since workers sometimes did not come to the workplace for certain reasons (health, family, etc.). For this reason, it was not possible to collect data continuously from some workers for 6 days a week. Apart from that, after participating in the data collection process, only two workers stopped measuring their physiological values in the middle of the study. The collected data from these workers were not included in the analysis and completely erased. The data collection process continued by finding other workers instead of these two workers. There were not any problems encountered with other workers during the data collection process.

Due to the injection of the BSL measurement sensor under the skin, some of the workers rejected to participate in this research. The injection process sometimes caused difficulties in finding a worker to participate in this study voluntarily.

5.5. Unique Aspect and Impact of the Research

This research was grounded on the hypothesis development strategy to test the correlation between the physiological measurements (Heart Rate (HR), Skin Temperature (ST), Blood Sugar Level (BSL) and Electrodermal Activity (EDA)) and accident times (hour of the day and season of the year). It is necessary to answer the questions of when and how the physiological factors could play a role in the construction accidents quantitatively. In other words, this research is attempted to examine how these human body internal indicators (HR, ST, BSL, and EDA) change during the time (hour of the day and month of the year). However, there is a gap in the literature in exploring the direct association between construction accidents and physiological variables. Diverse studies have focused on the changes in the physiological values of the workers when they conduct construction activities.Another unique feature of this research is a monitoring real-time BSL of the workers in the real construction site, which could be the first study in the construction safety area. In this study, the required sample size according to statistical analysis was calculated with respect to the Power Analysis. The sample size in previous studies related to physiological variables was not estimated quantitatively. In addition, a correlation analysis framework between countable accident data and time-series physiological measurements was developed and introduced in this study. Besides, several suggestions such as short breaks, early warning systems, refreshments, novel construction implementation methods are introduced. These recommendations are also given in a precaution model generated for the construction industry.

One of the main contributions and unique impact of this study is introducing a model that shows the general associations between construction accidents and root cause factors. In special, this model is an illustration of the relationship between human factors and the time of construction accidents. The developed model consists of four main different parts i) list of attributes, ii) attribute selection, iii) research design and iv) preventive measures (Figure 5.4). In the first part of this model, the list of attributes including construction accident parameters and root cause factors of the accidents are given. Most of the studies (Gürcanlı and Müngen 2013, Haslam *et al.* 2006, Abdelhamid and Everett, 2002) attempted to understand the root cause factors of construction accidents according to diverse attributes. However, the point of departure is to assess relations between construction accidents and physiological risk factors with respect to time patterns of these attributes in this study. Therefore, the attributes which are the time of the construction accidents and physiological indicators were selected and included in the second part of the model. The physiological variables are major indicators to evaluate human body strains such as fatigue, anxiety, emotion, attention, heat stress, and mental stress. In the third part, different physiological indicators (i.e., HR, BSL, EDA, and ST) are included in the research design part to understand the role of the body strains in construction accidents. Besides, since the construction accidents have a distinct hourly and seasonal pattern, the associations between construction accident and physiological variables are evaluated according to these time distributions. In addition, three different time intervals (i.e., before and after the lunch break, whole working day) in the hourly analysis are considered in the third section of the model as the lunch break changes the human physiology significantly. The main target of this part is how human body strains have an impact on construction accidents by observing physiological indicators. According to the obtained results, the preventive measures are provided in the last section of the model to decrease hourly and seasonal adverse effects of body strain on the construction workers. In the preventive measures part, advanced technologies (i.e., BIM technologies and early warning systems) and practical implementations (e.g., short breaks, drinking water points, refreshments, and lean construction methods) are included.

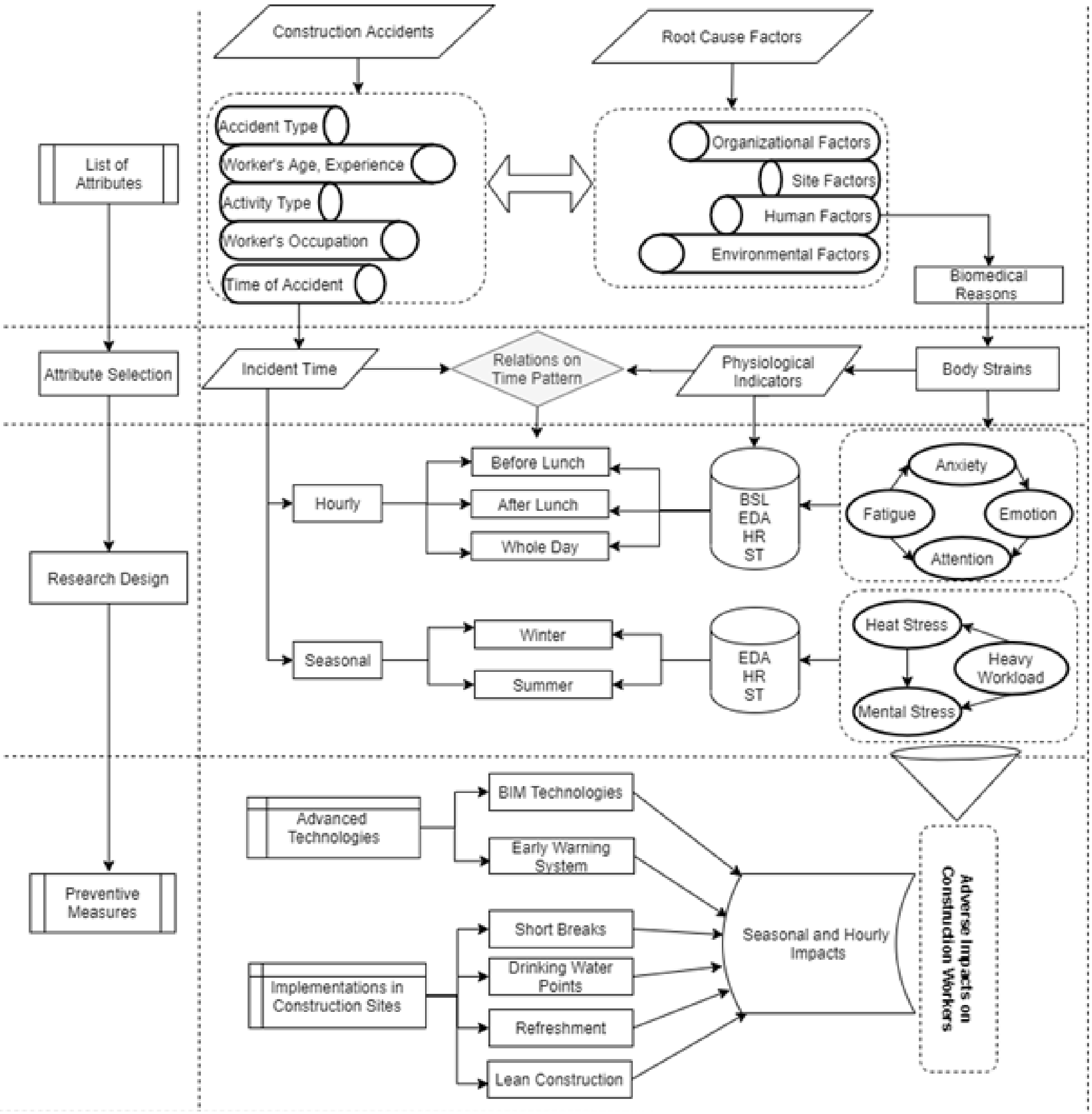


Figure 5.4. Developed Research Model.

Reducing or preventing construction accidents by implementing these practices have also major benefits for the legal costs. The occupational accidents significantly increase costs of litigation, court costs, costs of counsel, discovery, experts, settlement, and investigation. Thus, it is important to consider these suggestions to decrease legal costs arising due to occupational incident events. Besides, conflicts between parties (i.e., labor unions and construction companies) can be eliminated considerably by reducing accidents with provided recommendations. Decreasing accidents enable construction companies to reduce cost and time efficiency on the project process. The construction activities can be carried out in a precise way. The productivity of the construction workers could be significantly increased in safe construction workplaces. All these benefits are related to social well-being and have major impacts on the social and financial components.

In addition, this study provides to understand the pattern of construction accidents for the perspective of the physiological variables. When only the pattern of the construction accidents taken into account, it is impossible to understand and find root cause factors of these incidents. However, implementing seasonal and hourly correlation analysis between construction accidents and physiological variables give opportunities to evaluate and understand the time pattern of the accidents in one window. Although there are a number of reasons factors for construction accidents, this study has the potentials to explain and understand the reasons for the construction accidents quantitatively. All these aspects stated above can be unique properties of this research.

5.6. Limitations and Future Study

With the crucial contributions of this study, there are also a few limitations that exist. Although the sample size or the number of workers is required to be at least sixteen (16) according to Power Analysis, 21 construction workers participated in this study. However, more workers can be invited to study to collect physiological data. Furthermore, the datasets (construction accidents and physiological measurements) in this research were only gathered from the Turkish construction industry. Therefore, the obtained results from this research may not be generalized and the findings and suggested recommendations might be different for different locations. Besides, the measurement of the physiological variables can be extended to all months to gather more reliable data at different seasons. However, due to the time limit of the project, it could be done for future study. One of the most crucial parameters is the activity type performedby the workers during the physiological data collection process. This factor should be also included to understand the physical workload and mental stress of the workers in a precise way. During physiological data collection, the activities carried out by construction workers can be recorded via video camera. Therefore, physiological changes could be accurately assessed. Another important limitation is that the psychological and living conditions of the workers (sleep quality, working time, tobacco usage, income level, working, and accommodation conditions) can be included to understand physiological risk factors in a more precise way. Besides, the diet patterns of the workers especially what kind of breakfast they had should be asked before physiological data collection on each day in the morning. It is a well-known fact that breakfast has major impacts on human physiology (i.e, BSL, EDA, ST, and HR). Thus, the hourly changes in the physiological variables of the construction workers can be precisely evaluated.At that point, the decreases in BSL values of the workers toward noontime should be assessed and understood in detail. Such variables were collected via surveys, but not included in the analysis since the main objective of this project is to observe a correlation between the physiological risk factors and construction accidents. All stated limitations of this research have the potential to be studied in future studies.

6. CONCLUSION

It is a well-known fact that construction activities pose high risks to workers due to the complex and dynamic conditions of the construction workplaces. To find the root causes of occupational accidents in construction sites, a number of studies have focused on diverse factors such as company size, accident time, accident type, age, and experience of the workers, location, etc. On the other hand, some previous research was conducted to understand the impact of the physiological and physical variables on the construction workers during working time. It is widely believed that such monitored human body factors play a crucial role in construction accidents because of leading physical fatigue and mental stress on the workers.Although such physiological stress could inevitably cause accidents in construction sites, a direct relationship between the accidents and human physiological factors is needed to be studied quantitatively. For this purpose, the relevant hypotheses were developed to test the correlation between the physiological variables and construction accidents. In total, eight different hypotheses were developed between the physiological variables and construction accidents with respect to seasons and working hours.

The real-time physiological variables were collected from a total of 21 workers at two different seasons in the construction site. While ten of the workers participated in this research in the summer season, the rest of them participated voluntarily in the winter season. The physiological variables were collected during a week (from Monday to Sunday; 6 days) from each worker. The data collection process was started at 8 am and finished at 5 pm for each day. Although workers whose physiological variables collected in this research carried out different construction activities, most of them were using scaffold or working at height. This is another objective of this study to collect data from workers who are under more accident risks. About 26 million points of the real-time physiological values were collected from the construction workers in the construction site. A total of 91 days BSL, HR, and ST data were collected from the workers. Also, EDA data was collected in 73 days in total, which is less than other physiological variables due to the oxidation issue (Table 4.1 - Table 4.3). The physiological values were monitored in different frequencies; HR (1 Hz), EDA and ST (4 Hz), and BSL (per 5 minutes). The HR, EDA, and ST were resampled to 1 minute to study at the same time interval.

The demographic information of the workers such as weight, height, age, work experience, and which construction task they conduct were gathered from the workers. In addition to demographic information, HR and BSL values they gave before starting to work at the construction site were received from the construction company upon permission of the workers.. The physiologicalvalues of the workers as health indicators such as BSL, HR, weight, and height informationwere received. In this study, all these values were used to understand whether the workers whose physiological data were collected were healthy. BMI, BSL, and HR ranges were utilized to evaluate the body health conditions of the workers. The evaluation results show that most of the workers who participated in this research meet the health criteria, which is another objective of this study. During the data collection process, there were not any accidents or health issues that were encountered among the workers. This is the most important point of this study. Only one wristband failed due to the oxidization problem at the beginning of the data collection process. Therefore, the EDA data could not be collected by a failed wristband and had to continue with another wristband. On the other hand, BSL measurement devices completed the data collection process without any issue.

Historical construction accident data was received from Social Security Insurance (SSI) established in Turkey. The SSI has collected all the accident information (age, location, time, work experience of the workers, company size, etc.) based on the ESAW methodology since 2013. ESAW methodology is a compulsory data collection system that is required from EU or EU candidate countries. ESAW data collection system provides considerably reliable information about the accidents seen in all industries. Although SSI provided time information of the construction accidents between 2010 and 2018 years, the accidents recorded since 2013 was included the analysis process in this study. Accordingly, time information of 199.817 construction accidents was considered.

The hourly and seasonally correlation analysis between the accident times and real-time monitored four physiological variables (EDA, HR, BSL, and ST) were performed in this study. Based on the research questions, related hypotheses were developed and tested by Spearman's Correlation analysis method. To perform correlation analysis, the datasets had to be prepared and modeled in different ways. Firstly, since the physiological data were collected at the real construction site, it was inevitable that these physiological signals were noisy. During the data collection process, the physiological values are corrupted due to site dynamic conditions such as body movements, environmental factors, sensor movements, and sweating. Noisy signals have to be removed and cleaned from the original data to make a more reliable assessment. For this purpose, different filtering methods (e.g., Hampel, low-pass, high-pass) were implemented to remove the artifacts from the original measurements. At the end of the data preparation, there were two variables; one of them was countable accident data and another one was time-series physiological values.To perform the correlation analysis, it is required that the values of two different variables correspond to each other and have to be the same length. However, the variables in this study did not meet these criteria and it was not easy to perform correlation analysis between one countable data (accident time) and time-series physiological measurements. To overcome this issue, the ratio was firstly assigned to each accident with respect to its occurrence time. Thus, each countable accident data was converted to time-series data. At this point, although there were two time-series variables, the time intervals of these variables were different. Then, all time-series data were converted to categorical variables. For instance, an accident or measured physiological variable between 8 and 9 am was categorized as 8. Therefore, it was achieved two categorical variables within values. Also, since the values had different ranges (e.g., BSL between 60 and 140 mg/dl and accidents had ratio values), all of them were between -2 and +2. After this point, they only needed to be at the same length to perform the correlation analysis. To overcome the length issue, the interpolation method was implemented to accident data, and thus all categorical variables were converted to the same length. Then, the normality test was applied to understand whether data were normally distributed before correlation analysis.According to normality test results, all of the variables did not fit the normal distribution. Therefore, Spearman's Correlation analysis (non-parametric correlation method) was performed between the standardized values computed for construction accidents and physiological measurements. To validate the results, the correlation analysis was also conducted on a small scale. Small scale analysis represents the correlation between the collected physiological variables and the construction accidents occurring at the same time interval with the collected data. In other words, construction accidents only occurred in summer, and winter days were considered and included in the small scale analysis process.

The results of this study show that the construction accidents are significantly inverse correlated with BSL of the workers at morning hours (before lunch). While the construction accidents start to increase at mid-morning times, the BSL of the workers significantly decreases, which shows the inverse and significant relation between the accident and BSL. The small scale analysis results are consistent with the general analysis approach, which shows the reliability of the analysis methods. On the other hand, there is a significant correlation between the physiological variables (HR, EDA, ST) and construction accidents seasonally. In other words, the physiological variables could have adverse impacts on construction accidents with respect to the season. These physiological variables (HR, EDA, ST) significantly increase on summer days with respect to the winter season. To overcome such issues induced by the high temperature during the summer season, the efficient work-rest cycle should be implemented in the construction sites. More short breaks can be provided to construction workers during a day. Besides, such breaks enable us to prevent and manage heat stress in summer seasons. Another important suggestion is that drinking water points and air ventilation should be located at different places in construction sites especially on summer days. Lean construction methods and Building Information Management (BIM) technologies should be widely implemented in the construction project, which could have a major role to reduce construction accidents. Such advanced technological methods should be integrated with the safety management systems. Moreover, the physiological variables of the workers can be tracked via a real-time monitoring system.Therefore, a worker who is under physiological stress (e.g., high blood pressure and body temperature, low blood sugar level, physical fatigue) can be reported via alert messages to safety or occupational health managers. Such preventive recommendations are simple and easy to implement and could have serious potential to reduce construction accidents. Besides, the implementation of these suggestions provides healthier and safer construction workplaces considerably.

All these recommendations and implementations could provide theoretical and practical benefits to the construction safety area. On the practical side, such preventive applications have the potentials to reduce construction accidents. Decreasing the number of incident cases reduces conflicts between all construction (i.e., labor unions, construction companies) and government parties (e.g., ministries and official institutions). Achieving more safety construction workplaces influences the progress of construction activities effectively. Especially, time delays and cost expenditures due to occupational accidents in the construction projects could be reduced with these measures. Also, the health and leg costs of the government will decrease due to occupational accidents. These applications have also potential to reduce social and financial problems arising because of construction accidents. It is a well-known fact such occupational accidents significantly influence workers life and their family. These impacts on society could be also eliminated with these recommendations.

In addition, this research has diverse theoretical contributions to the construction safety field. The first one is examining the correlation between the physiological variables and construction accidents in a quantitative way. Accordingly, it is possible to understand the relationship between the construction accidents and physiological indicators of the workers with respect to different time variables. The second contribution of this study is introducing a new analysis model to be performed between countable accident and time-series physiological data. This model also shows the relations between human factors, human body strains, biometric factors, and construction accident in the big picture.This research also identif the effects of the physiological factors on the accidents based on the hourly and seasonal analysis. The crucial physiological variables which could play roles in construction accidents were defined for different time perspectives. This study shows that such real-time physiological variables can be measured and assessed to understand the reasons for construction accidents from a different perspective. Another crucial contribution of this study is highlighting the importance of the BSL values especially before the lunch break and EDA, ST, and HR values on summer days. Therefore, these findings could be an important guideline for the ruler and administrations in the construction industry.

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APPENDIX A: PARTICIPANT SURVEY

General Information

(i) Age:
(ii) Sex:
(iii) Height:
(iv) Iight:
(v) How many years that you have been working in construction site?
(vi) Have you ever been received an occupational safety training?

Information Related to Occupation and Health

(vii) Information Related to Occupation and Health
(viii) Do you have any chronic health problems? If yes, please write them.
(ix) Is there any medicine you take regularly? If yes, please write them.
(x) Have you ever encountered any occupational accidents at the construction site? If you have, give detailed information about the accident.

Table A.1. How many hours.

	1-3 hours	**3-5 hours**	**5-7 hours**	**7-9 hours**	**9-11 hours**
How many hours do you sleep on average per day?					
How many hours do you work on average per day?					
	1- Never	**2- Rarely**	**3-Sometimes**	**4- Often**	**5- Always**
Do you smoke?					
Do you drink alcohol or other tobacco?					
Do you do sports?					
Do you have acrophobia?					
Do you work faster when you have a limited time					
Do you have a fear of having an accident while working?					

APPENDIX B: COLLECTED PHYSIOLOGICAL DATA OF EACH WORKERS

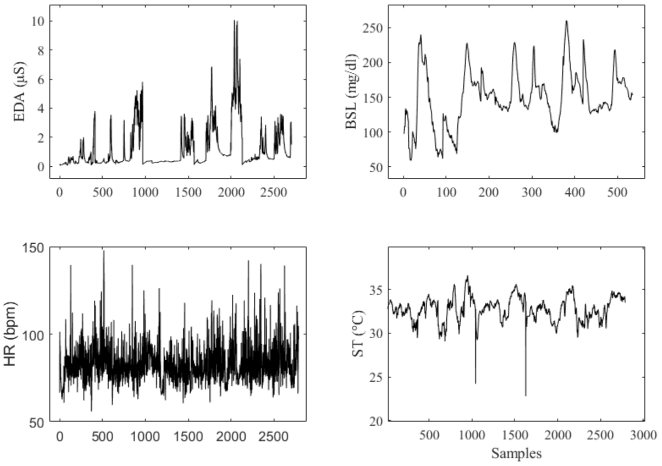


Figure B.1. Worker 1.

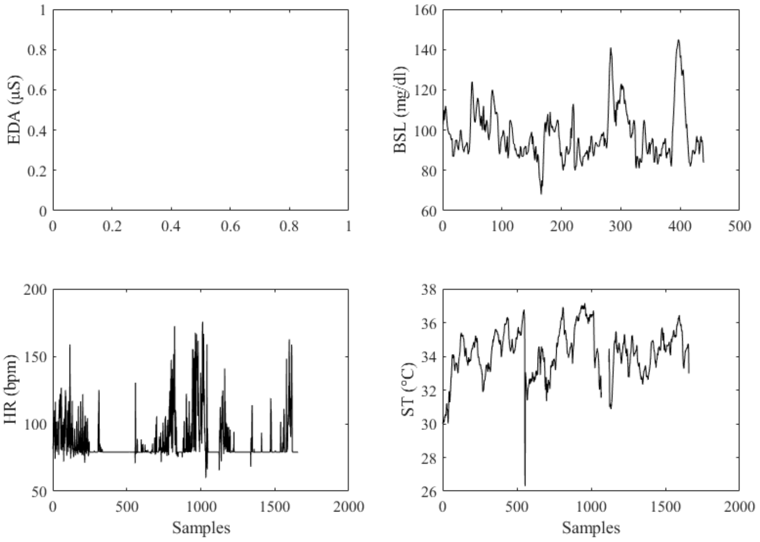


Figure B.2. Worker 2.

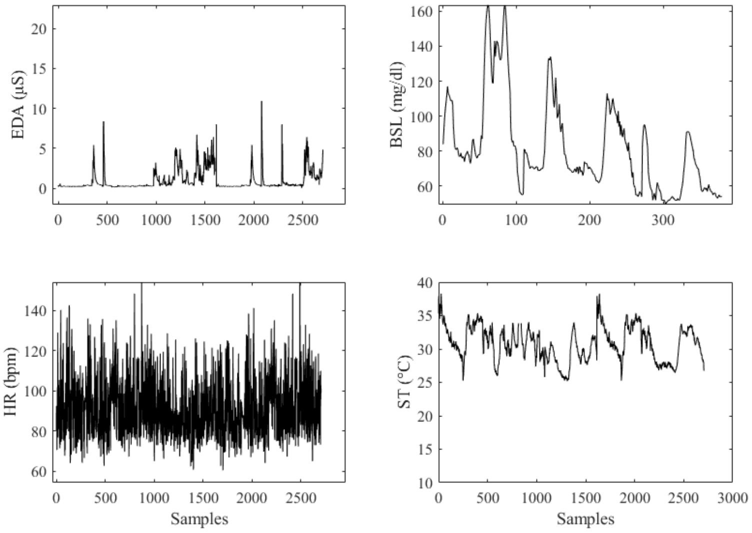


Figure B.3. Worker 3.

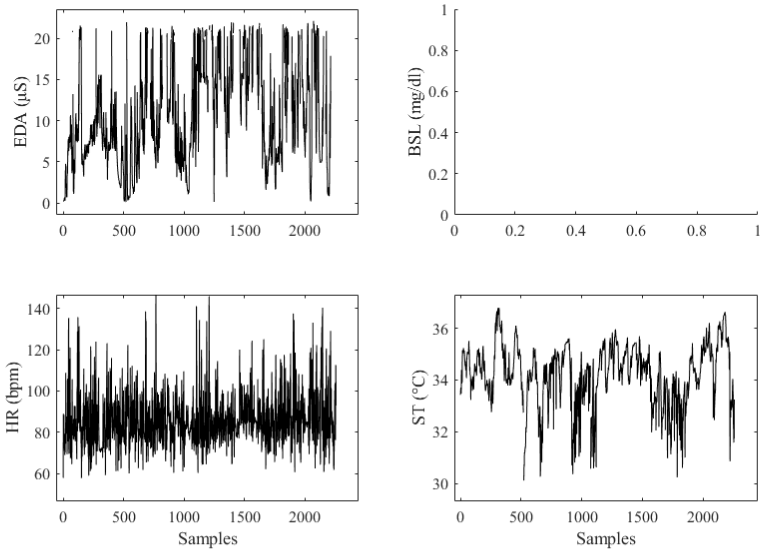


Figure B.4. Worker 4.

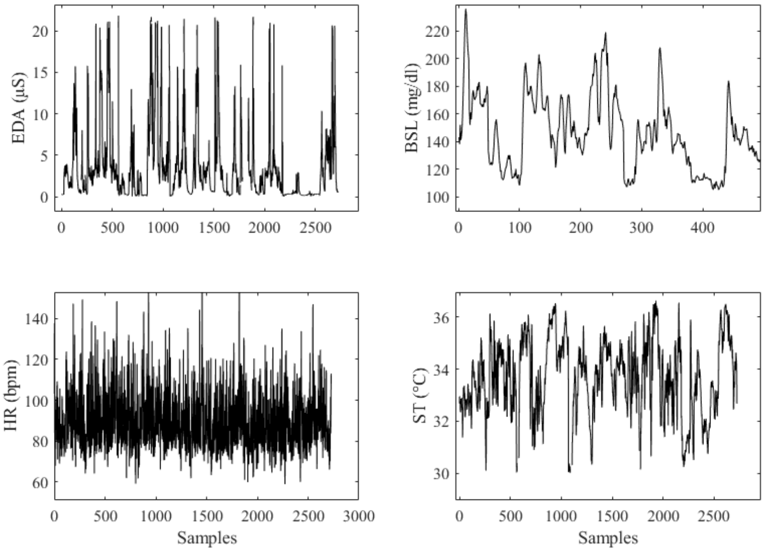


Figure B.5. Worker 5.

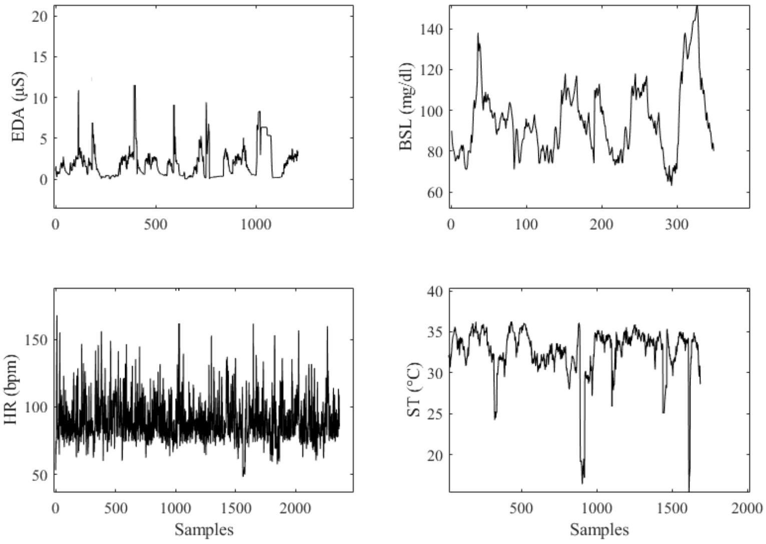


Figure B.6. Worker 6.

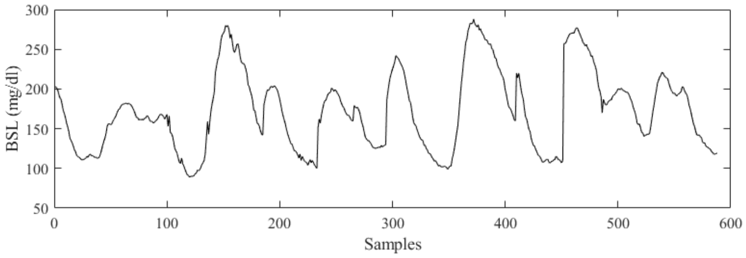


Figure B.7. Worker 7.

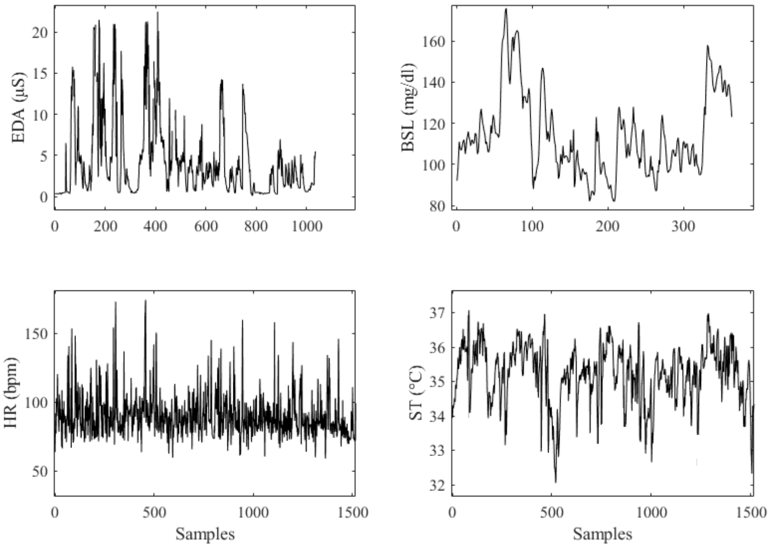


Figure B.8. Worker 8.

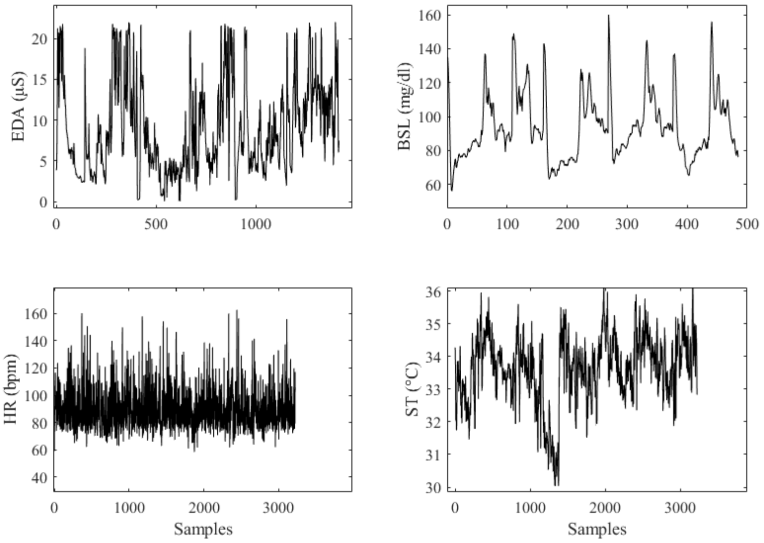


Figure B.9. Worker 9.

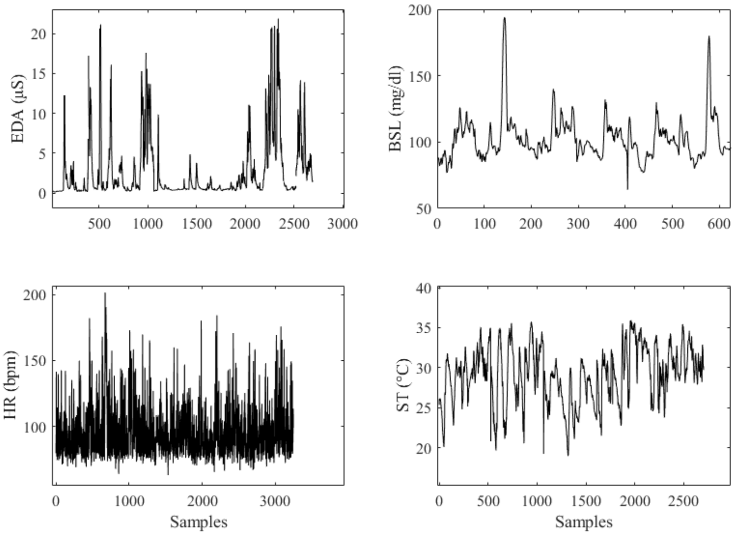


Figure B.10. Worker 10.

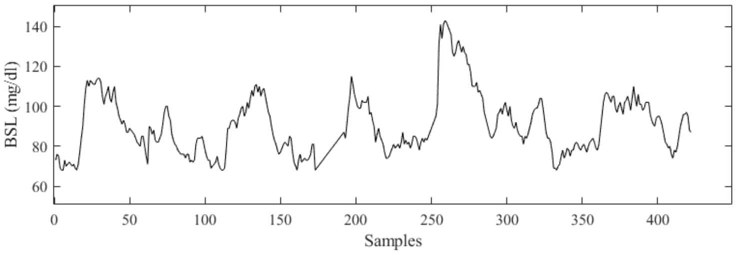


Figure B.11. Worker 11.

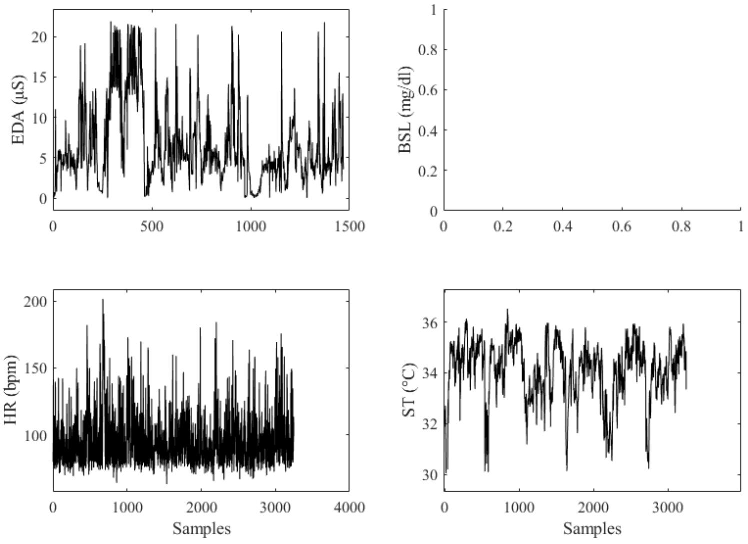
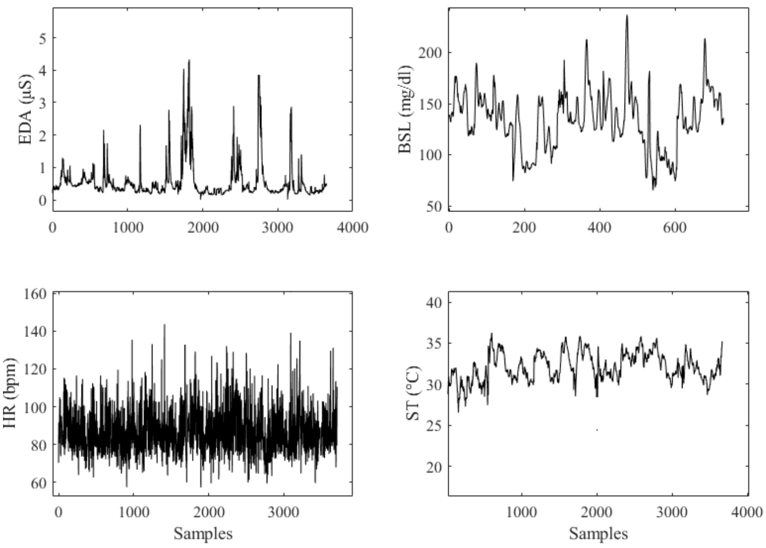


Figure B.12. Worker 12.



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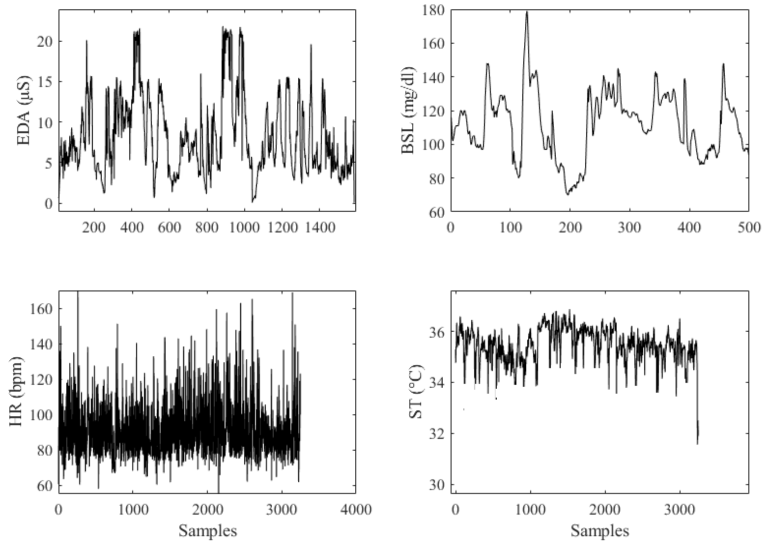

Figure B.14. Worker 14.

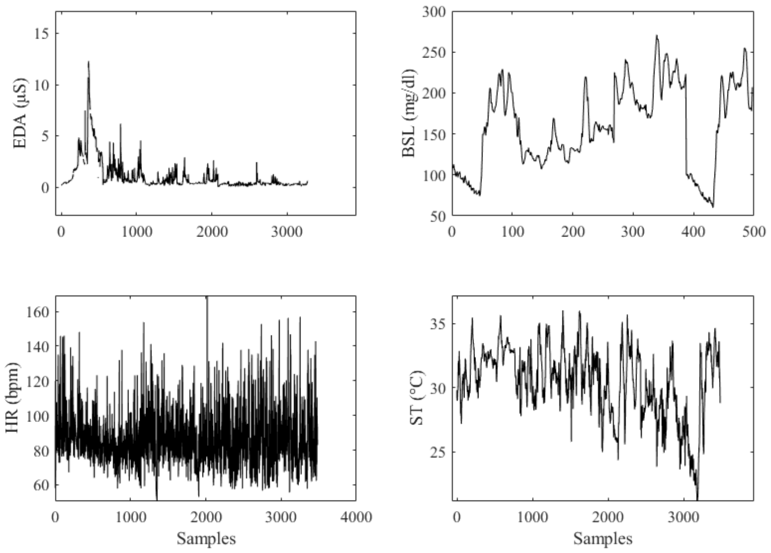

Figure B.15. Worker 15.

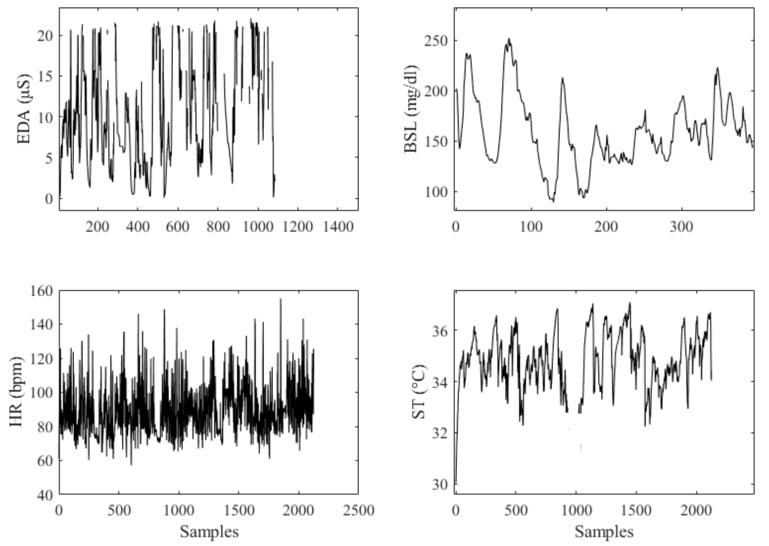

Figure B.16. Worker 16.

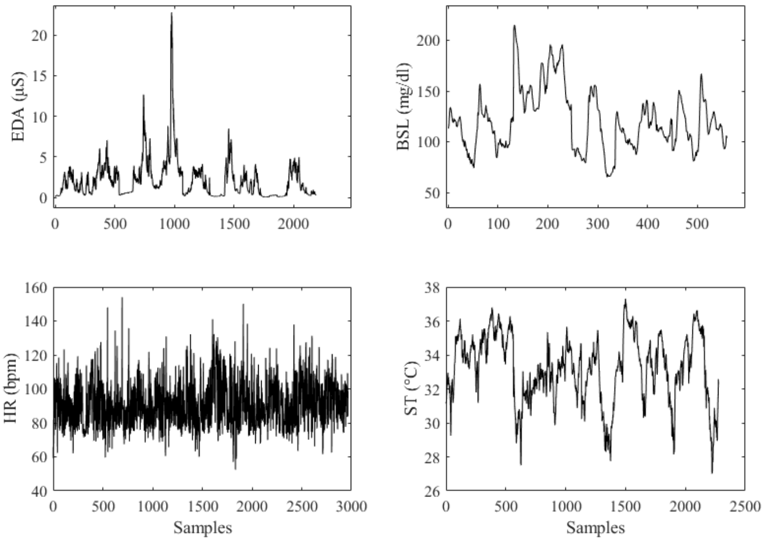

Figure B.17. Worker 17.

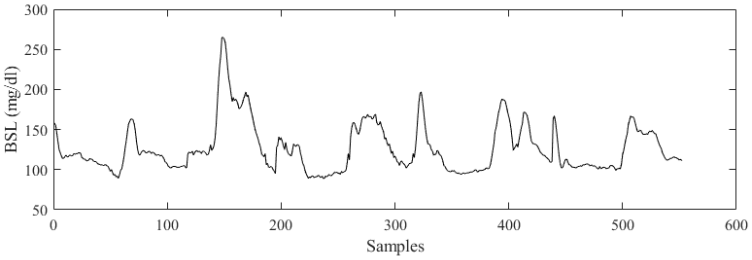

Figure B.18. Worker 18.

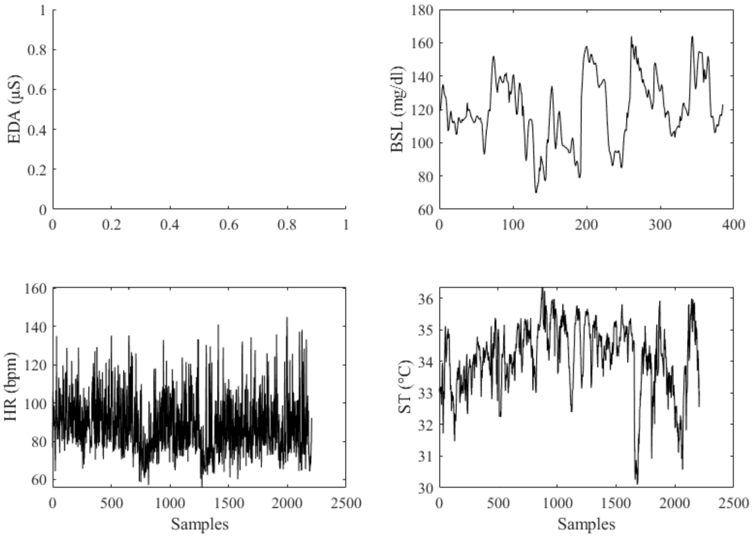

Figure B.19. Worker 19.

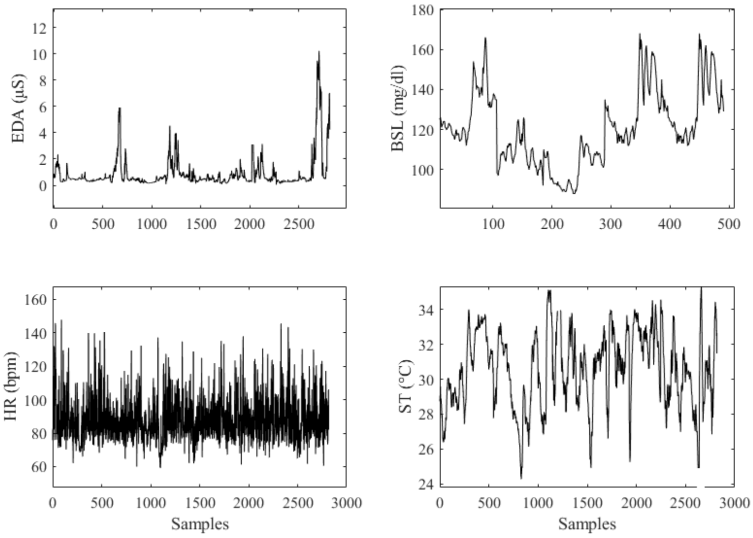

Figure B.20. Worker 20.

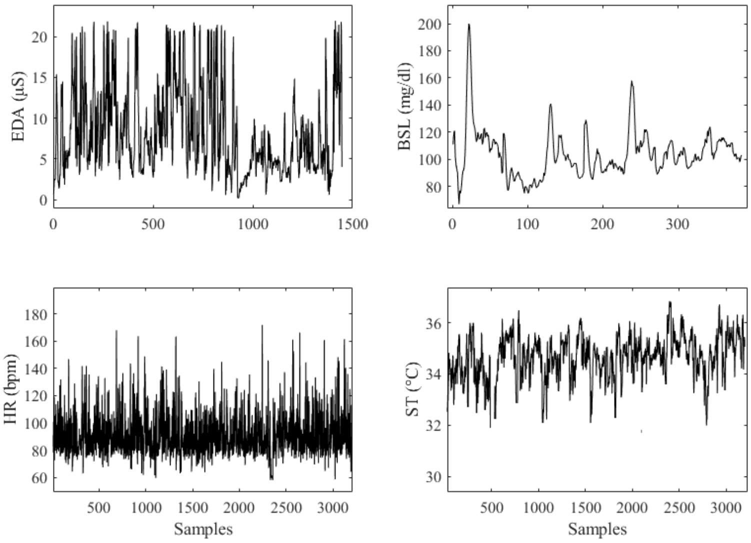

Figure B.21. Worker 21.

APPENDIX C: SURVEY CONDUCTED WITH OCCUPATIONAL HEALTH MANAGERS AND MEDICAL DOCTORS QUESTIONS

(i) A significant inverse correlation was found between the construction accidents that occurred before noon and the blood glucose values collected from the workers. Especially in the time periods before lunch break (between 10:00-12:00), the blood sugar levels of the workers decreases and the construction accidents increase significantly toward noontime. How do you interpret these results and what would you suggest to prevent this issue?

(ii) A significant correlation was found between the accidents that occur in the summer season and the heart rate values of the workers. Both the accidents at the construction site and the heart rate (bpm) of the workers increase significantly in this season. How do you interpret these results and what would you suggest to prevent this issue?

(iii) A significant correlation was found between the accidents that occur in the summer season and the galvanic skin responses of the workers. Both the accidents at the construction site and the galvanic skin responses or electrodermal activities of the workers increase significantly in this season. How do you interpret these results and what would you suggest to prevent this issue?

(iv) A significant correlation was found between the accidents that occur in the summer season and the skin temperature of the workers. Both the accidents at the construction site and the skin temperature of the workers increase significantly in this season. How do you interpret these results and what would you suggest to prevent this issue?

(v) What are your general suggestions to provide healthier working conditions for workers in the construction site?