

A FRAMEWORK FOR PREDICTIVE MODELING IN SUSTAINABLE
PROJECTS

by

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DEDICATION

This thesis is dedicated to my dad, mom, and brothers. Thank you for your support and unconditional love. Dedicating this thesis is the least I can do to you.

Abstract

Project management systems typically target the completion of a project within budget, on time, and fulfilling stakeholders' expectations and environmental needs from the project. The aim becomes harder to achieve when talking about sustainable construction project particularly in the transport sector. Many construction projects in the transportation sector are delayed and have major cost overruns. Most of these projects, in the planning stage, lack predictive mechanisms to support the team's decision making process. This study reviewed a considerable amount of literature on sustainable construction projects and the transportation sector. It was clear from the literature that project teams can benefit from further research and model theory building to help in predicting the cost, schedule, environmental impacts, and safety levels of the projects. Moreover, substantial research has shown the relationship between planning and project outcomes. Thus, this research used documented sustainable management practices and planning indicators and developed a predictive model for absolute cost, absolute schedule, relative cost, relative schedule, environmental impacts, and safety levels. Using this predictive model, the project team will have a solid decision making tool during the planning phase of the project. The predictive model has 50 sub-inputs combined into ten index/input variables and six outputs from several mathematical algorithms. The inputs and the outputs were combined in a format capable of applying multiple regression analysis or artificial neural networks. This model framework will provide a base for future data collections, validation and more detailed feedback and model review. Furthermore, the project team can take the decision to proceed or stop the project at the end of the planning phase or find an alternative project that has better predicted values.

Search Terms: Sustainable Construction, Transportation Projects, Planning Indicators, Cost, Schedule, Environmental Impacts, Safety Levels.

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Chapter 1: Introduction

1.1 Overview

A project can be defined as a temporary endeavor undertaken to come up with a unique service or product, while project management is concerned with applying the knowledge, tools, skills, and techniques in order to manage the project. When it comes to construction project, new terms have been introduced recently which are sustainable development and sustainable construction.

All over the world, sustainable development has been growing for the last three decades. Many international and national conferences and meetings focused on sustainable development and sustainability, starting from the U.N Summit on Environment and Development in 1972, ‘Agenda 21’, going through the UN ‘Earth Summit’ in 1992 in Rio de Janeiro, and up till today. All of those meetings and conferences showed the growing concern to protect the environment for a better future for the generations to come by introducing the sustainable development concept [1]. Generally, construction projects have noteworthy impacts on the environment, accounting for a significant percentage of the world energy and resource consumption, pollution and carbon dioxide emissions.

According to Chaharbaghi and Willis [2], the ideal world is composed of a society where people everywhere can live in security and peace, eat unpolluted food, drink clean water, and breathe fresh air. People can enjoy their lives and raise healthy, educated and pleased children. This way, they will leave behind them good and healthy manmade and environmental assets for the next generation. Those assets should not be less than what this generation has inherited from the previous generation. However, the real world is not even close from this ideal world. Yet, it is noticeable that there is an increasing concern regarding the resources of the planet, the long-term future, the environment itself, and the high levels of poverty that are directly linked with the social unrest, population growth, spread of disease, and environmental degradation. Sustainable development is introduced to close, as much as possible, the gap between the real and ideal worlds [2].

Focusing on sustainable practices all over the world has been significantly noticed in the past decade [2]. For instance, the term “green design” has been well

known when referring to environmentally friendly techniques, especially when it comes to buildings. Green design principles assist to accommodate flexibility while recognizing the challenges of the environment. Programs such as the Green Globes and the Leadership for Energy and Environmental Design (LEED) have been developed to improve the eco-efficiency for and all the way through several types of infrastructures [3]. However, the main focus of these programs was towards construction of buildings and not transportation projects. In all cases, sustainability in transportation projects is recently introduced.

Different definitions have been suggested for sustainable transportation in the recent years. However, most of them agree on certain points such as allowing for the basic needs of individuals and the society, in general, to be met safely and in a manner consistent with human and ecosystem health. Another important point is that sustainable transportation systems shall be affordable and operate efficiently. Finally, sustainable transportation systems should limit emissions and waste while reducing the impact on the use of land and the generation of noise. In order to facilitate the sustainable construction of transportation projects, a theoretical frame work for modeling information about these projects is important. It is significant to have a new model to know more about those projects. Currently, there is very limited documentation on predicting cost, schedule and safety models in construction projects and particularly sustainability driven construction projects in the transportation sector.

A theoretical framework for assessing the impacts, if they are controllable, by elements during the construction phase would be of great significance. For predictive modeling, sustainable construction indicators in the transportation sector must be defined. Predictive analytics is the area of data mining concerned with forecasting probabilities and trends. The study will basically focus on literature review to come up with a predictive model. Model contributors will be 50 sub-inputs combined into ten index/input variables chosen and developed through necessary literature review, which will focus on sustainable construction in the transportation sector.

1.2 Statement of the Problem

Sustainability can be applied on different construction projects. As a concept, sustainability is simple, yet its application is complicated. Observing sustainable indicators in most construction projects is a challenge because construction projects

are diverse and have varied stakeholders. Construction projects in the transportation sector such as roads, highways, bridges etc. also boast several stakeholders with different priorities. When constructing transportation projects, for instance, environmental impact assessment studies and scope definition influence the overall life cycle of the project and ultimately the sustainable indicators in an economy. For example, materials choices include asphalt versus concrete impact the construction process, the environmental footprint, the safety of users and their commuting experience.

Therefore, some of the worst contributors to environmental problems are construction projects in the transportation sector. Transportation projects are considered major projects for any country due to their high costs and importance of the project for the population use and the development of the economy. However, transportation projects also have considerable environmental, social, and economic impacts. Moreover, the construction decisions of the transportation projects will dictate future usage patterns and hence impact on the environment due to the carbon dioxide emissions. In order to reduce these impacts on the environment, the term sustainable transportation has been introduced lately. It has been adopted by many governments of the European countries, US, and recently the UAE. However, the literature of sustainable transportation lacks a program that can predict the cost, time, and the safety level of sustainable construction projects in the transportation sector. Therefore, the aim of this thesis is to develop a predictive model that can be used to predict the absolute cost, absolute time, relative cost, relative schedule, environmental impacts and safety level of a sustainable construction project in the transportations sector. The literature review is missing a predictive model that will help in predicting cost, schedule, environmental impacts, and safety level during the planning phase of sustainable construction projects in the transportation sector.

1.3 Objective

The objective of this research was to establish the theoretical framework for predictive modeling in sustainable construction projects. In this paper, predictive modeling was used to predict the absolute cost, absolute schedule, relative cost, relative schedule, environmental impacts, and safety level of sustainable construction projects in the transportation sector. Model outcomes focused on successful projects

indicators such as the expected cost, time, environmental impact, and the level of safety. The resulting model could be the basis of a decision support system to help users come up with informed decision while selecting and planning for sustainable construction projects in the transportation sector.

1.4 Significance

The main contributions of this research include the following:

1. Supplementing the sustainable construction and sustainable transportation literature review with a new predictive model that can be used to know more about the proposed projects.
2. Predicting cost and schedule of sustainable construction projects in the transportation sector.
3. Minimizing the environmental impacts of sustainable construction projects in the transportation sector.
4. Improving the safety level of sustainable construction projects in the transportation sector.
5. Introducing a decision making tool that will help during the planning phase of the transportation projects.

1.5 Methodology

Step 1: Literature and Theory Review

Review the literature related to sustainable indicators and sustainable development in construction projects within the transportation sector.

Step 2: Selecting Inputs and Outputs

Inputs and outputs were selected based on literature review. Project score sheets were developed for each input to predict the level of impact of this input on each output. The predictive model had fifty sub-inputs categorized into 10 index/input variables. From those ten index/input variables, six outputs could be predicted.

Step 3: Model Creation

The predictive model creation was based on the literature review. The predictive model had fifty sub-inputs combined into 10 index/input variables and six outputs. Relationships between the inputs and the outputs would be found using multiple regression or artificial neural networks.

Step 4: A decision Support System

The decision support system would make the model useful and practical as a user interface option. The decision support system was developed using suitable software such as SPSS and Microsoft Excel.

1.6 Thesis Organization

Chapter 1 shows the introduction of the research as well as the objectives. Chapter 2 stands for the literature review. Chapter 3 talks about predictive models and discusses multiple regression and artificial neural networks. Chapter 4 presents the research methodology. Chapter 5 shows a hypothetical example. Finally, Chapter 6 ends the thesis with the conclusion as well as the recommendations.

Chapter 2: Literature Review

2.1 Sustainability

In general, sustainability can be considered as the ability of a system to last normally on an indefinite basis, incorporating environmental, social, and economic issues. This concept is basically assuring that the human activities in nature remain within limits in order to avoid any impact on the ecological systems [3].

Sustainability does not have a universal definition. Different people and organizations define it differently. For instance, in 1987, the Bruntland Report by the World Commission on Environment and Development defined sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987) [4]. This paper is written after considering this definition for sustainability. Some other definitions that can give a better understanding of sustainability such as:

“Relationship between human economic systems and larger dynamic, but normally slower-changing ecological systems, in which (1) human life can continue indefinitely, (2) human individuals can flourish, and (3) human cultures can develop; but in which effects of human activities remain within bounds, so as not to destroy the diversity, complexity, and function of the ecological support system” [5].

“Sustainability is equity and harmony extended into the future, a careful journey without an endpoint, a continuous striving for the harmonious co-evolution of environmental, economic, and sociocultural goals” [6].

In many cases, sustainability is mainly viewed from an ecological perspective concentrating on problems, such as resource depletion and pollution [3]. However, a more useful methodology can be looking at sustainability by considering the approach called the triple bottom line, also known as the three pillar approach. This approach combines economic, social, and environmental issues [7]. The best way to think about the triple bottom line approach to sustainability is by using a Venn-diagram format, where each circle represents the economic, social, and environment perspectives respectively. Figure 1 represents sustainability as seen from the triple bottom line approach perspective. The figure shows the context for certain sustainability issues.

This multidimensional view illustrates how the three issues are interconnected to achieve sustainability that should address “planet, prosperity, and people” [8].

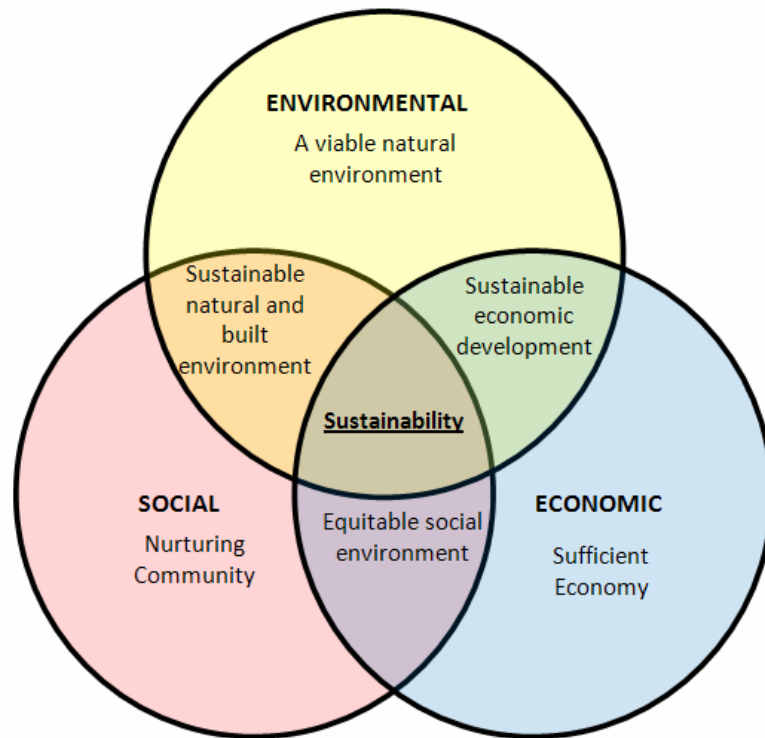


Figure 1: Triple Bottom Line Approach [9]

Each issue is associated with specific criteria that will help in defining the environmental, social, and economic implications within each of the triple bottom line perspective. For instance, the environmental issue refers to emissions, biodiversity, and climate change. On the other hand, the social issue relates to community livability, public involvement, and human health. Finally, the economic issue relates to business activity, trade, and employment [10].

The main concern of environmental sustainability is to improve the condition of Earth, or to the very least, not make it worse off. A human activity can only be considered environmentally sustainable when it can be performed and maintained open-endedly without degrading the natural environment or reducing the natural resources. This requirement is met by keeping the resource consumption minimal, minimizing the waste and pollution, eliminating the toxic substances, and using materials made completely from postconsumer recycled materials or from renewable resources that were collected without imposing either destruction to the environment or reduction of the resource base. Moreover, environmental sustainability requires that

the energy must be conserved and the energy supplies must be completely renewable and non-polluting (bio-mass, wind power, solar thermal and electric, etc...). Other requirements of environmental sustainability include the efficient use of natural resources, the reduction of both waste and greenhouse gases' emissions, the complete fulfillment of streams waste recycling, the alleviation of road traffic, the reduction of human health impact, and the protection of natural diversity. In addition, environmental sustainability should assure the good quality of rivers, the construction of new homes on brown fields, the use of renewable raw materials, and the reduction of emissions to the environment, etc...

Sustainable economy consists of sub-themes including the provision of job opportunities, the creation of new opportunities and markets for sales growth, the investment in people and equipment for a competitive economy, the provision of accessible services which reduce the use of cars, the reduction of cost by efficiency developments and reduced raw material inputs and energy, etc...

Parkin [11] divided all the resources available to a society for achieving sustainable development into five categories or what he called five capitals. The five capitals are financial capital, manufactured capital, social capital, human capital, and natural capital. Financial capital has no fundamental value. It can take the form of banknotes, bonds, or shares. Its value is normally representative of manufactured, human, social, or natural capital. Financial capital is a vital capital since it reflects the productive power of the other types of capital. Moreover, it enables them to be owned or traded. Another type of capital is the manufactured capital, which is the capital comprising the entire human fabricated infrastructure that is already in existence. Manufactured capital includes the buildings, roads, machines, or tools that we live in and use to work. The third type of capital is the social capital, which includes all of the various organizational frameworks and cooperative systems people use to work and live together. For instance, social capital includes voluntary groups, governments, trade unions, families, businesses, schools, communities, etc... The human capital, the fourth type of capital, involves the skills, knowledge, motivation, health, and spiritual ease of people. It includes everything that will help people feel good about themselves and about each other, and most importantly, participate in the society and add significantly towards its well-being and wealth. The last capital is the natural capital, which is also known as environmental or ecological capital. This capital mainly

represents the stock of assets that are provided environmentally. It includes non-renewable and renewable resources. Natural capital includes as well systems and services, such as the natural waste processing system.

2.2 Sustainable Development

Although the terms sustainable development and sustainability have been used interchangeably throughout literature, there exists a notable difference between the two [12]. Generally, sustainability refers to a system that can withstand for an infinite amount of time. On the other hand, sustainable development is directly related to the growth of human population fundamentally connecting economics to it [13]. Like sustainability, sustainable development has different definitions throughout the literature. A couple of definitions will be discussed in this paper to increase the understanding of sustainable development.

According to Sage [14], sustainable development can be defined as maintaining of human needs through protection of Earth's natural systems. Sustainable world progress depends on continued cultural, social, economic, and technological progress. Nonetheless, special attention should be given to the preservation of Earth's natural resources. Generally, sustainable development is used to represent the achievement of increased techno-economic growth combined with conservation of the natural capital that involves natural and environmental resources. Consequently, sustainable development requires the growth of rational institutions and infrastructure and the appropriate management of knowledge imperfections, uncertainties, risks, and information in order to reach intergenerational equity and preservation of the ability of Earth's natural systems to serve people [14].

Similarly, the UK's sustainable development charity provides another definition for sustainable development stating that, "Sustainable development is a process which enables all people to realize their potential and improve their quality of life in ways that simultaneously protect and enhance the Earth's life support systems."

Sustainable development is mainly about making sure that a better quality of life will be possible for everyone now and for generations to come. This outcome can be achieved by wisely using the natural resources, effectively protecting the

environment, recognizing the needs of everyone through social progress, and maintaining high and stable levels of employment and economic growth [15].

According to Chaharbaghi and Willis [2], a common definition for sustainable development was mentioned in 1983 by the World Commission on Environment and Development (WCED), which was led by the Norwegian Prime Minister Gro Harlem Brundtland. The definition states that “Sustainable development is development, which meets the needs of the present without compromising the ability of future generation to meet their own needs.” The word ‘development’ in the definition above involves two vital aspects of the concept. The first aspect is that it is appropriate to the whole world and everyone and everything on it, now and in the future. So, development cannot be restricted to certain disciplines or areas. The second aspect is that there is no final target. Instead, the continuation of development is the target of sustainable development.

In order to achieve those aspects, two concepts must be introduced and understood. The first concept is the concept of needs, which stands for providing certain conditions that can maintain an acceptable life standard for everybody. Primarily, the needs include the basic needs such as housing, clothing, food, and employment. Secondly, every person all over the world has the chance to attempt and promote his or her life standard above this absolute minimum. The second concept is the concept of limits, which stands for the fact that the capacity of the environment to accomplish the needs of the present and the future is determined by the social organizations and the state of technology. Limits basically include shrinking of biodiversity, facing natural limitation such as finite resources, declining quality of water, and declining productivity caused by over-exploitation of resources. For a better future for everybody, the best practice will be to greatly fulfill the needs, while not increasing, but rather decreasing, the limits. This would lead to the conclusion that all technical, political, social, economic, and environmental developments can be evaluated based on sustainable development using these points. Any development to be sustainable should aid in fulfilling the needs without increasing already existing limitations.

A widely used definition of sustainable development is “development that meets the needs of the present generation without compromising the ability of future

generations to meet their own needs” [16]. The above definition symbolizes the four main principles that lead to sustainable development. The first principle is that it is multi-dimensional while applying the triple bottom line approach of sustainability that focuses on environmental, economic, and social issues. The second principle is that it is dynamic, or in other words, it has the necessity of adaptation with the aim of accommodating the changing needs of society. The third principle is the intergenerational equity, which stands for the equitable distribution of resources in order to give the future generations a chance to enjoy a high quality of life. The last principle is that sustainable development is continuum, which means that it can be defined through varying degrees of sustainability rather than discrete indications of whether it is sustainable or not.

According to Litman [10], the chief objective of sustainable development from a person’s perspective is to maximize the efficiency in a way that material wealth provides social welfare (happiness). It can be noticed that as mobility and material wealth increase, the social welfare (happiness) is significantly increased. Nonetheless, with the purpose of maintaining sustainability, the mobility and material wealth must stay within the comfort level and should not exceed the measures of luxury to extravagance [10]. For that reason, the ideal objective of sustainable development involves a maximization of increased happiness with a level of comfort with respect to mobility and material wealth. Nevertheless, sustainability from a social perspective is not reached once material wealth drops below the comfort level and toward poverty. Figure 2 summarizes the sustainable development relationship between social welfare and the increased mobility and material wealth.

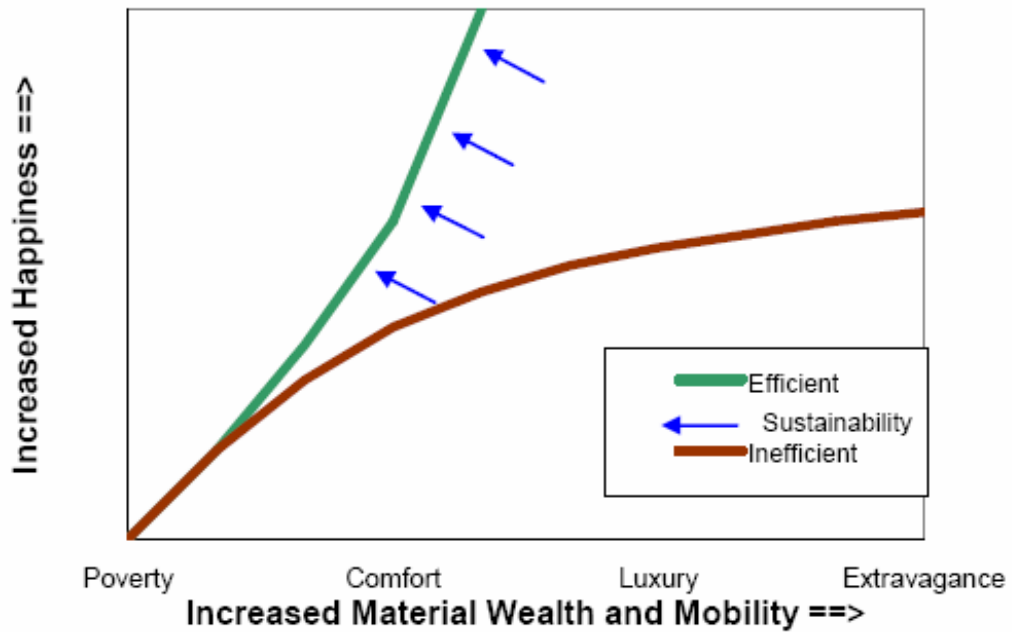


Figure 2: Sustainable Development [10]

Sustainable development does not only include the three (environmental, social, and economic) multidimensional issues of sustainability. Instead, it is directly related to human society through legal, environmental, political, material, social, cultural, ecological, economic, and psychological dimensions [16]. For each dimension mentioned above, the human society struggles for sufficiency with the intention of obtaining a high level of social welfare, while minimizing environmental impacts and resources.

Restrictions can be found in the way to achieving a balance between each sustainable development dimension, [16]. Many researchers claim that development cannot be sustainable. Instead they consider the term to be oxymoron [8]. The three main constraints restrict societal development from obtaining sustainability are described here. The first and most obvious constraint is the resource constraint which stands for the fact that consumption of renewable resources cannot surpass the rate upon which they are reproduced. The second constraint is the environmental constraint, which describes that excessive pollution can affect the health implications for humans, animals, and plants without ignoring the fact that it can induce climate changes. The third and last constraint is the ecological constraint, which mentions that the waste cannot go into the ecological system at a faster rate than the rate at which it

can be safely absorbed. As a result of these constraints, some researchers use the term “equilibrium engineering” to describe development, which is based on sustainability objectives. This term usually replaces the typically common term, sustainable development [8].

The concept of sustainable development is often achieved only partially even though it has been addressed considerably recently. According to Gallo [17], the three main reasons for this issue are the following. The first reason is problems in defining and identifying the laws and regulations that can provide suitable guidelines to new construction projects. The second reason is difficulties in preparing and submitting quantitative estimates of savings that can be gained. The last reason is the problems in the ascription of precise economic costs to such products.

Dincer and Rosen [18] mentioned that a society willing to reach sustainable development ideally should utilize mainly if not only energy resources that does not provide environmental impact. Such resources must be used since they release no emission to the environment. Moreover, they argued that a relation exists between environmental impact and energy efficiency. Since, for exactly the same products or services, less pollution and resource utilization is typically linked with increased energy efficiency. Energy is remarked as the central theme to accomplish the objectives of sustainable development. For that reason, the key push of sustainable development is to keep these valuable assets [19].

Long-term potential actions for sustainable development are required in order to achieve solutions to environmental problems that the world is facing recently and will face in the future. Incidentally, one of the most effective and efficient solutions is to use renewable energy resources. For this reason, we notice close connection between sustainable development and renewable energy. The renewable energy resources can also reduce the greenhouse effect, stratospheric ozone depletion, and acid precipitation [20].

2.3 Sustainable Construction

One of the most important themes of sustainable development is sustainable construction. More precisely, sustainable construction is commonly used when applying sustainable development to the construction industry. The construction

industry can be defined as all who alter, plan, develop, produce, build, design, or maintain the built environment. It includes as well, the manufacturers, building material suppliers, occupiers, end users, and clients. Consequently, sustainable construction can be labeled as a subset of sustainable development, which includes actions such as tendering, recycling, material selection, site planning and organization, and waste minimization [21].

Miyatake [22] proposed six principles for the sustainable construction, which are the protection of the natural environment, the creation of a non-toxic and healthy environment, the minimization of the resource consumption, the utilization of recyclable and renewable resources, the maximization of the resource that can be reused, and following quality while creating the built environment. Miyatake [22] suggested three ways that civil engineering and more precisely the construction industry can practice to implement sustainable construction. The ways are to improve arid environments, to restore damaged and polluted environments, and to create built environments.

Miyatake [22] suggests that the industry must change the processes of creating the built environments in order to succeed in sustainable construction. This can be created by accepting a change from linear processes to cyclic processes inside the construction industry. In other words, the industry must change the way in which most of the construction activities are undertaken. The industry is using material, energy, and many other resources to create buildings, roads, and other civil engineering projects. Yet, it is important to mention that the end result of all these activities is massive volume of released waste during and at the end of the project's life. Thus, changing this linear process into cyclic process will significantly decrease the use of energy and other natural resources. On the other hand, it will significantly increase the use of renewed, recycled, and reused resources. Alternatively, with the purpose of restoring polluted and damaged environments, efforts such as treatments of spoiled and contaminated soils, water, and air have been done. The main idea is to recover large scale arid environments like deserts and make them livable for animals, plants, and of course human beings. The leading priority is to enhance the built environments with the aim of transforming its linear process into cyclic processes.

2.4 Green Building and Design

In recent times, the attentiveness and significance of maintaining sustainable developments in the planning and engineering segment has guided many engineers and researchers to search for new, advanced ways that can incorporate sustainability into their new designs. The term “green” building has been used frequently to refer to environmentally friendly technologies and techniques used during the design and construction of the built environment. According to O’Grady [13], the requirement for “green building” is based on the facts that the buildings are accountable for a main part of the human footprint on Earth. Green buildings are persuasive in determining economic vitality and quality of life. Moreover, they have fairly fixed assets that are lasting for many decades.

No one can ignore the fact that buildings have a remarkable impact on the environment not only during the construction but also throughout their operation. "Green building" can be roughly defined as the gathering of building design, land-use, and construction strategies that will lessen these environmental impacts. The green building approach to the built environment contains an all-inclusive approach to the design of buildings. All the resources that can go into a building, such as fuels, materials, or the contribution of the users, must be considered if a sustainable construction is to be formed and practiced. Producing green buildings consists of undertaking numerous requirements and conflicting issues. As a result, different design decisions will have various environmental implications. Measures for green buildings can be divided into reducing energy in use, minimizing damage to health and internal pollution, reducing resource depletion and embodied energy, and minimizing environmental damage and external pollution.

A "green" building must be primary concerned with environmental, health, and resource conservation performance over its life cycle. These new priorities add and complement the main classical building design concerns such as durability, utility, economy, and delight. Green design highlights a couple of new resources, environmental impacts, and occupant health concerns such as minimizing the ecological impact of energy and materials used, saving and restoring local air, soils, flora, water, and fauna, reducing human exposure to noxious materials, using renewable energy and materials that are sustainably collected, conserving scarce

materials and non-renewable energy, and supporting bicycles, pedestrians, mass transit, or any other alternative to fossil-fuelled vehicles. The majority of green buildings are high-quality buildings. Usually, they are designed to cost less to operate and maintain, to last longer, and to provide a higher occupants' satisfaction than standard developments. Sophisticated buyers and lessors target green buildings. Such buyers are willing to pay the best for their own advantages and satisfaction.

Sustainable building is another term that is similar to green building. Both terms tend to be used interchangeably. Nevertheless, sustainable building is just a part of the development known as green building. Figure 3 shows the relationship between sustainable building and green building.

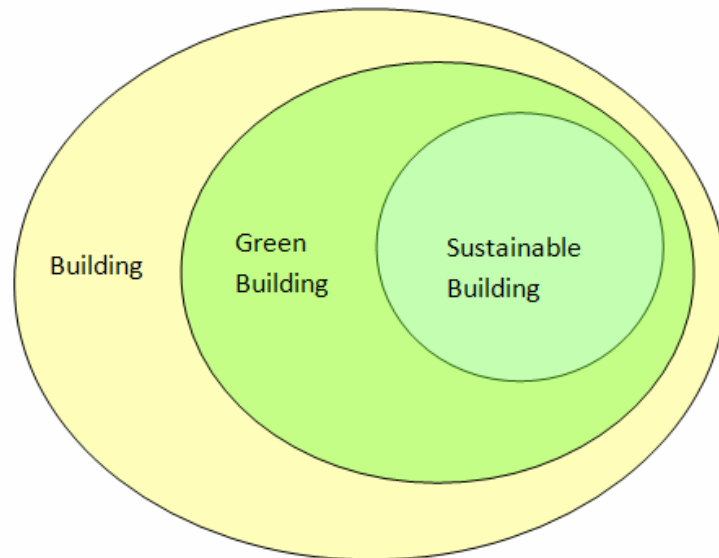


Figure 3: Relationship between Sustainable Building and Green Building [13]

The primary difference between the two terms is that the aim of green building is not to directly achieve sustainability. Instead, the main aim is to achieve Eco-efficiency [13]. Eco-efficiency is related to the improvement of economic efficiency by a factor of 10 with the purpose of decreasing the materialization impacts such as packaging, waste, and transportation of goods [23]. Programs such as Green Globes (Energy and Environment Canada Ltd., 2004) and Leadership in Energy and Environmental Design (LEED) (United States Green Building Council, 2008) have been using this concept in green building rating systems.

On the other hand, sustainable buildings principally focus on sustainability. The main aim is to attain a built environment that is independent, resulting in infrastructures that are self-regulating (systems that can function automatically without any control from outside) and net-zero structures (buildings that have a net energy consumption of zero over a single year) [13]. As a result, sustainable building is only one aspect of green building. In other words, not all green buildings are sustainable buildings. The previous figure describes the major difference between a sustainable building and a green building.

Sustainable design is the first step towards the sustainable construction. Sustainable design involves ground-breaking solutions to technical problems. These solutions must always take into consideration the impact upon the environment. Innovative solutions must conserve energy and natural materials, cost less, and reduce pollution. Moreover, they should provide a healthier and a more comfortable internal environment to the occupants. Sustainable designed building aims at reducing their impacts on the environment through resource and energy efficiency. Sustainable designed building includes few principles such as eliminating or at least minimizing the use of toxins, enhancing the natural environment, and minimizing non-renewable resource consumption.

Sustainably designed building can be considered as buildings that have minimum opposing impacts on the built and natural environment. Sustainably designed building is considered to have practices that make every effort for essential quality (including environmental, social, and economic performance) in a very comprehensive way. Thus, the balanced use of natural resources and the suitable management of the building stock will lead to improving environmental quality, reducing energy consumption (energy conservation), and saving scarce resources.

Sustainable designed building considers the entire life cycle of buildings. Sustainable designed building takes into account the functional quality, environmental quality, and future values. Earlier in many countries, attention has been principally focused on the size of the building stock. Quality issues have barely played a major role. However, now and in most of the countries, the quantities of buildings are almost high and housing market is now saturated. So, the demand for quality is becoming more significance. In view of that, policies that pay special attention to

sustainability of building practices should be applied based on the existing market conditions. Together, the demands of users and the environmental impacts of construction are vital factors in the market. Governments should give a significant impulse to sustainable buildings by encouraging and supporting these developments.

2.5 Sustainable Transportation

Transportation is mainly one aspect of reaching sustainability and is combined within the environment and the economy. Unlike other sectors, transportation can be regulated through policy making with the aim of having a more sustainable transportation system. The regulations can inspire economic and environmental decisions that are directly related to transportation and will determine the system's long term practicality.

Sustainable transportation talks about the transportation sector's concept of sustainable development [24]. Similar to other sustainable terms, sustainable transportation does not officially have one generally accepted definition. Various definitions are used to define sustainable transportation such as

“Transportation that does not endanger public health or ecosystems and meets mobility needs consistent with the use of renewable resources at below their rates of regeneration and the use of non-renewable resources at below the rates of development of renewable substitutes” [24].

“One in which fuel consumption, emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world” [25].

“Sustainable transportation allows the basic access needs of individuals and societies to be met safely, and in a manner consistent with human and ecosystem health, and with equity within and between generations; is affordable, operates efficiently, offers choice of transportation mode, and supports a vibrant economy; limits emissions and waste within the planet's ability to absorb them, minimizes consumption of nonrenewable resources, reuses and recycles its components and minimizes the use of land and the production of noise” [26].

For the purposes of this research, the last definition will be used to define sustainable transportation since it includes almost all aspects of transportation. Nonetheless, all of the definitions have a strong harmony. For instance, each

definition refers to meeting the environmental, social, mobility, and economic needs of the society [27]. However, more emphasis is given to environmental sustainability and minimizing transportation impacts on the natural system [28].

Transportation systems are considered to be unsustainable systems [29]. Unsustainable activity is basically defined as “one that cannot continue to be carried on the way it is now without serious difficulties” [24]. Transportation is usually related to problems such as climate change and air pollution. Moreover, the increased dependence on automobiles is a significant point in most societies. Various reasons cause the current transport systems to be unsustainable [28]. For instance, Black [29] mentioned long and short term implications of current transportation systems such as reliance on oil reserves which are finite, vehicle causing excessive injury and fatality, stimulation of urban sprawl, petroleum-based emissions impacting the environment and more precisely the air quality, water pollution due to runoff, vehicle coolants affecting the ozone shield, structural damage due to vibration, loss of open space, loss of wetlands, loss of historic buildings, productivity losses because of accidents, decreases in property value, national security concerns, marine pollution due to oil spills, noise pollution, and traffic congestion. However, these impacts are not the only reasons why the current transportation system cannot be assumed to be a sustainable form of development.

Shiftan et al. [30] mentioned nine sustainable transportation development goals divided into the three main categories of social, environmental, and economic goals. The social goals aim to maximize the availability of public transport to everybody, to increase the road safety by decreasing the number of road accidents and their severity of course, and finally to improve the accessibility to employment, cultural activities, and open land areas. The environmental goals aim to protect wildlife and natural habitats, to preserve open land, and finally to reduce the air pollution and noise from road vehicles. Nonetheless, the economic goals aim to minimize the costs of transportation infrastructure, to save energy, and to save travel time.

Chapter 3: Predictive Model

3.1 Overview

In simple terms, a predictive model is used to forecast the likelihood of future events based on data collected from the past. The model consists of various predictors, which are variable factors that might influence or be indicative of future results or behavior. In order to create a predictive model, data must be collected for the relevant outcomes and predictors. After that, predictions are calculated and the new model is tested and then validated using supplementary data.

Predictive modeling is basically used to analyze patterns and trends in historical and operational data with the purpose of transforming data into decisions. This can be accomplished by analyzing and then modeling the dynamics of the used data. The interesting fact about predictive modeling is that it uses the data that had limited value and was mainly used for reporting what happened earlier to come up with a model and make decision based on it. Nonetheless, the data is collected to come up with a compact model that can be a great tool for proactively predicting what will happen in the future. In general, a predictive model is a computational tool that can precisely forecast an outcome of interest (output or dependent variable) when supplied with input data (independent variables) that have a measurable causal relationship to the output.

Two fundamental assumptions must exist in order for predictive modeling to be useful in a given application. The first assumption is that outcomes should have a certain level of predictability from existing data. In other words, similar patterns characterized through model inputs must be revealing similar outputs. Moreover, some measurable relationship must exist between the set of existing data values to be used as model inputs and the subsequent output values, which the model is supposed to approximate. The second assumption is that the relationships that already existed in the past shall continue to hold in the future. If this is the case, the researcher will find it reasonable to use past observations to conclude future behavior. At the end, predictive modeling is a body of technologies made for approximating the relationship between existing input data measures and some subsequent outputs.

Generally, there are two classes of predictive modeling applications. Each one of them differs by the type of output that the model produces. The first class is used for classification. Classification models usually generate outputs that are 1-of-n discrete probable outcomes. Such models are used to do prospect classification, fraud detection, churn prediction, vote forecasting, bankruptcy prediction, target recognition, etc... The second class is used for forecasting. Forecasting models usually generate outputs that are considered continuous-valued. In other words, the output should have a value ranging from the maximum to the minimum value allowed. Those models can be used to forecast or to estimate yields, sales, costs, volumes, scores, rates, temperatures, etc....

3.2 Multiple Regression

Back to 1885, San Francis Galton introduced the concept “regression” to all researchers to think about. He introduced regression to study the relationship between sons’ and fathers’ heights. In that study, Galton noticed that the sons usually do not tend to their father’s heights. Instead, the son’s heights “regress to” the average of the population. Then, he formulated the concept of “regression towards mediocrity.”

A variable is anything that can take at least two values. For a better understanding of the relationship between variables, simple and multiple regressions were introduced. A simple regression is used to explain a dependent variable as a function of a single independent variable. So, we use a simple regression analysis to relate a dependent variable as function of another independent variable. On the other hand, a multiple regression analysis is a valuable statistical tool for understanding the relationship between two or more variables. It allows us to control the variables that are simultaneously affecting the dependent variable [31]. This is very important tool in evaluating sustainability, which usually relies on non-experimental data.

Multiple regression includes a variable, called the dependent variable, as well as other explanatory variables (independent variables) that are supposed to yield or be linked with variations in the dependent variable. Multiple Regression models are models that can accommodate many variables when studying a dependent variable. So, the more we add explanatory variable to the dependent variable, y , we expect to have a better explanation to the variety in y . In other words, multiple regression is used to build better models, which can predict the dependent variable in a better way.

In simple regression models, just one function of only a single explanatory variable can appear in the equation. However, the multiple regression models are basically more flexible during analysis. There is a tension between any effort to have conclusions that are very close to certainty and the probabilistic nature of multiple regression analysis. Generally, statistical analysis includes the usual expression of uncertainty using probabilities.

Multiple regression is just one kind of statistical analysis that involves different variables at the same time. Other types include stratification, discriminant analysis, matching analysis, analysis of variance, logit analysis, probit analysis, and factor analysis. However, due to its practicality and reasonableness, multiple regression analysis is considered now and again well suited to the analysis of data when numerous likely explanations for the relationship between various explanatory variables are possible. In most cases, multiple regression has a single dependent variable and various explanatory variables to measure how the statistical data are applicable to these theories. Multiple regression is useful while measuring the magnitude of a particular effect. It is used as well in determining whether or not a particular effect is present. Finally, it can be used in forecasting what a specific effect would be, but for an intervening event.

When interpreting the outcomes of a multiple regression analysis, it is vital to differentiate between the two terms correlation and causality. Two variables are considered to be correlated if the events connected with the variables happen more often together than it cannot be expected by chance. For instance, if higher grades are associated with more time spent while studying, and lower grades are associated with less time spent while studying, then there is a positive correlation between those two variables. Conversely, if higher grades are associated with less studying time, and lower grades are associated with more studying time, then there is a negative correlation between those two variables.

The relationship between two variables can be indicated by a correlation coefficient, which ranges in value from (-1) that stands for a perfect negative relationship to (+1) that stands for a perfect positive relationship. Additionally, negative and positive correlations can be relatively weak or relatively strong. Yet, it is significant to mention that a correlation between two variables does not always mean

that one event causes the second to occur. Therefore, while making causal inferences, it is vital to avoid spurious correlation. Spurious correlation occurs when two variables are closely related but do not have a causal relationship since both of them are caused by a third, unexamined variable.

As explained earlier, causality cannot be inferred by data analysis alone. Instead it is better to infer that a causal relationship happens based on the underlying causal theory, which explains the relationship between the two variables. Even if an applicable theory has been recognized, causality by no means is inferred straight. The researcher should look for empirical evidence that proves a causal relationship. Moreover, the existence of a non-zero correlation concerning the two variables does not assure that a relationship exists between them. In fact, it could happen because the model does not reflect the accurate relationship between the explanatory variables. In contrary, the nonexistence of correlation does not mean that the causal relationship between the variables does not exist. A lack of correlation could occur for various reasons such as if the data available are insufficient, if the data are measured incorrectly, if the data do not permit multiple causal relationships to be arranged, and if the model is identified mistakenly.

Multiple regression allows the researcher to select between alternative hypotheses or theories. Moreover, it assists the researcher to find out correlations between variables that have valid relationships from those that are normally spurious. The research must begin with a strong preparation of a research question. The data, which will be collected and analyzed, should be related directly to the same issue. Otherwise, suitable inferences cannot be made from the statistical analysis at the end.

Model specification includes some steps, which are essential for the success of the research. Usually, a multiple regression analysis is based on a theory, which labels the variables to be involved in the study. Models are regularly described in terms of parameters, which are the numerical characteristics of this model. Multiple regression is based on a sample, or a selection of data, picked up from the population, or all the units of interest. Multiple regression is used to find estimates of the values of the parameters of the model. An estimate related to a certain explanatory variable is a regression coefficient. Failure to come up with the right theory, failure to pick up the suitable variables, and failure to select the precise form of the model can bias

significantly the statistical results. This can happen because it can generate a systematic tendency for an estimate of a model parameter to be too low or too high.

The first step in multiple regression analysis is to choose the dependent variable. The variable to be studied must be the proper variable for analyzing the subject at hand. The second step is to choose the explanatory variable that is related to the subject of study. The explanatory variables to be chosen should be selected appropriately in order to allow for the evaluation of alternative hypotheses. The third step would be to choose the additional explanatory variables. An effort must be made to classify the extra known and hypothesized explanatory variables. Some of those variables are measurable, so they can support alternative substantive hypotheses during the regression analysis. It is important to note that not all possible variables that might affect the dependent variable can be counted for the analysis to be successful. That is because some variables cannot be measured while others may cause little impact or difference.

Sometimes, it happens that the researcher fails to take into consideration a main explanatory variable, which is correlated with the dependent variable of interest in a regression model. This might cause the included variable to be credited with an effect that in fact is caused by the excluded variable. Over-all, omitted variables, which are correlated with the dependent variable, diminish the probative value of the regression analysis. On the other hand, in general, omitting variables, which are not correlated with the variable of interest, is less of a concern. That is because the parameter, which measures the consequence of the variable of interest on the dependent variable, is expected without bias. However, it is noteworthy to mention that the bias caused by the omission of significant variables, which are related to the included variables of interest, can cause a serious problem. Nevertheless, it is a good idea to account for bias qualitatively if the researcher has enough knowledge about the relationship between the explanatory variable and the omitted variable. The accuracy of the measure of the influence of a variable of interest on the dependent variable is similarly significant. Overall, the more complete the described relationship between the dependent variable and the included explanatory variables are, the more accurate the results will be. On the other hand, including explanatory variables that are irrelevant will decrease the precision of the regression results and analysis.

In a multiple regression model, it is important to choose the fundamental form of the model. To choose the suitable set of variables to be involved in the multiple regression model for sure does not finish the modeling exercise. The researcher should choose the correct form of the regression model as well. In practice, the most commonly selected form is the linear regression model. In the linear regression model, the amount of the change in the dependent variable related to the variation in any of the explanatory variables is the same regardless the level of that explanatory variable.

In certain occasions, there might be a reason to believe that variations in explanatory variables will have a degree of difference regarding the effects on the dependent variable as the values of the explanatory variables change as well. In this case, the researcher should use a nonlinear model. Yet, the failure to account for nonlinearities can cause either an understatement or overstatement of the effect on the dependent variable due to the change in the value of an explanatory variable. A certain type of nonlinearity includes the interaction among different variables. An interaction variable is the outcome of two other variables, which are involved in the multiple regression model. The interaction variable lets the researcher consider the possibility that the effect of a change in one variable on the dependent variable might change based on the level of a different explanatory variable changes.

During the multiple regression framework, the researcher regularly assumes that changes in explanatory variables affect the dependent variable, but not vice versa. In other words, the researcher does not assume that changes in the dependent variable will affect the explanatory variables and this is what is called no feedback. Furthermore, it is vital in multiple regression analysis that the explanatory variable of interest is not perfectly correlated with one or more of the other explanatory variables. For instance, if there was a perfect correlation between two variables, the researcher will not be able to isolate the effect of the variable of interest on the dependent variable from the effect of the other variable. Perfect collinearity occurs when two or more explanatory variables are correlated perfectly. In this case, the researcher will not be able to estimate the regression parameters.

On the other hand, multicollinearity occurs when two or more variables are highly, but not perfectly, correlated. In this case, the researcher can estimate the

regression, but some concerns remain. Obviously, the less the multicollinearity among the two variables, the more precise are the estimates of individual regression parameters.

In multiple regression models, errors can arise from various reasons, such as the failure of the model to contain the proper explanatory variables, the addition of wrong variables in the model, and the failure of the model to show the nonlinearities, which might be present. It is valuable to notice the cumulative effect of all of these sources of modeling error. In multiple regression models, all of these errors are being represented by an additional variable, the error term. A significant assumption in multiple regression analysis is that each of the explanatory variables and the error term are independent of each other.

Multiple regression analysis is more than just calculating the correlations. It is a method in which a regression line is used to relate the average of the dependent variable to the values of other explanatory variables. Simply, regression analysis could be used to forecast the values of one variable using the values of other variables. In fact, a regression line is the best-fitting, straight line of a set of points in the scatterplot. So, if there is only one explanatory variable, the straight line is shown using the equation shown below:

$$Y = a + bX$$

In this equation, “a” stands for the intercept of the line with the y-axis when X equals 0, while “b” is the slope, which is basically the amount of vertical change in the line for every unit of variation in the horizontal direction. The regression line is normally estimated by applying the standard method of least squares. In this method the values of “a” and “b” are calculated in a way that the sum of the squared deviations of the points from the line are decreased. As follows, negative deviations and positive deviations of equal sizes are counted equally. Moreover, large deviations are counted more than small deviations.

The vital variables that analytically might affect the dependent variable, and for which data can be found, should normally be included clearly in a statistical model. All other influences, which must be small separately, but can be considerable in the aggregate, are contained within the additional random error term. Accordingly,

multiple regression is a method that separates the systematic effects based on the explanatory variables from the random effects included in the error term. When more than one explanatory variable exist, the linear regression model becomes as shown below:

$$Y = b_0 + b_1X_1 + b_2 X_2 \dots + b_k X_k + e$$

In this equation, Y stands for the dependent variable and $X_1 \dots X_k$ stand for the explanatory variables. Moreover, the error term “e” stands for the cumulative unobservable effect of any omitted variables. In linear regression, each of the added terms involves unknown parameters, $b_0, b_1 \dots b_k$, that are estimated by “fitting” the equation to the data using least-squares. It is noteworthy to mention that many researchers use the least-squares regression technique due to its simplicity and its appropriate statistical properties [32].

3.3 Artificial Neural Networks

In this research, the predictive model can be developed using Artificial Neural Networks (ANN) and not only using multiple regression. ANNs are made of neurons or simple processing units that arranged in layers. The connection and function of these networks is a simplification of those of the biological nervous system. ANNs are relatively simple computer-based systems, which can learn patterns with data. ANNs are not algorithmic models but instead learn patterns within data through repeat exposure. ANNs represent a type of models that are designed to carry out the mapping of an input into an output [33]. In ANNs, the input layer hold independent variables. On the other hand, the output layers contain the dependent or target variables.

In order to build non-linear models, one or more hidden layers may be used between the input and out layers. Usually, the neurons are connected across layers. In ANNs, the information is kept in the interneuron connection weights. ANNs have forward pass and backward pass that are used to achieve better predictions. When starting ANN training, the connection weights among layers can be set randomly. In the forward pass, the inputs are added into the input nodes. The information from input nodes is fed into subject nodes by passing through hidden nodes and hidden layers. From all hidden nodes, transformed output signals are summed to come up

with predictive values. Those predictive values should be compared with known experimental values to calculate the amount of error. This amount of error is then fed back into the network, a process called backward pass. Repeating the forward and backward passes adjusts the weights. This process is repeated until the calculated outputs are matching with the experimental ones within a certain level of accuracy.

ANNs do not use any algorithmic approach to come up with the model. Moreover, unlike statistical models, ANNs do not require assumptions about the form of the function of the input-output relationship. By repeated exposure of the input-output data patterns, ANNs learn the inner relationships between the inputs and outputs. A successful ANN is one that is well trained to come up with values that are correct for the data patterns that were not used for training or even for new cases. ANNs are particularly suited when many inputs exist, and when the relationships between the inputs and the outputs are ambiguous and not understood. Therefore, a successful ANN is a one that can find or predict logical relationships between inputs and outputs and not only memorize the data.

The computational efficiency of the ANN fundamentally depends on the interconnection weights. It is important to mention that before starting to develop the network, it is impossible to know the number of neurons within each layer as well as the number of hidden layers. Basically, both numbers depend on the complexity of the relationships between the inputs and the outputs. There is no specific rule to determine the number of hidden layers and number of nodes, yet this determination is essential in the network development phase. ANNs develop models through learning rather than programming, which is a great advantage since programming is time consuming. In all cases, ANNs have already proven to be a useful modeling technique. ANNs have been used in different domains and sustainable construction is one of them.

3.4 Benchmarking and Indices

The predictive model will be developed based on inputs and outputs as mentioned earlier. Based on the fact that what cannot be measured cannot be controlled, this paper will be measuring the inputs based on the concept of benchmarking while developing suitable indices for each input. Benchmarking is the process of comparing the practice done to the best practices done earlier. The

dimensions that are usually measured are cost, time, and quality. In this research, benchmarking will be used to come up with better indices that can evaluate the inputs in order to come up with a more realistic and reliable predictive model. The terms benchmarks and indices are misplaced in many situations since people use them interchangeably although they are not the same. A benchmark usually serves as standards that can help in measuring or judging a certain practice if it is applied in the best possible way. On the other hand, indices are statistical tools that are made to measure the performance over a certain period of time. So, good and reliable indices are the ones that have defined objectives and use methodologies that are satisfying the objectives perfectly.

From the time when the United Kingdom Egan (1998) report was written based on survey practices in the car industry, systems for benchmarking performance in the construction projects started gaining widespread popularity [34], [35]. Construction project benchmarking could be considered to be the outcome of a mixture of ideas taken from the project success literature and customer satisfaction surveys. In all cases, benchmarking has been used widely within the construction industry in the recent years. Therefore, it can be a great concept to use in this research.

Chapter 4: Research Methodology

The predictive model, which is called the Sustainable Project Index, is basically divided into inputs and outputs. The sustainable project index (SPI) will be based on multiple regression or ANN. This predictive model can be developed using any statistical software such as SPSS, Microsoft Excel, etc... This section will discuss the research methodology that was followed to come up with the predictive model. First, the inputs of the predictive model will be discussed clearly. Later, the outputs will be discussed and how each output is related to certain inputs.

4.1 Input Variables

The predictive model has ten input variables. Each input variable will be discussed separately. Moreover, how to measure each input variable will be shown afterwards. The input variables will be evaluated based on particular Project Score Sheet. Each Project Score Sheet will have five questions that can evaluate the level of planning for each input. The score given to each of the five questions will be added to come up with the total score for that input. That total score will indicate how good the planning for this particular input was. The input variables are the following:

- A. Government Regulations
- B. Scope Definition
- C. Route Selection
- D. Risk Management
- E. Resource Allocation
- F. Labor Productivity
- G. Nighttime Construction
- H. Long Lead Item Procurement
- I. Environmental Impact Assessment Studies
- J. Safety Plans

A. Government Regulations

Construction activities are usually high risk and labor-intensive in occupational safety and health terms. While the number of workers is increasing and at the same time the number of fatalities is increasing recently, a tightening of the regulation of health, safety and welfare in the sector has become vital by the majority

of governments all over the world in order to control those construction practices. Some of the costs that are directly related to the impact of health and safety issues in the sector include legal fees, inquiries, lost output, insurance, costs of shutdowns or site closures, fines, liabilities, etc...

Earlier government regulations used to introduce training costs for a task-specific construction skills certification and general safety awareness scheme. Based on that, government regulations have been developed by most countries to control aspects, such as construction injuries, construction fatalities, environmental impacts, public wealth, and many other aspects that can benefit the people and reduce the harm of construction.

The main objectives of most governmental regulations are many, such as making the regulations comprehensible to those that must comply with them, introducing a flawless framework of responsibilities all over the construction industry to make sure that the safety, health and welfare of employees are always protected, setting out obligations on the delivery of well-being facilities for workers, providing appreciations for the qualifications of all workforces in the construction industry, and making particular requirements for all high-risk elements that can be found in the construction industry. Such objectives can be achieved by putting high fines for contractors who are not following those regulations. Moreover, objectives can be controlled by continuous and unannounced inspections from the government to the construction sites.

Moreover, government regulations can have environmental and economic impacts. Especially those days, governments are more aware about the environmental impacts that can happen due to construction. Therefore, governments are setting certain regulations related to sustainability in order to achieve more sustainable construction projects in the near future. Such regulations are new and have impacts on cost and schedule of projects especially when it comes to construction of transportation projects.

Other than the environmental impacts, there are economic impacts. The economic impacts due to governmental regulations are different from country to the other, depending on the amount of construction happening in that country. The economic impacts usually benefit the public more than the contractors. Regarding

transportation projects, for example, government regulations can include specific route selection, certain safety planning, and high quality products. Certain regulations emphasize the safety of the workers and the safety of the public, especially when it comes to building bridges, for example. Moreover, sustainable construction and products are the main goal of many governments nowadays.

Government regulations are part of the complex nature of construction projects and the contractors must be able to deal with such situations. In all cases, the construction team who is responsible to start a new project in any country should be aware of all the governmental regulations that are within the country. It is important to mention that in certain countries, governmental regulations can differ from one city or state to other cities or states within the same country. Therefore, the responsible teams must be aware of such cases and plan their projects accordingly.

In the predictive model, government regulations will be evaluated based on the Project Score Sheet shown below. The project score sheet has five questions that can be used to evaluate the level of planning for government regulations. The explanation for each question is as follow:

A1. Project Teams identified government regulations related to the project?

Explanation: It is important for any project team to know the government regulations that will impact the project. Being aware of the government regulations will enhance the planning phase of the project.

A2. Project Team prepared all documents required by government regulations or for construction permits?

Explanation: Knowing the government regulations and construction permits is not enough for the project to be properly planned. Instead, the project team should prepare the documents required by the government regulations and the construction permits in order to proceed.

A3. Project Team submitted all permit applications?

Explanation: The project team should make sure to submit the permit application on time in order to avoid any delay.

A4. Project Team received required permits?

Explanation: The project team should make sure that permits are already received in order to proceed with the project.

A5. Project Team has previous experience with similar projects in same construction zone?

Explanation: Having previous experience is vital for project team especially if the experience was for similar projects and in the same zone. Having the needed experience, the project team can manage the project smoothly.

The project score sheet for government regulations is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions A. Government Regulations | Definition Level —————→ | | | | | | Score |
|---|----------------------------|---|---|---|---|-----------|-------|
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| A1. Project Teams identified government regulations related to the project? | 0 | 1 | 2 | 3 | 4 | 5 | |
| A2. Project Team prepared all documents required by government regulations or for construction permits? | 0 | 1 | 2 | 3 | 4 | 5 | |
| A3. Project Team submitted all permit applications? | 0 | 1 | 2 | 3 | 4 | 5 | |
| A4. Project Team received required permits? | 0 | 1 | 2 | 3 | 4 | 5 | |
| A5. Project Team has previous experience with similar projects in same construction zone? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | | Out of 25 | |

B. Scope Definition

Pre-project planning is actually the project phase that includes all the tasks between the project initiations to the detailed design. Many researchers have been studying this project phase carefully and the results obtained were showing that greater pre-project planning efforts can improve the performance on construction projects when talking about scope, schedule, and cost [36]. Researches have shown the significance of pre-project planning on construction projects and its great influence on project success. Findings have proven that higher levels of pre-project planning effort could result in noteworthy cost and schedule savings in any construction project. Therefore, the decisions taken during this stage have high impact on the outcome.

One of the major practices done during the pre-project planning process is defining the scope of work of the project. Project scope definition is the practice when projects are defined and planned for execution. It is a very critical stage because the risks related to the project are analyzed and the particular project execution approach is also defined. The level of effort consumed during this scope definition phase will influence the success of the detailed design, construction, and start-up phases of a construction project [36]. Due to the noteworthy savings linked with improved project predictability, a comprehensive scope definition preceding project execution is vital to project success.

Regarding the construction of transportation projects, it is important to mention that pre-planning phase requires careful and complete coordination among all elements involved in the project tasks, such as environmental assessment, planning and programming, right-of-way acquisition, design, utility adjustments, construction, maintenance plans, specifications, and estimates development. In order to achieve the best results for all elements mentioned above, the project should have a good definition of scope. The involved teams should know the reason behind this project, the quality of product needed, and any other element that will give them a better understanding of the project. In conclusion, without proper scope definition, a transportation project will not achieve its goals including cost, time, safety level, and environmental impacts.

In the predictive model, scope definition will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for scope definition. The explanation for each question is as follow:

B1. Project scope discussed with engineering team?

Explanation: The project scope must be discussed with the engineering team in order to assure proper understanding of the project scope. Confirming that the engineering team properly understands the project scope will guarantee proper planning for the project as well.

B2. Project Scope discussed with all stakeholders in formal documented meetings?

Explanation: Project scope is the core of any project. Any change in the project scope will lead to major changes in the project plan, design, construction, etc... Therefore, it is recommended to discuss the project scope with all stakeholders by having format meetings documents.

B3. Project scope draft documents reviewed by all stakeholders?

Explanation: Due to the criticality of the project scope, all stakeholders should review the scope draft documents and make sure they are matching in order to approve them at a later stage.

B4. Project scope documents approved?

Explanation: The project team should assure that the project scope is approved by all stakeholders before proceeding further in the project. If the project scope documents are not approved, this might cause serious problems in the future that can be avoided at this stage.

B5. Project Scope is finalized and frozen by all stakeholders?


Explanation: After approving the project scope documents, the project scope must be frozen so no one can change it in the future. Changing the project scope leads to major changes that might cost a lot for the consultant, contractor, and the owner. The project score sheet for scope definition is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions B. Scope Definition | Definition Level | | | | | | Score |
|--|--|---|---|---|-----------|---|-------|
| |  | | | | | | |
| B1. Project scope discussed with engineering team? | 0 | 1 | 2 | 3 | 4 | 5 | |
| B2. Project Scope discussed with all stakeholders in formal documented meetings? | 0 | 1 | 2 | 3 | 4 | 5 | |
| B3. Project scope draft documents reviewed by all stakeholders? | 0 | 1 | 2 | 3 | 4 | 5 | |
| B4. Project scope documents approved? | 0 | 1 | 2 | 3 | 4 | 5 | |
| B5. Project Scope is finalized and frozen by all stakeholders? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

C. Route Selection

As mentioned earlier, transport planning plays an unquestionably strategic role in the economic growth of any country. However, when done carelessly, this planning can be harmful to the biophysical and social environment of the country. In transport route planning, usually, few alternative routes are proposed, typically showing the interest of the proponent. If needed, an environmental impact assessment can be carried out for each alternative. A good plan is one in which the planning system directly takes into consideration environmental and socio-economic concerns when choosing alternative routes. Such a plan facilitates sustainable development. Political and industrial lobbying is likewise known to have an important role in the identification of the route alternatives. However, this will lead to stakeholder disappointment and dissatisfaction with the whole planning process [37; 38].

A good route selection shall account for environmental and regulations concerns. The plan should have a proper land use. A main concern must be to reduce the number of cuts and fill during the construction of the transportation project. This selection will reduce cost, schedule, and environmental impact of the construction. The cost will be reduced because less effort will be needed due to less work. When work is reduced, the cost is reduced as well as the schedule is shortened. In other words, it can be considered a good choice as the infrastructure costs are kind of reduced. Environmental impacts will reduce as well due to the fact that less machine time will be required to finish the construction of the transportation project. This will happen because proper route selection will reduce the energy required to build the highway.

Proper route selection is a major decision that teams shall take before starting the project. Some other considerations that shall be taken into account are safety, transport system efficiency, technical and financial viability, and socio-economic demands. A good route selection is a one that can provide good supply chain. As long as the route is accessible, materials and equipment can be supplied easily without delay and without causing major congestions in the surrounding areas. It is important to mention that reducing the waiting time on roads is one major goal for all transportation projects. This is applicable for projects under construction where reducing the delay time of people on adjacent roads is the main goal. Similarly, after

finishing the construction of the transportation project, the main aim is to save people's time and reduce the amount of time people spend on roads. This will benefit the whole economy, rather than only individuals. Moreover, a proper road selection is a one that meets the public demand and expectations. For better route selection, programs such as Geographic Information Systems (GIS) can be used to determine the best route selection by considering multiple criteria that the selection will be based on.

In the predictive model, route selection will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for route selection. The explanation for each question is as follow:

C1. Project Team finalized and froze project scope before starting route selection?

Explanation: Route selection cannot start before finalizing the project scope and having it frozen. If the project scope is not finalized, starting the route selection is useless.

C2. Project Team set practical criteria for route selection?

Explanation: The project team should put certain criteria for route selection. Those criteria should be practical and reasonable in order to select the best alternative at a later stage.

C3. Project Team considered alternative route options?

Explanation: The project team should find various alternatives. Having one alternative is not a good practice as it might be impractical or unfeasible for example.

C4. Project Team discussed pros and cons of each route alternative and documented the study?

Explanation: After coming up with alternatives, the project team must discuss the pros and cons of each alternative in order to have the best decision later on. Knowing the pros and cons of each alternative will make the planning better after knowing the needed information.

C5. Project Team decided on optimal route and issued document to that effect?

Explanation: The project team shall select the optimal route. The selection shall be based on the criteria suggested earlier.


The project score sheet for route selection is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions C. Route Selection | Definition Level | | | | | | Score |
|--|--|---|---|---|-----------|---|-------|
| |  | | | | | | |
| C1. Project Team finalized and froze project scope before starting route selection? | 0 | 1 | 2 | 3 | 4 | 5 | |
| C2. Project Team set practical criteria for route selection? | 0 | 1 | 2 | 3 | 4 | 5 | |
| C3. Project Team considered alternative route options? | 0 | 1 | 2 | 3 | 4 | 5 | |
| C4. Project Team discussed pros and cons of each route alternative and documented the study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| C5. Project Team decided on optimal route and issued document to that effect? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

D. Risk Management

The construction industry is a risky industry by nature due to the high complexity involved in it and due to the uncertainties associated. Risk management has been emerging in the past decade to study all types of risks involved in the construction industry. Various types of risks have been discussed and studied to help contractors evaluate risk and take appropriate decisions such as taking the risk, mitigating the risk, ignoring the risk, or sharing the risk. In all cases, a decision must be taken that will suit all parties involved in the construction project. However, when talking about transportation projects, risks are also involved in such types of projects. Accordingly, decision shall be taken to minimize the impact of those risks on the project cost, schedule, safety level, and environmental impacts.

Considering project scope elements is perhaps one of the most applicable ways to identify sources of risk. That is because scope elements will describe the entire work, which the project team shall perform. By totally defining all the work included in the scope and properly describing the scope elements, the project team basically addresses risk sources. This will lead to minimize the risks that might arise due to the lack of satisfactory management of these sources. A similar approach has been productively used in several efforts in the past, such as those by Construction Industry Institute [39, 40].

The risks involved in a transportation project can be divided into three categories such as risks due to project decision, risks due to design, and risks due to execution. The risks involved in the project decision can occur due to certain project strategies, such as need and purpose documentation, programming and funding data, public involvement, investment studies and alternatives assessments, and key team member coordination. More risks can occur due to project decision because of owner or operator philosophies such as design philosophy, operating philosophy, maintenance philosophy, and future expansion and alteration considerations. Additional risks might occur due to project decision regarding project requirements such as functional classification and use, survey of existing environmental conditions, value engineering, evaluation of compliance requirements, and determination of utility impacts [41].

Risks due to design might be because of certain site information such as geotechnical characteristics, hydrological characteristics, permitting requirements, and environmental documentation. More risks due to design can occur because of property description such as ownership determinations, constraints mapping, right-of-way mapping, and right-of-way site issues. Additional risks involved are due to location and geometry such as horizontal and vertical alignment, schematic layouts, control of access, and cross-sectional elements. Extra risks can occur due to structures such as bridge structure elements, hydraulic structures, and miscellaneous design elements. Risks due to design parameters such as constructability and provisional maintenance requirements shall be considered as well. Finally, the risks involved due to installed equipment such as equipment list, equipment location drawings, and equipment utility requirements must be included [41].

Risks that are involved with the execution approach are due to acquisition strategy, including long-lead parcel and utility adjustment identification, local public agencies utilities contracts and agreements, long-lead/critical equipment and materials identification, project delivery method and contracting strategies, procurement procedures and plans, utility agreement and joint-use contracts, design or construction plan and approach, advance acquisition requirements, and appraisal requirements. Extra risks due to deliverables must be considered as well. Additional risks due to project control are the right-of-way and utilities cost estimates, design and construction cost estimates, project schedule control, project cost control, safety procedures, and project quality assurance and control. Furthermore, risks involving project execution plan, such as environmental commitments and mitigation, interagency coordination, local public agency contractual agreements, interagency joint-use agreements, preliminary traffic control plan, and substantial completion requirements, must be included as well [41]. All of those risks must be considered before the start of the project, and proper action must be taken to reduce the impact of those risks.

In the predictive model, risk management will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for risk management. The explanation for each question is as follow:

D1. Project Team discussed uncertainties involved in the project?

Explanation: The project team should fully understand the project. Moreover, the project team should discuss the uncertainties involved in the project. Having previous experience in similar project in the same zone will help at this stage in order to know more about the uncertainties.

D2. Project Team identified possible sources of risk?

Explanation: the project team should sit together and identify the possible sources of risk. Again, having previous experience in similar project in the same zone will help at this stage in order to know more about the sources of risk.

D3. Project Team documented sources of risk?

Explanation: After knowing the sources of risk, the project team shall document those possible sources of risk in order to refer to them in the future if that was required.

D4. Project Team simulated and modeled risk sources and possible outcomes?

Explanation: The project team should not only identify and document the possible sources of risk. The project team should study those sources of risk and know the possible outcomes. The project team should have the needed knowledge to come up with the best possible plan.

D5. Project Team developed detailed plans to combat possible risk sources in the project?

Explanation: After completely studying possible sources or risk and the possible outcomes, the project team should develop detailed plans to combat the possible risk sources in the project.

The project score sheet for risk management is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions D. Risk Management | Definition Level —————→ | | | | | | Score |
|---|----------------------------|---|---|---|-----------|---|-------|
| D1. Project Team discussed uncertainties involved in the project? | 0 | 1 | 2 | 3 | 4 | 5 | |
| D2. Project Team identified possible sources of risk? | 0 | 1 | 2 | 3 | 4 | 5 | |
| D3. Project Team documented sources of risk? | 0 | 1 | 2 | 3 | 4 | 5 | |
| D4. Project Team simulated and modeled risk sources and possible outcomes? | 0 | 1 | 2 | 3 | 4 | 5 | |
| D5. Project Team developed detailed plans to combat possible risk sources in the project? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

E. Resource Allocation

Resources in sustainable construction project are vital. Without the right resources, construction projects cannot be done. Similarly, without the right resources, a sustainable construction will not be considered sustainable. Resources mainly include equipment, materials, manpower, money, natural resources, and everything needed to successfully finish construction projects on time, within budget, and meeting the scope of work.

In sustainable construction projects, it is recommended to use energy rated construction equipment, which consumes low energy to work. The main aim is to reduce the equipment's emissions during construction. Moreover, reducing fuel use is also a target during construction. In addition, materials are recommended to be renewable such as wind, solar, water, etc... On the other hand, it is recommended to deplete nonrenewable resources. Recycled materials can be used as well in order to eliminate or at least reduce the waste. Improving the reliability and performance of materials and systems is important for sustainable construction projects. Other practices, such as increasing the knowledge of recycling on site between the workers, are important as well.

For the construction of transportation projects, such as highways, reducing the energy required to build the highway is one of the major practices for better sustainable construction. Moreover, construction should be done using quality materials that will reduce maintenance costs of cars in the future. In sustainable construction projects, one of the major goals is to have quality products that would last long and function properly. Nonetheless, it is significant to use the available resources effectively and efficiently. This practice will save the contractor time and money. Finally, improving the transportation of materials to the site will always enhance the project schedule and cost.

In the predictive model, resource allocation will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for resource allocation. The explanation for each question is as follow:

E1. Project Team discussed required resources?

Explanation: The project team should discuss the required resources for the project in order to plan properly for them.

E2. Project Team defined required resources?

Explanation: The project team should define the required resources properly. The project team should know what the project needs from resources in order to be completed without major problems. The project team should know the quality and quantity of resources.

E3. Project Team documented required resources?

Explanation: After defining the resources, the project team should document the required resources in order to refer to them in the future.

E4. Project Team prepared a detailed project schedule?

Explanation: the project team should prepare a detailed project schedule in order to prepare a resource loaded schedule at a later stage.

E5. Project Team prepared resource loaded schedule?

Explanation: The project team should prepare a resource loaded schedule in order to know the resources required for each activity and during a certain period of time in order to finish the project successfully.

The project score sheet for resource allocation is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions E. Resource Allocation | Definition Level | | | | | | Score |
|--|------------------|---|---|---|-----------|---|-------|
| | <div>→</div> | | | | | | |
| E1. Project Team discussed required resources? | 0 | 1 | 2 | 3 | 4 | 5 | |
| E2. Project Team defined required resources? | 0 | 1 | 2 | 3 | 4 | 5 | |
| E3. Project Team documented required resources? | 0 | 1 | 2 | 3 | 4 | 5 | |
| E4. Project Team prepared a detailed project schedule? | 0 | 1 | 2 | 3 | 4 | 5 | |
| E5. Project Team prepared resource loaded schedule? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

F. Labor Productivity

In fact, the construction industry has regularly been categorized to have a very low or even negative rate of productivity increase [42]. So, increasing the rate of productivity will benefit the contractor as the project will be done on faster basis and within a lower cost. However, increasing the labor productivity is not an easy task and depends on various factors such as the safety of the labor, the experience they have, the atmosphere they are having throughout the construction of the project. Additionally, the labor productivity depends heavily on the learning curve concept, which states that as time passes while doing work, workers are gaining experience and this will allow them to finish the same work in the future within a shorter period of time. According to Huang et al. [43], construction productivity can be examined at industry, company, project, and activity level.

Construction industry is a very complicated industry where many factors take place. The contractor should be aware of such factors and must take action accordingly. Some actions that can be taken by the contractor that will influence the productivity are working overtime, increasing the crew, and increasing the number of starting points. Other factors that might influence the productivity, whether positively or negatively, are learning curve, delays in receiving the materials and equipment, and interruptions due to injuries or fatalities on-site [44].

Therefore, safety plans affect the productivity of the labor in any construction project. If an accident happens on site, the workers located in the place will be interrupted to check the accident and the people who are injured. If a fatal accident happens and the workers lost one of them, this will reduce their productivity due to their low morale. In all cases, productivity of the labor depends on various factors and the contractor must be aware of it during the planning phase of the project. It is important to mention that, at the end, workers are human beings that could get tired or sick at any time. Due to various reasons such as the ones mentioned earlier, predicting and measuring the productivity of labor is extremely hard for managers during any construction project [45].

In the predictive model, labor productivity will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for labor productivity. The explanation for each question is as follow:

F1. Project Team discussed the project labor requirement?

Explanation: the project team is asked at the beginning of the project to sit and discuss the labor requirement. The project team should be aware of the quality and amount of labor required to finish the project successfully.

F2. Project Team discussed labor availability?

Explanation: The project team should sit and discuss the available labor. This will aid in predicting the labor productivity.

F3. Project Team discussed the expected labor productivity?

Explanation: after knowing the available labor, the project team can expect the labor productivity based on normal construction conditions.

F4. Project Team consulted available past and current data for information on labor productivity in similar projects?

Explanation: Having available past and current data from previous similar projects will help in predicting the labor productivity. Data from previous similar projects will make the labor productivity more reliable.

F5. Project Team carried out extensive labor research study?

Explanation: Having data from previous, similar projects is not enough since extensive research is also required for better labor productivity predictions. Research should include the factors that affect the labor productivity.

The project score sheet for labor productivity is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions F. Labor Productivity | Definition Level —————→ | | | | | | Score |
|---|----------------------------|---|---|---|-----------|---|-------|
| F1. Project Team discussed the project labor requirement? | 0 | 1 | 2 | 3 | 4 | 5 | |
| F2. Project Team discussed labor availability? | 0 | 1 | 2 | 3 | 4 | 5 | |
| F3. Project Team discussed the expected labor productivity? | 0 | 1 | 2 | 3 | 4 | 5 | |
| F4. Project Team consulted available past and current data for information on labor productivity in similar projects? | 0 | 1 | 2 | 3 | 4 | 5 | |
| F5. Project Team carried out extensive labor research study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

G. Nighttime Construction

In certain construction projects, project managers should take the decision whether to increase the working hours or not. Increasing the working hours usually results either in working overtime or working in night shifts. Similarly, in highway construction, nighttime construction is being practiced recently. However, nighttime construction has advantages and disadvantages that would affect the decision of the project team.

One of the advantages of nighttime construction is improving the schedule of the project. Moreover, in some countries such as the UAE, the high temperature during summer times will not allow the workers to work properly, which will impact the progress of the work. Therefore, nighttime construction might be the solution in order to maintain workers' health and productivity. Some of the disadvantages of nighttime construction would be the impact on the total cost of the project, noise pollution, and the safety level of the project [46]. Another limitation for nighttime construction is huge amount of lightning required to perform the work at night. In all cases, nighttime construction can be a good solution for any project team in order to enhance the progress of the work.

In the predictive model, nighttime construction will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for nighttime construction. The explanation for each question is as follow:

G1. Project Team discussed project scheduling strategy?

Explanation: For a better planning of the project, the project team is asked to discuss the project scheduling strategy. This will help them in identifying the time required to finish each activity and the whole project at the end. Obviously, the schedule of the project will depend heavily on labor productivity and on the data of previous, similar projects.

G2. Project Team discussed the possible need for overtime or night shifts?

Explanation: The project team is asked to discuss the possible need for overtime or night shifts. This way the project team will have a plan to speed up the project if required.

G3. Project Team studied the possible effects of overtime/night shifts strategy?

Explanation: The project team should know and study the possible effects of overtime or night shift strategy. This way the project team will be able to analyze the situation properly in order to take the right decision.

G4. Project Team documented the cost and schedule results of overtime study?

Explanation: The project team should document the cost and schedule results of the overtime or night shift study. Knowing the impact on cost and schedule will enhance the project plan.

G5. Project Team reviewed the project strategy based on the cost and schedule study?

Explanation: The project team should review the project strategy based on the cost and schedule study. The new strategy can be with overtime, night shifts, or without both.

The project score sheet for nighttime construction is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions G. Nighttime Construction | Definition Level | | | | | | Score |
|--|------------------|---|---|---|-----------|---|-------|
| | <div>→</div> | | | | | | |
| G1. Project Team discussed project scheduling strategy? | 0 | 1 | 2 | 3 | 4 | 5 | |
| G2. Project Team discussed the possible need for overtime or night shifts? | 0 | 1 | 2 | 3 | 4 | 5 | |
| G3. Project Team studied the possible effects of overtime/night shifts strategy? | 0 | 1 | 2 | 3 | 4 | 5 | |
| G4. Project Team documented the cost and schedule results of overtime study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| G5. Project Team reviewed the project strategy based on the cost and schedule study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

H. Long Lead Item Procurement

When talking about the construction industry, the term procurement system is defined as “the framework within which construction is brought about, acquired or obtained” [47]. When referring to infrastructure development and delivery, from the viewpoint of a client, procurement includes the set of strategic decisions taken to get capital assets and services that will meet specified project goals. The delivery of infrastructure projects is a complicated process due to various challenges, such as program delays, safety, budget constraints, quality, and now environmental concerns. It is well known that efficient planning of materials procurement, especially long lead item procurement and storage on construction sites, can cause important improvements in project profitability and construction productivity.

Material procurement and storage on construction sites need to be appropriately planned and fulfilled in order to avoid the negative impacts such as excessive material inventory on-site or material shortage. It is important to mention that material shortage will reduce the productivity and will definitely cause the projects to delay. So, problems in the supply and flow of construction material were repeatedly mentioned as the main causes of financial losses and productivity degradation [48].

Ordering fewer quantities of material more regularly reduces the locked-up capital in material inventories. Nevertheless, it increases the chance of project delays due to material shortages. In contrast, ordering more quantities of material less regularly reduces the chance of project delays due to material shortage. However, it can increase the cost of locked-up capital on-site. Good planning should consider this critical tradeoff during the planning of material procurement and storage on-site. This will become more important when it comes to long lead items procurement due to the risk involved in supplying such items on time without delaying the construction of the projects. Numerous research studies were done to study the procurement and storage of material on-site. Such material procurement studies focused basically on examining the impact of material procurement on construction labor productivity [49]. Other studies focused on applying “just-in-time” strategy in construction projects [50]. In all cases, for long lead item, the major concern is when to order the item so the construction of the transportation project will not be delayed by any chance due to

those long lead items. Knowing when to order long-lead/critical equipment and materials will save time during construction and improve the productivity in the project.

In the predictive model, long lead items procurement will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for long lead items procurement. The explanation for each question is as follow:

H1. Project Team discussed the equipment and/or materials that require long time to reach on site?

Explanation: the project team is asked to discuss the long lead items or the equipment and materials that require long time to reach to site due to various reasons, such as fabrication time, shipping time, etc...

H2. Project Team defined long lead items?

Explanation: The project team should define the long lead items that are required for this particular project. To avoid possible delays, this should happen at an early stage of the project.

H3. Project Team documented long lead items (equipment or materials)?

Explanation: The project team is asked to document the long lead items whether equipment or materials. This will be essential during the ordering of the items.

H4. Project Team ordered long lead items?

Explanation: After documenting the long lead items, the project team is asked to order those items at the earliest possible time in order to avoid any delays.

H5. Project Team received long lead items on site?

Failing to have the long lead items on site at the right time will lead to delays in the project schedule if the activities that need those items are critical. Therefore, receiving the items at the right time is essential for smooth project progress.

The project score sheet for nighttime construction is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions H. Long Lead Items Procurement | Definition Level → | | | | | | Score |
|--|-----------------------|---|---|---|-----------|---|-------|
| H1. Project Team discussed the equipment and/or materials that require long time to reach on site? | 0 | 1 | 2 | 3 | 4 | 5 | |
| H2. Project Team defined long lead items? | 0 | 1 | 2 | 3 | 4 | 5 | |
| H3. Project Team documented long lead items (equipment or materials)? | 0 | 1 | 2 | 3 | 4 | 5 | |
| H4. Project Team ordered long lead items? | 0 | 1 | 2 | 3 | 4 | 5 | |
| H5. Project Team received long lead items on site? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 25 | | |

I. Environmental Impact Assessment Studies

A key function of planners is to make the best use of a country's land and resources for various construction projects. This will have a greater meaning when it comes to infrastructure projects on which economic development depends. Transportation projects usually include both economic and environmental issues facing a country as it develops and changes. Considerations of sustainability, along with the extensive use of collaborative planning, design, and construction, need tools that help long-term impact analysis. For those reasons, environmental impact assessment studies have been made.

Developments in the transportation industry have a significant impact on the environment because transportation is one of the main sources of greenhouse gas emissions. In addition, transportation facilities can generate noise and vibration, cause habitat fragmentation, affect historic resources, lead to community cohesion, and impact wetlands and other natural ecosystems as well as other social and community characteristics. Consequently, applying a transportation project includes dealing with a variety of challenges to control unwanted effects on the environment. Environmental impact assessment (EIA) has been used as a tool to consider environmental issues in decision making. Over the years, the environmental impact assessment process has grown to meet concerns about applying such decision-making processes to strategic environmental assessments [51].

Glasson et al. [52] defined EIA to be a systematic process that studies, beforehand, the environmental consequences of a certain development action. In EIA, the environment is considered to be a system comprising human beings, the climate, air, water, soil, and the landscape. Moreover, EIA is concerned as well with the interactions among these components. EIA delivers a unique opportunity to suggest ways that can reduce the impact on the environment. Besides, EIA expects the constraints and conflicts between a proposed project and the environment [53]. There are no standard rules concerning how to do an environmental assessment, even though EIA is dependent on geospatial information to reach an assessment. In conclusion, environmental impact assessment studies will enhance the understanding of the environmental impacts of certain transportation projects.

In the predictive model, environmental impact assessment studies will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for environmental impact assessment studies. The explanation for each question is as follow:

I1. Project Team discussed general sustainability and environmental impacts of construction?

Explanation: the project team is asked to discuss the general sustainability and environmental impacts of the construction project. This will help in having a better sustainable plan for construction.

I2. Project Team discussed specific construction activities that affect resource use and pollution?

Explanation: The project team should discuss specific construction activities that will affect resource use and pollution. The project team should try to utilize properly the available resources. Moreover, the project team should take care of the air, water, and noise pollution that might be caused due to certain construction activities.

I3. Project Team reviewed locally available renewable resources?

Explanation: The project team should review the locally available renewable resources. This will allow the project team to use efficiently the local renewable resources such as water, wind, etc... Having previous experience on similar projects in the same construction zone can help when looking for available renewable resources.

I4. Project Team performed an Environmental Impact Assessment (EIA) study?

Explanation: the team is asked to perform an Environmental Impact Assessment (EIA) study before starting the project. This will aid in a better sustainable planning of the project. The EIA study will give the project team an idea about the environmental impacts that might occur because of the project.

I5. Project Team reviewed their environmental shortcomings according to the results of the EIA study?

Explanation: After finishing the EIA study, the project team is asked to review the environmental shortcomings and take the needed action to reduce those shortcomings if possible.

The project score sheet for environmental impact assessment studies is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions I. Environmental Impact Assessment Studies | Definition Level —————→ | | | | | | Score |
|---|----------------------------|---|---|---|---|-----------|-------|
| I1. Project Team discussed general sustainability and environmental impacts of construction? | 0 | 1 | 2 | 3 | 4 | 5 | |
| I2. Project Team discussed specific construction activities that affect resource use and pollution? | 0 | 1 | 2 | 3 | 4 | 5 | |
| I3. Project Team reviewed locally available renewable resources? | 0 | 1 | 2 | 3 | 4 | 5 | |
| I4. Project Team performed an Environmental Impact Assessment (EIA) study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| I5. Project Team reviewed their environmental shortcomings according to the results of the EIA study? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | | Out of 25 | |

J. Safety Plans

All over the world, the efforts through the last couple of decades were to improve the safety and health of workers on construction sites. Previous researches emphasized that the designer, contractor, subcontractor and even the owner can influence the safety and health of the construction workers [54]. Researchers identified ways to enhance the safety and health of construction workers during construction. Huang [55] proved that the owner has a great influence on the safety level of construction projects. Project owners can have a main role in workers' safety by taking certain actions such as putting project safety goals, selecting constructors after considering their safety performance, mentioning safety in the construction contract, and proactively participating in safety on the project. Furthermore, recent research findings keep on revealing that the owner's role in jobsite safety is important and cannot be ignored.

Comparing to other parties that are involved in a project, contractors normally take the main role in addressing construction worker safety and health. Many studies have been made on how the contractors can improve the safety level of a project. According to Occupational Safety and Health Act (OSHA) the employee safety is the sole responsibility of the employer. Moreover, the general conditions of a construction contract usually state that the contractor has a major responsibility for safety on the construction site [56].

A lot of studies have been made about the contractor's role and his or her impact on the construction site safety and health. Various studies suggested elements for successful safety programs. In 1994, Meridian Research Group issued a report mentioning several elements as vital for an effective construction safety program [57; 58]. Elements that are vital for an effective construction include complete written safety and health plan/program, the involvement of the employee in the design and then the operation of the safety and health program, a safety and health responsibility and accountability noticeably established and applied, and finally regular worksite inspections.

Liska et al. [59] made a research study that lead to the development of eight safety-related techniques (zero accident techniques). If applied in a quality manner within a total safety program, those techniques will result in superb project safety performance. Out of the eight techniques, mainly five had the greatest impact on attaining a zero or near zero accident projects. The five techniques are Pre-Project/Pre-Task Planning, Safety Incentives, Accident and Near Miss Investigation, Safety Orientation/Training, and Alcohol and Substance Abuse Program. Jaselskis et al. [60] suggested extra strategies for attaining excellence in construction safety performance at the project as well as the company levels.

Moreover, Hinze et al. [61] introduced nine practices that can be followed by contractors to make zero accidents a reality. The study was made to observe the changes made from the time when the initial zero accidents research was issued [59]. The nine elements, which resulted from that research are staffing for safety, recognition and rewards, accident or incident reporting and investigations, demonstrated management commitment, safety planning, safety training and education, subcontractor management, worker participation and involvement, and drug and alcohol testing.

Recently, studies are showing that designers can influence the safety and health of workers in the construction industry. Rajendran, S. and Gambatese, J. A. [62], showed that architects and designer can influence the safety level of a project as well. Removing the hazard is generally recognized as a more effective way to enhance safety than providing personal protective equipment to workers or minimizing the hazard [63; 64]. Designers are considered to be in the best position to implement certain safety design recommendations that can prevent hazardous conditions on the site [65]. Various examples can be given to show how architects and designers can improve construction site safety through the design process [66]-[69].

Subcontractor as well can influence the safety level knowing that in certain projects the safety level is influenced by them [70], [71]. Researchers identified and assessed safety performance of a project given that the four parties, involved and dedicated to worker safety, are needed. All of the parties should do their best to develop a good safety culture and assure to create work environment free of injuries on all of the projects they will perform. If present, such acknowledgment would be

considered as an additional motivation to project teams to maintain a high level of safety performance [72]. However, the important question that arises right now is that if an accident happens and an injury or fatality occurs during the construction of a project that is supposed to be sustainable, can we still consider the project to be sustainable?

The safety and health of the construction workers play a major role in completing sustainable projects in the construction industry. From the construction industry's current viewpoint of sustainability, construction should include safety and health of the facility occupants as well as the workers. It should be known that assuring the safety and health of the workers who construct the facilities is a major part of sustainability. Sustainable construction practices must consider the entire lifecycle of the facility including the construction phase of the project. The sustainable safety and health concept targets to take into consideration the construction worker's safety and health. The worker's safety and health should be considered from start to finish of a particular project. It should be considered for each future project a worker will be involved in. Finally, it should be considered after retirement, during the worker's remaining lifetime [62].

The safety plan starts from project team selection, which is comprised of designer selection, contractor selections and subcontractor selection. Safety and health should be mentioned in contracts. Moreover, safety hazard identification should be mentioned in construction drawings. Specification of less hazardous materials is also important. Construction projects should have safety and health professionals including competent personnel for all high hazard tasks, contractor safety representative, subcontractor safety representative, and owner safety representative. Furthermore, management commitment to safety and health, and owner/representative commitment to safety and health as well should be considered.

Safety planning must look ahead schedule and include safety and health during conceptual planning phase, constructability review, pre-task planning, designing for worker safety and health, job hazard analysis, on and off site traffic plan, life cycle safety design review, safety checklist for designers, contractor site specific safety plan, subcontractor site specific safety plan, and good housekeeping plan. In addition, certain training and education practices, such as safety training for

designers, assessment of all equipment operators' skills and training, safety orientation for all workers, toolbox meetings, safety training for all field supervisors, OSHA 10 h training for all workers, regular safety training for all project personnel, and contractor mentors subs to improve safety performance, should be done. Additionally, safety resources such as task-based hazard exposure database should be available.

Drug and Alcohol Program should take place as well through frequent testing programs. Moreover, accident investigation and reporting should be done on site. On the other hand, safety inspection should take place in case in order to identify and correct safety violations identified and corrected. Additionally, employees empowered with stop authority and employee safety committee and leadership team should be developed. Another important point is the safety accountability and performance measurement, such as project accountability and responsibility, contractor evaluation based on safety performance, safety performance evaluation using safety metrics, and supervisors evaluated based on safety performance. Finally, industrial hygiene practices, such as engineering controls for health hazards, hearing protection program, respiratory protection program, stretch and flex program, and ergonomic task analysis and remediation, should be considered.

From proper safety plans, contractors can decrease the risk for accidents in the construction zone. In other words, the main aim is to minimize the number of accidents during construction. Moreover, contractors can avoid nearby property damages, which might be costly in some cases due to compensation costs. Another vital goal from proper safety planning is to improve workers' health, which will reduce medical expenses and insurance costs in the near future.

In the predictive model, safety plans will be evaluated based on the Project Score Sheet shown below. The Project Score Sheet has five questions that can be used to evaluate the level of planning for safety. The explanation for each question is as follow:

J1. Project Team defined Safety Risks?

Explanation: The project teams should define the safety risks that will be involved in the project. Previous experience on similar project in the same zone can help in defining safety risks.

J2. Project Team studied the site?

Explanation: The project team should study the site properly before starting construction. This will enhance the safety plans due to a better understanding of the place where the project will be constructed.

J3. Project Team prepared Plans for Safety as per OSHA or local equivalent?

Explanation: The project team is asked to prepare the safety plans based on OSHA or local equivalent. This is the least the project team shall do in order to have a good safety plan.

J4. Project Teams prepared lists of safety equipment required during construction?

Explanation: The project teams should prepare lists of safety equipment that is required during construction. This will help in maintaining a good safety level during the construction.

J5. Project Team prepared safety training courses for white and blue color workers on the project?

Explanation: The project team should give safety training courses before starting construction to all workers (white or blue workers) who will be working on the project. Safety training is essential for a better understanding of how to avoid bad practices that might the workers' safety during construction.

The project score sheet for safety plans is shown on the next page.

Sustainable Planning Index (SPI)

Project Score Sheet

Definition Level:

- 0- Point is not discussed**
- 1- Point discussed but no action is taken**
- 2- Point discussed and action decided**
- 3- Actions already started**
- 4- Actions are almost done**
- 5- Actions are complete and reviewed**

| Input Questions J. Safety Plans | Definition Level → | | | | | | Score |
|--|-----------------------|---|---|---|---|-----------|-------|
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| J1. Project Team defined Safety Risks? | 0 | 1 | 2 | 3 | 4 | 5 | |
| J2. Project Team studied the site? | 0 | 1 | 2 | 3 | 4 | 5 | |
| J3. Project Team prepared Plans for Safety as per OSHA or local equivalent? | 0 | 1 | 2 | 3 | 4 | 5 | |
| J4. Project Teams prepared lists of safety equipment required during construction? | 0 | 1 | 2 | 3 | 4 | 5 | |
| J5. Project Team prepared safety training courses for white and blue color workers on the project? | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | | Out of 25 | |

4.2 Output Variables

The predictive model has six output variables. Each output variable will be discussed separately. Moreover, how to measure each output variable will be shown afterwards. Each output will be studied separately and related directly to the input variables that will affect it. The output variables are the following:

1. Absolute Cost
2. Absolute Schedule
3. Relative Cost
4. Relative Schedule
5. Environmental impacts
6. Safety Level

1. Absolute Cost

Every construction project has its own cost. Calculating the cost at the end of the project will result in knowing how much did this project cost to be constructed. This cost, calculated at the end, can be considered to be the actual cost of the construction project. Absolute cost can be calculated by dividing the actual cost of a project by the actual cost of previous similar projects. A project can have an actual cost that is different from other construction projects. The actual cost of the project can be more than the actual cost of previous projects or the other way around. In this paper, the absolute cost factor is a measure in percentage. For instance, a project that has 1.15 absolute cost factor indicates that the actual cost of the project is 15% more than the actual cost of the previous projects. On the other hand, if a project has a 0.8 absolute cost factor indicates that the actual cost of the project is 20% less than the actual cost of previous projects. There are no fixed percentages for actual cost factors. For this project, the hypothetical value of absolute cost ranges between 0.75 and 1.25 since the actual cost of any project is 25% plus or minus the actual cost of most construction projects. The absolute cost depends on the ten inputs that were mentioned earlier in this paper. The impact of each input on absolute cost is discussed briefly below:

- A. **Government Regulations:** *The absolute cost depends on the government regulations since the government regulations might increase the cost due to limitations in construction working hours, for example.*
- B. **Scope Definition:** *Scope Definition will impact the cost as well due to the fact that the scope decides what the cost will be. Furthermore, a change in the scope will change the cost as well.*
- C. **Route Selection:** *Route selection will impact the cost of the project as well. For instance, different roads will have different infrastructure costs.*
- D. **Risk Management:** *Risk management will definitely impact the cost. A good risk management will reduce the impact of risks on the project in the future. Accordingly, cost is saved as well.*
- E. **Resource Allocation:** *Resource allocation will impact the cost as well since the amount of labor and the facilities such as accommodation will cost more. For instance, an accommodation for one thousand workers will not fit five thousand workers, so they will need a bigger accommodation which will cost more.*
- F. **Labor Productivity:** *Labor productivity will impact the cost as well since low labor productivity means that the contractor is asked to pay workers for more days of work.*
- G. **Nighttime Construction:** *Nighttime construction will have cost impact also since working overtime will cost more. The increase is considerable since the payment for an overtime hour is more than the payment for a regular hour. Moreover, payment for a night shift hour is more than the payment for a regular day hour.*
- H. **Long Lead Item Procurement:** *Long lead items will impact the cost since a delay in long lead items means paying more indirect costs as work is stopped and project is delayed.*
- I. **Environmental Impact Assessment Studies:** *Environmental impact assessment studies will have cost impact as well since such studies might result in huge changes in terms of construction activities and strategies.*

J. **Safety Plans:** *A better safety plan will definitely impact the cost as it will save a lot of money in terms of compensation, medical treatment for labors, etc...*

2. Absolute Schedule

Every construction project has its own schedule. Checking the schedule at the end of the project will result in knowing how much time was required to construct this project. This schedule, done at the end, can be considered to be the actual schedule of the construction project. Therefore, the actual schedule is the schedule of how the project was built. Absolute schedule can be calculated by dividing the actual duration of a project by the actual duration of previous similar projects. A project has an actual duration that is different from other construction projects. The actual duration of the project can be more than actual duration of previous projects or the other way around. In this paper, the absolute schedule factor is a measure in percentage. For instance, a project that has 1.15 absolute schedule factor indicates that the actual duration of the project is 15% more than the actual duration of the previous projects. On the other hand, if a project has a 0.8 absolute schedule factor indicates that the actual duration of the project is 20% less than the actual duration of previous projects. There are no fixed percentages for absolute schedule factors. For this project, the hypothetical values of absolute schedule ranges between 0.75 and 1.25 that is for the reason that the actual duration of any project is 25% plus or minus the actual schedule of most construction projects. The absolute schedule depends on the ten inputs mentioned earlier. The impact of each input on absolute schedule is discussed briefly below:

A. **Government Regulations:** *The absolute schedule depends on the government regulations since the government regulations might affect the schedule due to certain limitations in construction working hours, for example.*

B. **Scope Definition:** *Scope Definition will impact the schedule as well due to the fact that the scope decides what the schedule shall be. Furthermore, changing in the scope will change the schedule of the project as well.*

C. **Route Selection:** *Route selection will impact the schedule of the project as well. For instance, different roads require different timings to finish the infrastructure activities.*

D. **Risk Management:** *Risk management will impact the schedule. A good risk management will save time of the project in the future. If risks are studied properly, those risks can be avoided or mitigated, for example. This will impact the schedule due to quick action taken ahead of time before the possible risk happens.*

E. **Resource Allocation:** *Resource allocation will impact the schedule as well since the amount of labor will impact the schedule. For a certain activity, having three workers is better than having two. This will reduce the time to finish this activity.*

F. **Labor Productivity:** *Labor productivity will impact the schedule as well since low labor productivity means that the contractor will not finish the activity as per the schedule.*

G. **Nighttime Construction:** *Nighttime construction will have schedule impact also since working overtime will improve the schedule. The impact on the schedule is more considerable if the contractor decided to have a night shift. This way, the schedule will improve for sure.*

H. **Long Lead Items Procurement:** *Long lead items will impact the schedule since long lead items if they are delayed then the work will be stopped and the project will be delayed.*

I. **Environmental Impact Assessment Studies:** *Environmental impact assessment studies will have schedule impact as well since such studies might take some time to finish. Moreover, such studies might cause the contractor to change certain strategies that will impact the schedule.*

J. **Safety Plans:** *A better safety plan will definitely impact the schedule as it will save a lot of time that workers spend helping an injured worker for example.*

3. Relative Cost

In the construction industry, cost cannot be predicted perfectly due to the complex nature of construction projects. The actual cost of a project will rarely be the same as the estimated cost. The problem of cost overrun is a worldwide phenomenon. Due to those cost overruns, problems occur between owners (especially government owners), project managers, and contractors. Such problems happen because of the

project cost variation following the owner's decision to build. Cost overruns have a higher frequency [73], even though, in theory, it can be predicted that cost underruns have the same chance of occurring as cost overruns. Moreover, construction of transportation projects is mainly affected by this phenomenon. Historically, transportation projects experienced noteworthy construction cost overruns [74].

Relative Cost can be calculated by dividing the estimated cost of a project by the actual cost of the project. A project can have a relative cost that is different from other construction projects. The estimated cost can be more than actual cost or the other way around. In this research, the relative cost factor is measured in percentage. For instance, a project that has 1.15 relative cost factor indicates that the estimated cost of the project is 15% more than the actual cost of the project. On the other hand, if a project has a 0.8 relative cost factor indicates that the estimate cost is 20% less than the actual cost. There are no fixed percentages for relative cost. For this research, the hypothetical value of relative cost is within a range of 0.75 and 1.25 since the estimated cost is 25% plus or minus the actual cost in most of construction projects. Relative Cost depends on the ten index/inputs variables mentioned earlier in this research. The impact of each input on relative cost is discussed briefly below:

A. **Government Regulations:** *Relative cost depends on the government regulations since the government regulations might increase the cost due to limitations in construction working hours for example.*

B. **Scope Definition:** *Scope Definition will impact the cost as well due to the fact that the scope decides what the cost will be. So, changing in the scope will change the cost as well.*

C. **Route Selection:** *Route selection will impact the cost of the project as well. For instance, different roads will have different infrastructure costs.*

D. **Risk Management:** *Risk management will definitely impact the cost. Good risk management will reduce the impact of risks on the project in the future. Accordingly, cost is saved as well.*

E. **Resource Allocation:** *Resource allocation will impact the cost as well since the amount of labor and the facilities, such as accommodation, will cost more.*

For instance, an accommodation for one thousand workers will not fit five thousand workers, so they will need a bigger accommodation which will cost more.

F. **Labor Productivity:** *Labor productivity will impact the cost as well since low labor productivity means that the contractor is asked to pay workers for more days of work.*

G. **Nighttime Construction:** *Nighttime construction will have cost impact also since working overtime will cost more. The increase is considerable since the payment for an overtime hour is more than the payment for a regular hour. Moreover, payment for a night shift hour is more than the payment for a regular day hour.*

H. **Long Lead Item Procurement:** *Long lead items will impact the cost since a delay in long lead items means paying more indirect costs as work is stopped and project is delayed.*

I. **Environmental Impact Assessment Studies:** *Environmental impact assessment studies will have cost impact as well since such studies might result in huge changes in terms of construction activities and strategies. Moreover, such studies cost a lot/*

J. **Safety Plans:** *A better safety plan will definitely impact the cost as it will save a lot of money in terms of compensation, medical treatment for labors, insurance cost, etc...*

4. Relative Schedule

For any construction project, schedules are vital documents that set contract time [75]. From the schedules, engineers can know how long the project will take, which activity depends on the other, when the activity will start, when the activity will finish, and if the activity has any float. Moreover, some schedules can be resource loaded. Such schedules tend to give a good idea about the resources required to finish a certain activity. Schedulers usually try to be as accurate as possible, yet estimated schedules barely match with the actual schedules because of the complexity of the construction projects. There is a variation between the predicted schedule and the actual schedule, which differ from one construction project to the other.

Relative schedule can be calculated by dividing the estimated duration of a project by the actual duration of the project. A project can have a relative schedule that is different from other construction projects. The estimated duration can be more than actual duration or the other way around. In this research, the relative schedule factor is measured in percentage. For instance, a project that has 1.15 relative schedule factor indicates that the estimated duration of the project is 15% more than the actual duration of the project. On the other hand, if a project has a 0.8 relative schedule factor indicates that the estimated duration is 20% less than the actual duration. There are no fixed percentages for relative schedule. For this research, the hypothetical value of relative schedule is within the range of 0.75 and 1.25 since the estimated duration is 25% plus or minus the actual duration in most of construction projects. Relative schedule depends on the ten index/inputs mentioned earlier. The impact of each input on schedule predictability is discussed briefly below:

A. **Government Regulations:** *The relative schedule depends on the government regulations since the government regulations might affect the schedule due to certain limitations in construction working hours for example.*

B. **Scope Definition:** *Scope Definition will impact the schedule as well due to the fact that the scope decides what the schedule shall be. Furthermore, changing in the scope will change the schedule of the project as well.*

C. **Route Selection:** *Route selection will impact the schedule of the project as well. For instance, different roads require different timings to finish the infrastructure activities.*

D. **Risk Management:** *Risk management will impact the schedule. Good risk management will save time of the project in the future. If risks are studied properly, those risks can be avoided or mitigated for example. This will impact the schedule due to quick action taken ahead of time before the possible risk happens.*

E. **Resource Allocation:** *Resource allocation will impact the schedule as well since the amount of labor will impact the schedule. For a certain activity, having three workers is better than having two. This will reduce the time to finish this activity.*

F. **Labor Productivity:** *Labor productivity will impact the schedule as well since low labor productivity means that the contractor will not finish the activity as per the schedule.*

G. **Nighttime Construction:** *Nighttime construction will have schedule impact also since working overtime will improve the schedule. The impact on the schedule is more considerable if the contractor decided to have a night shift. This way, the schedule will improve for sure.*

H. **Long Lead Items Procurement:** *Long lead items will impact the schedule since delaying long lead items will stop the work and delay the project.*

I. **Environmental Impact Assessment Studies:** *Environmental impact assessment studies will have schedule impact as well since such studies might take some time to finish. Moreover, such studies might cause the contractor to change certain strategies that will impact the schedule.*

J. **Safety Plans:** *A better safety plan will definitely impact the schedule as it will save a lot of time that workers spend helping an injured worker, for example.*

5. Environmental Impacts:

When talking about sustainable construction projects or sustainable transportation project, the main aim is to reduce the environmental impacts caused by those projects. Environmental impacts include air pollutions, gas emissions, noise pollution, proper land use, human health, proper use of local resources, and many other points that can impact the environment. Environmental impacts can be measured using Environmental Impact Assessment (EIA) studies, for example. The main purpose of such assessments is to give the project team an idea about the environmental impacts of the project to be constructed for proper decision making. As an output, the environmental impact can be affected by using nine inputs out of the ten mentioned earlier. The only input that does not have any effect on it is the long lead items procurement. The impact of each input on environmental impacts is discussed briefly below:

A. **Government Regulations:** *The environmental impacts depend on the government regulations since the government regulations might not allow certain activities that have environmental impacts.*

B. **Scope Definition:** *Scope Definition will impact the environment as well due to the fact that the scope decides what the environmental impact shall be. Because of a sustainable project scope, the project can have lower environmental impacts.*

C. **Route Selection:** *Route selection will impact the environment of the project as well. For instance, some routes might affect the wildlife and those shall be avoided.*

D. **Risk Management:** *Risk management can impact the environment. A decision on how to deal with a certain type of risk might have impact on the environment. For instance, to avoid the risk of not finishing on time, the contractor decides to use extra machines that will impact the air pollution on site.*

E. **Resource Allocation:** *Resource allocation will impact the schedule as well since the amount of labor will impact the schedule. For a certain activity, having three workers is better than having two. This will reduce the time to finish this activity.*

F. **Labor Productivity:** *Labor productivity will impact the environment. For instance, low labor productivity on a certain activity that requires the use of machines that produce gas emissions means that the contractor will not finish the activity on time. So, the contractor is forced to use those machines that produce gas emissions for additional days (instead of 7 days now 10days).*

G. **Nighttime Construction:** *Nighttime construction will have environmental impact. For instance, working at night causes noise pollution.*

H. **Long Lead Items Procurement:** *Long lead items procurement has no significant impact on the environment.*

I. **Environmental Impact Assessment Studies:** *Environmental impact assessment studies will definitely impact the environment. A good EIA study allows the project team to have a project with less environmental impacts.*

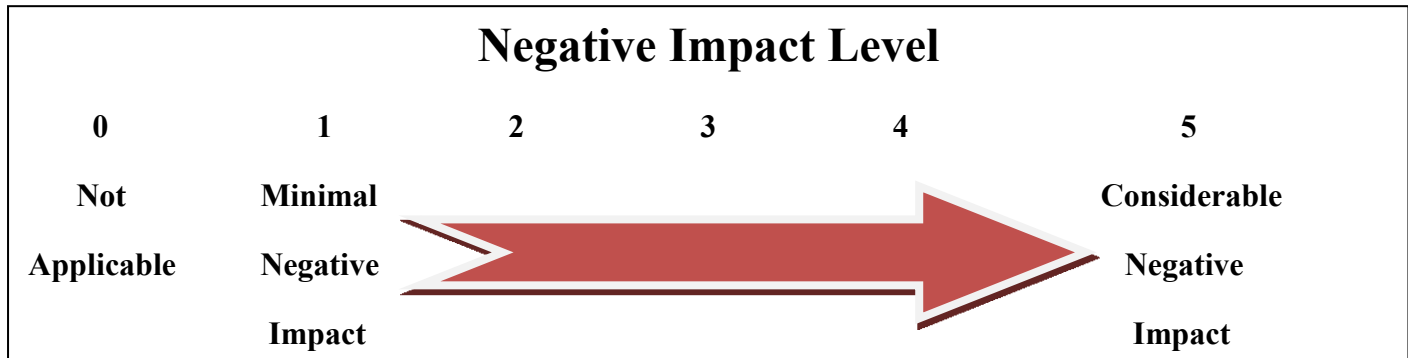
J. **Safety Plans:** *Since human health is part of the environmental impacts, good safety plans reduce the number of accidents. Consequently, the environmental impacts are less.*

This research suggests measuring the environmental impact of a project by using the environmental impact assessment (EIA) shown below. The total allowed score is 35 in this assessment. The lowest possible score is 0. However, the lower the total score, the lower the environmental impact. The EIA has seven assessment factors to look at when checking the negative impact on the environment. The seven assessment factors and how to measure each factor mentioned below:

- 1- Land Use: *How good is the land cover or the use of land?*
- 2- Site Contamination: *How clean and unpolluted is the site of the project?*
- 3- Historical Sites: *How would this project impact the nearby historical sites?*
- 4- Local Wildlife: *How bad would this project impact the local wildlife such as the nearby nature, animals, plants, etc...*
- 5- Human Health: *How would this project impact the human health?*
- 6- Air Pollution: *How bad is the project impacting the air?*
- 7- Water Pollution: *How bad is the project impacting the water?*

Sustainable Planning Index (SPI)

Project Score Sheet



| Environmental Impact Assessment Assessment Factors | Negative Impact Level | | | | | | Score |
|---|------------------------|---|---|---|-----------|---|-------|
| | <div><div></div></div> | | | | | | |
| 1- Land Use | 0 | 1 | 2 | 3 | 4 | 5 | |
| 2- Sites Contamination | 0 | 1 | 2 | 3 | 4 | 5 | |
| 3- Historical Sites | 0 | 1 | 2 | 3 | 4 | 5 | |
| 4- Local Wildlife | 0 | 1 | 2 | 3 | 4 | 5 | |
| 5- Human Health | 0 | 1 | 2 | 3 | 4 | 5 | |
| 6- Air Quality | 0 | 1 | 2 | 3 | 4 | 5 | |
| 7- Water Quality | 0 | 1 | 2 | 3 | 4 | 5 | |
| Total Score: | | | | | Out of 35 | | |

The lower the total scores → the lower the environmental impact.

6. Safety Level:

Safety level means to what degree is the project safe during the construction phase of the project. Level of safety differs from one project to the other, from one company to the other, from one construction team to the other. The level of safety is of major importance to all companies because it will be a part of the history of the company. Few clients would choose contractors that had many accidents on previous projects [54]. Having accidents, whether they tend to be fatal or less severe, will impact the progress of the project. It will delay the project and increase the cost of the project. Many construction companies, recently, understood the importance of the safety level and decided to take serious actions to limit the number of accidents and to limit the possibility of having any accident on site.

The safety level is only affected by seven inputs out of the ten. The inputs that affect the safety level are safety plans, government regulations, risk management, nighttime construction, scope definition, resource allocation, and environmental impact assessment studies. The impact of each input on the safety level is discussed briefly below:

A. **Government Regulations:** *The safety level depends on the government regulations since government regulations will look for the safety of the workers in the first place.*

B. **Scope Definition:** *Scope Definition will impact the safety level as well due to the fact that the project scope should take into consideration a project that contains safe activities and not dangerous ones.*

C. **Route Selection:** *Route selection has no significant impact on the safety level.*

D. **Risk Management:** *Risk management can impact the safety level. A decision on how to deal with a certain type of risk might have impact on the environment. For instance, to avoid the risk of not finishing on time, the contractor decides to use extra machines that are old and not functioning properly, which might cause some workers working on them to get injured.*

E. **Resource Allocation:** *Resource allocation will impact the safety level as well. In certain activities, having inexperienced workers might cause serious accidents on site. At least, he would injure himself if not others as well.*

F. **Labor Productivity:** *Labor productivity has no significant impact on the safety level.*

G. **Nighttime Construction:** *Nighttime construction will impact safety level for sure. For instance, working at night with limited amount of light is a major reason for accidents. In addition, people and especially workers usually lose some of their concentration at night which might increase the number of accidents.*

H. **Long Lead Items Procurement:** *Long lead items procurement has no significant impact on the safety level.*

I. **Environmental Impact Assessment Studies:** *Since human health is part of the environmental impacts assessment studies, good EIA studies reduce the number of accidents.*

J. **Safety Plans:** *Safety plans impact the safety level heavily. Without safety plans, accidents are expected to happen more frequently and this will affect the safety level of the project.*

The best way to measure safety levels is to count the number of fatalities, injuries, and near misses. To measure the safety level of a project, this research suggests to use weighted multiple regression of the fatalities, injuries, and near misses. The weights shall be as follow: 50% for fatalities as they are the hugest possible threat. 30% for injuries as injuries are a great threat that might be serious in some cases such as causing a certain worker to retire. Finally, 20% for near misses as those near misses might turn into injuries or even fatalities in the future so it should be taken seriously as an important measure. The lowest possible safety level is zero and the highest is infinity depending on the numbers of accidents, injuries, and near misses of a certain project. Obviously, the lower the safety level value, the safer the project.

Chapter 5: Validation Example

After defining the inputs and the outputs of the predictive model, it is the time to present a validation example to demonstrate the significance of this predictive model. As mentioned earlier, the predictive model is using the multiple regression concept. SPSS or Statistical Package for the Social Sciences is chosen as the software to come up with the multiple regression equation. Hypothetical data from 33 projects are randomly chosen to come up with the model. Using the ten inputs, the multiple regression equation of each output is determined. Each output will be discussed separately.

1. Absolute Cost

The ten inputs were included in the model to come up with a multiple regression equation for absolute cost. The regression (R) value of the data is 0.746 while R-squared is 0.557. The multiple regression equation is as Follow:

$$Y (\text{Absolute Cost}) = -0.10A + 0.12B + 0.11C - 0.002D + 0.001E - 0.004F + 0.003G - 0.005H - 0.009I - 0.007J + 1.231$$

2. Absolute Schedule

The ten inputs were included in the model to come up with a multiple regression equation for absolute schedule. The regression (R) value of the data is 0.324 while R-square is 0.105. The multiple regression equation is as Follow:

$$Y (\text{Absolute Schedule}) = 0.003A - 0.003B - 0.004C - 0.000013D - 0.001E - 0.006F + 0.002G - 0.002H - 0.00I + 0.001J + 1.10$$

3. Relative Cost

The ten inputs were included in the model to come up with a multiple regression equation for relative cost. The regression (R) value of the data is 0.596 while R-square is 0.355. The multiple regression equation is as Follow:

$$Y (\text{Cost Predictability}) = -0.006A - 0.006B + 0.004C + 0.002D - 0.10E + 0.008F - 0.002G - 0.007H - 0.07I + 0.006J + 1.106$$

4. Relative Schedule

The ten inputs were included in the model to come up with a multiple regression equation for relative schedule. The regression (R) value of the data is 0.613 while R-square is 0.376. The multiple regression equation is as Follow:

$$Y (\text{Schedule Predictability}) = -0.002A - 0.002B - 0.001C - 0.004D + 0.005E - 0.005F + 0.006G + 0.003H - 0.10I - 0.11J + 1.409$$

5. Environmental Impact:

The nine inputs were included in the model to come up with a multiple regression equation for Schedule predictability. All inputs were included except long lead items procurement. The regression (R) value of the data is 0.628 while R-square is 0.395. The multiple regression equation is as Follow:

$$Y (\text{Environmental Impact}) = 0.184A - 0.203B - 0.182C - 0.211D - 0.18E - 0.164F - 0.177G + 0.304I - 0.047J + 30.698$$

6. Safety Level:

The seven inputs were included in the model to come up with a multiple regression equation for Schedule predictability. All inputs were included except long lead items procurement, route selection, and labor productivity. The regression (R) value of the data is 0.455 while R-square is 0.207. The multiple regression equation is as Follow:

$$Y (\text{Safety Level}) = -0.006A + 0.012B - 0.010D + 0.006E - 0.008G + 0.005I - 0.022J + 1.259$$

This was a validation example that shows how to come up with multiple regression equation using the project score sheets. For all the equations,

A = Government Regulations Score

B = Scope Definition Score

C = Route Selection Score

D = Risk Management Score

E = Resource Allocation Score

F = Labor Productivity Score

G = Nighttime Construction Score

H = Long Lead Item Procurement Score

I = Environmental Impact Assessment Studies Score

J = Safety Plans Score

Below are the data of a hypothetical data of a project to start soon. The project teams sat and filled out the project score sheets. The total scores for this project are as follow:

Table 1: Project Total Scores of a Hypothetical Project

| Index/Input Variables | Project Total Score |
|---|---------------------|
| A. Government Regulations | 25 |
| B. Scope Definition | 16 |
| C. Route Selection | 10 |
| D. Risk Management | 20 |
| E. Resource Allocation | 5 |
| F. Labor Productivity | 22 |
| G. Nighttime Construction | 19 |
| H. Long Lead Item Procurement | 0 |
| I. Environmental Impact Assessment Studies | 6 |
| J. Safety Plans | 4 |

The results of the model based on the multiple regression equation, which was based on 33 hypothetical projects, mentioned earlier are as follow:

Table 2: Factors for the Six Outputs of the hypothetical Project

| Output Variables | Factor |
|------------------------------|----------------|
| Absolute Cost | 1.603 |
| Absolute Schedule | 0.99174 |
| Relative Cost | 0.182 |
| Relative Schedule | 0.226 |
| Environmental Impacts | 19.775 |
| Safety Level | 1.097 |

From the results found, we can predict that the actual cost of this project might reach to 60.3% more than the actual cost of previous construction projects. The actual duration is predicted to be almost the same as the actual duration of other transportation projects since the factor is around 1. From the relative cost factor, we can predict that the estimated cost can be less than the actual cost around 81.8%. From the relative schedule factor, we can predict that the estimated duration of the project can be 77.4% less than the actual duration of the project. The environmental impact of the project is predicted to be 19.775 which is a high number, so we are expecting this project to have significant environmental impacts. This high number is mainly because of the poor safety plans in this project. Finally, the safety level factor is 1.097 which is kind of expected high number. For a safer project, the project team should be concerned in reducing the safety level factor as much as possible by improving the safety plans so the value of the safety level is closer to zero.

Chapter 6: Conclusion and Recommendations

Sustainable development and sustainable construction have gained considerable momentum over the last three decades; while sustainable transportation is following suit in recent years. Different definitions had been suggested for sustainable transportation in the recent years. However, most of them agreed on certain points such as allowing for the basic needs of individuals and the society, in general, to be met safely and in a manner consistent with human and ecosystem health.

The construction decisions of the transportation projects dictates future usage patterns and hence impact on the environment due to the carbon dioxide emissions, for example. In order to reduce these impacts on the environment, the term sustainable transportation had been introduced lately. It had been adopted by many governments of the European countries, US, and recently the UAE. However, the literature of sustainable transportation lacked a program that can predict the cost, time, and the safety level of sustainable construction projects in the transportation sector. Therefore, the aim of this thesis was to develop a predictive model that can be used to predict the absolute cost, absolute time, relative cost, relative schedule, environmental impacts and safety level of a sustainable construction project in the transportations sector.

The objective of this research was to establish the theoretical framework for predictive modeling in sustainable construction projects. In this research, predictive modeling was used to predict the absolute cost, absolute time, relative cost, relative schedule, environmental impacts and safety level of sustainable construction projects in the transportation sector. The outcome of the research was a decision making tool based on predictive modeling. The predictive model can be used during the planning phase of the project in order to take appropriate actions such as selecting the project, selecting alternative project(s), taking actions to improve the outputs of the predictive model and consequently improve the project. In other words, this predictive model can be very useful for the project teams at the authorization stage to explore the possible gaps in their sustainable project planning.

The research shows that absolute cost, absolute schedule, relative cost, and relative schedule depend on the ten index/inputs (government regulations, scope definition, route selection, risk management, resource allocation, labor productivity, nighttime construction, long lead item procurement, environmental Impact assessment studies, safety plans). Moreover, it was shown that the environmental impacts depend on nine inputs after excluding the long lead items procurements. Moreover, it was presented that the safety level depends on the seven inputs (government regulations, scope definition, risk management, resource allocation, nighttime construction, environmental Impact assessment studies, safety plans).

In conclusion, the research showed that further research can be done on predicting the cost, schedule, environmental impacts, and safety levels of sustainable construction projects within the transportation sector. A predictive model can be very useful for the project team to come up with decisions based on information and studies. This research developed a predictive model that can be used directly by project teams to predict cost, schedule, environmental impacts, and safety levels. Using this model, project teams can save problems, money, and time in the future since the planning phase is the phase which allows for changes within limited cost and schedule impacts.

This research is an important preliminary step to come up with better planning of sustainable construction projects in the transportation sectors. Project management aims to complete the project within budget, on time, and finally meet or even exceed stakeholders' expectations and environmental needs from the project. Therefore, good planning leads to successful projects that meet the main aims of project management. This can be achieved by using the predictive model suggested in this research.

In this research, ANN can be used efficiently to predict the six outputs (absolute cost, absolute schedule, cost predictability, schedule predictability, environmental impacts, and safety level). The inputs of the ANN are the fifty sub-inputs/questions coming from the project score sheets of the ten index/inputs variables (government regulations, scope definition, route selection, risk management, resource allocation, labor productivity, nighttime construction, long lead item procurement, environmental Impact assessment studies, safety plans). The predictive results shall be based on the relationships between the fifty inputs and the six outputs developed by

the ANN. ANN can be used in a better way if the project team is able to have previous data from more than 100 previous projects. 75 projects can be used to train the neural networks and 25 projects to test how matching are the predicted values suggested by the ANN with the real values.

This research recommends validating this model by collecting true historical data of previous construction projects within the transportation sector. Data collecting can validate this predictive model or improve it. This research recommends using multiple regression or Artificial Neural Networks (ANN) to develop a predictive model that accurately links the relationships between the input variables and the outputs variables. This research recommends using a real case study to validate the framework of the predictive model. After going through the case study, it is recommended to recheck and rework on the predictive model if needed. After going through the case study and reworking on the model, this research suggests having a focus group (experts) that can evaluate this model for better results in the future.

Additional topic for future research is to provide a similar predictive model while considering weights for inputs based on research or surveys. This way the future predictive model can be more accurate and more reliable. Another additional topic for future research is to review the fifty sub-inputs variables suggested in this research. Reviewing can be done either by adding new sub-inputs to the fifty or by eliminating a number of the sub-inputs.

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Appendix A**Output Tables****Table 8.1: Absolute Cost Table**

| | Absolute Cost | Total Score | Weighted |
|----------|----------------------|--------------------|-----------------|
| A | -0.1 | 25 | -2.5 |
| B | 0.12 | 16 | 1.92 |
| C | 0.11 | 10 | 1.1 |
| D | -0.002 | 20 | -0.04 |
| E | 0.001 | 5 | 0.005 |
| F | -0.004 | 22 | -0.088 |
| G | 0.003 | 19 | 0.057 |
| H | -0.005 | 0 | 0 |
| I | -0.009 | 6 | -0.054 |
| J | -0.007 | 4 | -0.028 |

Table 8.2: Absolute Schedule Table

| | Absolute Schedule | Total Score | Weighted |
|----------|------------------------------|--------------------|-----------------|
| A | 0.003 | 25 | 0.075 |
| B | -0.003 | 16 | -0.048 |
| C | -0.004 | 10 | -0.04 |
| D | -0.000013 | 20 | -0.00026 |
| E | -0.001 | 5 | -0.005 |
| F | -0.006 | 22 | -0.132 |
| G | 0.002 | 19 | 0.038 |
| H | -0.002 | 0 | 0 |
| I | 0 | 6 | 0 |
| J | 0.001 | 4 | 0.004 |

Table 8.3: Relative Cost Table

| | Relative Cost | Total Score | Weighted |
|----------|----------------------|--------------------|-----------------|
| A | -0.006 | 25 | -0.15 |
| B | -0.006 | 16 | -0.096 |
| C | 0.004 | 10 | 0.04 |
| D | 0.002 | 20 | 0.04 |
| E | -0.1 | 5 | -0.5 |
| F | 0.008 | 22 | 0.176 |
| G | -0.002 | 19 | -0.038 |
| H | -0.007 | 0 | 0 |
| I | -0.07 | 6 | -0.42 |
| J | 0.006 | 4 | 0.024 |

Table 8.4: Relative Schedule Table

| | Relative Schedule | Total Score | Weighted |
|----------|------------------------------|--------------------|-----------------|
| A | -0.002 | 25 | -0.05 |
| B | -0.002 | 16 | -0.032 |
| C | -0.001 | 10 | -0.01 |
| D | -0.004 | 20 | -0.08 |
| E | 0.005 | 5 | 0.025 |
| F | -0.005 | 22 | -0.11 |
| G | 0.006 | 19 | 0.114 |
| H | 0.003 | 0 | 0 |
| I | -0.1 | 6 | -0.6 |
| J | -0.11 | 4 | -0.44 |

Table 8.5: Environmental Impact Table

| | Environmental Impacts | Total Score | Weighted |
|----------|------------------------------|--------------------|-----------------|
| A | 0.184 | 25 | 4.6 |
| B | -0.203 | 16 | -3.248 |
| C | -0.182 | 10 | -1.82 |
| D | -0.211 | 20 | -4.22 |
| E | -0.18 | 5 | -0.9 |
| F | -0.164 | 22 | -3.608 |
| G | -0.177 | 19 | -3.363 |
| H | 0 | 0 | 0 |
| I | 0.304 | 6 | 1.824 |
| J | -0.047 | 4 | -0.188 |

Table 8.6: Safety Level Table

| | Safety Level | Total Score | Weighted |
|----------|---------------------|--------------------|-----------------|
| A | -0.006 | 25 | -0.15 |
| B | 0.012 | 16 | 0.192 |
| C | 0 | 10 | 0 |
| D | -0.01 | 20 | -0.2 |
| E | 0.006 | 5 | 0.03 |
| F | 0 | 22 | 0 |
| G | -0.008 | 19 | -0.152 |
| H | 0 | 0 | 0 |
| I | 0.005 | 6 | 0.03 |
| J | 0.022 | 4 | 0.088 |

Vita

Tarek Z. Labban was born in 1988, in Beirut, Lebanon. Few years later, he moved to Dubai, United Arab Emirates and attended Dubai International School. He graduated from Dubai International School in 2006. He decided to study Civil Engineering in the American University of Sharjah in Sharjah, United Arab Emirates, from which he graduated in 2010 with a Bachelor of Science in Civil Engineering along with a minor in Engineering Management.

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