A HOLISTIC INTERSECTION RATING SYSTEM (HIRS)

by

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Dedication

To my Father and Mother…

Abstract

Signalized urban intersections are key components of urban transportation networks. They are traditionally viewed and designed as primarily motorized traffic facilities thus their physical and operational designs are aimed at maximizing traffic throughput. However, seen from a holistic viewpoint, they are transport and community facilities with direct and indirect impacts on traffic functionalities, the environment, public health and community wellbeing. Thus this study proposed a new rating system, a Holistic Intersection Rating System (HIRS), that is necessary to analyze the comprehensive operational performance of these intersections from a holistic viewpoint. This performance, in essence, covers traffic functionality, sustainability, and public health and community wellbeing. Additionally, this rating system can be used as a guide to design new intersections or revamp existing ones. HIRS is designed to rate signalized urban intersections based on all technologies, physical design, and operational features that allow those intersections to operate holistically. The proposition behind this study is that incorporating and/or enhancing certain technologies, physical design, and operational features as proposed in HIRS, would lead to a more human-centric and sustainable operational performance of the enhanced intersections. Holistic operational performance can be measured through five quantifiable indicators: *enhanced traffic performance, reduced air pollution, reduced noise pollution, enhanced user's physical and mental health, and better safety performance*. HIRS was created via an extensive literature review and validated using a panel of experts in the field of construction, transportation, and public health. HIRS was used to collect field data sample based on twenty intersections within the United Arab Emirates (UAE). The Relative Importance Index (RII) method was used to weigh the HIRS indicators. The analysis results showed noticeable gaps in services provided to pedestrians, cyclists, and nearby households. The tested intersections scored a mean of 32% on "Public health and community wellbeing section". This section is dedicated to the service provided for those users, (mean of 37% on pedestrians sub-section and 15% on cyclist sub-section). Via HIRS, these services can be improved considerably to combine design and operational features and technologies.

Keywords: ***Signalized urban intersections, Rating systems, Public health.***

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List of Abbreviations

HIRS	Holistic Intersection Rating System
HIPI	Holistic Intersection Performance Indictors
AV	Autonomous Vehicles

Chapter 1. Introduction

1.1. Overview

Earlier transportation planners, designers, and operators focused on improving the transportation system so that it enabled more motorized traveler and freight modes to move from one place to another. However, in more recent times the focus is shifting to developing a sustainable and equitable transportation system that addresses new environmental and health challenges [1]. Signalized urban intersections are key components of urban transportation systems [2]. They were traditionally designed to maximize motorized traffic throughput. In fact, the previous signalized urban intersection rating systems focused on rating only the vehicular service that the intersections provides. However, the proposed holistic intersection rating system (HIRS) is a new rating system that utilizes a holistic operational performance of signalized urban intersections. The rating will be based on the presence of new innovative technologies, physical design and operational features at intersections that enables a holistic view of operational performance.

As mentioned earlier, transportation systems are now expected to operate more sustainably. The proposed HIRS will introduce transportation planners, designers, and operators to the importance of the new technologies, physical design, and operational features, and how to systematically integrate those features and technologies in our signalized urban intersections. Integrating those technologies, physical design, and operational features will result in a more comprehensive and equitable operational performance of urban intersections. Moreover, comprehensive operational performance results in a better traffic functionality, support sustainability, and fosters public health & community wellbeing. Promoting those aspects leads to a better service to pedestrians, cyclists and households located nearby signalized urban intersections.

This study proposes a new rating system (HIRS). HIRS consists of all suitable technologies, physical design, and operational features that can be used in signalized urban intersections. The presence or absence of those technologies, physical design, and operational features will be used to rate the signalized urban intersections. This rating system is composed of two main sections. The first section concerns motorized/vehicular traffic. This section is composed of several sub-sections that focus on integrating the new transportation features that result in optimizing the throughput

of vehicles. The second section is devoted to public health and community wellbeing, and includes several sub-sections that focus on integrating the new transportation features that result in operating the signalized urban intersection which contributes positively to sustainable solutions at signalized intersections, public health and community wellbeing.

1.2. Problem Definition

In times past the focus of transportation systems was to facilitate the movement of motor vehicles [1]. Less attention was given to other users such as pedestrians, cyclist, and nearby residents [3]. Environmental concerns rarely featured in the analysis [4].

However, from a holistic point of view, transportation today should be about mobility and accessibility: moving system traffic, motorized and non-motorized, and using the most suitable mode of transportation. In addition, the transportation system should be operated to promote sustainable solutions that contribute to a better environment, better health and community wellbeing. HIRS was designed to cover all the technologies, physical design, and operational features that can be used to operate signalized urban intersections (new or existing intersections) to give a better service in terms of holistic operational performance. Holistic operational performance can be measured through: Traffic performance, Air pollution, Noise pollution, User's mental health, User's safety.

1.3. Thesis Objective

The aim of this study is to create an approach to assess signalized urban intersections, one that uses a holistic view (traffic functionalities, sustainability, public health and the community wellbeing). Creating the HIRS allows transportation authorities and international consultants to identify the level of usage of the technologies, psychical design and operational features that lead to completeness of the operational performance at which the signalized urban intersection is operating. Secondly, HIRS can also be used to as a guide for traffic planners and designers to design or revamp new/existing signalized urban intersections to enable the integration of relevant new technologies, physical design, and operational features.

1.4. Research Contribution

- The proposed HIRS tackles the importance of public health and community wellbeing, which previous rating systems missed. However, from a holistic view of a signalized urban intersection (which is a part of urban transportation systems), public health and community wellbeing factors should be considered. According to the ASCE (American Society of Civil Engineers) code of ethics: "Engineers should take into consideration that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices" [5].
- The proposed HIRS supports active transportation (walking and cycling). However, some previous rating systems focused mainly on rating the performance of signalized urban intersections based on the vehicular service being provided. Active modes of transportation have two main benefits. First, they reduce the number of auto trips. Second, they have positive health benefits resulting from the physical exercise that users perform to commute from one point to another [6].
- The proposed HIRS addresses two new topics in the field of transportation: readiness of existing infrastructure to support autonomous vehicles and psychological effect of transportation systems on the mental health of users. This study will focus on those two topics in the context of signalized urban intersections only. Those two topics are new and important aspects that currently do not feature in previous rating systems.

1.5. Thesis Organization

The rest of the thesis was organized as follows: Chapter 2 provides background and definitions of the terminologies. Additionally, this chapter provides the discussion of related previous rating systems. Chapter 3 discusses the research proposition and methodology. Chapter 4 presents in detail the development of HIRS. Chapter 5 discusses the field data collection approach for 20 signalized urban intersections. Chapter 6 discusses in detail the results and the analysis of the 20 signalized urban intersections. Chapter 7 states the study conclusions and presents recommendations for future work.

Chapter 2. Background and Literature Review

2.1. Signalized Urban Intersection

The road intersection "covers the area of pavement jointly used by the intersection streets plus the segments of the intersecting streets affected by the design, and those segments of the road adjacent to the intersection for which the grade of cross section have been modified for its typical design are considered part of the intersection" [7].

Basically, there are two main geometric features of the road intersection: the angle of intersection and the intersection legs. The angle of the intersection is formed by the intersecting streets' centerlines. However, if the intersection angle is more than 20 degrees and not forming a right angle, then it is known as a skewed intersection [7].

The other geometric feature is the intersection legs, which are the segments of the roadway that are connecting to the intersection. The intersection leg is known as the approach leg for the approaching traffic, and the departure leg for the leaving traffic [7].

In addition, crosswalks, sidewalks, and pedestrian curbs are also considered to be part of the intersection. Figure 1 shows all the parts and terminology of the intersection [7]. Moreover, in a signalized urban intersection. An electronic traffic control device is used to assign the right-of-way for each approach [2].

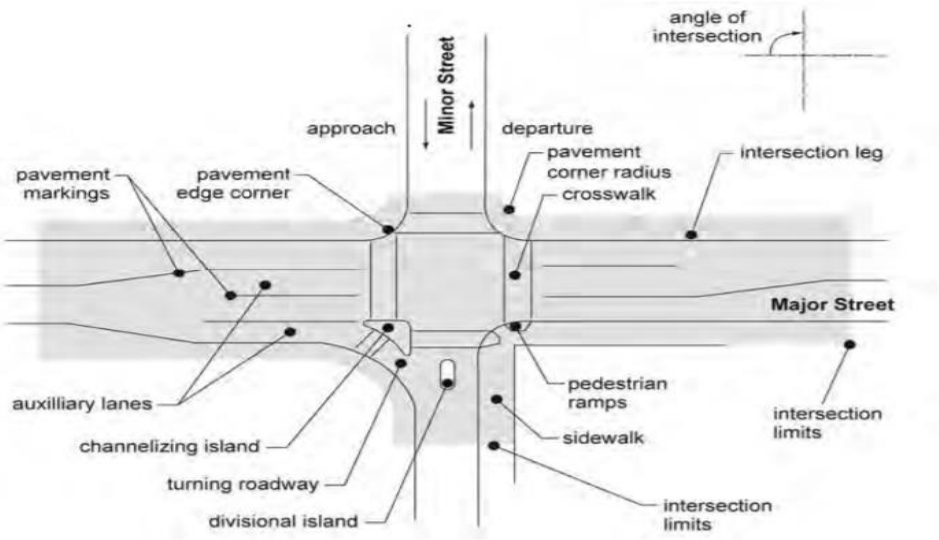

Figure 1: Intersection main components [7]

2.2. Benchmarking

Benchmarking is a continuous process that tends to measure services against the toughest competitors or companies known as industry leaders. Benchmarking can be used to measure a product or a service. The term benchmarking entails a process of measurement

Steps of developing benchmarking [8].

1. Identify what is to be benchmarked

2. Identify comparative

3. Determine data collection method and collect the data

4. Determine current performance 'GAP'

5. Project future performance levels

6. Communicate benchmark findings and gain acceptance

7. Establish functional goals

8. Develop action plans

9. Implement specific action and monitor process

10. Recalibrate benchmarks

2.3. Definition of Sustainability

Sustainability is a broad term that covers previous pavements, green materials, the heat island effect, energy independence, social justice, and health of local waterways. However, from a civil point of view, sustainability is usually referred to by the Brundtland Commission as: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" or by the triple bottom line of planet, profit, and people [9].

2.4. Relative Importance Index (RII)

$$RII = \frac{\sum W}{A * N} = \frac{5n_5 + 4n_4 + .. + 1n_1}{5 * N}$$

Where RII= Relative importance index value ranging from 0 to 1[10]

W= Weights given to the factors by the respondents from 1 to 5, based on the importance (*n5*= number of respondents for the most important - *n1* = number of respondents for the least important)

A= the height weight given in the study

N=total number of respondents

2.5. Public Health and Community Well-being

In the past, transportation systems were associated with physical injures due to crashes and pollution problems due to vehicle emissions. However, "in the modern day, noncontagious ailments such as obesity, physical inactivity, stress, and cardiovascular diseases are all linked to urban transportation systems" [6]. Moreover, as shown in Figure 2, transportation has a huge impact on health. In addition according to the Federal Highway Administration Research and Technology, transportation systems help in shaping the way communities operate and have a major influence on public health. Transportation systems can have a positive or a negative influence on public health [11].

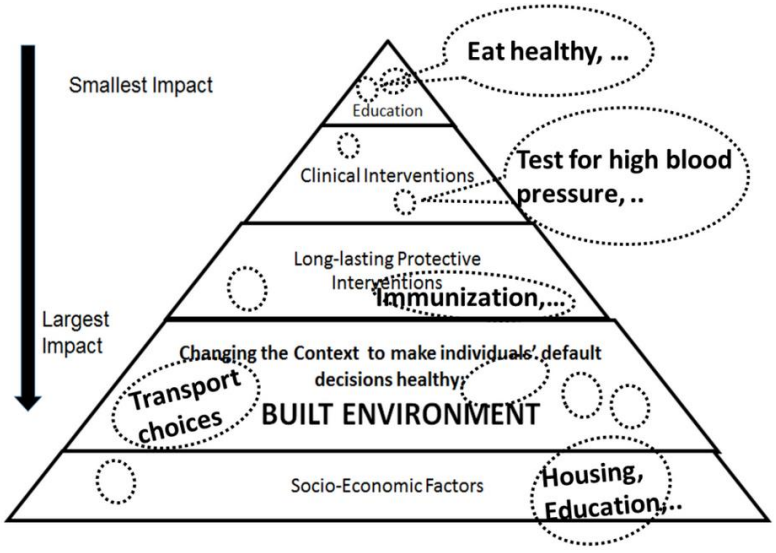

Figure 2: Health impact pyramid [6]

Individuals' physical health comes from several aspects such as social wellbeing and mental health. Public health comes from the social wellbeing and health of the individuals living in the community. All health-related elements are affected by transportation systems [6].

There is a strong relationship between urban traffic systems and public health. This is proved in the fact that the traffic noise and stress that result from long and congested commuting have a considerable impact on mental health. Moreover, the ease at which individuals can commute to health and educational facilities impacts the quality of life and the health of the community. Moreover, the ease at which individuals within the community meet and interact with each other impacts on social wellbeing [6].

2.6. Related Previous Rating Systems

2.6.1. Green guide for road rating system. The green guide for road rating system is a rating system for roads that was developed by Matthew Clark, Christopher Paulli, Zachary Tetreault, and Justin Thomas. This rating system is composed of seven main sections that include mobility for all, transportation planning, energy and atmosphere, materials and resources, environmental impacts, community impacts, innovation and design process [12].

Most of the sections have prerequisites, however even when those prerequisites are met, no points are given. Each section has a specific number of points that the road can get based on the requirements. The sum of all the points from all the seven sections are 100 points that can be achieved by the roads [12].

2.6.2. Green LITES. Green LITES is a rating system that is developed by the New York State Department of Transportation (NYSDOT). Their target was to develop transportation and infrastructure in a sustainable way. This rating system is composed of 8 different main sections which include bridges, pavements, drainage, signals and lighting, snow and ice, facilities and rest areas, roadside environment and signs, and innovative/unlisted actives. Each of the main sections has subsections, and based on the total score that comes from all sub-sections the certification level is achieved. There are four certification levels, Certified, Silver, Gold, and Evergreen. Certified is the lowest level that can be achieved, while Evergreen is the highest level [13].

2.6.3. Green Pave. Green Pave is a rating system developed by the Ministry of Transportation in Canada. The system was developed to improve the sustainability of the transportation infrastructure. This rating system consists of two main components. The first component is the design while the second component is the

construction. Under those two components, there are four categories on which the infrastructure will be rated to meet the requirements. The four categories are: pavement design technologies, materials and resources, energy and atmosphere, innovation and design process. Moreover, under the four main categories, there are several sub-categories. In this rating system, the maximum total points that can be achieved is 32 points. There are four different levels of certification that can be achieved: bronze, silver, gold, and trillium [14].

2.6.4. I Last illinois. I Last Illinois was developed by the Illinois Department of Transportation, the American Consulting Engineers Council, and the Illinois Road and Transportation Builders Association. The rating system is developed to offer a list of practices that will bring sustainable outcomes on the highways. Moreover, the target was to develop a simple system that can rate the transportation projects based on the livability, sustainability and effect on the natural environment. Furthermore, the target was also to record the sustainable practices on highways and motivate the use of new sustainable concepts. This system is composed of nine different sections which cover planning, design, environment protection, water, transportation, lighting, materials, and innovation [15],[16].

2.6.5. INVEST infrastructure. INVEST infrastructure was developed by the Federal Highway Administration (FHWA). This rating system is a 'web-based self-evaluation tool'. The first version of this system (1.0) was released in October 2012; version 1.2 was released in September 2015. This rating system has four main sections which include system planning for states, system planning for regions, project development, and operations and maintenance. Each of these four sections has several subsections. There are four levels of achievements in this rating system: platinum, gold, silver, and bronze. Highways that achieve 30% of the possible points earn bronze; highways that achieve 40% of the possible points earn silver. However, highways that achieve 50% of the possible points earn gold, and highways that achieve 60% of the possible points earn platinum [17].

2.6.6. CEEQUAL. CEEQUAL is the international evidence-based sustainability assessment, rating and awards scheme for civil engineering. This rating system was developed by a team from the Institution of Civil Engineers (ICE). There are twelve different sections in this rating system. They include project management,

land use, landscape issues (including rural landscape and townscape), ecology and biodiversity, the historic environment, water resources and the water environment, energy and carbon, material use, waste management, transport, effects on neighbors, and relations with the local community and other stakeholders. There are four levels of awards that can be achieved in this rating system. A Pass award is earned if over 25% of the points available is achieved; the Good award is earned if over 40% of the points available is achieved; the Very Good award is earned if over 60% of the points available is achieved. Finally, the Excellent award is earned if over 75% of the points available is achieved. However, a score of 100% is impossible to achieve [18].

2.6.7. STARS. STARS (Sustainable Transportation Access Rating System) is a rating system developed by the Santa Cruz County Regional Transportation Commission. This rating system has four main sections. They include integrative process, access, climate and energy, and benefit/cost [19].

2.6.8. BEST-In-Highways TM. Best-in-highways TM is a rating system that was developed by the recycled materials resource center located at the College of Engineering at the University of Wisconsin. This rating system is composed of 10 sections. They include social requirements including regulation and local ordinances, greenhouse gas emission, energy use, waste reduction (including ex situ materials), waste reduction (recycling in situ materials), water consumption, social carbon cost saving, life cycle cost, traffic noise, and hazardous waste. There are three ratings that can be achieved: gold, silver, and bronze. Gold is awarded for a score of 90% of the total points available. Silver is awarded for a score of 75% of the total points available. Bronze is awarded for a score of 50% of the total points available. [20], [21].

BE2ST-in-Highways rating system assesses in different ways, and its rates are based on the LCA (life cycle assessment) and the LCCA (lifecycle cost analysis). The assessment involves producing different pavement designs, estimating the service life of each of the designs, identifying rehabilitation strategies, and finally conducting life cycle assessment and lifecycle cost analysis [22].

2.6.9. Envision TM. Envision was developed by the Zofnass program for sustainable infrastructure at Harvard University and the Institute for sustainable infrastructure. This rating system is composed of five main sections which include quality of life, leadership, resources allocation, natural world, and climate and risk.

There are 143 possible points. Bronze is awarded if 20% of the total points is achieved; silver is awarded if 30% of the total points is achieved; gold is awarded if 40% of the total points is achieved, and platinum is awarded if 50% of the total points is achieved [23].

2.6.10. Green roads TM. Green roads is a rating system developed by the University of Washington and CH2M HILL in 2009. This rating system is composed of five main sections. They include environment and water, construction activities, materials and design, utilities and controls, access and livability, and creativity and effort. In this rating system, there are two types of credits: mandatory credits and voluntary credits. When the mandatory credits are achieved, no points are awarded. However, if the voluntary credits are achieved, points are awarded. There are 4 types of certification levels: bronze which is awarded when 40 points or more are scored; silver which is awarded when 50 points or more are scored; gold which is awarded when 60 points or more are scored; and finally, evergreen which is awarded when 80 points or more are scored [24].

2.6.11. A landslide hazard rating system for colorado highways. This rating system was developed in 2014 by Dan Pratt. The main goal of this system was to help in quantifying the hazards and risks of the existing landslide on the Colorado highways. This system was developed based on the old existing rock-fall rating systems used by the Colorado Department of Transportation. The new system is composed of eleven hazard factors and eight consequence factors. The hazard factors include the following: soil/rock, uses classification, rock strength, permeability, jar slake test, discontinuity orientation, and bedrock geology. The other 10 hazard factors are: vegetation, annual precipitation, slope aspect, groundwater seepage, surface water influence, drainage condition, peak ground acceleration, failure frequency, pavement damage, and slope angle. The eight consequence factors include extent of slide beyond row, depth to slide plane, size, detour options, worst case detour time, average daily traffic, annual maintenance costs, and length of roadway affected. All these Hazard and consequence factors lead to calculate a final risk score [25] [26].

2.6.12. Performance evaluation of signalized urban intersections under mixed traffic conditions. This study provides a quantitative evaluation of the signalized intersections under mixed traffic conditions. The evaluation of those

intersections is done based on only five parameters which are: degree of saturation, the separation ratio average stopped delay, and queue length and conflict ratio. This study was tested on urban intersections in China. [27]

2.7. Conclusion

Most of the rating systems that came into existence in the past had three main weakness. Firstly, the previous rating system focused on judging how green the highways are. In other words, from a sustainability point of view some of those rating systems such as Green Guide for Road Rating System, Green Lites, Green Pave, and Best-In-Highways focus on rating highways based on the application of sustainable construction activities and the usage of recycled materials. However, those previous rating systems ignored transportation services that highways provide to the vehicle drivers, pedestrians, cyclists and people living within close proximity [12][13][14][20][21][22]. In addition to all the previous rating systems did not include the effect of autonomous vehicles on our transportation systems. However, the HIRS helps in improving the services that the transportation facility provides for all of the different users. Since a complete street, is one that is designed and operated to allow a safe access for all the users [28] [29].

Secondly, the previous rating system did not include the factors that affects the mental health of the users by the transportation systems. However, transportation systems affect the health of the users and help in shaping the communities. Thus, a comprehensive transportation system, allows users to transport from one place to another without compromising the health of the users. The government should be committed to create a transportation system that promotes public health. In addition, transportation systems should be operated in a way that positively impacts society and the environment [28]. Development of a new rating system (HIRS) would help the traffic authorities to improve on how the signalized urban intersection are currently operating by taking into consideration the all the different users and the impact on society and the environment [29].

Finally, most of the rating systems that have been used before aimed at rating the highway in general without focusing on the details of the different components of the highway. Whereas, HIRS rates only signalized urban intersections.

Chapter 3. Research Proposition and Methodology

3.1. Research proposition

This research proposition states that the usage of the technologies, physical design and operational features stated in HIRS results in the improved holistic operational performance of signalized urban intersection. The holistic operational performance covers five measurable outcomes: enhancement in the traffic performance, reduction in air pollution, reduction in noise pollution, improvement user's mental health, and enhancement user's safety, as shown in Figure 3.

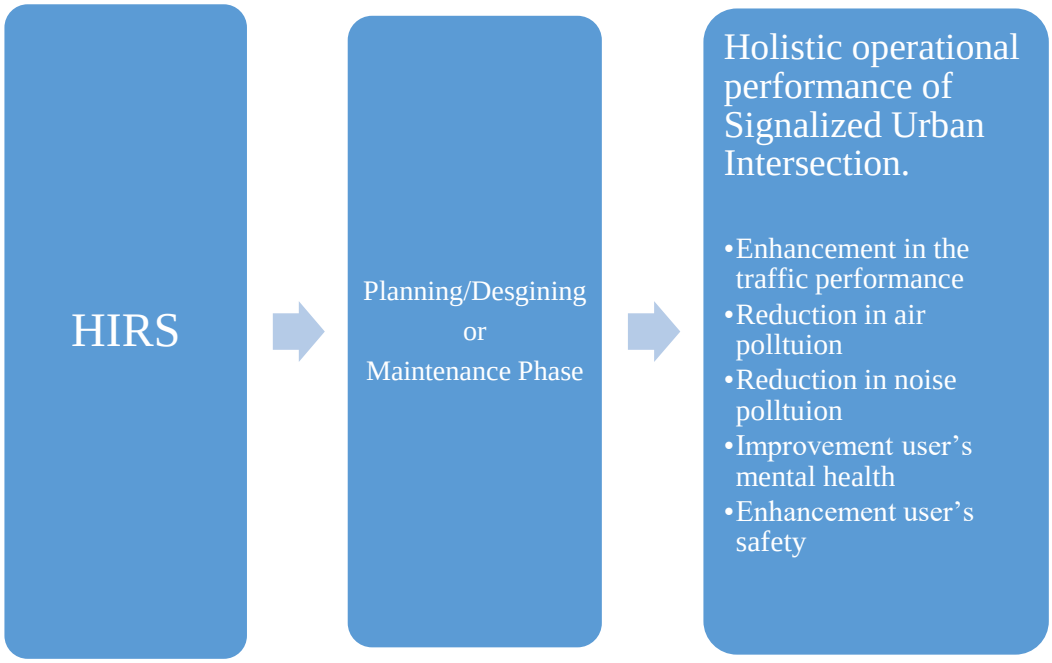

Figure 3 HIRS Proposition (this chart was developed for this study)

HIRS is composed of two main sections: motorized/vehicular traffic and public health and community wellbeing. Under those two main sections fall nine sub-sections:

- Sub-section 1 Traffic signal management
- Sub-section 2 Special features in vehicular service
- Sub-section 3 Autonomous vehicle ready criteria
- Sub-section 4 Sustainable solutions at signalized urban intersections
- Sub-section 5 Ways and features to reduce noise pollution
- Sub-section 6 Ways and features to reduce light pollution
- Sub-section 7 Convenience and safety of pedestrians

- Sub-section 8 Convenience and safety of cyclists
- Sub-section 9 Psychological effect of transportation system

Those nine sub-sections support the proposition of this research, since all of those sub-sections lead to the holistic view of operational performance indicated by enhancement in the traffic performance, reduction in air pollution, reduction in noise pollution, improvement user's mental health, and enhancement user's safety.

3.1.1. Traffic signal management and traffic performance enhancement/air pollution reduction. Traffic signal management involves having a system that will be able to collect real-time data of vehicular presence and analyzing this data to optimize different parameters of the traffic signal timing. Having such a system compares favorably to the outdated fixed timing or uncoordinated systems present in the old traffic signals, which results in

- Improved travel time
- Improved average speed of vehicle
- Fewer stops
- Reduction in fuel emissions and consumption
- Reduction in number of accidents
- Reduction in saturated conditions

All of those benefits of traffic signal management result in operating the signalized urban intersections in better traffic performance. However, it also promotes sustainability and public health. Since fewer fuel emissions and less fuel consumption is a result of this system [30].

3.1.2. Special features in vehicular service and traffic performance enhancement. Several special features can be added to the signalized urban intersections that would enhance the performance of the signalized urban intersections in terms of traffic functionality and safety. Some of those features are yellow box junction, traveler information, incidents management. The advantages of those features can be seen in Table 1.

Table 1 Special features in vehicular service and their advantages

Special features	Advantage on signalized urban intersections
Flashing green light Traffic signal equipped with countdown timer	Which causes a safer response from the motorized vehicle drivers [31]
Yellow box junction	Avoids traffic blockage at the center of the intersection and keeps the traffic flowing in all directions [32]
Traffic Signal equipped with Battery Backup System	This system prevents major problems such as accidents and traffic jams that happen after a complete shutdown in the traffic signals at an intersection
RED light running camera (RLR)	Leads to significant reduction in all types of red light running crashes [33]
Traveler information system	Maximize the capacity of the system [34] Increases safety [34] Reduction in congestion [34]
Incident management system	Reduction in the average traffic incident delay [35]

As shown in Table 1, the advantages of the different features that signalized urban intersections can be equipped with lead to better traffic performance.

3.1.3. Autonomous vehicle ready criteria and traffic performance enhancement/user's safety. This section of the HIRS tackles the expected challenges that AVs might face when they are deployed on the roads. The use of autonomous vehicles nowadays makes it imperative for researchers to exert real effort to make sure that signalized urban intersections are safe. "Vehicle automation is rapidly rising up the agenda of the automotive sector; new cars increasingly contain systems that enable high levels of partial-automation" [36]. This section addresses the challenges and provides solutions to be used on the signalized urban intersection, and in particular those that contribute to the safety of the signalized urban intersection which result in fewer

accidents involving AVs. Fewer AV accidents adds to the traffic functionality of signalized urban intersections.

3.1.4. Sustainable solutions (at signalized urban intersections) and reduction in air pollution. This section tackles the solutions that can be used at signalized urban intersections to promote sustainability. For instance, this section is dedicated to one item, which is powering the traffic signals and traffic lights through renewable energy such as solar panels and wind turbines. Powering traffic signals and traffic lights through solar panels and/or wind turbines results in:

- Reduction in air pollution
- Reduction in power costs

Those two benefits would definitely promote sustainability in the field of transportation [37].

3.1.5. Ways and features to reduce noise pollution and light pollution. The transportation sector has always been directly associated with noise annoyance, sleep disturbance and several other health problems. Recent data on noise exposure in Europe suggested that 42 million European residents are exposed to noise coming from road traffic [38]. The noise level that comes from traffic is above Lden = 55 dB (the World Health Organization's maximum recommended noise level). This problem is partially caused by urban and traffic planners along with building designers [39].

Moreover, in the past light pollution was observed as an issue only for astronomers. However, in recent years, light pollution has been recognized as a serious issue for both the environment and human health. Therefore, this issue can cause negative consequences. Moreover, physiological evidence has shown a strong association between both artificial light and light pollution and many disorders and diseases like diabetes, obesity, cancer, and sleep deprivation [40].

HIRS has two sections that tackle all the solutions that can be used at signalized urban intersections to reduce both the noise and light pollutions. Operating the signalized urban intersections while taking into consideration the harm of those two types of pollution would definitely add to the health of the individuals living near the signalized urban intersections. A community's health comes from the health of the individuals living in the community [6].

3.1.6. Safety of pedestrians and cyclists. About 270,000 pedestrians lose their lives very year around the world [41]. While in 2015 more than two cyclists in the United States lost their lives every day due to bicycle and vehicle accidents [42]. HIRS have two sections that deal with the new and advanced technologies, physical design, and operational features that tend to make the pedestrian and cyclist more comfortable and safe while walking or cycling. As mentioned earlier, walking and cycling are considered as active modes of transportation. Those two modes have several benefits such as [43] [44].

- Reduction in depression/anxiety
- Reduction in body fats
- Reduction in stress levels
- Improves muscle strength

All of those benefits have a positive effect on our mental and physical health. This indicate how HIRS adds to the health of the individuals and the public health.

3.1.7. Psychological effect of transportation systems. "The built environment can either promote or hinder our mental health" [45]. "Urban transportation systems are fundamental infrastructure in our cities" [46]. Some features that can be added to our built environment can promote our mental health. For instance, contact with nature which comes in different forms in the built environment such as views from the window, biophilic design, and green space. Adding such features to our built environment proves that it helps in reducing stress levels, leads to faster recovery rates from illness, [47] reduces mental fatigue, and increases concentration levels [46]. Those benefits result from integrating those features into our urban environment and proves that if those features were taken into consideration the metal health of the signalized urban intersection's users would be boosted.

3.1.8. Conclusion. In conclusion, this study propostiton states that the integration of HIRS technologies, physical design and operational features in urban intersections leads to operating the urban intersections in a better way in terms of the holistic operational performance. Operating signalized urban intersections holistically results in: traffic performance enhancement, air pollution reduction, noise pollution reduction, user's mental health improvement, and user's safety enhancement. Figure 4

illustrates the influence diagram of HIRS technologies and features on the signalized urban intersections.

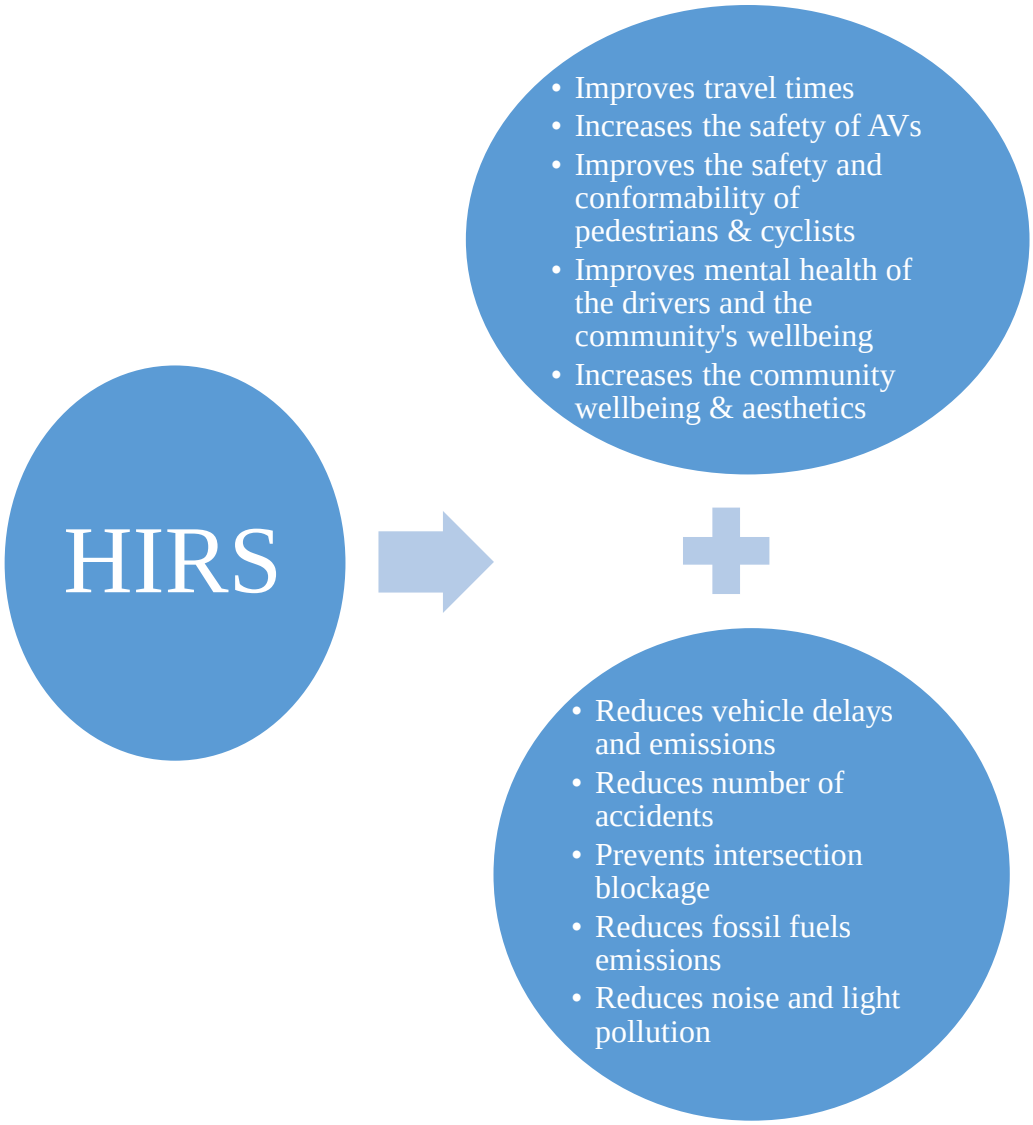

Figure 4 Proposition influence diagram (this chart was developed for this study)

3.2. Research Methodology

3.2.1. Assessment of the previous rating systems. Extensive research has been done to evaluate the rating systems previously used for the different components of a highway. After the research and assessments were done, the weaknesses and gaps in the previous rating systems were identified in order to develop a new rating system.

3.2.2. Development of the HIRS. Similarly, research has been done for finding all the new and advanced technologies, physical design, and operational

features and technologies that are present today. After obtaining all the new and advanced technologies, physical design, and operational features that can be used at signalized urban intersections, the HIRS has been developed. It was designed to rate the signalized urban intersections based on two main criteria: Motorized/vehicular traffic and public health and community wellbeing. Under those two main sections fall nine subsections such as traffic signal management and sustainable solutions at signalized urban intersections. While under the sub-section fall items such as signal coordination and use of clean modes of power generation (for traffic lights and traffic signals). Those items focus on new technologies, physical design, and operational features that lead to traffic performance enhancement, air pollution reduction, noise pollution reduction, user's mental health enhancement, and user's safety improvement. Promoting those five aspects leads to the holistic operational performance of signalized urban intersections.

3.2.3. Validation of HIRS. HIRS items were validated through a panel of seven experts in the field of transportation and public health in which a survey was given to indicate the significance of each item under the sub-sections. Based on the data collected from the panel using the Relative Importance Index (RII) formula, the weightage of every item under the sub-section was given.

3.2.4. Field data collection using HIRS. Real data from 20 signalized urban intersections was collected from four cities: Abu Dhabi, Dubai, Sharjah, and Ajman. The final score that each of the 20 tested signalized urban intersections reflected the level of holistic operational performance at which the intersections are operating.

3.2.5. Analysis of the field data collected. The real data from the 20 signalized urban intersections that was collected previously was analyzed using statistical methods: mean, maximum, minimum and standard deviation. To obtain useful results the whole collected data was statistically analyzed, then the collected data was statistically analyzed by city, finally the details were analyzed for each section of the HIRS.

3.2.6. Development of HIPI and abbreviated HIPI. To facilitate future research and measurement of the effectiveness of HIRS, two more questionnaires were developed, The Holistic Intersection Performance Indicators Survey (HIPI) and an

abbreviated form of HIPI, only targeting a selected set of indicators. Future research can test the soundness of further models testing HIRS and HIPI as inputs and outputs.

3.2.7. Conclusions and recommendations. Based on the results some conclusions and recommendations for the improvement of signalized urban intersections in the region were stated. Finally, some recommendations for future work were also stated.

Chapter 4. Rating System Development

This study is concerned mainly with HIRS. HIRS is a survey that is to be used to rate the level of usage of the technologies, physical design, and operational features that leads to the holistic operational performance of a signalized urban intersection. The performance of a signalized urban intersection will be rated based on the presence or absence of technologies, physical design and operational features that could be used to make the signalized urban intersection support the holistic optional performance (better traffic functionalities, sustainability, and public health and community wellbeing). The survey was composed mainly of two main sections which were: motorized/vehicular traffic and public health and community wellbeing. Under those two mains aspects falls nine sub-sections, such as *Traffic signal management, Special features in vehicular service, Autonomous vehicle readiness, Sustainable solutions at intersections, Ways and features to reduce Noise pollution, Ways and features to reduce Light pollution, Convenience and safety of Pedestrians, Convenience and safety of Cyclists, Psychological effect of transportation system.* Several items fall under those various sub-sections. Those items deal with all the new or advanced technologies, physical design and operational features that lead to a holistic view of how a signalized urban intersection should be operated. Figure 5 shows a simplified structure of HIRS.

Additionally, this study provides a Holistic Intersection Performance Indicators (HIPI) survey and additional abbreviated HIPI survey. The HIPI survey is used to measure the effectiveness of those technologies, physical design, and operational features present in the HIRS survey. While the abbreviated HIPI survey is designed to measure the effectiveness of few selected technologies, physical design, and operational features of the extensive HIPI.

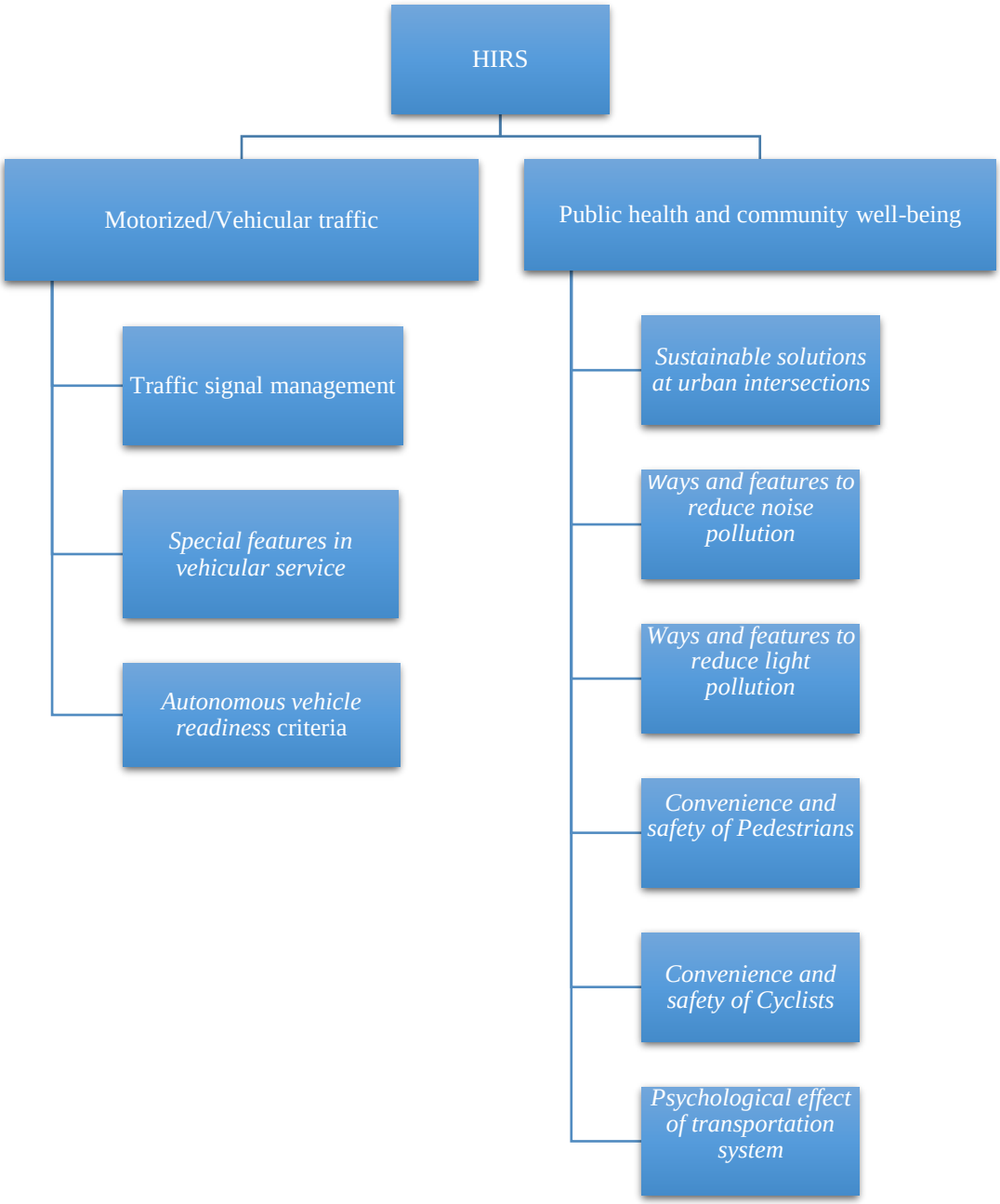

Figure 5 Simplified Structure of HIRS (this chart was developed for this study)

4.1 Motorized/vehicular traffic at signalized urban intersection.

4.1.1. Traffic signal management. Traffic signal management: known as active traffic management, it involves advanced technologies in the fields of communication, electronics and computing. The main components of the system are a central computer, roadside traffic sensors, wireless communication/fiber optic, traffic signal controllers at intersections [48]. Three items falls under the traffic signal management, namely: *Signal coordination, Dynamic signal optimization, Traffic signal priority*.

***4.1.1.1. Signal coordination*:** when the traffic signals are closely spaced, the green time should be timed efficiently between the signals so that the vehicles move more efficiently through a set of signals over a section of the road. Good signal coordination leads to better pollution reduction and fuel conservation [49]. As shown in Figure 6.

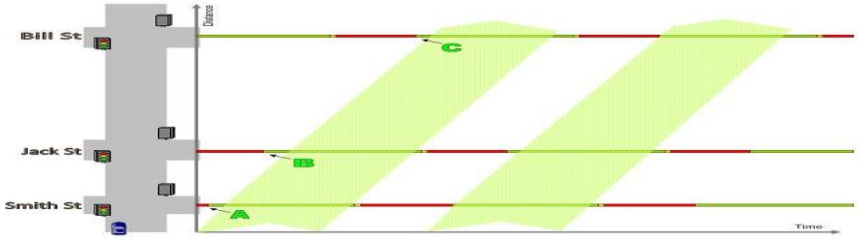

Figure 6 Signal coordination [50].

4.1.1.2. Dynamic signal optimization: the optimization logic involves calculating the optimal signal timing and green time allocation for every movement at the end of every cycle. This dynamic control system showed better results than fixed time control in terms of throughput at the intersections, reduction delays and environmental emissions, and improvement of travel times [51]. As shown in Figure 7.

Figure 7 Dynamic signal optimization system [52].

4.1.1.3. Traffic signal priority: Traffic signal priority is a system that detects the presence of a transit vehicle using a signal and receiver equipped on the transit vehicles and the traffic signals. After the traffic signal detects the presence of the transit vehicle system the traffic signal either holds the green or gives a nearly green [53]. As shown in Figure 8.

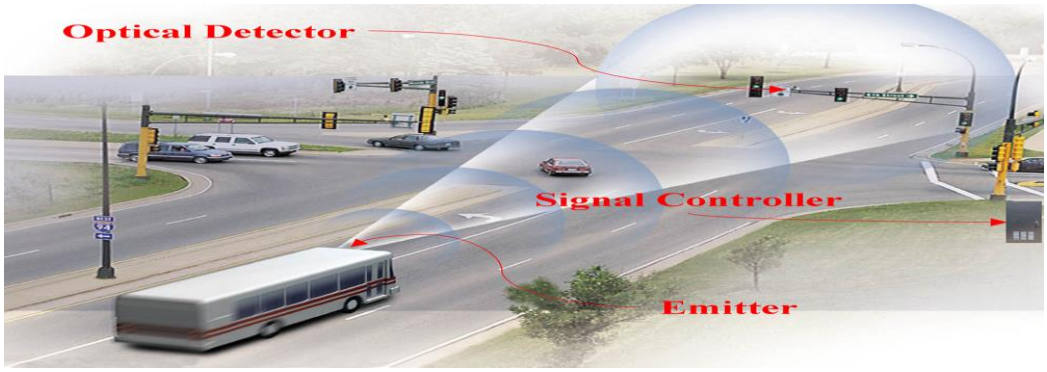

Figure 8 Traffic signal priority process [54].

Advantages of *Traffic Signal Management* [55]: Responsiveness to traffic demands, short cycles, effective use of capacity leading to and recovering from oversaturation

- Minimizing delay time and stops
- Prevent queues at an intersection

4.1.1.4. Measures of traffic signal management effect. The effect can be measured using the average control delay: d, units: sec/veh. [56].

Avg. control delay calculated based on:

d=d1(PF)+d2+d3

$$PF = \frac{1-p}{(1-(\frac{g}{c})} * fp$$

$$d1=\frac{.5(1-\left(\frac{g}{c}\right)^2}{(1-\min(1,X)\left(\frac{g}{c}\right))}$$

$$d2=900T((X-1)+\left((X-1)^2+\frac{8klX}{cT}\right)^{.5}$$

d3= delay due to preexisting queue (s/veh)

Where: T= duration of analysis period (h)

X= v/c ratio

C=cycle length (s)

k=incremental delay factor for actuated controller settings, 0.5 all pre-timed controllers, 1 upstream filtering/metering adjustment factor 1 for all individual intersection analyses

C= capacity (veh/h)

P= proportion of vehicles arriving during green interval fp=supplemental adjustment factor for platoon arriving during green phase [56].

Level of service can be indicated based on: [56]

d≤10 =LOS A

d>10-20 = LOS B

d>20-35 = LOS C

d>35-55 = LOS D

d>55-80 = LOS E

d>80 = LOS F

4.1.2. Special features in vehicular service. There are six different features that can be added to the signalized urban intersections to improve the traffic functionality of the intersections. The special features such as: *flashing green light, yellow box at the junction backup battery for traffic signal, RLR camera, Traveler information system, and Incident management system.*

***4.1.2.1.a. Flashing green light*:** traffic signals that are equipped with a flashing green light. This notifies the driver that the pedestrian signal can be activated at any time, in other words the vehicles' signal will turn red at any time [31].

Advantages of *flashing green light*:

- Results in a safer response from the motorized vehicle drivers [31].

4.1.2.1.b. Traffic signal equipped with countdown timer: traffic signals that are equipped with countdown timer. This results in a better response from the drivers. Since it lets the drivers know when the traffic signal will turn from green light to red light, which causes a safer response from the motorized vehicle drivers [57]. As shown in Figure 9.

Figure 9 Countdown timer of traffic signal [58].

Advantages of *traffic signal equipped with countdown timer***:**

- Results in a safer response from the motorized vehicle drivers [57].

4.1.2.2. Yellow box junction: It is a yellow framed box with crisscross lines inside the box, marked at the center of the intersection. This yellow box indicates that the vehicles are not allowed to enter the box unless the exit from the box is clear. The presence of the yellow box avoids traffic blockage at the center of the intersection and keeps the traffic flowing in all the directions [32]. As shown in Figure 10.

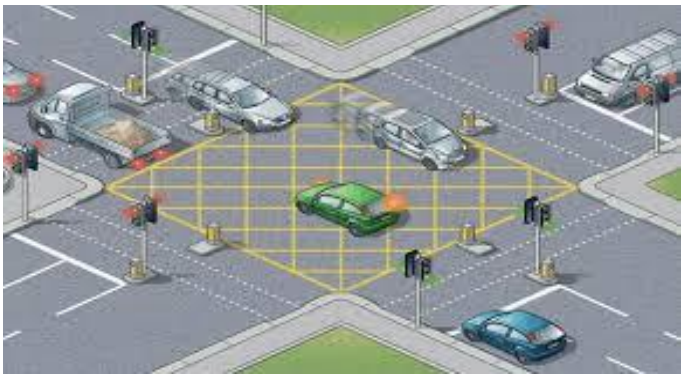

Figure 10 Yellow box present at the center of the intersection [59].

Advantages of the *yellow box junction***:**

- Avoids traffic blockage at the center of the intersection and keeps the traffic flowing in all directions [32].

4.1.2.3. Traffic Signal equipped with Battery Backup System: Traffic signal equipped with battery backup system that allows the traffic signal to function smoothly for limited hours even after a power failure [60].

Advantages of Traffic Signal equipped with Battery Backup System:

- This system prevents major problems such as accidents and traffic jams that happen after a complete shutdown in the traffic signals at an intersection.

4.1.2.4. RED light running camera (RLR)*:* It is a camera installed at the side of the road near the center of the intersection. The main function of this camera is the recording of vehicles that cross the intersection while the traffic signal indicates a red light. Those drivers are penalized for their dangerous maneuvers. Placement of RLR cameras leads to significant reduction in all types of RLR crashes [33]. As shown in Figure 11.

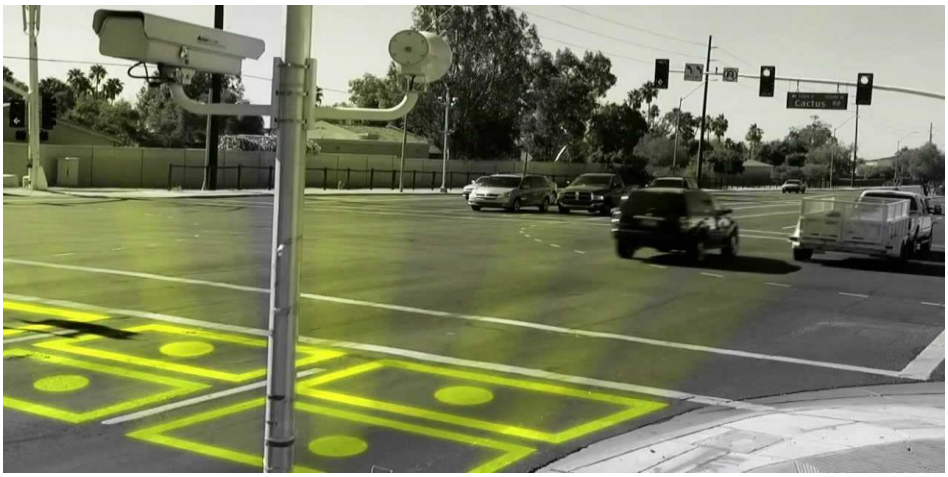

Figure 11 RLR camera [61].

Advantages *RED light running camera (RLR)***:**

- Leads to significant reduction in all types of red light running crashes. [33]

***4.1.2.5. Traveler information system*:** is an information system that provides three main types of real-time data: emergency advisors, traffic conditions, and road conditions through dynamic message signs, phone messages, internet websites and radio. This system requires the presence of sensors at the road to convey real data to the central traffic operator and then the central traffic operator delivers the message to the drivers either by dynamic message signs or phone messages or internet websites and radio [34]. As shown in Figure 12.

Advantages of the Traveler information system:

- Maximizes the capacity of the system [34]
- Increases safety [34]
- Reduction in congestion [34]

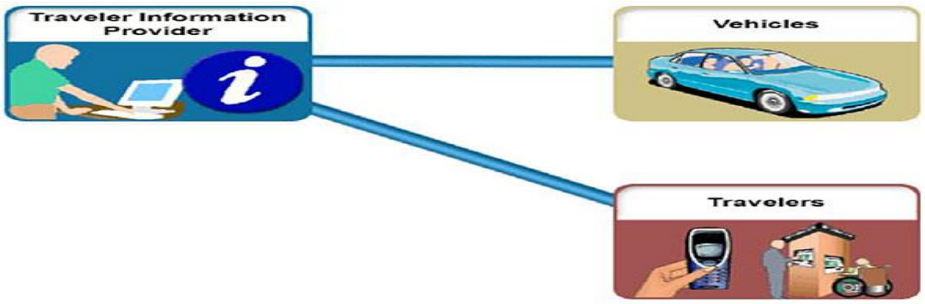

Figure 12 Simplified diagram of Traveler information system [62].

4.1.2.6. Incident management system: is a system that uses sensors to detect incidents and traffic roadway data. Once an incident occurs an emergency response from the traveler information system is broadcast. This system leads to reduction in fuel consumption (less CO, NO, hydrocarbon emissions). In addition it reduces the average delay time caused by incidents [35].

Advantages of Incident management:

- Reduction in the average traffic incident delay [35]

4.2.2.7. Measures of Special features effect. Measuring the effects of each of the special features can be seen in Table 2:

Table 2 Ways to measure the effect of each of the special features

Special Features	Ways to measure there effect
Flashing green light OR Traffic signal equipped with countdown timer	Number of accidents
Yellow box junction	Number of accidents
Traffic Signal equipped with Battery Backup System	Number of accidents
RED light running camera (RLR):	Number of accidents
Traveler information system	Statistics of the traffic congestions
Incident management system	Statistics about the traffic accident delays

4.1.3. Autonomous vehicle ready criteria.

4.1.3.1. Definition of Autonomous vehicle. Autonomous vehicle: a vehicle that drives autonomously, it detects obstacles, traffic lanes and the surrounding vehicles which means that the driver does not require to perform any manoeuvers [63].

There are five levels of autonomous vehicles:

- Level 0 (NO automation): the driver has complete control over the steering, brakes, motive power, and throttle all the time. In addition the driver is fully responsible for the safe of the vehicle's operation and monitoring the roadway [64].
- Level 1 (function-specific automation): the automation involves one or more specific control functions. The driver has overall control and is fully responsible for the safety of the operation. The autonomous system can provide added control aids to the driver such as dynamic brake support in emergency cases [64].
- Level 2 (combined function automation): the automation in the vehicle involves at least 2 primary functions. The driver at this level is still responsible for the

safety of the vehicle and monitoring the roadway. However, the automation can share authority when the driver gives up primary control. But the automation can also give up control with no advance warning which means the driver must be ready to take control to ensure the safety of the vehicle [64].

- Level 3 (limited self-driving automation): At this level the driver under certain environmental conditions can give up full control of all the safety-critical functions of the automation system. However, the driver is expected to be available to take control again occasionally [64].
- Level 4 (full self-driving automation): the vehicle at this level is designed to monitor the roadway for the whole trip and perform all safety-critical driving functions. The driver will only be required to input the destination of the trip, and the driver will not be expected to take control at any time during the trip [64].

4.1.3.2. Expected challenges of autonomous vehicles.

4.1.3.2.1. *Quality of the lane markings and clear signs*. Some smart driving technologies that AVs are supposed to perform such as lane keeping, lane departure, left run assists, requires no communication between the vehicle and the infrastructure. However, those operations require the physical presence of clear traffic signs and lane marking that will allow the AVs to determine the surrounding environment in order to perform those operations (lane keeping, lane departure, and left run assists) smoothly under normal conditions [65].

4.1.3.2.2. *Clear detection of traffic signal.* In certain weather conditions traffic signal detection might be one of the challenges that AVs might face. When there is a strong sunlight at low angles hitting the traffic signals, an AV's sensors would not be able to identify the correct signal information [66].

Advantages *Autonomous vehicle ready criteria*:

- Fewer accidents caused by AVs

4.1.3.3. Measurement of AV suggested features effect. The effect of those three features can be seen by counting the number of AV accidents before and after the placement of the three suggested features.

4.2. Public Health and Community Wellbeing.

4.2.1. Sustainable solutions at signalized urban intersections.

4.2.1.1. Definition of sustainability: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" or by the triple bottom line of planet, profit, and people [9].

4.2.1.1.1. *Usage of Clean modes of power generation (for traffic lights and traffic signals).* Powering the traffic signals and smart boards with sustainable energy sources such as wind turbines and solar panels leads to reducing the air pollution that is a result from burning fossil fuels [37]. As shown in Figure 13 and Figure 14.

Figure 13 Solar panels powering the traffic signals [67].

Figure 14 Wind turbine powering the Traffic signals [68].

Advantages of *Usage of clean modes of power generation*:

- Reduction in air pollution [37]

4.2.1.2. Measurement of sustainable solutions in transportation effects. The effect of those features cannot be seen on the field (intersection). However, the data of

fossil fuel usage can be collected from the authorities. Then the numbers can be compared before and after the placement of this feature.

4.2.2. Ways and features to reduce noise pollution in transportation (at signalized urban intersections)

4.2.2.1. Noise pollution definition. Noise pollution is defined as the harmful/unwanted outdoor sound created by human activities, such as noise coming from industrial sites, rail, road, and airports [69]. Effects of noise supported by scientific evidence implies the following outcomes: *annoyance, sleep disturbance, cardiovascular disease, cognitive impairment, tinnitus* [69].

According to the WHO European Centre for Environment and Health, the sources of environmental noise are: Transport (air traffic, rail traffic, and road traffic), Industry/construction, Community sources (television, radio, and neighbors), Social/ leisure sources (fireworks, concerts, and firearms) [69].

Limits/indicators of noise pollution:

The World Health Organization measures noise pollution based on the terminology below [70]:

LAmax: maximum outdoor sound pressure level

SEL: sound exposure level

Lnight: night-time noise indicators or 1 year LAeq (exposure to noise) over 8 hours outside at the most exposed façade

SEL = 23.9 + .81 *LAmax

Lnight = SEL + 10*lg(N) – 70.2

N= the number of events occurring in period T

T= time during which the events occur in seconds. For a night year 10*Ig(T) is 70.2

Lnight= Lnight, inside+ Y dB

Y is the year average insulation value of the (bedroom) facade.

Default value of 21 dB

Lnight.outside average level of sound pressure at night

Table 3 shows the recommended night noise guidelines taken from the Night Noise Guidelines for Europe 2009.

Table 3 Recommended night noise guidelines for Europe [70].

Night noise guideline (NNG)	Lnight,outside= 40 dB
Interim target (IT)	Lnight,outside= 55 dB

Table 4 shows the effect of the different night noise levels on the health of the population based on the Night Noise Guidelines for Europe 2009.

Table 4 Noise levels and their affect on the health of the effected population [70].

Average night noise level over a year Lnight,outside	**Health effects observed in the population.**
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. Lnight, outside of 30 dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. Lnight, outside of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise

40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

Figure 15 shows the number of people exposed to noise in Europe and the different sources of noise.

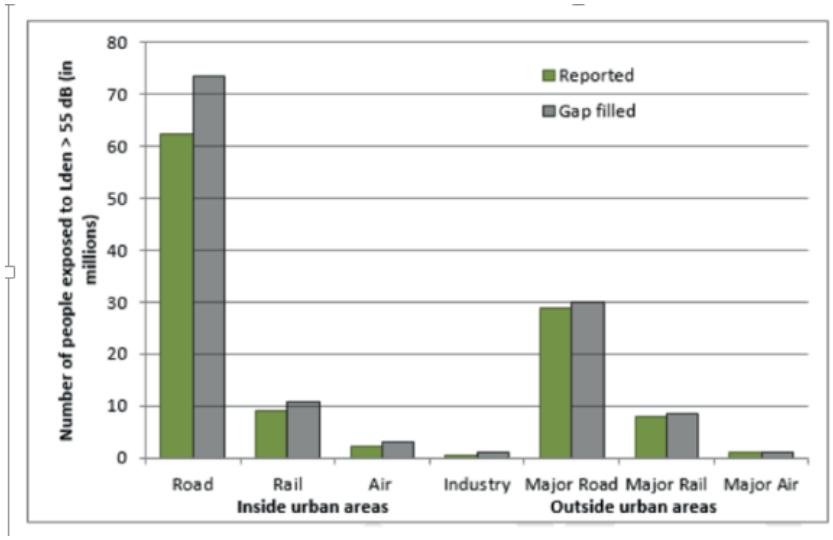

Figure 15 number of people exposed to noise in Europe and sources of noise [70].

4.2.2.2. Solution for noise pollution in general. Figure 16 explains noise management [70].

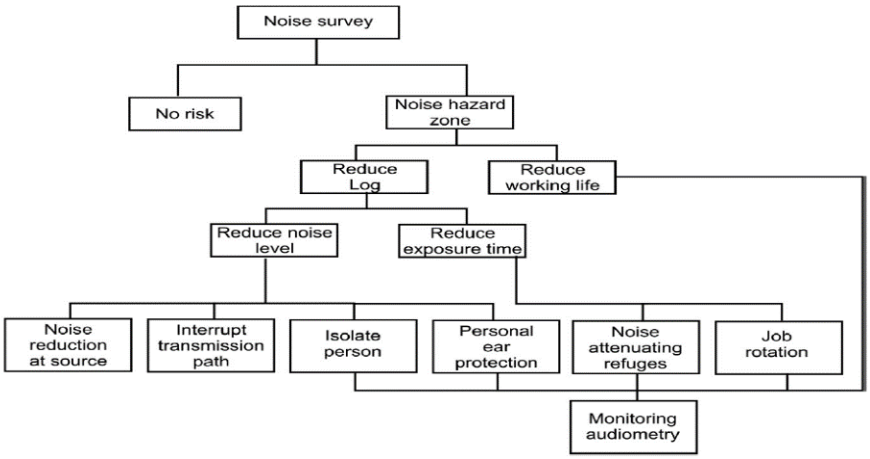

Figure 16 Noise management [70].

Figure 17 shows that the sound wave (noise) travels directly from the source to the receiver if there was no barrier in between the source and the receiver to fluctuate the sound wave. This implies that one way to reduce the noise level is by installing barriers to reduce the noise level [70].

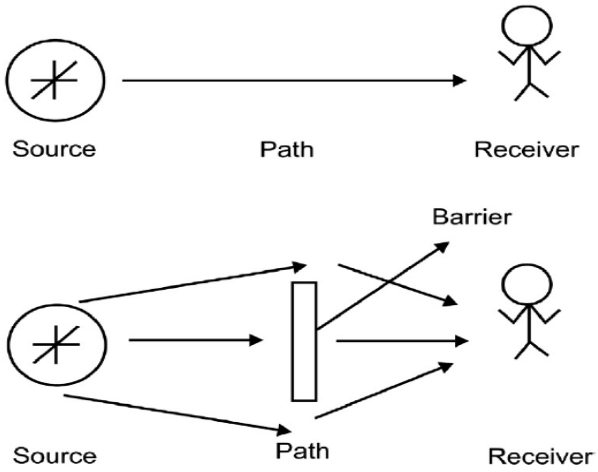

Figure 17 Noise pollution controls [70].

Traffic noise comes from the vehicle's tires, engine, exhaust noise, mufflers. Usually, the traffic noise level increases as the speed of the vehicles increase, or the volume increase, or the number of truck increases in the flow [71].

4.2.2.3. Solutions to reduce noise pollution in transportation (at signalized urban intersections).

4.2.2.3.1. *Planting vegetation on the side of the road.* Planting vegetation to absorb the noise that is caused by vehicles [70]. The planting of such dense vegetation as hedges, medium-height green barriers, trees, and integration of vegetation in the walls of the buildings nearby [72].

4.2.2.3.2. *Placing sound barriers*. Placing boxes made up of different materials to absorb the energy wave (sound waves). The materials such as wood, stucco, masonry, metal or any material that absorb the noise that is caused by vehicles [70]. As shown in Figure 18, Figure 19, and Figure 20.

Figure 18 Usage of sound barriers to absorb noise [70].

Figure 19 Usage of Medium Height dense vegetation, Hazza Bin Zayed Street, U.A.E.

Figure 20 Usage of Dense vegetation & a wooden box, Jumeirah street, U.A.E.

Advantages of *solutions to reduce noise pollution in transportation:*

- Reduction in noise pollution

4.2.2.4 Measurement of noise pollution. The indicator of noise pollution can be measured in decibel (dBS).

4.2.3 Ways and features to reduce light pollution in transportation (at signalized urban intersections).

4.2.3.1. Light pollution definition. Light pollution is known as the brightening of the night sky by any artificial lights such as light bulbs or any man-made sources of light that hinder our observation of the planets and stars [73].Light pollution can be artificial light that shines unneeded on areas that do not require illumination at night time [74]. The effects of light pollution are: psychological effects, disturbance in biological rhythms, the wasting of energy, and environmental degradation [74].

There are four indicators of light pollution:

Glare: visual discomfort due to excessive brightness, high intensity of light might cause reduction in visual performance and color perception.

Sky glow: brightening the bright sky of inhabited areas, leads to reducing the contrast between the night sky and the stars.

Light trespass (spillage of light): light falling over areas where illumination is not needed. In other words light unintentionally illuminating homes and businesses nearby.

Clutter: excessive and bright light due to grouping of light sources. [75], [73], [76].

Figure 21 illustrates the four components of light pollution:

Figure 21 indicators of light pollution [73].

4.2.3.2. Solutions for light pollution at signalized urban intersection

4.2.3.2.1. *Turn off street lighting*. Equipping street lights with motion sensors that turn off the lights when there is no need for light. Such practices reduce the light pollution caused by street lights [76]. As shown in Figure 22.

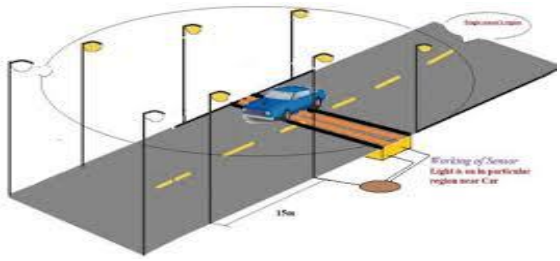

Figure 22 light bulbs equipped with motion detectors [77].

4.2.3.2.2. *Use of full cutoff fixtures to have no light above the horizontal level.* Use of full cutoff fixtures for the street lights leads to reduction in light pollution caused by the street lights [76].

There are four types of cutoff fixture [76].

- Full cutoff: no light at 90 degrees or above, and no more than 10 % of lamp lumens intensity at or above 80 degrees.
- Cut off: 2.5 % of the lamp lumens intensity at or above the 90 degrees, and no more than 10 % of lamp lumens at or above 80 degrees.

- Semi- cutoff: 5% of the lamp lumens intensity at or above 90 degrees, and no more than 20% of lamp lumens at or above 80 degrees.
- Non-cutoff: no limitation on the light at any angle.

The four types of cutoff fixtures can be seen in Figure 23.

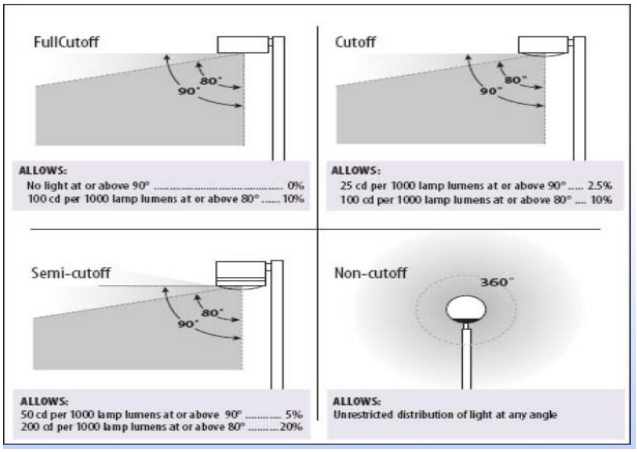

Figure 23 four types of cut-off fixtures [76].

Figure 24 shows usage of full cutoff fixture in the city of Abu Dhabi, UAE.

Figure 24 , Usage of Full cutoff Fixture,Hamadan Bin Mohamd street ,U.A.E.

4.2.3.3. Measures of Light pollution. Night sky brightness which is also known as NSB. This technique is used to quantify the brightness of sky glow. It measures the combination of scattered light from artificial lighting courses and natural emissions. The units of NSB includes candela per meter square (cd/m^2) magnitude per arc second squared (mag/arcsec^2) [78].

4.2.4. Convenience and safety of pedestrians

4.2.4.1. Definition of pedestrians. Pedestrians are defined as people who walk or use a self-propelled wheelchair/motorized tricycle/motorized quadracycle [79]. On average, pedestrian speed is estimated as 1.2m/s or 4ft/s. however their speed might

vary from 0.6 m/s-1.3 m/s or 2 ft/sec-4.3 ft/s. Pedestrians are classified as: pedestrian without walking difficulty, or pedestrians with disability, children, and older people [80].

4.2.4.2. Pedestrian service advanced features.

4.2.4.2.*a.* *Median Refuge Island:* A raised area designed to allow pedestrians to cross one direction of the street at a time [80].

4.2.4.2.*b*. *Advance Stop Line and Sign:* A stop line that is marked further away from the cross walk to improve the safety and the visibility of pedestrians by drivers [80].

4.2.4.2.*c.* *Advanced signing:* A sign that is placed to warn the drivers that pedestrians may be crossing the roadway [80].

4.2.4.2.*d.* *Raised crosswalk.* An elevated crosswalk above the adjacent driving lanes. It helps in warning the drivers to lower their speed when they are approaching an elevated surface [80]. As shown in Figure 25.

Figure 25 Raised crosswalks [81].

4.2.4.2.*e.* *Marking and crossing signs.* Marking and crossing signs that are used to alert the drivers that pedestrians are crossing at a specific point [80].

4.2.4.2.*f.* *Street pedestrian crossing signs.* Signs placed on the lane edge or street centerline [80]. As shown in Figure 26.

Figure 26 Street pedestrian crossing sign [80].

4.2.4.2.*g.* *Signs and High-Visibility Markings*. Signs and markings that are similar to the conventional signs and marking. However, they have higher reflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention [80]. As shown in Figure 27.

Figure 27 Comparison between a low and high visibility traffic signs [82].

4.2.4.2.*h.* *Warning light.* Flashing amber lights placed on the pavement in front of the pedestrian side walk [80]. As shown in Figure 28.

Figure 28 Warning light [83].

4.2.4.2.*i.* *Road diet/narrowing*. Narrowing the roadway can be achieved by reducing lane width and using the excess space to increase the bicycle lane or extend sidewalks [80]. As shown in Figure 29.

Figure 29 Road diet/ Road narrowing [84].

4.2.4.2.*j.* *Traffic signal with pedestrian countdown signal.* Traffic signal with pedestrian countdown signal that indicates how much time is left for the pedestrian to cross the roadway [85]. As shown in Figure 30.

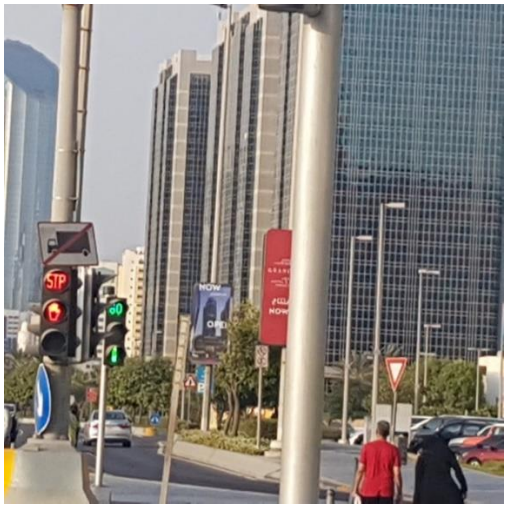

Figure 30 Pedestrian traffic signal with countdown timer, Al Corniche street, U.A.E.

4.2.4.2.*k.* *Warning tactile ground surface indicators.* Raised dots on the ground surface that indicate that there is a nearby hazard (the ground will be changing for a train/tram platform, or a warning of the presence of a coming stairs) [86]. As shown in Figure 31.

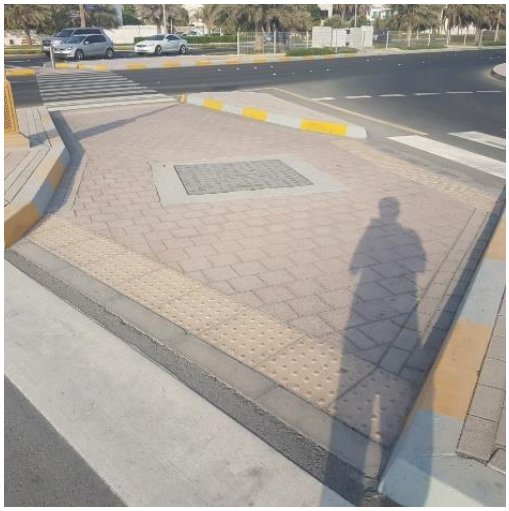

Figure 31 Warning Tactile ground surface indicators, Al Beteen street, U.A.E.

4.2.4.2.*l.* *Directional warning tactile ground surface indicators*. Raised dots oriented in parallel lines to indicate the direction of travel that pedestrians who have visual impairments can follow [86]. As shown in Figure 32.

Figure 32 Directional warning tactile ground surface indicators [87].

4.2.4.2.*m. Crossing audio tactile.* provides audio tactile indications to notify the pedestrian who has a sight disability when and when not to cross the intersection [88]. As shown in Figure 33.

Figure 33 Crossing audio tactile [89].

Advantages of Convenience and safety of Pedestrians features*:*

- *Reduces the number of pedestrian accidents*

4.2.4.3. Measures of pedestrian's service. The indicator of a pedestrian's service would be the number of pedestrian's accidents.

4.2.5. Convenience and safety of cyclist.

4.2.5.1. Definition of cyclist. Cyclist are people who use bicycled/tricycles/quadracycles to commute from one place to another [90].

4.2.5.2. Cyclist service advanced features.

4.2.5.2*.a.* *Bicycle lanes*: Lanes that are designated by solid white line, bicycle symbol that indicates that this lane is exclusively for bicycles. Typical bicycle lanes are 4-6 ft wide [90]. As shown in Figure 34.

Figure 34 bicycle Lane, Al Khaleej Al Arabi street, U.A.E.

4.2.5.2*.b.* *Bike parking.* There are two types of bicycle parking: bicycle racks (fixed object made up of metal to secure the bicycles to it), and bicycle lockers (they vary in design) [90].

4.2.5.2*.c.* *Bike boxes.* A designated area located at the head of the lane at the intersection. This area provides the cyclists a safe and visible way to get ahead of the queuing vehicles during the red phase of the signal intersection [90]. As shown in Figure 35.

Figure 35 Bike boxes [90].

4.2.5.2.*d.* *Intersection Crossing Markings.* Marking at the pavement that indicates the intended path of the bicyclist to cross the adjacent lane [90]. As shown in Figure 36.

Figure 36 Intersection crossing marking [90].

4.2.5.2.*e.* *Median Refuge Island.* Protected space placed to facilitate the pedestrian and bicyclist to cross one direction at a time [90].

4.2.5.2.*f.* *Bicycle Signal Heads*. Electronic traffic control device that should be used with the conventional traffic signal/hybrid beacon [90]. As shown in Figure 37.

Figure 37 Traffic signal for vehicles/pedestrians/cyclist, Al Betten street, U.A.E.

4.2.5.2.*g.* *Signal Detection and Actuatio*. Bicycle detection devices are used to detect the presence of bicycles and alert the signal controller about the presence of the bicycle. There are four types of bicycle detectors: Microwave radar, loop induction, video detections, and push button as shown in Figure 38 [90].

Figure 38 Signal detection and actuation [90].

4.2.5.2.*h.* *Colored Bike Facility*. Colored pavement within the bicycle lane [74]. As shown in Figure 39.

Figure 39 Colored bike facility, Al Khaleej al arabi street, U.A.E.

Advantages of convenience and safety of cyclist features*:*

- Reduces the number of cyclist accidents [91].

4.2.5.3. Measures of cyclist service. The indicator of cyclist service would be the number of cyclist accidents

4.2.6. Psychological effects of transportation systems. In the field of transportation there are three main aspects that deal with the effects of transportation systems on the mental health of the system users. The three aspects are:

- Context sensitivity
- Biophilic design
- Use of creative signs that have humor/emotions/emojis

4.2.6.1. Context sensitivity. Maintaining environmental harmony, the intersection should not disturb the surrounding area. The intersection should be in harmony with the social environment and the physical environment. [92] There should be harmony between the design and the surrounding area by using the materials needed for construction design from nearby areas [92].

Advantages of context sensitivity design [92]:

- Improve the quality of life for the community and community satisfaction, since the natural environment is a critical component of the community itself.

4.2.6.2 Biophilic design.

4.2.6.2.1. *Definition of biophilic design.* Biophilia is referred to as the native human attraction to nature. [93] Biophilic design involves adding nature and natural systems in a way that will be accessible/visible to the people who live in urban communities. It focuses on adding green features, creating a walkable environment, and adding spirit to a place [93].

Advantages of biophilic design at signalized urban intersections:

Studies have proven that biophilic designs at hospitals make the patients heal more quickly. While adding biophilic design at schools improved the test scores of the students. Moreover, adding biophilic elements at places of work, resulted in improvements in the productivity of employees [93].

However, adding biophilic elements at the road showed an indirect effect on the users of the road exposed to those elements, such as street trees and vegetation. The indirect effects were as follows [94]:

- reduction in absenteeism
- reduction in traffic incidents
- reduction in health care costs

As shown all of those benefits of adding biophilic designs to the signalized urban intersection would result in better mental health of the users of that intersection

4.2.6.2.2. *Components of a biophilic design (at signalized urban intersection).*

4.2.6.2.2.a. Green Street: a storm water management technique that involves using permeable pavement vegetation to capture rainwater instead of directing into sewer systems [95].95

4.2.6.2.2.b. *Urban trees: Planting trees on the side of the streets* [96]. As shown in Figure 40.

Figure 40 Urban trees and green vegetation, Hazza Bin Zayed street, U.A.E.

4.2.6.2.2.c. *Edible landscaping: Planting edible plants on the side of the streets* [96].

4.2.6.2.2.d. *Light color pavement: Pavements that have a lighter color (lighter than black) are more reflective than a black pavement* [96]. As shown in Figure 41.

Figure 41 Usage of light color pavement [97].

***4.2.6.3. Use of creative signs that have humor/emotions/emojis*.** The presence of humor/emotions/emoji in the traffic signs. Usage of such signs shape the driver's attitude and create happier and more positive emotions. Signs that have facial expressions directly affect the drivers psychologically. [98],[99]. Example of creative signs can be seen in Figure 42.

Figure 42 Usage of creative signs that has humor / emotions [99].

4.2.6.4. Measuring the effect of adding the features that affects us psychologically. Measuring the effect of those three aspects (*context sensitivity design, biophilic design, use of creative signs that have humor/emotions/emojis*) can be done by applying psychological tests to the users of the signalized urban intersections before and after integrating those three aspects in the design of the signalized urban intersection. Since those aspects affect our mental state, testing their effects can be valid by subjecting the signalized urban intersections' users to psychological assessments. Several physiological tests can be used. However, use of DAAS-21 is recommended since this test is composed of 21 items that are used to measure the three main mental health factors: depression, anxiety and the stress scale of adults [100].

All the components of the HIRS survey along with their explanation, importance, sources, and basis of points awarded are summarized in Table 5.

Table 5: HIRS' item description and the point awarding

Section A: Motorized/Vehicular traffic		
Subsection 1: Traffic signal management		
Sub section 1 Items:	Subsection description:	Points awarded based on:
Item 1: Signal coordination	The three main parameters of the traffic signal coordination: cycle length, spilt and offset are designed to allow the vehicle to cross multiple traffic signals on a section of the road [49]. Importance: • Responsiveness to traffic demands, short cycles, effective use of capacity leading to and recovering from oversaturation [55]. • Minimizing delay time and stops [55]. • Prevent queues from an intersection [55].	**1 point**: The platoon of vehicles are able to cross multiple traffic signal on a section of a road at one shot. **0 point**: The platoon of vehicles are *NOT* able to cross multiple traffic signal on a section of a road at one shot.
Item 2: Dynamic signal optimization	Signal timing is optimized based on the real-time data obtained from the loop detectors [51]. Importance: • Responsiveness to traffic demands, short cycles, effective use of capacity leading to and recovering from oversaturation [55].	**1 point:** Signal timing is optimized based on the real-time data obtained from the loop detectors. **0 point:** Signal timing is *NOT* optimized based on the real-time data

	• Minimizing delay time and stops [55]. • Prevent queues from an intersection [55].	obtained from the loop detectors.
Item 3: Traffic signal priority	Traffic signal priority detects the presence of a transit vehicle, the system either holds the green signal or gives an early green [53]. Importance: • Responsiveness to traffic demands, short cycles, effective use of capacity leading to and recovering from oversaturation [55]. • Minimizing delay time and stops [55]. • Prevent queues from an intersection [55].	**1 point**: Traffic signals are equipped to adapt traffic signal priority (TSP). **0 point**: Traffic signal are *NOT* equipped to adapt traffic signal priority (TSP).
Sub section 2: Special features		
Sub section 2 Items:	Subsection description:	Points awarded based on:
Item 1: Flashing green light	Flashing of a green light tells the drivers that the pedestrian signal is activated, this procedure notifies the drivers that the pedestrian signal can be activated at any time, in other words the vehicles' signal will turn red at any time [31]. Importance: • Which causes a safer response from the	**1 point**: Traffic signal has flashing green light. **0 point:** Traffic signal does *NOT* has flashing green light.

	motorized vehicle drivers [31].	
Item 2: Yellow box junction	A yellow box marked at the center of the intersection. Used to indicate to drivers that they are not allowed to enter the yellow box until the exit at the other leg of the intersection is clear, to prevent intersection blockage [32]. Importance: • Avoids traffic blockage at the center of the intersection and keeps the traffic flowing in all the directions [32].	**1 point**: Presence of Yellow box at the intersection **0 point**: Absence of Yellow box at the intersection.
Item 3: Traffic Signal equipped with Battery Backup System	Traffic signal equipped with battery backup system function smoothly for limited hours after power failure[60]. Importance: • This system prevents the major problems such as accidents traffic jams that happens after a complete shutdown in the traffic signals at an intersection.	**1 point:** Traffic signal can function for limited hours with no electricity supply. **0 point:** Traffic signal can ***NOT*** function for limited hours with no electricity supply.
Item 4: Presence of red-light running (RLR) camera	A camera installed at the intersection to capture the vehicles that proceed through the intersection (crosses the intersection) after the signal turns RED [33]. Importance: • Leads to significant reduction in all types of	**1 point**: Presence of RLR camera at the intersection **0point**: Absence of RLR camera at the intersection

	red light running crashes [33].	
Item 5:Traveler information	System that provides traffic conditions, road conditions, emergency advisors, either through dynamic signs on the roads, radio, websites, text messaging through cell phones [34]. Importance: • Maximize the capacity of the system [34]. • Increases safety [34]. • Reduction in congestion [34].	**1 point**: The intersection is equipped with the detector and dynamic signs to support the Traveler information system. **0 point**: The intersection is *NOT* equipped with the detector and dynamic signs to support the Traveler information system.
Item 6: Incident management	System that uses sensors to detect incidents/ traffic roadway data. Once incident occurs an emergency responder will broadcast the traveler information [35]. Importance: • Reduction in the average traffic incident delay [35].	**1 point**: The intersection is equipped with the sensors and the emergency responders to support the Incident system available. **0 point**: The intersection is *NOT* equipped with the sensors and the emergency responders to support the Incident system available.
Subsection 3: Autonomous vehicles		

Sub section 3 Items:	Subsection description:	Points awarded based on:
Item 1: Quality of Lane marking	Quality of lane markings involves: Retro-reflectivity, Chromaticity, Luminance, Skid Resistance [65]. Importance: • Quality of the lane marking affects the ability of Autonomous Vehicles to detect the lane marking [65].	**1 point**: The lane markings are bright (excellent condition). **0.75 point**: The lane markings are at medium quality. **0.5 point**: The lane markings are faded. **0.25 point**: Absence of lane markings.
Item 2 : Clear traffic signs	Clear traffic signs that regulate and control the traffic [65]. Importance: • Clear traffic signs are essential to guide the Autonomous Vehicles [65].	**1 point**: The traffic signs are in good condition. **0 point**: The traffic signs are ***NOT*** in good condition.
Item 3: Multiple traffic signals	Multiple traffic signals installed at different angles to ensure that in any weather conditions the sensors will be	**1 point**: Multiple traffic signals installed at different angles.

	able to detect traffic signals lights [66]. Importance: • Multiple traffic signals are needed to help Autonomous Vehicles detecting them at different times of the day [66].	**0 point**: *Absence* of multiple traffic signals installed at different angles.
Section B: Public health and community well-being		
Subsection 1: Sustainable solutions at signalized urban intersections		
Sub section 1 Items:	Subsection description:	Points awarded based on:
Item 1: Clean mode of power generation (for traffic lights and traffic signals).	Powering the traffic signals and electronic boards, traffic light with eco-friendly energy sources such as wind turbines and solar panels [37]. • Importance: Reduction in air pollution [37].	**1 point**: usage of ecofriendly energy sources to power the traffic lights traffic signals, and electronic boards. **0 point**: usage of ecofriendly energy sources to power the traffic lights traffic signals and electronic boards.
Subsection 2: Ways and features to Sound pollution		
Sub section 2 Items:	Subsection description:	Points awarded based on:

Item 1: Absorption of the sound wave.	Placing boxes made up of different materials to absorb the energy waves (sound waves) [70]. Importance: • Reduction in noise pollution [70].	**1 point:** Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal). **0 point:** Energy Dissipater *NOT* available on the side of the road (made up of wood, stucco, masonry, metal).
Item 2: Planting vegetation	Planting at the side of the road: plants absorb energy waves [72]. Importance: • Reduction in noise pollution [72].	**1 point:** Planting at the side of the road is present. **0 point:** Planting at the side of the road is *NOT* present.
Subsection 3: Ways and features to Light pollution		
Sub section 3 Items:	Subsection description:	Credit awarded based on:
Item 1: Turn off the lights when unneeded.	The light pole equipped with motion sensors/motion detectors. In case of presence of any object (humans/ vehicle/cyclists) the lights will turn on. While	**1 point:** Traffic lights equipped with motion sensors. **0 point:** Traffic lights are *NOT* equipped with motion sensors.

	in the absence of any object (humans/ vehicle/cyclists) the lights will turn off [76]. Importance: • Reduction in Light pollution [76].	
Item 2: Use cutoff fixtures to have no light above the horizontal level	There are four types of cutoff fixture that cover the light bulbs [76]. Full cutoff: no light at 90 degrees or above. Cut off: 2.5 % of the lamp. Lumens intensity at or above the 90 degrees. Semi-cutoff: 5% of the lamp lumens intensity at or above 90 degrees. Non-cutoff: no limitation On the light at any angle. Importance: Reduction in light pollution [76].	**1 point:** if full cutoff were used. **0.75 point**: if cutoff were used. **0.5 point**: if semi cutoff were used. **0.25 point:** if non-cutoff were used.
Subsection 4: Pedestrian service		
Sub section 4 Items:	Subsection description:	Points awarded based on:

Item 1: Median refuge island is wide enough to accommodate the pedestrians & cyclists.	Median refuge island is designed to allow pedestrians to cross one direction of the street at a time [80]. Importance: • Improve the safety of the pedestrian and cyclist, by being accommodated in a safe area [80].	**1 point**: If the median refuge island is wide enough to accommodate the pedestrians. **0 point**: If the median refuge island is *NOT* wide enough to accommodate the pedestrians.
Item 2: presence of Advance Stop Line and Sign	Advance Stop Line and sign is a stop line that is marked further away from the cross walk to improve the safety and the visibility of pedestrians by the drivers [80]. Importance: • Improves the safety of the pedestrian since this will increase the visibility of the pedestrians by the drivers [80].	**1 point**: If advanced stop line and sign is present further away from the cross walk. **0 point:** If advanced stop line and sign is *NOT* present further away from the cross walk.
Item 3: Presence Advanced signing	Advanced signing is a sign that is placed to warn the drivers that pedestrians may be crossing the roadway [80]. Importance: • Improves the safety of the pedestrian since the drivers have noticed the signs and the drivers are	**1 point**: If Advanced signing is present on a roadway. **0 point**: If Advanced signing is *NOT* present on a roadway.

	notified that pedestrians are waiting at this section of the road and may cross at any time [80].	
Item 4: presence of raised crosswalks	Raised crosswalks are elevated above the adjacent driving lanes. It help in warning the drivers to lower their speed since they are approaching an elevated surface [80]. Importance: • Improves the safety since the pedestrian will be on an elevated area which gives them more protection [80].	**1 point**: If the cross walk is raised above the adjacent lanes. **0 point**: If the crosswalks are *NOT* raised above the adjacent lanes.
Item 5: presence of marking and crossing signs	Marking and crossing signs are used to alert the drivers that pedestrians are crossing at a specific point [80]. Importance: • It will indicate to the drivers that they should be careful at this specific section of the intersection since pedestrians will be crossing at this point [80].	**1 point**: If the marking and crossing signs are present. **0 point**: If the marking and crossing signs are *NOT* present.

Item 6: street pedestrian crossing signs	Signs placed on the lane edge or street centerline [80]. Importance: • Warn drivers about the presence of pedestrian, so that they pay attention [80].	**1 point**: If street pedestrian crossing signs are placed on the lane edge/street centerline. **0 point**: If street pedestrian crossing signs are *NOT* placed on the lane edge/ street centerline.
Item 7: High-Visibility signs and Markings	Similar to conventional signs and markings. However, they have higher reflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention. [80] Importance: • Since they are highly reflective the driver will easily detect them and pay attention to them [80].	**1 point**: If High-Visibility signs and Markings are present. **0 point**: High-Visibility signs and Markings are *NOT* present.
Item 8: warning light	Warning light: flashing amber lights placed on the surface of the pavement in front of the pedestrian side walk [80]. Importance: • Another feature that notifies the driver about	**1 point**: If warning lights are present in front of the pedestrian sidewalk. **0 point**: If warning lights are *NOT* presence in front of the pedestrian sidewalk.

	the crossing sidewalk of the pedestrians [80].	
Item 9: road diet/narrowing (traffic calming)	Narrowing the roadway can be achieved by reducing lane width and using the excess space to increase the bicycle lane width or extend sidewalks [80]. Importance: • Increase the safety of the pedestrian since the driver will be forced to reduce their speed when the road gets narrower [80].	**1 point**: If the lanes are narrowed as the lanes approach the side walk and crosswalks. **0 point**: If the lanes are *NOT* narrowed as the lanes approach the sidewalks and crosswalks.
Item 10: Presence of traffic signal with pedestrian countdown signal	Traffic signal with pedestrian countdown signals are countdown signals that indicate how much time is left for the pedestrian to cross the roadway [85]. Importance: • Improves the safety of the pedestrian since they will be able to know if it is safe or not to start crossing the road [85].	**1 point**: If the traffic signal has a countdown signal. **0 point**: If the traffic signal has *NO* countdown signal.
Item 11: Warning Tactile Ground Surface Indicators	Raised dots on the ground surface that indicates that there is a nearby hazard (the ground will be changing for a train/tram	**1 point:** Presence of Warning Tactile Ground Surface Indicators are at

	platform, or a warning of the presence of coming stairs [86]. Importance: • Improves the safety of the pedestrian by guiding pedestrians who have a sight disability through their steps on the ground [86].	the hazardous areas of the intersection. **0 point**: Absence of the Warning Tactile Ground Surface Indicators are at the hazardous areas of the intersection.
Item 12: Directional Warning Tactile Ground Surface Indicators	Raised dots oriented in parallel lines to indicate the direction of travel that pedestrians with a sight disability can follow [86]. Importance: • Improves the safety of pedestrians by guiding pedestrians with a sight disability along a path they can follow [86].	**1 point:** Presence of Directional Tactile Ground Surface Indicators. **0 point**: Absence of the Directional Tactile Ground Surface Indicators
Item 13: crossing audio tactile	Provides audio tactile indications to notify pedestrians with a sight disability when and when not to cross the intersection [88]. Importance: • Improves the safety of pedestrians in crossing the intersection [88].	**1 point:** Presence of crossing audio tactile at the intersection. **0 point**: Absence of crossing audio tactile at the intersection.

Subsection 5: Cyclist service		
Sub section 5 Items:	Subsection description:	Points awarded based on:
Item 1: Bicycle lanes	Lanes that are designated by solid white line, bicycle symbol that indicates that this lane is exclusively for bicycles. Typical bicycle lanes are 4-6 ft wide [90]. Impotence: • Increase the convenience of the bicyclist [90]. • Increase the predictability of the vehicle's positioning and the bicyclist's positioning [90]. • Stress on the bicyclist's right to use the street [90].	**1 point**: Presence of bicycle lane at the intersection. **0 point:** Absence of bicycle lane at the intersection
Item 2 :Bicycle Parking	There are two types of bicycle parking: bicycle racks (fixed object made of metal to secure the bicycles to it), and bicycle lockers (these vary in design) [90]. Importance: • Improves the service to the cyclist as cyclists won't be worried about	**1 point**: Presence of bicycle parking at or near the intersection. **0 point:** Absence of bicycle parking at or near the intersection.

	where and how to park their bicycles [91].	
Item 3: Bike boxes	A designated area located at the head of the lane at the intersection. This area provides the cyclists with a safe and visible way to get ahead of queuing vehicles during the red phase of the signal intersection [90]. Importance: • Reduces the signal delay for bicyclists [90]. • Reduces the conflicts with travelling vehicles at the beginning of the green indication [90]. • Gives the bicyclist priority to cross the major streets [90].	**1 point:** Presence of bike boxes at the intersection. **0 point**: Absence of bike boxes at the intersection.
Item 4: Intersection Crossing Markings	Marking at the pavement that indicates the intended path of bicyclists to cross the adjacent lane [90]. Importance: • Reduces the conflicts between vehicles and bicyclists by making the bicyclist movements more predictable [90].	**1 point**: Presence of the Intersection Crossing Markings at the intersection. **0 point**: Absence of the Intersection Crossing Markings at the intersection

	• Indicates that bicyclists have priority over vehicles in crossing the streets [90].	
Item 5: Median Refuge Island	Protected space placed to facilitate pedestrians and bicyclists crossing one direction at a time [90]. Importance: • Makes bicyclists more comfortable when crossing streets [90]. • Reduces overall exposure to vehicles.[90].	**1 point**: Presence of the Median Refuge Island. **0 point:** Absence of Median Refuge Island.
Item 6: Bicycle Signal Heads	Electronic traffic control device that should be used with the conventional traffic signal/hybrid beacon [90]. Importance: • Provide priority to bicycle movements at intersection [90]. • Synchronize with the main traffic signal to accommodate the bicycle-only movement [90]. • Simplify bicycle movement and improve	**1 point**: Presence of the bicycle signal head at the intersection. **0 point**: Absence of the bicycle signal heads at the intersection.

	operation and reduce conflicts [90].	
Item 7: Signal Detection and Actuation	Bicycle detection devices are used to detect the presence of bicycles and alert the signal controller about the presence of bicycles. There are four types of bicycle detectors: Microwave radar, loop induction, video detections, and push button [90]. Importance: • Reduce delay time for bicycles [90]. • Improve the safety of bicyclists [90].	**1 point**: Presence of the signal detection and actuation feature at the intersection. **0 point**: Absence of the signal detection and actuation feature at the intersection.
Item 8: Colored Bike Facility	Colored pavement within the bicycle lane [90]. Importance: • Increases the visibility of cyclists [90]. • Increases the comfort of the cyclist [90]. • Reduces conflicts between turning motor vehicles and bicycles [90]. • Identifies the conflict areas [90].	**1 point**: Presence of colored bike lanes. **0 point**: Absence of colored bike lanes.

Sub section 6: Psychological effect of transportation		
Sub section 6 Items:	Subsection description:	Points awarded based on:
Item 1: Components of biophilic design: Green street	A storm water management technique that involves using permeable pavement vegetation to capture rain water instead of directing into sewer systems [95]. Impotence: • reduction in absenteeism [94]. • reduction in traffic incidents [94]. • reduction in health care costs [94].	**1 point**: If the sides of the street of the intersection are planted. **0 point**: If the sides of the street of the intersection are NOT planted.
Item 2: Components of biophilic design: urban trees	Planting trees on the side of the streets [96]. Importance: • reduction in absenteeism [94]. • reduction in traffic incidents [94]. • reduction in health care costs [94].	**1 point**: If trees are present at the sides of the street of the intersection. **0 point**: If trees are NOT present at the sides of the street on the intersection
Item 3: Components of Biophilic design: edible landscaping	Planting edible plants on the side of the streets [96]. Importance: • reduction in absenteeism [94]. • reduction in traffic incidents [94].	**1 point**: If the sides of the street at the intersection are planted with edible plants.

	• reduction in health care costs [94].	**0 point**: If the sides of the street at the intersection are NOT planted with edible plants.
Item 4: Components of Biophilic design:Light color pavement	Pavements that have a lighter color (lighter than black) are more reflective than black pavements [96]. Impotence: • reduction in absenteeism [94]. • reduction in traffic incidents [94]. • reduction in health care costs [94].	**1 point**: If light color pavement is used at the intersection. **0 point**: If NO light color pavement is used at the intersection.
Item 5 : context sensitivity (physical, operational)	Maintain environmental harmony: the intersection should not disturb the surrounding area. The intersection should be in harmony with the social environment and the physical environment [92]. Importance: • Improve the quality of life for the community [92]. • Improve community satisfaction [92].	**1 point**: If the intersection deigns fits the nearby environment. **0.5 point:** If the intersection design somewhat fits the nearby environment. **0 point**: If the intersection design does NOT fit the nearby environment.

Item 6: use of creative signs that has humor /emotions	Presence of humor /emotions in the traffic signs [98][99]. Importance: • Has a positive effect on the mood of drivers, pedestrians, cyclists [99].	**1 point**: If the traffic signals have humor/emotions. **0 point**: if the traffic signals have NO humor/emotions.

4.3 HIRS Validation

The main objective of RII analysis is to rank the items and distribute the weightages of each item based on their relative impotence index value. Based on the data collected from the Relative Importance Index survey (shown in App. A) and completed by a panel of professors and experts in the field. The relative importance index (RII) of each item will be calculated using the equation (1) [10]

$$RII = \frac{\sum W}{A * N} = \frac{5n_5 + 4n_4 + .. + 1n_1}{5 * N} \quad (1)$$

Where RII= Relative importance index value ranging from 0 to 1

W= Weights given to the factors by the respondents from 1 to 5, based on the importance (*n5*= number of respondents for the most important- *n1* = number of respondents for the least important)

A= the height weight given in the study

N=total number of respondents

Table 6 shows a summary of the seven experts' inputs.

Table 6 Summary of the Experts inputs

HIRS 44 Items	Extremely Imp.	Very Imp.	Imp	Some what Imp.	Not at all Imp.
Signal coordination:	2	4	1		
Dynamic signal optimization:	4	2	1		

Traffic signal priority:		3	2	2	
Flashing green light or a countdown timer:		2	2	1	2
Yellow box junction		2	2	3	
Traffic Signal equipped with Battery Backup System:	3			3	1
Presence of red-light running (RLR) camera	3	1	3		
Traveler information	1	3		3	
Incident management	3	2		2	
Quality of Lane marking:	3	4			
Clear traffic signs:	1	5	1		
Multiple traffic signals:	2	2	3		
Clean mode of power generation (for traffic lights & traffic signals):	1	2	2	2	
Absorption of sound waves:		3		3	1
Planting vegetation:	1	3	2	1	
Turn off the lights when not needed:		2	2	1	2
Use cutoff fixtures to have no light above the horizontal level:		2	4		1
Median refuge island is wide enough to accommodate pedestrians & cyclists:	6		1		
Presence of Advance Stop Line and Sign:	3	3	1		
Presence of advanced signing:	3	2	1	1	

Presence of raised crosswalks:	1	2	2	1	1
Presence of marking and crossing signs:	5				
Street pedestrian crossing signs:	4	1	1	1	
High-Visibility signs and Markings:	4	3			
Warning light:	2	4		1	
Road diet/narrowing (traffic calming)	1	3	1		2
Presence of traffic signal with pedestrian countdown signal:	5	1	1		
Warning Tactile Ground Surface Indicators:	2	1	1	3	
Directional Warning Tactile Ground Surface Indicators:	3	2	1	1	
Crossing audio tactile:	3	3		1	
Bicycle lanes:	5	2			
Bicycle Parking:	1	1	2	2	1
Bike boxes:	1	4	1	1	
Intersection Crossing Markings:	4	1	1	1	
Median Refuge Island:	3	2	1	1	
Bicycle Signal Heads:	2	2	1		2
Signal Detection and Actuation:	1	3	1	2	
Colored Bike Facility:	2	3		1	1
Component of a biophilic design - Green street:	1	1	3	2	

Component of a biophilic design - Urban trees:		1	3	1	2
Component of a biophilic design - Edible landscaping:			2	1	4
Component of a biophilic design - Light color pavement:			4	2	1
Use of creative signs that have humor/emotions/emojis		2	2	3	
Context sensitivity:		2	4	1	

Table 7 shows the RII values for each item using Equation (1) and the data collected shown in Table 6.

Table 7 HIRS 44 items and RII values

HIRS 44 items	RII values
Item 1: Signal coordination:	0.83
Item 2: Dynamic signal optimization:	0.89
Item 3:Traffic signal priority:	0.63
Item 4: Flashing green light or a countdown timer:	0.51
Item 5: Yellow box junction	0.57
Item 6: Traffic Signal equipped with Battery Backup System:	0.63
Item 7: presence of red-light running (RLR) camera	0.80
Item 8:Traveler information:	0.66
Item 9: Incident management:	0.77
Item 10: Quality of Lane marking:	0.89
Item 11: Clear traffic signs:	0.80
Item 12: Multiple traffic signals:	0.77
Item 13: Clean mode of power generation (for traffic lights & traffic signals):	0.66
Item 14: Absorption of sound waves:	0.54

Item 15: Planting vegetation:	0.71
Item 16: Turn off the lights when unneeded:	0.51
Item 17: Use cutoff fixtures to have no light above the horizontal level:	0.60
Item 18: Median refuge island is wide enough to accommodate pedestrians & cyclists:	0.94
Item 19: Presence of Advance Stop Line and Sign:	0.86
Item 20: Presence Advanced signing:	0.80
Item 21: Presence of raised crosswalks:	0.63
Item 22: presence of marking and crossing signs:	1.00
Item 23: street pedestrian crossing signs :	0.83
Item 24: High-Visibility signs and Markings:	0.91
Item 25: Warning light:	0.80
Item 26: Road diet/narrowing (traffic calming):	0.63
Item 27: Presence of traffic signal with pedestrian countdown signal:	0.91
Item 28: Warning Tactile Ground Surface Indicators:	0.66
Item 29: Directional Warning Tactile Ground Surface Indicators:	0.80
Item 30: Crossing audio tactile:	0.83
Item 31: Bicycle lanes:	0.94
Item 32:Bicycle Parking:	0.57
Item 33: Bike boxes:	0.74
Item 34: Intersection Crossing Markings:	0.83
Item 35: Median Refuge Island:	0.80
Item 36: Bicycle Signal Heads:	0.66
Item 37: Signal Detection and Actuation:	0.69
Item 38: Colored Bike Facility:	0.71
Item 39: Green street:	0.63
Item 40: Urban trees:	0.49
Item 41: Edible landscaping:	0.34
Item 42:Light color pavement:	0.49

Item 43:Use of creative signs that have humor/emotions/emojis	0.37
Item 44: context sensitivity:	0.63

Sample calculation 1

Item 1 Traffic signal coordination.

Extremely important: 2

Very important: 4

Important: 1

Somewhat important: 0

Not at all important: 0

$$\text{RII} = \frac{5(2)+4(4)+3(1)+2(0)+1(0)}{5*(2+4+1+0+0)} = 0.83$$

Sample Calculation 2

Item 2: Dynamic signal optimization:

Extremely important: 4

Very important: 2

Important: 1

Somewhat important: 0

Not at all important: 0

$$\text{RII} = \frac{5(4)+4(2)+3(1)+2(0)+1(0)}{5*(4+2+1+0+0)} = 0.89$$

The weighted factors have been given based on the RII value. Items that had higher RII values were given higher weighted factors. While items that had lower RII values were given lower weighted factors. Table 8 show the weighted factor of each of the 44 items of HIRS.

Table 8 HIRS 44 items, RII values, Ranking and Weighted Factor

HIRS 44 items	**RII values**	**Weighted Factor**
Item 1: Signal coordination:	0.83	0.83
Item 2: Dynamic signal optimization:	0.89	0.89

Item 3:Traffic signal priority:	0.63	0.63
Item 4: Flashing green light or a countdown timer:	0.51	0.51
Item 5: Yellow box junction	0.57	0.57
Item 6: Traffic Signal equipped with Battery Backup System:	0.63	0.63
Item 7: presence of red-light running (RLR) camera	0.80	0.80
Item 8:Traveler information:	0.66	0.66
Item 9: Incident management:	0.77	0.77
Item 10: Quality of Lane marking:	0.89	0.89
Item 11: Clear traffic signs:	0.80	0.80
Item 12: Multiple traffic signals:	0.77	0.77
Item 13: Clean mode of power generation (for traffic lights & traffic signals):	0.66	0.66
Item 14: Absorption of sound waves:	0.54	0.54
Item 15: Planting vegetation:	0.71	0.71
Item 16: Turn off the lights when unneeded:	0.51	0.51
Item 17: Use cutoff fixtures to have no light above the horizontal level:	0.60	0.60
Item 18: Median refuge island is wide enough to accommodate pedestrians & cyclists:	0.94	0.94
Item 19: Presence of Advance Stop Line and Sign:	0.86	0.86
Item 20: Presence of Advanced signing:	0.80	0.80
Item 21: Presence of raised crosswalks:	0.63	0.63
Item 22: presence of marking and crossing signs:	1.00	1.00
Item 23: street pedestrian crossing signs:	0.83	0.83
Item 24: High-Visibility signs and Markings:	0.91	0.91
Item 25: Warning light:	0.80	0.80
Item 26: Road diet/narrowing (traffic calming):	0.63	0.63
Item 27: Presence of traffic signals with pedestrian countdown signals:	0.91	0.91
Item 28: Warning Tactile Ground Surface Indicators:	0.66	0.66

Item 29: Directional Warning Tactile Ground Surface Indicators:	0.80	0.80
Item 30: Crossing audio tactile:	0.83	0.83
Item 31: Bicycle lanes:	0.94	0.94
Item 32: Bicycle Parking:	0.57	0.57
Item 33: Bike boxes:	0.74	0.74
Item 34: Intersection Crossing Markings:	0.83	0.83
Item 35: Median Refuge Island:	0.80	0.80
Item 36: Bicycle Signal Heads:	0.66	0.66
Item 37: Signal Detection and Actuation:	0.69	0.69
Item 38: Colored Bike Facility:	0.71	0.71
Item 39: Green street:	0.63	0.63
Item 40: Urban trees:	0.49	0.49
Item 41: Edible landscaping:	0.34	0.34
Item 42:Light color pavement:	0.49	0.49
Item 43:Use of creative signs that have humor/emotions/emojis	0.37	0.37
Item 44: context sensitivity:	0.63	0.63

Table 9 shows the final breakdown of the HIRS survey, which is composed of item descriptions, points available, points awarded for weighted factor, and final score for each of the 44 items that fall under the nine subsections.

Table 9: Holistic Intersection Rating System (HIRS)

Holistic Intersection Rating System (HIRS)				
Section A: Motorized/Vehicular traffic				
Section 1: Traffic signal management:	*Points available*	*Points awarded*	*Weightage factor*	*Score* (points awarded x weightage factor)
Item 1: Signal coordination: It. descrip.The intersection traffic signal is designed to allow the vehicle to cross the coming nearby traffic signals at one shot, instead of waiting at every traffic signal to turn green. 1 point: The platoon of vehicles are able to cross multiple traffic signal on a section of a road at one shot 0 point: The platoon of vehicles are NOT able to cross multiple traffic signal on a section of a road at one shot.	0/1		0.83	
Item 2: Dynamic signal optimization: It. descrip.: The traffic signal uses				

the real-time data to optimize every cycle length, resulting in dynamic cycle lengths instead of the fixed cycle lengths.	0/1		0.89	
1 point: Signal timing is optimized based on the real-time data obtained from the loop detectors.				
0 point: Signal timing is NOT optimized based on the real-time data obtained from the loop detectors.				
Item 4:Traffic signal priority:	0/1		0.63	
It. descrip.: Traffic signal priority detects the presence of a transit vehicle, the system either holds the green signal or gives an early green to the leg that has the transit vehicle.				
1 point: Traffic signal are equipped to adapt traffic signal priority (TSP).				
0 point: Traffic signal are NOT equipped to adapt				

traffic signal priority (TSP).				
Sub section 2: Special features:	*Points available*	*Points awarded*	*Weightage factor*	*Score* *(points awarded x weightage factor)*
Item 1: Flashing green light or a countdown timer:	0/1		0.51	
It. descrip. Flashing of a green light alerts the drivers that the pedestrian signal is activated; this procedure notifies the driver that the green time will end soon.				
1 point: Traffic signal has flashing green light				
0 point: Traffic signal does NOT has flashing green light.				
Item 2 : Yellow box junction	0/1		0.57	
It. descrip.: A yellow box marked at the center of the intersection. Used to indicate to drivers that they are not allowed to enter the yellow box until the exit at the other leg of the intersection is clear, to prevent intersection blockage.				

1 point: Presence of Yellow box at the intersection 0 point: Absence of Yellow box at the intersection.				
Item 3: Traffic Signal equipped with Battery Backup System: It. descrip. : Traffic signal equipped with battery backup system that allows the traffic signal to function smoothly for limited hours after power failure. 1 point: Traffic signal can function for limited hours with no electricity supply. 0 point: Traffic signal can NOT function for limited hours with no electricity supply	0/1		0.63	
Item 4: presence of red-light running (RLR) camera It. descrip.: A camera installed at the intersection to capture the vehicles that proceed through the intersection (crosses the intersection) after	0/1		0.80	

the signal turns RED. 1 point: Presence of RLR camera at the intersection 0point: Absence of RLR camera at the intersection				
Item 5:Traveler information: It. descrip.: The intersection has a system that provides traffic conditions, road conditions, emergency advisors, either through dynamic signs on the roads, radio, websites, or cell phone text messaging. 1 point: The intersection is equipped with the detector and dynamic signs to support the Traveler information system. 0 point: The intersection is NOT equipped with the detector and dynamic signs to support the Traveler information system.	0/1		0.66	

Item 6: Incident management: It. descrip.: The intersection has a system that uses sensors to detect incidents/ traffic roadway data. Once incident occurs an emergency responder broadcasts the traveler information. 1 point: The intersection is equipped with the sensors and the emergency responders to support the incident system available. 0 point: The intersection is NOT equipped with the sensors and the emergency responders to support the incident system available.	0/1		0.77	
Sub section 3: Autonomous vehicles:	*Points available*	*Points awarded*	*Weightage factor*	*Score* (points awarded x weightage factor)
Item 1: Quality of Lane marking: It. descrip.: Quality of lane marking involves: Retro-reflectivity, Chromaticity,				

Luminance, and Skid Resistance in good physical condition allowing AV sensors to detect them easily. 1 point: The lane markings are bright (excellent condition). 0.5 point: The lane markings are of medium quality. 0 point: The lane markings are faded	0/.5/1		0.89	
Item 2 : Clear traffic signs: It. descrip.: Traffic signs that regulate and control the traffic are clean and in good physical condition allowing AV sensors to detect them easily. 1 point: The traffic signs are in good condition. 0 point: The traffic signs are NOT in good condition.	0/1		0.80	
Item 3: Multiple traffic signals: It. descrip.: Multiple traffic signals installed at different angles to ensure that in any weather condition the AV sensors	0/1		0.77	

will be able to detect traffic signals lights. 1 point: Multiple traffic signals installed at different angles. 0 point: Absence of multiple traffic signals installed at different angles.				
Section B: Public health and community wellbeing				
Sub section 1 Sustainable solutions at intersections	*Points available*	*Points awarded*	*Weightage factor*	*Score* (points awarded x weightage factor)
Item 1: Clean mode of power generation (for traffic lights & traffic signals): It. descrip.: Usage of ecofriendly energy sources (wind turbines & solar panels) to power the traffic lights, traffic signals and electronic boards. 1 point: usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 point: usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards.	0/1		0.66	

Sub section 2 Ways and features to reduce Noise pollution	*Points available*	*Points awarded*	*Weightage factor*	*Score* (points awarded x weightage factor)
Item 1: Absorption of the sound wave:	0/1		0.54	
It. descrip.: Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal).				
1 point: Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal).				
0 point: Energy Dissipater NOT available on the side of the road (made up of wood, stucco, masonry, metal).				
Item 2: Planting vegetation:	0/1		0.71	
It. descrip.: Planting at the side of the road is present.				
1 point: Planting at the side of the road is present.				
0 point: Planting at the side of the road is NOT present.				
Sub section 3 Ways and features to	*Points available*	*Points awarded*	*Weightage factor*	*Score*

reduce Light pollution				*(points awarded x weightage factor)*
Item 1: Turn off the lights when unneeded:	0/1		0.51	
It. descrip.: Traffic lights equipped with motion sensors to shut-off the light when the intersection is totally empty (NO pedestrians/vehicles/cyclists).				
1 point: Traffic lights equipped with motion sensors.				
0 point: Traffic lights are NOT equipped with motion sensors.				
Item 2: Use cutoff fixtures to have no light above the horizontal level:	0.25/0.5/ 0.75/1		0.60	
It. descrip.: Usage of cutoff fixtures, that covers the street light bulbs allowing NO light trespassing of the houses near the intersection.				
1 point: if full cutoff were used.				
0.75 point: if cutoff were used.				
0.5 point: if semi-cutoff were used.				

0.25 point: if non-cutoff were used.				
Sub section 4 Pedestrian service	*Points available*	*Points awarded*	*Weightage factor*	*Score* *(points awarded x weightage factor)*
Item 1: Median refuge island is wide enough to accommodate the pedestrians & cyclist:	0/1		0.94	
It. descrip.: The median refuge island is wide enough to accommodate pedestrians & cyclists.				
1 point: If the median refuge island is wide enough to accommodate the pedestrians.				
0 point: If the median refuge island is NOT wide enough to accommodate the pedestrians.				
Item 2: Presence of Advance Stop Line and Sign:	0/1		0.86	
It. descrip.: It is a solid line marking on the pavement, however it is marked further away from the cross walk to				

improve the safety of the pedestrians. 1 point: If advanced stop line and sign is present further away from the cross walk. 0 point: If advanced stop line and sign is NOT present further away from the cross walk.				
Item 3: Presence of Advanced signing: It. descrip.: Sign that is placed further away from the crossing zone, to warn the drivers that pedestrians may be crossing the roadway. 1 point: If Advanced signing is present on a roadway. 0 point: If Advanced signing is NOT present on a roadway.	0/1		0.8	
Item 4: Presence of raised crosswalks: It. descrip.: Raised cross walks are elevated above the adjacent driving lanes. 1 point: If the crosswalks are	0/1		0.63	

raised above the adjacent lanes. 0 point: If the crosswalks are NOT raised above the adjacent lanes.				
Item 5: presence of marking and crossing signs: It. descrip.: The conventional marking and crossing signs are used to alert the drivers that pedestrians are crossing at a specific point. 1 point: If the marking and crossing signs are present. 0 point: If the marking and crossing signs are NOT present.	0/1		1	
Item 6: street pedestrian crossing signs : It. descrip.: Signs placed on the lane edge or street centerline used to remind the drivers that the pedestrians have the right of way by law. 1 point: If street pedestrian crossing signs are placed on	0/1		0.83	

the lane edge/street centerline. 0 point: If street pedestrian crossing signs are NOT placed on the lane edge/ street centerline.				
Item 7: High-Visibility signs and Markings: It. descrip.: Are similar to the conventional signs and marking. However, they have higher reflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention. 1 point: If High-Visibility signs and Markings are present. 0 point: High-Visibility signs and Markings are NOT present.	0/1		0.91	
Item 8: Warning light: It. descrip.: Flashing amber lights placed on the surface of the pavement in front of the pedestrian side walk. 1 point: If warning lights are present	0/1		0.80	

in front of the pedestrian side walk. 0 point: If warning light are NOT present in front of the pedestrian side walk.				
Item 9: Road diet/narrowing (traffic calming): It. descrip.: Lanes are narrowed as the lanes approach the side walk and crosswalks of the intersection. 1 point: If the lanes are narrowed as the lanes approach the side walk and crosswalks. 0 point: If the lanes are NOT narrowed as the lane approaches the sidewalks and crosswalks.	0/1		0.63	
Item 10: Presence of traffic signal with pedestrian countdown signal: It. descrip.: Traffic signal with pedestrian countdown signal that displays a time countdown that indicates how much time is left for the pedestrian	0/1		0.91	

to cross the roadway. 1 point: If the traffic signal has a countdown signal. 0 point: If the traffic signal has NO countdown signal.				
Item 11: Warning Tactile Ground Surface Indicators: It. descrip.: Raised plastic/metal dots on the ground surface indicates that there is a nearby hazard, such as train/tram platform, or of coming stairs. 1 point: Presence of Warning Tactile Ground Surface Indicators are at the hazardous areas of the intersection. 0 point: Absence of Warning Tactile Ground Surface Indicators are at the hazardous areas of the intersection.	0/1		0.66	
Item 12: Directional Warning Tactile Ground Surface Indicators: It. descrip.: Raised plastic/metal dots	0/1		0.80	

oriented in parallel lines to indicate the direction of travel that pedestrians with sight disabilities can follow. 1 point: Presence of Directional Tactile Ground Surface Indicators. 0 point: Absence of Directional Tactile Ground Surface Indicators				
Item 13: Crossing audio tactile: It. descrip.: Audio tactile indications to notify pedestrians with sight disabilities when and when not to cross the intersection. 1 point: Presence of crossing audio tactile at the intersection. 0 point: Absence of crossing audio tactile at the intersection.	0/1		0.83	
Sub section 5 Cyclist service	*Points available*	*Points awarded*	*Weightage factor*	*Score* *(points awarded x weightage factor)*
Item 1: Bicycle lanes: It. descrip.: Lanes that are designated by solid white lines				

& bicycle symbol that indicates that this lane is exclusively for bicycles 1 point: Presence of bicycle lane at the intersection. 0 point: Absence of bicycle lane at the intersection	0/1		0.94	
Item 2: Bicycle Parking: It. descrip.: Presence of Bicycle Parking at/or near the intersection. 1 point: Presence of Bicycle Parking at or near the intersection. 0 point: Absence of Bicycle Parking at or near the intersection.	0/1		0.57	
Item 3: Bike boxes: It. descrip.: Designated area located at the head of the lane at the intersection. This area provides the cyclists a safe and visible way to get ahead of the queuing vehicles during the red phase of the traffic signal.	0/1		0.74	

1 point: Presence of bike boxes at the intersection. 0 point: Absence of the bike boxes at the intersection.				
Item 4: Intersection Crossing Markings: It. descrip.: Marking at the pavement that indicates the intended path of bicyclist to cross the adjacent lane. 1 point: Presence of the Intersection Crossing Markings at the intersection. 0 point: : Absence of the Intersection Crossing Markings at the intersection	0/1		0.83	
Item 5: Median Refuge Island: It. descrip.: Protected space placed to facilitate pedestrians and bicyclists to cross one direction at a time. 1 point: Presence of the Median Refuge Island 0 point: Absence of Median Refuge Island.	0/1		0.80	

Item 6: Bicycle Signal Heads: It. descrip.: Electronic traffic control device that should be used with the conventional traffic signal/hybrid beacon. 1 point: Presence of the bicycle signal head at the intersection. 0 point: Absence of the bicycle signal heads at the intersection.	0/1		0.66	
Item 7: Signal Detection and Actuation: It. descrip.: Bicycle detection devices placed in the pavement, used to detect the presence of bicycles and alert the signal controller about the presence of the bicycle to give the priority to cyclists. 1 point: Presence of the signal detection and actuation feature at the intersection. 0 point: Absence of the signal detection and	0/1		0.69	

actuation feature at the intersection.				
Item 8: Colored Bike Facility: It. descrip.: Usage of colored pavement for the bicycle lane. 1 point: Presence of colored bike lanes. 0 point: Absence of colored bike lanes.	0/1		0.71	
Sub section 6 Psychological effect of transportation	*Points available*	*Points awarded*	*Weightage factor*	*Score* *(points awarded x weightage factor)*
Item 1: Components Biophilic design Green street: It. descrip.: The sides of the street of the intersection are planted. 1 point: If the sides of the street of the intersection are planted. 0 point: If the sides of the street of the intersection are NOT planted.	0/1		0.63	
Item 2: Components of biophilic design - Urban trees: It. descrip.: Trees are present at the			0.49	

sides of the street of the intersection. 1 point: If trees are present at the sides of the street of the intersection. 0 point: If trees are NOT present at the sides of the street to the intersection	0/1			
Item 3: Components of biophilic design - Edible landscaping: It. descrip.: The sides of the street at the intersection are planted with edible plants. 1 point: If the sides of the street at the intersection are planted with edible plants. 0 point: If the sides of the street at the intersection are NOT planted with edible plants.	0/1		0.34	
Item 4: Components of biophilic design - Light color pavement: It.4descrip.: Usage of light colored pavement is used at the intersection.	0/1		0.49	

1 point: If light color pavement is used at the intersection. 0 point: If NO light color pavement is used at the intersection.				
Item 5 : context sensitivity: It. descrip.: The intersection should not disturb the surrounding area. The intersection should be in harmony with the social environment and the physical environment. 1 point: If the intersection design fits the nearby environment. 0.5 point: If the intersection design somewhat fits the nearby environment 0 point: If the intersection deign does NOT fit the nearby environment	0/0.5/1		0.63	
Item 6: use of creative signs that have humor/emotions/emojis: It. descrip.: Presence of humor/emotions/e	0/1		0.37	

mojis such as happy face :), sad face :(in the traffic signs. 1 point: If the traffic signals have humor/emotions. 0 point: if the traffic signals have NO humor/emotions.				
Final Score of the Signalized Urban Intersection				=

The level of usage of technologies and physical design and operational feature that lead to the holistic operational performance of the given signalized urban intersection will be judged based on the breakdown shown in Table 10. For instance, if the given signalized urban intersection had a final score of 30 points, this indicates that the signalized urban intersection has a very high level of usage of technologies and physical design and operational feature that lead to the holistic operational performance. While if the given signalized urban intersection had a final score of 5 points this indicates that the signalized urban intersection has a Very low level of usage of technologies and physical design and operational feature that lead to of holistic operational performance.

Table 10: Level of usage of technologies and physical design and operational feature break down for HIRS survey

Final score= 0 - 6.25 (0%-20%) Very low level of usage of technologies and physical design and operational feature	Final score= 6.25-12.5 (20%-40%) Low level of usage of technologies and physical design and operational feature	Final score= 12.5-18.75 (40%-60%) Moderate level of usage of technologies and physical design and operational feature	Final score= 18.75-25 (60%-80%) High level of usage of technologies and physical design and operational feature	Final score= 25-31.25 (80%-100%) Very high level of usage of technologies and physical design and operational feature

Table 11 shows HIPI survey. This survey list the main advantages of the 44 items of the HIRS survey. Moreover, it also indicates how each of the 44 items' effect can be measured.

Table 11 Holistic intersection performance indicator (HIPI)

Holistic Intersection performance Indicators		
Section A: Motorized/Vehicular traffic		
Traffic signal management		
Items	Advantages	Measurement
Signal coordination Dynamic signal optimization Traffic signal priority	• Responsiveness to traffic demands, short cycles, effective use of capacity leading to and recovering from oversaturation [55]. • Minimizing delay time and stops [55]. • Prevent queues from an intersection [55].	Avg. control Delay (d)(Sec/veh) [56]. Calculated based on the: d=d1(PF)+d2+d3 where PF = $\frac{1-p}{(1-(\frac{g}{c})} * fp$ d1=$\frac{.5(1-\left(\frac{g}{c}\right)^2}{(1-\min(1,X)\left(\frac{g}{c}\right))}$ d2=$900T((X-1)+\left((X-1)^2+\frac{8klX}{cT}\right)^{.5}$ T= duration of analysis period (h) X= v/c ratio C=cycle length (s) k=incremental delay factor for actuated controller settings,0.5 all pre timed controllers 1 upstream filtering/metering adjustment factor 1 from all individual intersection analyses

		C= capacity (veh/h) P= proportion of vehicles arriving during green interval fp=supplemental adjustment factor for platoon arriving during green phase. D3= delay due to preexisting queue (s/veh)
Special features in vehicular service		
Items	Advantages	Measurement
Flashing green light OR Traffic signal equipped with countdown timer	Which causes a safer response from the motorized vehicle drivers [31].	Number of vehicle accidents
Yellow box junction	avoids traffic blockage at the center of the intersection and keeps the traffic flowing in all directions [32].	
Traffic Signal equipped with Battery Backup System	This system prevents major problems such as the accidents and traffic jams that happen after a complete shutdown in the traffic signals at an intersection.	
RED light running camera (RLR):	Leads to significant reduction in all types of red light running crashes [33].	
Traveler information **sys**tem	• Maximize the capacity of the system [34]. • Increases safety [34]. • Reduction in congestion [34].	Statistics concerning traffic congestion

Incident management system	Reduction in the average traffic incident delay [35].	Statistics concerning traffic accident delays**.**
Autonomous vehicle ready criteria		
Items	Advantages	Measurement
Quality of the lane marking And	Fewer accidents caused by AVs [65] [66].	Number of AV accidents
Clear signs		
Clear detection of traffic signals		
Section B: Public health and community wellbeing		
Sustainable solutions at signalized urban intersections		
Items	Advantages	Measurement
Usage of Clean mode of power generation (for traffic lights and traffic signals	Reduction in air pollution [37].	Data of fossil fuel usage can be collected from the authorities.
Ways and features that reduce Noise pollution		
Items	Advantages	Measurement
of Item 1: Absorption the sound wave:	Reduction in noise pollution [70][72].	Decibel (dBs).
Item 2: Planting vegetation		
Ways and features that reduce light pollution		
Items	Advantages	Measurement
Item 1: Turn off the lights when unneeded		Night sky brightness

Item 2: Use cutoff fixtures to have no light above the horizontal level	Reduction in light pollution [76].	The units of NSB includes candela per meter square (cd/m²) magnitude per arc second squared (mag/arcsec²). [78]
Convenience and safety of Pedestrians		
Items	Advantages	Measurement
Item 1: Median refuge island is wide enough to accommodate the pedestrians & cyclists	Reduction in pedestrian accidents [80].	Number of pedestrian accidents
Item 2: Presence of Advance Stop Line and Sign:		
Item 3: Presence of Advanced signing		
Item 4: Presence of raised crosswalks:		
Item 5: presence of marking and crossing signs:		
Item 6: street pedestrian crossing signs :		
Item 7: High-Visibility signs and Markings		
Item 8: Warning light		
Item 9: Road diet/narrowing		

(traffic calming):		
Item 10: Presence of traffic signal with pedestrian countdown signal		
Item 11: Warning Tactile Ground Surface Indicators		
Item 12: Directional Warning Tactile Ground Surface Indicators		
Item 13: Crossing audio tactile:		
Convenience and safety of Cyclists:		
Items	Advantages	Measurement
Item 1: Bicycle lanes	Reduces the number of cyclist accidents [90].	Number of cyclist accidents
Item 2 :Bicycle Parking		
Item 3: Bike boxes:		
Item 4: Intersection Crossing Markings:		
Item 5: Median Refuge Island		
Item 6: Bicycle Signal Heads		

Item 7: Signal Detection and Actuation:		
Item 8: Colored Bike Facility		
Psychological effect of transportation system		
Items	Advantages	Measurement
Item 1: Biophilic design: Green street	• Reduction in absenteeism [94]. • Reduction in traffic incidents [94]. • Reduction in health care costs [94].	Apply DAAS-21 to the intersection's users. [100] (DAAS 21 is a psychological test used to measure Depression, Anxiety, and Stress of adults [100].)
Item 2: Biophilic design - Urban trees		
Item 3: Biophilic design - Edible landscaping:		
Item 4: Biophilic design - Light color pavement:		
Item 5 : context sensitivity:	• Improve quality of life for the community [92]. • Improve community satisfaction [92].	Apply DAAS-21 to the intersection's users. [100] (DAAS 21 is a psychological test used to measure Depression, Anxiety, and Stress of adults [100].)
Item 6: use of creative signs that have humor/emotions/emojis:	• Has a positive effect on the mood of drivers, pedestrians, cyclists [99].	Apply DAAS-21 to the intersection's users. [100] (DAAS 21 is a psychological test used to measure Depression, Anxiety, and Stress of adults [100].)

Table 12 shows the abbreviated HIPI. While Table 13 indicates the breakdown of the level of Performance indicators.

Table 12 Abbreviated HIPI survey

<table>
<tr><th colspan="3">Abbreviated HIPI</th></tr>
<tr><th>Holistic Factors</th><th>Measurements</th><th>Points awarded based on</th></tr>
<tr><td>Factor 1:Traffic performance</td><td>Avg. control Delay: d [56].
Units: Sec/veh

Avg. control delay calculated based on:
d=d1(PF)+d2+d3

PF = $\frac{1-p}{(1-(\frac{g}{c})} * fp$

d1=$\frac{.5(1-\left(\frac{g}{c}\right)^2}{(1-\min(1,X)\left(\frac{g}{c}\right))}$
d2=$900T((X-1)+\left((X-1)^2+\frac{8klX}{cT}\right)^{.5}$

d3= delay due to preexisting queue (s/veh)

Where
T= duration of analysis period (h)
X= v/c ratio
C=cycle length (s)
k=incremental delay factor for actuated controller settings,0.5</td><td><table><tr><th></th><th>Level of service [56].</th><th>Points awarded</th></tr><tr><td>d≤10</td><td>LOS A</td><td>1</td></tr><tr><td>d>10-20</td><td>LOS B</td><td>0.75</td></tr><tr><td>d>20-35</td><td>LOS C</td><td>0.5</td></tr><tr><td>d>35-55</td><td>LOS D</td><td>0.25</td></tr><tr><td>d>55-80</td><td>LOS E</td><td>0</td></tr><tr><td>d>80</td><td>LOS F</td><td>0</td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td>all pre timed controllers,1 upstream filtering/metering adjustment factor 1 for all individual intersection analyses

C= capacity (veh/h)

P= proportion of vehicles arriving during green interval
fp=supplemental adjustment factor for platoon arriving during green phase.</td><td></td></tr>
<tr><td>Factor 2: Air pollution</td><td>Air Quality Health Index: AQHI

AQHI $\left(\frac{1000}{10.4}\right) * \left((e^{0.00005378*O_3} - 1) + (e^{0.000871*NO_2} - 1) + (e^{0.000487*PM_{2.5}} - 1)\right)$

Where

O_3 Ozone

NO_2 Nitrogen dioxide

$PM_{2.5}$ Particulate matter [101][102[103].</td><td><table><tr><td>AQHI Levels[101][102][103].</td><td>Points awarded</td></tr><tr><td>AQHI= 1-3</td><td>1 points</td></tr><tr><td>AQHI= 4-6</td><td>0.5 points</td></tr><tr><td>AQHI= 7-10</td><td>0.25 points</td></tr><tr><td>AQHI= >10</td><td>0 points</td></tr></table></td></tr>
<tr><td>Factor 3: Noise pollution</td><td>Decibel (dBs).</td><td><table><tr><td>Average night noise level over a year Lnight, outside[70].</td><td>Point awarded</td></tr><tr><td>Up to 30 dBs</td><td>1 points</td></tr><tr><td>30-40 dBs</td><td>0.75 points</td></tr><tr><td>40-55 dBs</td><td>0.5 points</td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td></td><td><table><tr><td>Above 55 dBs</td><td>0.25 points</td></tr></table></td></tr>
<tr><td rowspan="2">Factor 4: User’s mental health</td><td>millimeters of mercury (mm Hg) [104].</td><td><table><tr><th>Systolic mm Hg (upper number) [104].</th><th>Diastolic mm Hg (lower number) [104].</th><th>Points awarded</th></tr><tr><td>Less than 120</td><td>Less than 80</td><td>0.5 points</td></tr><tr><td>120-129</td><td>Less than 80</td><td>0.4 points</td></tr><tr><td>130-139</td><td>80-89</td><td>0.3 points</td></tr><tr><td>140 or higher</td><td>90 or higher</td><td>0.2 points</td></tr><tr><td>Higher than 180</td><td>Higher 120</td><td>0.1 points</td></tr></table></td></tr>
<tr><td>Heart rate per minute or (heartbeat) bpm [105].</td><td><table><tr><th>BPM readings [105].</th><th>Points awarded</th></tr><tr><td>60-100 bpm</td><td>0.5 point</td></tr><tr><td>Above 100 bpm</td><td>0 point</td></tr><tr><td>Below 60 bpm</td><td>0 point</td></tr></table></td></tr>
</table>

Factor 5: User's safety	Rate of pedestrians killed per vehicle	0.5 point: If the rate of the tested intersection is below the average rate of the country. 0.25 point if the rate of the tested intersection equals the average rate of the country. 0 point if the rate of the tested intersection is higher than the average rate of the country.
	Rate of cyclists killed per vehicle	0.5 point: If the rate of the tested intersection is below the average rate of the country. 0.25 point if the rate of the tested intersection equals the average rate of the country. 0 point if the rate of the tested intersection is higher than the average rate of the country.
Total points collected		=

Table 13 Level of performance Indicator

Final score = 0-1.6 points Low performance Indicators	Final score = 1.6-3.2 points Medium performance Indicators	Final score = 3.2-5 points High performance Indicators

4.4. Conclusion.

In conclusion, this chapter explains the survey development algorithm for HIRS, HIPI and Abbreviated HIPI. It also shows the final breakdown of the HIRS and HIPI survey. HIRS is designed to rate the level of use of technologies, physical design and operational features that lead to better holistic operational performance of signalized urban intersections. On the other hand, HIPI measures the effectiveness of HIRS in terms of solutions. In essence, HIPI measures the output of the HIRS holistic technology and design inputs indicators.

Chapter 5: Field Data Collection for HIRS

5.1 Introduction

This section deals with details of the data collection that was done in this study. HIRS has been used to rate the performance of 20 signalized urban intersections in the UAE. Moreover, this section covers the methodology used to collect the data. Finally, the summarized data will be presented at the end of this chapter.

5.2 Data Collation Methodology

As mentioned before HIRS is composed of two main sections (Motorized/vehicular traffic at signalized urban intersection and Public health and Community wellbeing). Under those two main sections fall nine sub-sections.

5.2.1. Data collection methodology for sub section 1: traffic signal management. This sub section involves three items: Signal coordination, Dynamic signal optimization, Traffic signal priority. Based on HIRS one point will be awarded for each item, if the intersection is operated using that feature. For the signal coordination, the surveyor drove over two intersections to examine if the tested intersections had traffic signal management or not. If the examiner was able to reach the following intersection at the green phase of the second traffic signal, one point was awarded. If the examiner was not able to reach the following intersection at the green phase of the second intersection, zero points were awarded.

Moreover, for the dynamic signal optimization, the examiner tracked the length of the green phase of the tested traffic signal intersection several times. If the green phase length (in seconds) was different for each trial, one point was awarded. If the green phase length (in seconds) was exactly the same time for all the trials, zero points were awarded.

Finally, for the traffic signal priority, the examiner tested the traffic signal of the examined intersection in the presence of a transit vehicle. If the traffic signal extended or changed the cycles sequence to allow the transit vehicle to pass the intersections with no delays or stoppages, one point was awarded. If the traffic signal did not extend or change the cycle's sequence to allow the transit vehicle to pass the intersections with no delays or stoppage, zero points were awarded.

5.2.2. Data collection methodology for sub section 2: special features in vehicular service. This sub section is composed of six items: Flashing green light or a countdown timer, Yellow box junction, Traffic Signal equipped with Battery Backup System, red-light running (RLR) camera, Traveler information, and Incident management. One point will be awarded for each item, if the intersection is operated using that feature.

Flashing green light or a countdown timer: the examiner awarded one point when the tested traffic signal had a flashing green light at the end of the green phase, or a countdown timer that indicates how many seconds are left of the green phase. While zero points were awarded by the examiner when the tested traffic signal did not have a flashing green light at the end of the green phase, or there was no countdown timer indicating many seconds are left of the green phase.

Yellow box junction: the examiner awarded one point when the yellow marking of the yellow box junction at the center of tested intersections was present. While zero points were awarded by the examiner when there was no yellow marking of the yellow box junction present at the center of the intersection.

Red-light running (RLR) camera, the examiner awarded one point when there was a red-light running camera present at the tested intersection. While zero points were awarded when there was no red-light running camera present at the tested intersection.

Traveler information: the examiner awarded one point to the tested intersection when there were live updates about the traffic situation sent via radio, cell phones massages or any other way of conveying the information about the traffic at the tested intersection. While zero points were awarded by the examiner when there were no live updates about the traffic situation sent via radio, cell phones massages or any other way of conveying the information about the traffic at the tested intersection.

Incident management: the examiner awarded one point when the traveler information during an accident at the tested intersection was broadcast using any way of conveying the information. While the examiner awarded zero points when the traveler information under an accident at the tested intersection was not broadcast using any way of conveying the information.

5.2.3. Data collection methodology for sub section 3: autonomous vehicle ready criteria. This sub section is composed of three items: quality of lane marking, clear traffic signs, and multiple traffic signals. One point can be awarded for each of the three items.

Quality of lane marking: the examiner gave one full point for the examined intersections that had excellent quality of lane marking on the pavement. While if the lane marking on the pavement was of a medium quality (somewhat faded), the examiner gave half a point for the assessed intersection. However, the examiner gave no points for the assisted intersections that had faded (erased) lane markings on the pavement.

Clear traffic signs: for this item the examiner gave one point for the intersections that had clear traffic signs. While the examiner gave no points for the intersections that had unclear traffic signs.

Multiple traffic signals: the examiner gave one point for intersections that had multiple traffic signals installed at different angles at the intersection. While the examiner gave zero points for the intersections that had no multiple intersections installed at multiple angles at the intersection.

5.2.4. Data collection methodology for Sub section 4: sustainable solutions at signalized urban intersections. This sub section is composed of only one item: clean mode of power generation (for traffic lights & traffic signals). The examiner awarded one point when the traffic signal/signs were operated using power generated by wind turbines or solar panels at the tested intersection. While the examiner awarded zero points when the traffic signal/signs were not operated using power generated by wind turbines or solar panels at the tested intersection.

5.2.5. Data collection methodology for sub section 5: ways and features to reduce noise pollution. This sub section is composed of two items: Absorption of sound waves and planting of vegetation. Based on HIRS one point can be awarded for each item.

For the absorption of sound waves, the examiner awarded one point when there were boxes made of wood, stucco, masonry, metal, or any material that absorbs noise, present at the intersection. While zero points were awarded by the

examiner when there was no boxes made up of wood, stucco, masonry, metal, or any material that absorbs noise, present at the intersection.

For the planting of vegetation, the examiner awarded one point when there was planting such as dense vegetation, hedges, medium height green barriers, trees, and integration of vegetation in the walls of the buildings nearby, present at the tested intersection. While zero points were awarded when there was no planting such as dense vegetation, hedges, medium height green barriers, trees, and integration of vegetation in the walls of the buildings nearby, present at the tested intersection.

5.2.6. Data collection methodology for sub section 6: ways and features to reduce light pollution. This sub section is composed of two items: turn off the lights when unneeded and use cutoff fixtures to have no light above the horizontal level. One point can be awarded for each item. For the first item, the examiner gave one point for intersections that had street lights equipped with motion detectors. While the examiner gave no points for the intersections that had no motion detectors equipped on the street lights.

For the second item in this sub-section, the examiner gave one point for intersections that had full cutoff fixtures used for the street lights. Three quarters of a point was awarded for intersections that were using cut-off fixtures for street lights. Half a point was awarded for intersections that were using semi-cutoff fixtures for street lights. Finally, quarter of a point was awarded for intersections that were using non-cutoff fixtures for street lights.

5.2.7. Data collection methodology for sub section 7: convenience and safety of pedestrians. This sub section is composed of thirteen items: Median Refuge Island is wide enough to accommodate pedestrians and cyclists, Presence of Advance Stop Line and Sign, Presence of Advanced Signing, Presence of raised crosswalks, Presence of marking and crossing signs, Street pedestrian crossing signs, High-Visibility signs and Markings, Warning light, Road diet/narrowing (traffic calming), Presence of traffic signal with pedestrian countdown signal, Warning Tactile Ground Surface Indicators, Directional Warning Tactile Ground Surface Indicators, Crossing audio tactile. Based on HIRS one point can be awarded for each of the items. The examiner awarded one point for the items that were present at the intersections, while the items that were missing at the intersections received no points.

5.2.8. Data collection methodology for sub section 8: convenience and safety of Cyclists. This sub section, is composed of eight items: Bicycle lanes, Bicycle Parking, Bike boxes, Intersection Crossing Markings, Median Refuge Island, Bicycle Signal Heads: Signal Detection and Actuation, Colored Bike Facility. Based on HIRS survey one point can be awarded for each of the items. The examiner awarded one point for the items that were present at the intersections, while the items that were missing at the intersections received no points.

5.2.9. Data collection methodology for sub section 9: psychological effect of transportation system. This sub section, is composed of four items that covers the components of a biophilic design: Green street, Urban trees, Edible landscaping, Light color pavement. And two more items: context sensitivity design, use of creative signs that have humor/emotions/emojis. Forming a total of six items for this sub-section. Based on HIRS, one point can be awarded for each of the six items. The examiner awarded one point for each of the items that are related to the biophilic design, present at the examined intersection.

While for the context sensitivity design, the examiner awarded one full point for intersections that had the intersection designs fitting the nearby environment. While the examiner awarded half a point for intersections that had their intersection design somewhat fitting the nearby environment. While the examiner awarded no points for intersection whose designs did not fit the nearby environment.

Finally, the examiner awarded one point for intersections that used either humor or emotion or emojis in its traffic signs. And no points for intersections that did not use humor or emotion or emojis in its traffic signs.

5.3. Summary of the Field Data Collection

HIRS, was used to rate ten signalized urban intersections in the city of Abu Dhabi. While HIRS was used to rate five signalized urban intersections in the city of Dubai, three signalized urban intersections in the city of Sharjah, and two signalized urban intersections in the city of Ajman. Table 14, summarizes the details of the 20 signalized urban intersections that were rated using HIRS. The table covers the name of the city, street name, final score of the tested intersections, and the level of holistic operational performance that the tested intersections achieved.

Table 14 Urabn Intersection Street Name and Final score

NO.	City	Street Name	Final score out of 31.25 points	Final score % form
1	Abu Dhabi	Al Bateen	15.35	49%
2	Abu Dhabi	Al Khaleej Arabi	14.38	46%
3	Abu Dhabi	Al Marsa	14.56	47%
4	Abu Dhabi	Delma 3	14.42	46%
5	Abu Dhabi	Khalifa Al Mobark	15.07	48%
6	Abu Dhabi	Rashid Bin Saeed	12.47	40%
7	Abu Dhabi	Shakboot Bin Sultan	12.12	39%
8	Abu Dhabi	Sultan Bin Zayed	11.81	38%
9	Abu Dhabi	Zayed First	12.67	41%
10	Abu Dhabi	Hamdan Bin Mohamad	10.03	32%
11	Dubai	Downtown (Boulevard)	11.32	36%
12	Dubai	Festival City	10.51	34%
13	Dubai	Qusais (school area)	7.57	24%
14	Dubai	Jumeirah Al Thanya	11.32	36%
15	Dubai	Amman Qusais	13.16	42%
16	Sharjah	Gold center	10.64	34%
17	Sharjah	Hulwan	10.52	34%
18	Sharjah	Al Whada	10.09	32%
19	Ajman	AL Rashidia 3	9.36	30%
20	Ajman	Zahra	9.49	30%

In conclusion, this chapter showed in detail the methodology that was used by the examiner to examine the 20 signalized urban intersections in the UAE. After examining the intersections using HIRS, Abu Dhabi showed a better level of usage of technologies, physical design, and operational features than the three other cities (Dubai, Sharjah, and Ajman). Moreover, the results showed that Dubai, Sharjah, and Ajman are operating their signalized urban intersections at almost the same level of usage of technologies, physical design, and operational features that lead to the holistic operational performance.

Chapter 6. Results and Analysis for the Data Collected Using HIRS

This chapter has three main sections. The sections are as follows: *Statistical analysis of field data collected in UAE, Statistical analysis by cities for the field data collected in UAE, and detailed analysis by HIRS's sections for the field data collected in UAE.*

Statistical analysis of field data collected in UAE, this section shows the mean, maximum, minimum, and SD of the final score achieved by the 20 signalized urban intersections. The objective of this section is to give a general view of the level of usage of the technologies, physical design and operational features that leads to holistic operational performance of UAE signalized urban intersections. While *Statistical analysis by cities for the field data collected in UAE,* shows the mean, maximum, minimum, and SD of the final score achieved by the selected intersection for every city by itself. The objective of this section is to have a closer look on the level of usage of the technologies, physical design and operational features of each city.

Finally, *Detailed analysis by HIRS's sections for the field data collected in UAE.* This section shows the mean, maximum, minimum, and SD of each sub section of the HIRS score achieved by the 20 signalized urban intersections. The objective of this section is to indicate the strengths and weaknesses of the signalized urban intersections in the UAE at each of HIRS's sections.

6.1. Statistical Analysis of Field Data Collected in UAE

Based on the statistical analysis that has been done on the 20 signalized urban intersections in the four major cities of UAE: Abu Dhabi, Dubai, Sharjah, and Ajman. The result were as follows. The final score mean for tested signalized urban intersection was about 11.84 (out of 31.25) which is 38%. This indicates that there is a poor usage of the technologies, physical design and operational features that lead to holistic operating performance in most of the tested signalized urban intersections. Moreover, the maximum value that was scored out of the 20 signalized urban intersections was equal to 15.35 (out of 31.25) which is 49%, while the minimum final score that was scored was equal to 7.57 (out of 31.25) which is 24%. This also indicates that the best tested signalized urban intersection is not using almost half the technologies, physical design and operational features that lead to holistic operating performance, since its

final grade is below 50%. Those two values also indicate the deficiency of the tested signalized urban intersections, based on the items that this study tackles.

The standard deviation was almost equal to 2.15. This indicates that the final score of the signalized urban intersection's operation performance are close to the mean calculated earlier. Finally, all the values (mean, max, min, range, SD) indicate that there is a serious problem with the tested signalized urban intersections. A summary of the Mean, Max, Minimum, and SD of the final scores of the 20 signalized urban intersections can be seen in table 15.

Table 15 UAE Signalized urban intersections Score on HIRS

UAE Signalized urban intersections Holistic operational performance		
Mean (avg.) Final score	11.84	38%
Maximum Final score	15.35	49%
Minimum Final score	7.57	24%
Standard deviation Final score	2.15	-

6.2. Statistical Analysis by Cities for the Field Data Collected in UAE

Based on the mean values calculated for each city. It turned out that Abu Dhabi's signalized urban intersections have are the best, followed by Dubai's, then Sharjah's, and finally Ajman's.

Standard deviation values were about 2 for every city. Low Standard deviation values shows that in the four cities there are no significant differences between the signalized urban intersections within the same cities in terms of the poor usage of the level of usage of the technologies, physical design and operational features that lead to holistic operating performance. In Sharjah and Ajman the Standard deviation values were 0.29 and 0.09 respectively.

Tables 16,17,18,and 19 show the Mean, Maximum, Minimum, and SD of the final score achieved by Abu Dhabi, Dubai, Sharjah, and Ajman respectively.

Table 16 Abu Dhabi, UAE Signalized urban intersections Score on HIRS

Abu Dhabi, UAE Signalized urban intersections Score on HIRS		
Mean (avg.) Final score	13.29	43%
Maximum Final score	15.35	49%
Minimum Final score	10.03	32%
Standard deviation Final score	1.72	-

Table 17 Dubai, UAE Signalized urban intersections Score on HIRS

Dubai, UAE Signalized urban intersections Score on HIRS		
Mean (avg.) Final score	10.78	34%
Maximum Final score	13.16	42%
Minimum Final score	7.57	24%
Standard deviation Final score	2.04	-

Table 18 Sharjah, UAE Signalized urban intersections Score on HIRS

Sharjah, UAE Signalized urban intersections Score on HIRS		
Mean (avg.) Final score	10.42	33%
Maximum Final score	10.64	34%
Minimum Final score	10.09	32%
Standard deviation Final score	0.29	-

Table 19 Ajman, UAE Signalized urban intersections Score on HIRS

Ajman, UAE Signalized urban intersections Score on HIRS		
Mean (avg.) Final score	9.42	30%
Maximum Final score	9.49	30%
Minimum Final score	9.36	30%
Standard deviation Final score	0.09	-

6.3. Detailed Analysis by HIRS Sections for the Field Data Collected in UAE.

This section analyses the scores that the 20 signalized urban intersections achieved for each sub section of the HIRS. As mentioned earlier HIRS contains nine sub sections, which are:

1. *Traffic signal management*

2. Special features in vehicular service

3. Autonomous vehicle readiness

4. Sustainable solutions at intersections

5. Ways and features to reduce Noise pollution

6. Ways and features to reduce Light pollution

7. Convenience and safety of Pedestrians

8. Convenience and safety of Cyclists

9. Psychological effect of transportation system

6.3.1. Performance analysis of traffic signal management sub section.

This sub section is composed of three items:

- Item 1: Signal coordination
- Item 2: Dynamic signal optimization
- Item 3: Traffic signal priority

Table 20 shows a hypothetical example in which signalized urban intersection could score 100% on this sub section.

Table 20 Hypothetical example of an Ideal intersection for Sub Section 1

Sub Section 1: Traffic signal management:	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Signal coordination	0/1	1	0.83	=0.83
Item 2: Dynamic signal optimization	0/1	1	0.89	=0.89
Item 3: Traffic signal priority	0/1	1	0.63	=0.63
Total score				=2.35
Total score in % form				100%

Table 21 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The mean of the total score for sub section 1 achieved by the 20 signalized urban intersections equals 2.1.59 (out of 2.35) or about 68%. This somewhat high percentage shows that the signalized urban intersections in UAE are equipped with the new technologies, physical designs, and operational features that lead to a better service that the traffic signal provides to the vehicular divers at the signalized urban intersections.

Moreover, the maximum score that was achieved equals to 1.72 (out of 2.35) or 73%. This high value also indicates that the signalized urban intersections in the UAE are up-to-date with all the new features that a signalized urban intersection could have. Moreover, the low standard deviation (less than 0.5) shows that the total score that is achieved by sample data collected is very close to the mean value. This indicates that most of the signalized urban intersections in UAE are providing the vehicular drivers with a very good operational service.

Table 21 Summary of the Sub Section1 total score achieved by the 20 intersections

	Sub Section 1 Total score out of 2.35	**Sub Section 1 Total score % form**
Mean	1.59	68%
Maximum	1.72	73%
Minimum	0.83	35%
Standard deviation	0.3	

6.3.2. Performance analysis of special features in vehicular service sub section. This sub section is composed of six items:

- Item 1: Flashing green light or a countdown timer:
- Item 2: Yellow box junction
- Item 3: Traffic Signal equipped with Battery Backup System:
- Item 4: presence of red-light running (RLR) camera
- Item 5:Traveler information
- Item 6: Incident management

Table 22 shows a hypothetical example in which an intersection could score 100% on this sub section.

Table 22 Hypothetical example of an Ideal intersection for Sub Section 2

Sub Section 2: Special features in vehicular service	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Flashing green light or a countdown timer	0/1	1	0.51	=051
Item 2: Yellow box junction	0/1	1	0.57	=0.57
Item 3: Traffic Signal equipped with Battery Backup System	0/1	1	0.63	=0.63
Item 4: presence of red-light running (RLR)	0/1	1	0.80	=0.8
Item 5:Traveler information	0/1	1	0.66	=0.66
Item 6: Incident management	0/1	1	0.77	=0.77
Total score				=3.94
Total score in % form				= 100%

Table 23 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The mean value of the total score achieved by the 20 signalized urban intersections in UAE is 1.54 (out of 3.94) or about 39%. This value shows that the signalized urban intersections are missing many features that could be added to the signalized urban intersections that would lead to better service for the drivers.

The low standard deviation value of 0.60 shows that most of the signalized urban intersections that were investigated are missing pretty much the same features

that the other signalized urban intersections miss. This also indicates the deficiency that the tested signalized urban intersections have, especially in the Traveler information system and Incident management system feature. Those features add to vehicle optimization and safety.

Table 23 Summary of the Sub Section 2 total score achieved by the 20 signalized

	Sub Section 2 Total score out of 3.94	**Sub Section 2 Total score % form**
Mean	1.54	39%
Maximum	1.94	49%
Minimum	0	0%
Standard deviation	0.6	

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6.3.3. Performance analysis of autonomous vehicle readiness sub section.

This sub section is composed of three items:

- Item 1: Quality of Lane marking
- Item 2: Clear traffic signs
- Item 3: Multiple traffic signals

Table 24 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 24 Hypothetical example of an Ideal intersection for Sub Section 3

Sub Section 3: Autonomous vehicle readiness	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Quality of Lane marking	0/.5/1	1	0.89	=0.89
Item 2: Clear traffic signs	0/1	1	0.80	=0.80
Item 3: Multiple traffic signals	0/1	1	0.77	=0.77
Total score				=2.46
Total score in % form				= 100%

Table 25 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. Based on the items that this study tackles, the mean value of the 20 signalized urban intersections achieved in this sub section was 63%. This value indicates that the signalized urban intersections are not completely ready for AVs and more features should be added to the signalized urban intersections to accommodate AVs.

Moreover, the very low standard deviation shows again that more features need to be added to most of the signalized urban intersections that are operating now in UAE.

Table 25 Summary of the sub Section 3 total score achieved by the 20 intersections

	Sub Section 3 Total score out of 2.46	**Sub Section 3 Total score % form**
Mean	1.55	63%
Max	1.69	69%
Minimum	0.8	33%
Standard deviation	0.3	

6.3.4 Performance analysis of sustainable solutions at signalized urban intersections sub section. This sub section is composed of one item:

- Item 1: Clean mode of power generation (for traffic lights and traffic signals)

Table 26 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 26 Hypothetical example of an Ideal intersection for Sub Section 4

Sub Section 4: Sustainable solutions in signalized urban intersections	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Clean mode of power generation (for traffic lights & traffic signals	0/1	1	0.66	=0.66

Total score	= 0.66
Total score in % form	= 100%

Table 27 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The values in table 25 shows that the tested signalized urban intersections are not at all operated using sustainable methods that this study tackles.

Table 27 Summary of the Sub Section 4 total score achieved by the 20 intersections

	Sub Section 4 Total score out of 0.66	**Sub Section 4 Total score % form**
Mean	0.00	0%
Maximum	0	0%
Minimum	0	0%
Standard deviation	0.0	

6.3.5. Performance analysis of ways and features to reduce noise pollution sub section. This sub section is composed of three items:

- Item 1: Absorption of sound waves
- Item 2: Planting vegetation

Table 28 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 28 Hypothetical example of an Ideal intersection for Section 5

Sub Section 5: Ways and features to reduce noise pollution	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Absorption the sound waves	0/1	1	0.54	=0.54

Item 2: Planting vegetation	0/1	1	0.71	=0.71
Total score				= 1.25
Total score in % form				= 100%

Table 29 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The mean value total score for this sub section achieved by the 20 signalized urban intersections is 0.55 (out of 1.25) or about 44%. This indicates that half of the tested signalized urban intersections have only one out of the two features that leads to noise reduction, that this study tackles. The rest of the values in Table 21 also indicate that most of the tested signalized urban intersections are lacking at least one of the features mentioned earlier, and only a few signalized urban intersections have the two features for noise reduction.

Table 29 Summary of the Sub Section 5 total score achieved by the 20 intersections

	Sub Section 5 Total score out of 1.25	**Sub Section 5 Total score % form**
Mean	0.55	44%
Maximum	1.25	100%
Minimum	0	0%
Standard deviation	0.4	

6.3.6. Performance analysis of ways and features to reduce light pollution sub section. This sub section is composed of two items:

- Item 1: Turn off the lights when unneeded
- Item 2: Use cutoff fixtures to have no light above the horizontal level

Table 30 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 30 Hypothetical example of an Ideal intersection for Sub Section 6

Sub Section 6: Ways and features to reduce Light pollution	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Turn off the lights when unneeded	0/1	1	0.51	=0.51
Item 2: Use cutoff fixtures to have no light above the horizontal level	.25/.5./.75/1	1	0.60	=0.60
Total score				=1.11
Total score in % form				= 100%

Table 31 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The values in table 23 indicate that the tested signalized urban intersections are not supported with the new features that can be added to the street light poles to reduce the light pollution caused by those poles. Light pollution is a serious issue that urban communities suffer from, as mentioned earlier in this study.

Table 31 Summary of the Sub Section 6 total score achieved by the 20 intersections

	Sub Section 6 Total score out of 1.11	**Sub Section 6 Total score % form**
Mean	0.44	39%
Max	0.6	54%
Minimum	0	0%
Standard deviation	0.2	

6.3.7. Performance analysis of convenience and safety of pedestrians sub section. This sub section is composed of thirteen items:

- Item 1: Median Refuge Island is wide enough to accommodate pedestrians & cyclists:
- Item 2: Presence of Advance Stop Line and Sign
- Item 3: Presence Advanced signing
- Item 4: Presence of raised crosswalks
- Item 5: presence of marking and crossing signs
- Item 6: street pedestrian crossing signs
- Item 7: High-Visibility signs and Markings
- Item 8: Warning light
- Item 9: Road diet/narrowing (traffic calming)
- Item 10: Presence of traffic signal with pedestrian countdown signal
- Item 11: Warning Tactile Ground Surface Indicators
- Item 12: Directional Warning Tactile Ground Surface Indicators
- Item 13: Crossing audio tactile

Table 32 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 32 Hypothetical example of an Ideal intersection for sub Section 7

Sub Section 7: Convenience and safety of Pedestrians	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Median Refuge Island is wide enough to accommodate the pedestrians & cyclists:	0/1	1	0.94	=0.94
Item 2: Presence of Advance Stop Line and Sign	0/1	1	0.86	=0.86
Item 3: Presence of	0/1	1	0.80	=0.80

advanced signing				
Item 4: Presence of raised crosswalks	0/1	1	0.63	=0.63
Item 5: presence of marking and crossing signs	0/1	1	1.00	=1.00
Item 6: street pedestrian crossing signs	0/1	1	0.83	=0.83
Item 7: High-Visibility signs and Markings	0/1	1	0.91	=0.91
Item 8: Warning light	0/1	1	0.80	=0.80
Item 9: Road diet/narrowing (traffic calming)	0/1	1	0.63	=0.63
Item 10: Presence of traffic signal with pedestrian countdown signal	0/1	1	0.91	=0.91
Item 11: Warning Tactile Ground Surface Indicators	0/1	1	0.66	=0.66
Item 12: Directional Warning Tactile Ground Surface Indicators	0/1	1	0.80	=0.80

Item 13: Crossing audio tactile	0/1	1	0.83	=0.83
Total score				= 10.6
Total score in % form				= 100%

Table 33 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The mean value is about 3.91 (out of 10.6) or less than 40%. This low value shows that there is a major problem with the tested signalized urban intersections. This sub section contains all the features and technologies that add up to the convenience and safety of the pedestrian using the signalized urban intersections. Adding those features and technologies are a must at every signalized urban intersection since those result in making the pedestrian more comfortable and it could also save their lives on the intersections. The maximum score that was achieved by the 20 signalized urban intersection was not any better since it was 50%, which means that also half of the new features and technologies are missing even in the best tested signalized urban intersection.

Moreover, the standard deviation score was pretty low (less than 1) which indicates that all the signalized urban intersections scores in the UAE are very close to the score of the mean. This also reflects that a lot of features and technologies should be added to the tested signalized urban intersections.

Table 33 Summary of the Sub Section 7 total score achieved by the 20 intersections

	Sub Section 7 Total score out of 10.6	**Sub Section 7 Total score % form**
Mean	3.91	37%
Maximum	5	47%
Minimum	2.71	26%
Standard deviation	0.7	

6.3.8. Performance analysis of convenience and safety of cyclists sub section. This sub section is composed of eight items:

- Item 1: Bicycle lanes
- Item 2 : Bicycle Parking
- Item 3: Bike boxes
- Item 4: Intersection Crossing Markings
- Item 5: Median Refuge Island
- Item 6: Bicycle Signal Heads
- Item 7: Signal Detection and Actuation
- Item 8: Colored Bike Facility

Table 34 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 34 Hypothetical example of an Ideal intersection for Sub Section 8

Sub Section 8: Convenience and safety of Cyclists	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Bicycle lanes	0/1	1	0.94	=0.94
Item 2 : Bicycle Parking	0/1	1	0.57	=0.57
Item 3: Bike boxes	0/1	1	0.74	=0.74
Item 4: Intersection Crossing Markings	0/1	1	0.83	=0.83
Item 5: Median Refuge Island	0/1	1	0.80	=0.80
Item 6: Bicycle Signal Heads	0/1	1	0.66	=0.66
Item 7: Signal Detection and Actuation	0/1	1	0.69	=0.69

Item 8: Colored Bike Facility	0/1	1	0.71	=0.71
Total score				= 5.94
Total score in % form				= 100%

Table 35 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 intersections. The mean value of 0.89 (out of 5.94) or 15%, clearly shows that most of the signalized urban intersections in UAE are not designed to handle cyclists based on the factors that this study tackles. This is another major problem that needs to be taken into consideration by governments and authorities.

However, the maximum scored which is 3.94 out (5.94) or 66% and the standard deviation of 1.5, shows that some signalized urban intersections in UAE provide better service to the cyclist than other signalized urban intersections across the country.

Table 35 Summary of the Sub Section 8 total score achieved by the 20 intersections

	Sub Section 8 Total score out of 5.94	**Sub Section 8 Total score % form**
Mean	0.89	15%
Maximum	3.94	66%
Minimum	0	0%
Standard deviation	1.5	

6.3.9. Performance analysis of Psychological effect of transportation system sub section. This sub section is composed of six items:

- Item 1: Components of Biophilic design: Green street
- Item 2: Components of Biophilic design: Urban trees
- Item 3: Components of Biophilic design: Edible landscaping
- Item 4: Components of Biophilic design: Light color pavement
- Item 5: context sensitivity design
- Item 6: use of creative signs that have humor/emotions/emojis

Table 36 shows a hypothetical example in which a signalized urban intersection could score 100% on this sub section.

Table 36 Hypothetical example of an Ideal intersection for Sub Section 9

Sub Section 9: Psychological effect of transportation system	**Points available**	**Points awarded**	**Weightage factor**	**Final Score (score X weightage factor)**
Item 1: Green street	0/1	1	0.63	0.63
Item 2: Urban trees	0/1	1	0.49	0.49
Item 3: Edible landscaping	0/1	1	0.34	0.34
Item 4:Light color pavement	0/1	1	0.49	0.49
Item 5: context sensitivity	0/.5/1	1	0.63	0.63
Item 6: use of creative signs that have humor/emotions/emojis	0/1	1	0.37	0.37
Total score				=2.95
Total score in % form				= 100%

Table 37 shows the mean, maximum, minimum, and SD of the total score for this sub section scored by the 20 signalized urban intersections. The values in Table 29, show that the tested signalized urban intersections are missing one or two features that contribute to the psychology of the different users of the signalized urban intersections. The rest of the values in Table 29 indicate that more work needs to be done on the tested signalized urban intersections to make them more pleasant and welcoming for their different users.

Table 37 Summary of the Sub Section 9 total score achieved by the 20 intersections

	Sub Section 9 Total score out of 2.95	**Sub Section 9 Total score % form**
Mean	1.38	47%
Maximum	1.805	61%
Minimum	0.315	11%
Standard deviation	0.4	

Summary of the sub sections' total score mean values in percentages achieved by the 20 signalized urban intersections can be seen in Figure 43.

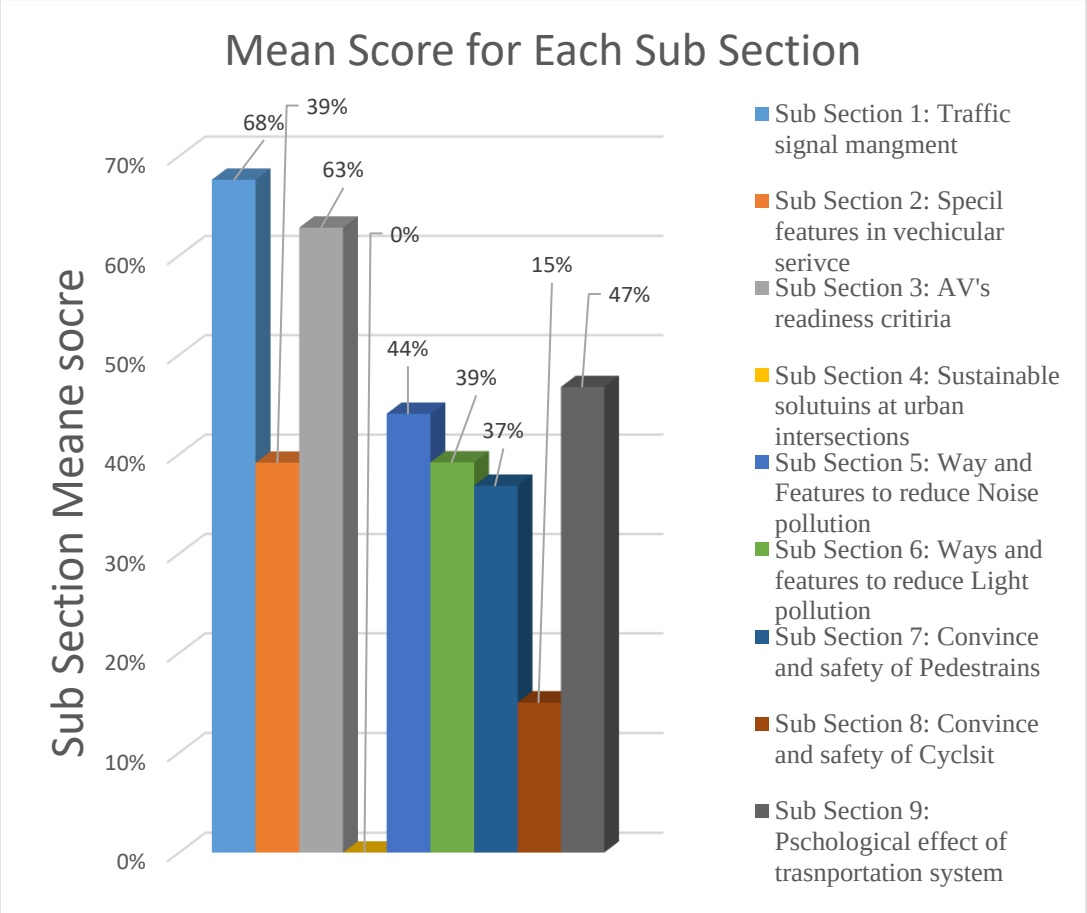

Figure 43 Total score Mean vs Section Number

6.4. Conclusion

After collecting and analyzing the data of the 20 signalized urban intersections in UAE's major cities (Abu Dhabi, Dubai, Sharjah, and Ajman) the outcomes were as

follows. The selected signalized urban intersections showed that they are equipped with most of the new technologies, physical designs, and operational features for the traffic signals, based on the challenges that AVs will face at the roads that were predicted by experience in the field of transportation. The results showed that the tested signalized urban intersections are somewhat ready for AVs, but some work is also needed. Moreover, the tested signalized urban intersections scored a mean 53% on "Motorized/vehicular traffic" section this shows that they are equipped with half of the technologies and physical design and operational features that lead to an improved service to the vehicle drivers.

However, the results showed that a lot of improvement needs to be made for the tested signalized urban intersections to operate better in terms of public health and community wellbeing. As shown in Figure 51, the percentage results varied from 50% to 0 % in the sub sections that falls under Public health and community wellbeing section, and a mean of 32% on "Public health and community wellbeing section" section. This indicates that the tested signalized urban intersections are missing most of the technologies, physical design and operational features that HIRS tackles that results in boosting the physical and mental health of the pedestrians, cyclists and people living nearby.

Chapter 7. Conclusion and Future Work

7.1. Conclusions

In conclusion, this study provides a new rating system designed to measure the degree of utilization of technologies, physical design and operational features to improve the holistic operational performance of signalized urban intersections. The items of HIRS cover all new technologies, physical design, and operational features that are not covered by the traditional transportation codes. However, usage of those technologies, physical design, and operational features allow the signalized urban intersections to operate holistically.

HIRS's items were weighed based on the Relative Importance Index (RII) values using the feedback of seven experts in the field of transportation and public health. Presence of "marking and crossing signs for pedestrians" scored the highest RII value which was equal to 1, presence of "Median refuge island is wide enough to accommodate pedestrians & cyclists", and "Bicycle lanes" scored the second highest RII value which was 0.94. While presence of "edible landscaping" scored the lowest RII value which was equal to 0.34.

The survey was used to collect field data of 20 signalized urban intersections in UAE (Abu Dhabi, Dubai, Sharjah, and Ajman). After analyzing the collected data of the 20 signalized intersections, the results were as the following, Abu Dhabi's signalized urban intersections scored the highest mean final score of 43%. Dubai's signalized urban intersections scored a mean final score of 34%, then Sharjah's scored a mean final score of 33%. Finally, Ajman's scored the lowest mean final score of 30%. The results showed that Abu Dhabi's signalized urban intersections are equipped with almost half of the technologies, physical features, and operational features that results in an improved holistic operational performance. While Sharjah and Ajman misses most of the technologies, physical features, and operational features that results in improved holistic operational performance.

Based on the detailed analysis by HIRS's sections. The tested signalized urban intersections are equipped with all the traffic signal technologies, physical design, and operational features. The 20 signalized urban intersections scored a mean of 68% on *Traffic signal management* section (this section deals only with the new technologies, physical design, and operational features for the traffic signal). Moreover, the tested

signalized urban intersections scored a mean 53% on “Motorized/vehicular traffic” section this shows that they are equipped with half of the technologies and physical design and operational features that lead to an improved service to the vehicle drivers.

While the tested signalized urban intersections showed weakness in using a lack of sustainable methods to power the traffic signals/signs. Those intersections scored a mean of 0% on the section that deals with sustainable solutions that can be used at urban intersections. Moreover, the results of the 20 tested signalized urban intersections, showed that they are missing most of the technologies, physical design, and operational features that this study tackles that lead to the convenience and safety of pedestrians and cyclists. Since the examined intersections scored a mean of 37% on the convenience and safety of pedestrians section, and a mean of 15% in the convenience and safety of cyclists section. Those very low percentages indicate that the UAE’s signalized intersections are missing most of the technologies and physical design and operational features that this study tackles that makes the intersection safe and convenient for pedestrians and cyclists. Finally, a mean of 32% on “Public health and community wellbeing section” section was scored by the tested signalized urban intersections. This indicates that the tested signalized urban intersections are missing most of the technologies, physical design and operational features that HIRS tackles that results in boosting the physical and mental health of the pedestrians, cyclists and people living nearby. This shows clearly that the tested signalized urban intersections have a deficiency in public health and wellbeing, based on the factors that this study tackles. However, improvements can be made easily by integrating the technologies, physical design, and operational features that are listed “public health and community wellbeing” section.

The new rating system will help urban planners and traffic engineers to incorporate the different items that this study tackles that will result in holistic operational performance, namely: enhancement in the traffic performance, reduction in air pollution, reduction in noise pollution, improvement of users’ mental health, and enhancement of users’ safety. In addition, the proposed rating system will help in making governments and authorities pay attention to the three other types of road user - pedestrians, cyclists, and people living near the signalized urban intersections - who are just as important as the drivers. Specifically, the analysis of the data collected

showed a major deficiency in the service that is being provided to the pedestrians, cyclists, and people living in households nearby.

Finally, to facilitate future research and measurement of the effectiveness of HIRS, two more questionnaires were developed, The Holistic Intersection Performance Indicators Survey (HIPI) and an abbreviated form of HIPI, only targeting a selected set of indicators. Future research can test the soundness of further models testing HIRS and HIPI as inputs and outputs.

7.2. Future Work

Future studies could be done that focus on collecting data for signalized urban intersections using the HIPI survey and abbreviated HIPI survey before and after the integration of technologies, physical design and operational features that were stated by the HIRS. Then the data could be analyzed to show the efficiency of each of the 44 items that HIRS addresses. Moreover, proofing a relationship between the abbreviated HIPI survey score and the HIRS score survey

Furthermore, a study could be done that creates a new way of measuring the effect of integrating the components of biophilic design, context sensitivity, and creative traffic signs on our roads. Until now there has been no research done that deals with this.

Moreover, more research that deals with other highway components such as tunnels and interchanges could be done from a holistic view similar to the one done for this research, as this research covered only signalized urban intersections.

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Appendix A

Sample of a filled expert opinion survey.

Holistic Intersection Rating System	Filled by: Dr. Issam Srour				
Section A: Motorized/Vehicular traffic	Please rate each item in terms of its importance, by placing a "✓" in the appropriate cell				
Sub section 1: Traffic signal management:	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Signal coordination: The intersection traffic signal is designed to allow the vehicle to cross the coming nearby traffic signals at one shot, instead of waiting at every traffic signal to turn green.		x			
Dynamic signal optimization: The traffic signal uses the real-time data to optimize every cycle length, resulting in dynamic cycle lengths instead of the fixed cycle lengths.	x				
Traffic signal priority: Traffic signal priority detects the presence of a transit vehicle; the system either holds the green signal or gives an early green to the leg that has the transit vehicle.		x			
Sub section 2: Special features:	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Flashing green light/countdown timer: Flashing of a green light alerts the drivers that the pedestrian signal is activated, this procedure notifies the driver that the green time will end soon.		x			
Yellow box junction A yellow box marked at the center of the intersection. Used to indicate to drivers that they are not allowed to enter the yellow box until the exit at the other leg of the intersection is clear, to prevent intersection blockage.		x			
Traffic Signal equipped with Battery Backup System: Traffic signal equipped with battery backup system that allows the traffic signal to function smoothly for limited hours after power failure.	x				
Red-light running (RLR) camera A camera installed at the intersection to capture the vehicles that proceed through the	x				

intersection (crosses the intersection) after the signal turns RED.					
Traveler information: The intersection has a System that provides Traffic conditions, Road conditions, emergency advisors, either through Dynamic signs on the roads, radio, websites, cell phone text messaging.		x			
Incident management: The intersection has a system that uses sensors to detect incidents/ traffic roadway data. Once an incident occurs an emergency responder broadcasts the traveler information.	x				
Sub section 3: Autonomous vehicles:	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Quality of Lane marking: Quality of lane markings involves: Retro-reflectivity, Chromaticity, Luminance, Skid Resistance in good physical condition allowing AV sensors to detect them easily.	x				
Clear traffic signs: Traffic signs that regulate and control the traffic are in clean and in good physical condition allowing AV sensors to detect them easily.	x				
Multiple traffic signals: Multiple traffic signals installed at different angles to ensure that in any weather conditions the AV sensors will be able to detect traffic signals lights.	x				
Section B: Public health and community wellbeing					
Sub section 1 Ways and features to reduce Air pollution	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Clean mode of power generation Usage of ecofriendly energy sources (wind turbines & solar panels) to power the traffic lights traffic signals, and electronic boards.	x				
Sub section 2 Ways and features to reduce Noise pollution	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Absorption of sound waves: Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal).		x			
Planting vegetation: Planting at the side of the road is present.			x		

Sub section 3 Ways and features to reduce Light pollution	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Turn off the lights when unneeded: Traffic lights equipped with motion sensors to shut off the light when the intersection is totally empty (NO pedestrians/vehicles/cyclists).		x			
Use cutoff fixtures to have no light above the horizontal level: Usage of cut-off fixtures that covers the street light bulbs allowing NO light trespassing of the houses near the intersection.		x			
Sub section 4 Pedestrian service	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Median refuge island is wide enough to accommodate the pedestrians and cyclists: The median refuge island is wide enough to accommodate the pedestrians and cyclists.	x				
Presence of Advance Stop Line and Sign: It is a solid line marking on the pavement, however it is marked further away from the crosswalk to improve the safety of the pedestrians.	x				
Presence Advanced signing: Sign that is placed further away from the crossing zone, to warn the drivers that pedestrians may be crossing the roadway.	x				
Presence of raised crosswalks: Raised crosswalks are elevated above the adjacent driving lanes.		x			
Presence of marking and crossing signs: The conventional markings and crossing signs are used to alert the drivers that pedestrians are crossing at a specific point.	x				
Street pedestrian crossing signs : Signs placed on the lane edge or street centerline used to remind the drivers that the pedestrians have the right of way by law.	x				
High-Visibility signs and Markings: Are similar to the conventional signs and markings. However, they have higher reflectivity and high conspicuity (higher	x				

visibility characteristics) to grab the drivers' attention.					
Warning light: Flashing amber lights placed on the surface of the pavement in front of the pedestrian side walk.		x			
Road diet/narrowing (traffic calming): Lanes are narrowed as the lanes approach the sidewalk and crosswalks of the intersection.		x			
Presence of traffic signal with pedestrian countdown signal: Traffic signal with pedestrian countdown signal that displays a time countdown that indicates how much time is left for the pedestrian to cross the roadway.	x				
Warning Tactile Ground Surface Indicators: Raised plastic/metal dots on the ground surface that indicates that there is a nearby hazard, such as train/tram platform, or of coming stairs.		x			
Directional Warning Tactile Ground Surface Indicators: Raised plastic/metal dots oriented in parallel lines to indicate the direction of travel that pedestrians who have sight disabilities can follow.		x			
Crossing audio tactile: Audio tactile indications to notify the pedestrians who have sight disabilities when and when not to cross the intersection.		x			
Sub section 5 Cyclist service	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Bicycle lanes: Lanes that are designated by solid white line & bicycle symbol that indicates that this lane is exclusively for bicycles	x				
Bicycle Parking: Presence of Bicycle Parking at/or near the intersection.		x			
Bike boxes: Designated area located at the head of the lane at the intersection. This area provides the cyclists with a safe and visible way to get ahead of the queuing vehicles during the red phase of the traffic signal.		x			

Intersection Crossing Markings: Marking at the pavement that indicates the intended path of the bicyclist to cross the adjacent lane.	x				
Median Refuge Island: Protected space placed to facilitate the pedestrian and bicyclist to cross one direction at a time.	x				
Bicycle Signal Heads: Electronic traffic control device that should be used with the conventional traffic signal/hybrid beacon.		x			
Signal Detection and Actuation: Bicycle detection devices placed in the pavement, used to detect the presence of bicycles and alert the signal controller about the presence of the bicycle to give the priority to the cyclist.		x			
Colored Bike Facility: Usage of colored pavement for the bicycle lane.	x				
Sub section 6 Psychological effect of transportation	Extremely Imp.	Very Imp.	Imp.	Somewhat Imp.	Not at all Imp.
Green street: The sides of the street of the intersection are planted.			x		
Urban trees: Trees are present at the sides of the street of the intersection.			x		
Edible landscaping: The sides of the street at the intersection are planted with edible plants.			x		
Light color pavement: Usage of light colored pavement is used at the intersection.			x		
Creative signs that have humor/emotions/emojis: Presence of humor/emotions/emojis such as happy face :), sad face :(in the traffic signs.			x		
Context sensitivity: The intersection should not disturb the surrounding area. The intersection should be in a harmony with the social environment and the physical environment.		x			

Appendix B

Sample of a filled HIRS survey.

Holistic Intersection Rating System (HIRS)				
Section A: Motorized/Vehicular traffic.				
Section 1: Traffic signal management:	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Signal coordination: It descrip.:The intersection traffic signal is designed to allow the vehicle to cross the coming nearby traffic signals at one shot, instead of waiting at every traffic signal to turn green. 1 point: The platoon of vehicles are able to cross multiple traffic signal on a section of a road at one shot 0 point: The platoon of vehicles are NOT able to cross multiple traffic signal on a section of a road at one shot.	0/1	1	0.83	0.83
Item 2: Dynamic signal optimization: It. descrip.: The traffic signal uses the real-time data to optimize every cycle length, resulting in dynamic cycle lengths instead of the fixed cycle lengths. 1 point: Signal timing is optimized based on the real-time data obtained from the loop detectors. 0 point: Signal timing is NOT optimized based on the real-time data obtained from the loop detectors.	0/1	1	0.89	0.89
Item 3:Traffic signal priority: It. descrip.: Traffic signal priority detects the presence of a transit vehicle, the system either holds the green signal or gives an early green to the leg that has the transit vehicle. 1 point: Traffic signal are equipped to adapt traffic signal priority (TSP). 0 point: Traffic signal are NOT equipped to adapt traffic signal priority (TSP).	0/1	0	0.63	0
Sub section 2: Special features:	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Flashing green light or a countdown timer: It. descrip. Flashing of a green light alerts the drivers that the pedestrian signal is activated; this procedure notifies the driver that the green time will end soon. 1 point: Traffic signal has flashing green light	0/1	1	0.51	0.51

0 point: Traffic signal does NOT has flashing green light.				
Item 2 : Yellow box junction It. descrip.: A yellow box marked at the center of the intersection. Used to indicate to drivers that they are not allowed to enter the yellow box until the exit at the other leg of the intersection is clear, to prevent intersection blockage. 1 point: Presence of Yellow box at the intersection 0 point: Absence of Yellow box at the intersection.	0/1	0	0.57	0
Item 3: Traffic Signal equipped with Battery Backup System: It. descrip. : Traffic signal equipped with battery backup system that allows the traffic signal to function smoothly for limited hours after power failure. 1 point: Traffic signal can function for limited hours with no electricity supply. 0 point: Traffic signal can NOT function for limited hours with no electricity supply	0/1	1	0.63	0.63
Item 4: presence of red-light running (RLR) camera It. descrip.: A camera installed at the intersection to capture the vehicles that proceed through the intersection (crosses the intersection) after the signal turns RED. 1 point: Presence of RLR camera at the intersection 0point: Absence of RLR camera at the intersection	0/1	1	0.80	0.80
Item 5:Traveler information: It. descrip.: The intersection has a system that provides traffic conditions, road conditions, emergency advisors, either through dynamic signs on the roads, radio, websites, or cell phone text messaging. 1 point: The intersection is equipped with the detector and dynamic signs to support the Traveler information system. 0 point: The intersection is NOT equipped with the detector and dynamic signs to support the Traveler information system.	0/1	0	0.66	0
Item 6: Incident management: It. descrip.: The intersection has a system that uses sensors to detect incidents/ traffic roadway data. Once incident occurs an emergency responder broadcasts the traveler information.				

1 point: The intersection is equipped with the sensors and the emergency responders to support the incident system available. 0 point: The intersection is NOT equipped with the sensors and the emergency responders to support the incident system available.	0/1	0	0.77	0
Sub section 3: Autonomous vehicles:	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Quality of Lane marking: It. descrip.: Quality of lane marking involves: Retro-reflectivity, Chromaticity, Luminance, and Skid Resistance in good physical condition allowing AV sensors to detect them easily. 1 point: The lane markings are bright (excellent condition). 0.5 point: The lane markings are of medium quality. 0 point: The lane markings are faded	0/.5/1	1	0.89	0.89
Item 2 : Clear traffic signs: It. descrip.: Traffic signs that regulate and control the traffic are clean and in good physical condition allowing AV sensors to detect them easily. 1 point: The traffic signs are in good condition. 0 point: The traffic signs are NOT in good condition.	0/1	1	0.80	0.8
Item 3: Multiple traffic signals: It. descrip.: Multiple traffic signals installed at different angles to ensure that in any weather condition the AV sensors will be able to detect traffic signals lights. 1 point: Multiple traffic signals installed at different angles. 0 point: Absence of multiple traffic signals installed at different angles.	0/1	0	0.77	0
<u>Section B: Public health and community wellbeing</u>				
Sub section 1 Sustainable solutions at intersections	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Clean mode of power generation (for traffic lights & traffic signals): It. descrip.: Usage of ecofriendly energy sources (wind turbines & solar panels) to power the traffic lights, traffic signals and electronic boards.				

1 point: usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 point: usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards.	0/1	0	0.66	0
Sub section 2 Ways and features to reduce Noise pollution	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Absorption of the sound wave: It. descrip.: Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal). 1 point: Energy Dissipater available on the side of the road (made up of wood, stucco, masonry, metal). 0 point: Energy Dissipater NOT available on the side of the road (made up of wood, stucco, masonry, metal).	0/1	0	0.54	0
Item 2: Planting vegetation: It. descrip.: Planting at the side of the road is present. 1 point: Planting at the side of the road is present. 0 point: Planting at the side of the road is NOT present.	0/1	0	0.71	0
Sub section 3 Ways and features to reduce Light pollution	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Turn off the lights when unneeded: It. descrip.: Traffic lights equipped with motion sensors to shut-off the light when the intersection is totally empty (NO pedestrians/vehicles/cyclists). 1 point: Traffic lights equipped with motion sensors. 0 point: Traffic lights are NOT equipped with motion sensors.	0/1	0	0.51	0
Item 2: Use cutoff fixtures to have no light above the horizontal level: It. descrip.: Usage of cutoff fixtures, that covers the street light bulbs allowing NO light trespassing of the houses near the intersection. 1 point: if full cutoff were used. 0.75 point: if cutoff were used.	0.25 /	1	0.60	0.6

0.5 point: if semi- cutoff were used. 0.25 point: if non- cutoff were used.	0.5 / 0.75 /1			
Sub section 4 Pedestrian service	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Median refuge island is wide enough to accommodate the pedestrians & cyclist: It. descrip.: The median refuge island is wide enough to accommodate pedestrians & cyclists. 1 point: If the median refuge island is wide enough to accommodate the pedestrians. 0 point: If the median refuge island is NOT wide enough to accommodate the pedestrians.	0/1	1	0.94	0.94
Item 2: Presence of Advance Stop Line and Sign: It. descrip.: It is a solid line marking on the pavement, however it is marked further away from the cross walk to improve the safety of the pedestrians. 1 point: If advanced stop line and sign is present further away from the cross walk. 0 point: If advanced stop line and sign is NOT present further away from the cross walk.	0/1	1	0.86	0.86
Item 3: Presence of Advanced signing: It. descrip.: Sign that is placed further away from the crossing zone, to warn the drivers that pedestrians may be crossing the roadway. 1 point: If Advanced signing is present on a roadway. 0 point: If Advanced signing is NOT present on a roadway.	0/1	0	0.8	0
Item 4: Presence of raised crosswalks: It. descrip.: Raised cross walks are elevated above the adjacent driving lanes. 1 point: If the crosswalks are raised above the adjacent lanes. 0 point: If the crosswalks are NOT raised above the adjacent lanes.	0/1	0	0.63	0
Item 5: presence of marking and crossing signs:				

It. descrip.: The conventional marking and crossing signs are used to alert the drivers that pedestrians are crossing at a specific point. 1 point: If the marking and crossing signs are present. 0 point: If the marking and crossing signs are NOT present.	0/1	1	1	1
Item 6: street pedestrian crossing signs : It. descrip.: Signs placed on the lane edge or street centerline used to remind the drivers that the pedestrians have the right of way by law. 1 point: If street pedestrian crossing signs are placed on the lane edge/street centerline. 0 point: If street pedestrian crossing signs are NOT placed on the lane edge/ street centerline.	0/1	0	0.83	0
Item 7: High-Visibility signs and Markings: It. descrip.: Are similar to the conventional signs and marking. However, they have higher reflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention. 1 point: If High-Visibility signs and Markings are present. 0 point: High-Visibility signs and Markings are NOT present.	0/1	0	0.91	0
Item 8: Warning light: It. descrip.: Flashing amber lights placed on the surface of the pavement in front of the pedestrian side walk. 1 point: If warning lights are present in front of the pedestrian side walk. 0 point: If warning light are NOT present in front of the pedestrian side walk	0/1	0	0.80	0
Item 9: Road diet/narrowing (traffic calming): It. descrip.: Lanes are narrowed as the lanes approach the side walk and crosswalks of the intersection. 1 point: If the lanes are narrowed as the lanes approach the side walk and crosswalks. 0 point: If the lanes are NOT narrowed as the lane approaches the sidewalks and crosswalks.	0/1	0	0.63	0
Item 10: Presence of traffic signal with pedestrian countdown signal: It. descrip.: Traffic signal with pedestrian countdown signal that displays a time countdown				

that indicates how much time is left for the pedestrian to cross the roadway. 1 point: If the traffic signal has a countdown signal. 0 point: If the traffic signal has NO countdown signal.	0/1	1	0.91	0.91
Item 11: Warning Tactile Ground Surface Indicators: It. descrip.: Raised plastic/metal dots on the ground surface indicates that there is a nearby hazard, such as train/tram platform, or of coming stairs. 1 point: Presence of Warning Tactile Ground Surface Indicators are at the hazardous areas of the intersection. 0 point: Absence of Warning Tactile Ground Surface Indicators are at the hazardous areas of the intersection.	0/1	0	0.66	0
Item 12: Directional Warning Tactile Ground Surface Indicators: It. descrip.: Raised plastic/metal dots oriented in parallel lines to indicate the direction of travel that pedestrians with sight disabilities can follow. 1 point: Presence of Directional Tactile Ground Surface Indicators. 0 point: Absence of Directional Tactile Ground Surface Indicators	0/1	0	0.80	0
Item 13: Crossing audio tactile: It. descrip.: Audio tactile indications to notify pedestrians with sight disabilities when and when not to cross the intersection. 1 point: Presence of crossing audio tactile at the intersection. 0 point: Absence of crossing audio tactile at the intersection.	0/1	0	0.83	0
Sub section 5 Cyclist service	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Bicycle lanes: It. descrip.: Lanes that are designated by solid white lines & bicycle symbol that indicates that this lane is exclusively for bicycles 1 point: Presence of bicycle lane at the intersection. 0 point: Absence of bicycle lane at the intersection	0/1	1	0.94	0.94
Item 2: Bicycle Parking:				

It. descrip.: Presence of Bicycle Parking at/or near the intersection. 1 point: Presence of Bicycle Parking at or near the intersection. 0 point: Absence of Bicycle Parking at or near the intersection.	0/1	0	0.57	0
Item 3: Bike boxes: It. descrip.: Designated area located at the head of the lane at the intersection. This area provides the cyclists a safe and visible way to get ahead of the queuing vehicles during the red phase of the traffic signal. 1 point: Presence of bike boxes at the intersection. 0 point: Absence of the bike boxes at the intersection.	0/1	0	0.74	0
Item 4: Intersection Crossing Markings: It. descrip.: Marking at the pavement that indicates the intended path of bicyclist to cross the adjacent lane. 1 point: Presence of the Intersection Crossing Markings at the intersection. 0 point: : Absence of the Intersection Crossing Markings at the intersection	0/1	1	0.83	0.83
Item 5: Median Refuge Island: It. descrip.: Protected space placed to facilitate pedestrians and bicyclists to cross one direction at a time. 1 point: Presence of the Median Refuge Island 0 point: Absence of Median Refuge Island.	0/1	1	0.80	0.80
Item 6: Bicycle Signal Heads: It. descrip.: Electronic traffic control device that should be used with the conventional traffic signal/hybrid beacon. 1 point: Presence of the bicycle signal head at the intersection. 0 point: Absence of the bicycle signal heads at the intersection.	0/1	1	0.66	0.66
Item 7: Signal Detection and Actuation: It. descrip.: Bicycle detection devices placed in the pavement, used to detect the presence of bicycles and alert the signal controller about the presence of the bicycle to give the priority to cyclists.				

1 point: Presence of the signal detection and actuation feature at the intersection. 0 point: Absence of the signal detection and actuation feature at the intersection.	0/1	0	0.69	0
Item 8: Colored Bike Facility: It. descrip.: Usage of colored pavement for the bicycle lane. 1 point: Presence of colored bike lanes. 0 point: Absence of colored bike lanes.	0/1	1	0.71	0.71
Sub section 6 Psychological effect of transportation	Points available	Points awarded	Weightage factor	Score (points awarded x weightage factor)
Item 1: Components Biophilic design Green street: It. descrip.: The sides of the street of the intersection are planted. 1 point: If the sides of the street of the intersection are planted. 0 point: If the sides of the street of the intersection are NOT planted.	0/1	1	0.63	0.63
Item 2: Components of biophilic design - Urban trees: It. descrip.: Trees are present at the sides of the street of the intersection. 1 point: If trees are present at the sides of the street of the intersection. 0 point: If trees are NOT present at the sides of the street to the intersection	0/1	1	0.49	0.49
Item 3: Components of biophilic design - Edible landscaping: It. descrip.: The sides of the street at the intersection are planted with edible plants. 1 point: If the sides of the street at the intersection are planted with edible plants. 0 point: If the sides of the street at the intersection are NOT planted with edible plants.	0/1	0	0.34	0
Item 4: Components of biophilic design - Light color pavement: It.4descrip.: Usage of light colored pavement is used at the intersection.				

1 point: If light color pavement is used at the intersection. 0 point: If NO light color pavement is used at the intersection.	0/1	0	0.49	0
Item 5 : context sensitivity: It. descrip.: The intersection should not disturb the surrounding area. The intersection should be in harmony with the social environment and the physical environment. 1 point: If the intersection design fits the nearby environment. 0.5 point: If the intersection design somewhat fits the nearby environment 0 point: If the intersection deign does NOT fit the nearby environment	0/0.5/1	1	0.63	0.63
Item 6: use of creative signs that have humor/emotions/emojis: It. descrip.: Presence of humor/emotions/emojis such as happy face :), sad face :(in the traffic signs. 1 point: If the traffic signals have humor/emotions. 0 point: if the traffic signals have NO humor/emotions.	0/1	0	0.37	0
Final Score of the Signalized Urban Intersection.				=15.35

Vita

Wesam Emad Saba was born in 1994, in Cairo, Egypt. He received his primary and secondary education in Dubai, U.A.E. he received his B.Sc. degree in Civil Engineering from the American University of Sharjah in 2016.

In September 2016, he joined the Civil Engineering master's program in the American University of Sharjah as a graduate teaching assistant. His research interests are in (Engineering management, Transportation, Sustainability, Public health).