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A Holistic Intersection Rating System (HIRS)—A Novel Methodology to Measure the Holistic Operational Performance of Signalized Urban Intersections

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Abstract: Signalized urban intersections are key components of urban transportation networks. They are traditionally viewed and designed as primarily motorized traffic facilities, and thus their physical and operational designs have traditionally aimed at maximizing traffic throughput subject to constraints dictated by vehicular safety requirements and pedestrian crossing needs. Seen from a holistic viewpoint, urban intersections are hubs or effective centers of community activities of which traffic flow is only one. Those hubs have direct and indirect impacts on the overlapping traffic functionalities, the environment, public health, community wellbeing, and the local economy. This study proposes a new rating system, the Holistic Intersection Rating System (HIRS), aimed at appraising signalized intersections from a more inclusive viewpoint. This appraisal covers traffic functionality, sustainability, and public health and community wellbeing. This rating system can be used as a guide to conceive, plan, or design new intersections or revamp existing ones. HIRS rates signalized urban intersections based on the level of use of relevant enabling technologies, and the physical and operational designs that allow those intersections to operate holistically, thus leading to a more human-centric and sustainable operational performance. HIRS was validated using a panel of experts in construction, transportation, and public health. The Relative Importance Index (RII) method was used to weigh the HIRS features. The rating system was piloted on a sample of 20 intersections in different cities in the UAE. The results revealed glaring gaps in services to or the consideration of pedestrians, cyclists, and nearby households. The sample intersections scored a mean of 32% on the public health and community wellbeing section, 37% on the pedestrian subsection, and 15% on the cyclist subsection. Such relatively low scores serve as indicators of areas for improvements, and if mapped to their specific features and their relative weights, specific physical and operations designs and technology integration can be identified as actionable items for inclusion in plans and/or designs.

Keywords: transportation system signalized urban intersections; rating systems; public health; sustainable operational performance

1. Introduction

An urban transportation system is a system composed of a set of physical transport infrastructure components, modes, and operational norms that enable the movement of freight and passengers [1]. In the recent past, transportation planners, designers, and operators focused on transportation systems' improvements that enabled motorized travelers and freight modes to move efficiently between origins and destinations. Economics was the overriding criterion, and sometimes the only one. However, in more recent times the focus has shifted from movement to the more encompassing issues of mobility and accessibility, and thus sustainability and equity aspects of transportation systems that

capture emerging environmental and health challenges have become central themes [2]. Signalized urban intersections, as key components of urban transportation systems, were traditionally designed to maximize motorized traffic throughput or some variant of it [3] and resulted from mostly economics-motivated thinking. Other factors that influence the design and operational performance of signalized intersections were not measured nor valued fully in the planning and design phases. At best they were often lumped together as externalities or issues of viability and only qualitatively addressed. In fact, the previous urban signalized intersection rating systems, such as "performance evaluation of signalized urban intersections under mixed traffic conditions", focused on rating only the vehicular service that intersections provide without considering other important elements in intersections design or operation [4]. HIRS is a step towards a more encompassing intersection rating system that bridges the gap in current thinking.

The Holistic Intersection Rating System (HIRS) is a new rating system that utilizes a holistic operational performance of signalized urban intersections. For the purpose of this work, "holistic" means a belief that the physical and operational features of an intersection, as well as the enabling technologies, both hard and soft, are all part of a complex bigger than their physical and operational sum and are intimately interconnected and explainable only by reference to the surrounding environment/community/area where the complex resides. This view is motivated by a belief that intersections serve a function far more encompassing and impactful than that implied by the current/traditional traffic operation- and economics-centric view. HIRS views intersections as activity nodes with community- and human-centric reach and impact. Included in the rating system are enabling technologies and physical and operational designs that both enable and support the holistic view noted earlier. In a way, HIRS also serves an awareness and advocacy role: it introduces transportation planners, designers, and operators to the relevance of those elements and how to systematically integrate them to (1) enable equitable operational performance, (2) support sustainability, and (3) foster public health and community wellbeing. Promoting those aspects leads to a better service for pedestrians, cyclists, and households located nearby signalized urban intersections. The HIRS rating system is composed of two main sections. The first section concerns motorized/vehicular traffic, and the second is devoted to public health and community wellbeing, which contributes positively to sustainable solutions at signalized intersections.

1.1. Problem Definition

Transportation systems are an integral element and shaper of the built environment. In times past, the focus of urban transportation systems was to facilitate the movement of motorized vehicles [2]. However, less attention was given to other users such as pedestrians, cyclists, and nearby residents [5]. In many cases, considerations for pedestrians and cyclists—and the needs of the surrounding environs—were accounted for only as constraints, if at all. From a more holistic viewpoint, urban transportation should be about both mobility and accessibility in relation to purposeful destinations, ones that meaningfully fit into the urban fabric and meet all needs (not just economics-centric ones) of system users. That is to say, transportation is about moving and facilitating access to system traffic, motorized and nonmotorized, regardless of whether it is serving a derived need or not [5]. Equally important now, especially given the many global challenges, transportation systems should be operated to promote sustainable means and solutions that contribute not only to eliminating excesses and protecting the environment, but also to enhancing health and community wellbeing. HIRS was designed with this in mind. It rates urban signalized intersections (new or existing) with respect to the inclusion of enabling technologies (T) and physical and operational designs (PD and OD) that are deemed necessary for an encompassing, more holistic performance. For the purpose of this paper, enabling technologies (ET) include hardware such as vehicle and pedestrian detection cameras and sensors and/or soft technologies such as detection and control protocols and algorithms and wireless communication. Physical design (PD) refers to specific or

specialized components or features within the intersection's right-of-way that serve one or more of three functions: (1) a core control and guidance role, (2) a supplemental role as delineation/accentuation or emphasis function, or (3) to mitigate unintended consequences. Operational designs (ODs) capture functionalities, norms, rules, and policies, the adherence to which is a necessary but mostly not a sufficient condition for optimum functioning of the intersection. In this context, and for the purpose of this paper, optimum and holistic are almost synonymous. Once sufficiently calibrated and tested, HIRS becomes a tool to guide planning and design decisions on urban signalized intersections. With optional built-in flexibility, the rating system may be customized for use in different jurisdictions and/or with varying policy emphases.

1.2. HIRS: Aims and Objectives

The work presented here is part of an effort to advance the intersecting notions of sustainability, public health, and community wellbeing in transportation systems. The objective of the research is to create a tool, the rating system HIRS, to help assess—and then scale up—those notions in signalized urban intersections. HIRS uses a holistic view that captures and values physical and operational features that support mixed-traffic needs, sustainability, public health, and community wellbeing. As a first step, existing rating systems that for the most part were created to rate highway links (as opposed to nodes) were evaluated for their relevance. The strengths and weaknesses of those systems were evaluated with an eye on applicability and relevance to signalized urban intersections. Secondly, an extensive search was conducted that aimed at understanding the relevance and utility of technologies and physical and operational designs that have the potential to support the holistic view of intersections and as such should be incorporated in the proposed rating system. The proposed rating system will help transportation authorities and professionals assess signalized intersections, as activity nodes within urban networks, more holistically by measuring the level of integration of enabling technologies and physical and operational designs (henceforth called features) that, when fused into the "mini-system" the intersection is, give rise to a more holistic operational performance or service level. HIRS can be used as a guide by traffic planners and designers to revamp existing signalized urban intersections to support the integration of relevant enabling technologies and physical and operational designs.

1.3. Significance of HIRS

HIRS is unique in the following respects:

- It explicitly acknowledges the importance of public health and community wellbeing in the design and operations of signalized intersections. It incorporates and weights pertinent features that effectively act as "pathways" to health and community wellbeing. In previous rating systems, such features were missing or, at best, only implicitly considered. The case for HIRS follows from the notion that when seen from a holistic viewpoint, signalized urban intersections are integral components of an urban transportation system with direct and indirect links to public health and community wellbeing. It is no longer a luxury that we design and operate those intersections in isolation from the bigger context. In fact, the American Society of Civil Engineers (ASCE) code of ethics explicitly notes health and welfare. It states that "Engineers should take into consideration that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices" [6]. Traditional health and welfare were thought of more as the domain of the public health profession. Not anymore. HIRS is at the heart of this transport–health nexus.
- It recognizes the worth of active modes of transportation (walking and cycling) and accords them due weight. Previous rating systems such as "performance evaluation of signalized urban intersections under mixed traffic conditions" focused on rating the performance of signalized urban intersections with respect to vehicular traffic [4]. As typical of most traditional rating systems, of which this study is one, a unimodal-

centric approach treats pedestrian and cyclist traffic as "background, noise, or source of friction". However, the transportation profession is changing in favor of a unified multi- or intermodal view of design and operations of transportation systems and their subsystems. Technological advances are both enabling and accelerating the change. Active modes of transportation are no longer part of the background. They are mainstream, and for good reasons: they reduce the number of auto trips and they have positive health benefits, not least of which are those resulting from the physical exercise that users perform during their transit between origins and destinations [7]. HIRS embodies this holistic view of all modes.

- It addresses two relatively new topics in urban transportation: the readiness of existing infrastructure to support autonomous vehicles (AV) and the effects of transportation systems on the mental health of users and residents of surrounding environs. HIRS aims to improve services that an intersection provides to users regardless of mode and level of technology penetration. Pedestrians, cyclists, and AVs are equally recognized and supported, consistent with the notion of creating complete streets [8,9]. HIRS also incorporates and rates features that affect the mental health of transportation system users and nearby residents. Subtle but significant issues of viability such as community severance and noise and light pollution have direct and indirect health impacts both on intersection users and nonuser nearby residents. HIRS captures and values the notion that a transportation system should not impede but, rather, facilitate the transit of users between points of interest while at the same time augmenting their experience through the promotion and enforcement of known positive health enablers (as physical designs, sound, and visual effects). Besides governmental agencies with traditional health-centric roles, now transportation units are increasingly seen as health-promoting agents; their traditional role of creating and maintaining the transportation system to support economic efficiency is now being augmented with promoting environmental sustainability, public health, and community character [8]. In the end, it is almost impossible to disconnect the notions of economic and environmental efficiency and technological advancement from social sustainability. The health of individuals and communities spans all those contemporary notions. HIRS is square at the intersection of all those conceptions.

1.4. Research Significance

Signalized intersections are key elements of urban transportation networks. They are deciders of network level-of-service (LOS), however that is determined. Their influence as nodes of control and tempering of vehicular traffic is thoroughly researched and established, but not their influence on other traffic—and certainly not on the surrounding environment. It is no surprise then that LOS has traditionally been vehicular traffic-oriented, a view that is hardly complete or equitable. Viewed more holistically, urban intersections are transit nodes for human and/or community-centric activities with economic, environmental, and socially derived needs and influences. It is in this sustainability-inspired context that HIRS will be applied and used.

Unlike previous systems which rate such multicomponent highway sections all in one go, HIRS views and rates an intersection as a system with physical and operational features, boundaries, and flows across those boundaries. With such a critical role for intersections, HIRS aims at improving (or, at minimum, preserving) operational performance and making an intersection that not only blends into its context (as would the traditional view) but proactively enriches it. Specifically, HIRS rates intersections on the level of incorporation of relevant enabling technologies (ETs), physical designs (PDs), and operational designs (ODs), features that, together, elevate the intersection's role to a human and community-centric activity node. Viewed this way, vehicular traffic flow through an intersection is treated as a human/community activity that, at a fundamental level, is more than a purely operational or economic one.

1.5. Literature Review

HIRS builds on and expands on already existing rating systems of civil infrastructure facilities but takes the notion of rating to a higher and more encompassing level. An extensive literature search was done on all previous infrastructure facility rating systems to assess their relevance and strengths, and to determine gaps that must be addressed as part of the development of HIRS. HIRS reframes the discussion of infrastructure civil systems as shapers of the built environment with a more integrative and proactive human-centric role. The summary below describes the purposes of existing transport infrastructure rating systems.

The Green Guide for Roads Rating System is a rating system for roads that was developed by Clark et al. [10]. 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 the design process. I-LAST Illinois was developed by the Illinois Department of Transportation, the American Consulting Engineers Council, and the Illinois Road and Transportation Builders Association. This system is composed of nine different sections which cover planning, design, environment protection, water, transportation, lighting, materials, and innovation [11,12]. Green Roads is a rating system for infrastructure 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 [13]. BEST-In-Highways 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 emissions, 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 [12,14,15]. Those four rating systems that have been used previously are not designed to rate the infrastructure facility at the operational phase. However, HIRS is designed to rate the signalized urban intersection at the operational phase.

Green LITES is a rating system that has been developed by the New York State Department of Transportation (NYSDOT) to help in developing transportation and infrastructure systems in a sustainable way. This rating system is composed of eight 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 [16]. This rating system rates different components of a highway transportation system while HIRS focuses only on one component of the transportation system, which is a signalized intersection system. INVEST infrastructure is a "web-based self-evaluation tool". This rating system has four main sections which include a system planning for states, a system planning for regions, project development, and operations and maintenance [17]. CEEQUAL is the international evidence-based sustainability assessment, rating, and awards scheme for civil engineering [18]. This rating system was developed by a team from the Institution of Civil Engineers (ICE). It has 12 different sections that 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. Sustainable Transportation Access Rating System (STARS) is a rating system developed by the Santa Cruz County Regional Transportation Commission. This rating system has four main sections on integrative process, access, climate and energy, and benefit/cost [19]. 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, the natural world, and climate and risk [20]. None of those above-mentioned rating systems rates

signalized urban intersections, however; only HIRS rates signalized urban intersections from a microscopic point of view.

Green Pave is a rating system developed by the Ministry of Transportation in Canada [21]. The system was developed to improve the sustainability of pavements as a component of the transportation infrastructure. This rating system consists of two main components. The first component is design, and the second is construction. This rating system focuses on the pavement component at the design and construction phase. By contrast, HIRS's focus is on the signalized urban intersection. Pavements are only indirectly accommodated (i.e., only to the extent they contribute to or impact operational features of the intersection).

A landslide hazard rating system for Colorado highways is a rating system that helps in quantifying hazards and risks of landslides on Colorado highways. This system was developed based on the existing rock-fall rating systems used by the Colorado Department of Transportation. The new system is composed of 11 hazard factors and 8 consequence factors. The hazard factors include the following: soil/rock, use classifications, rock strength, permeability, jar slake test, discontinuity orientation, and bedrock geology. This rating system's main focus is to rate the highway based on the hazards and risk factors [22,23]. However, HIRS rates the signalized urban intersection based on the level of performance on which the intersections are operating. The subject matter of this rating system is unrelated to HIRS, but its structure and valuation scheme are relevant.

The study conducted by Yue and Wong [4] provides a quantitative evaluation of the signalized intersections under mixed traffic conditions. The evaluation of those intersections is done based on only five parameters: degree of saturation, the separation ratio, average stopped delay, queue length, and conflict ratio. This rating system rates the signalized urban intersection based on only five items which are all related to vehicular traffic. However, HIRS has 44 features and both equitably and explicitly accommodates vehicle users, pedestrians, cyclists, and non-intersection-user nearby dwellers.

To conclude, most of the rating systems that came into existence in the past had three main weaknesses. First, the previous rating systems focused on judging how green the highways are. In other words, from a sustainability point of view, they focused on rating highways based on the application of sustainable construction activities and the usage of recycled materials. However, these previous rating systems ignored transportation services that highways provide to vehicle drivers, pedestrians, cyclists, and people living within close proximity.

Moreover, all the previous rating systems did not include the effect of autonomous vehicles on our transportation systems. The HIRS system helps in improving the services that the transportation facility provides for all of the different users. A complete street is one that is designed and operated to allow safe access for all the users. Second, the previous rating systems did not include the factors that affect the mental and physical health and wellbeing of users. Transportation systems do, however, affect the health of users and can help in shaping communities. Thus, a comprehensive transportation system allows users to transit from one place to another without compromising their health. Governments should be committed to creating a transportation system that promotes public health. In addition, transportation systems should be operated in a way that positively impacts society and the environment.

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. Development of a new rating system (HIRS) would help the traffic authorities to improve on how signalized urban intersections are currently operating by taking into consideration all the different users and the impact on society and the environment.

2. Methods

2.1. Research Proposition

The key proposition of this research is that the use of suitable enabling technologies and physical and operational design features such as those included in HIRS will improve

and make more holistic the operational performance of signalized urban intersections. Rating intersections with respect to those features using suitable tools such as HIRS is a necessary step. This proposition is depicted in Figure 1.
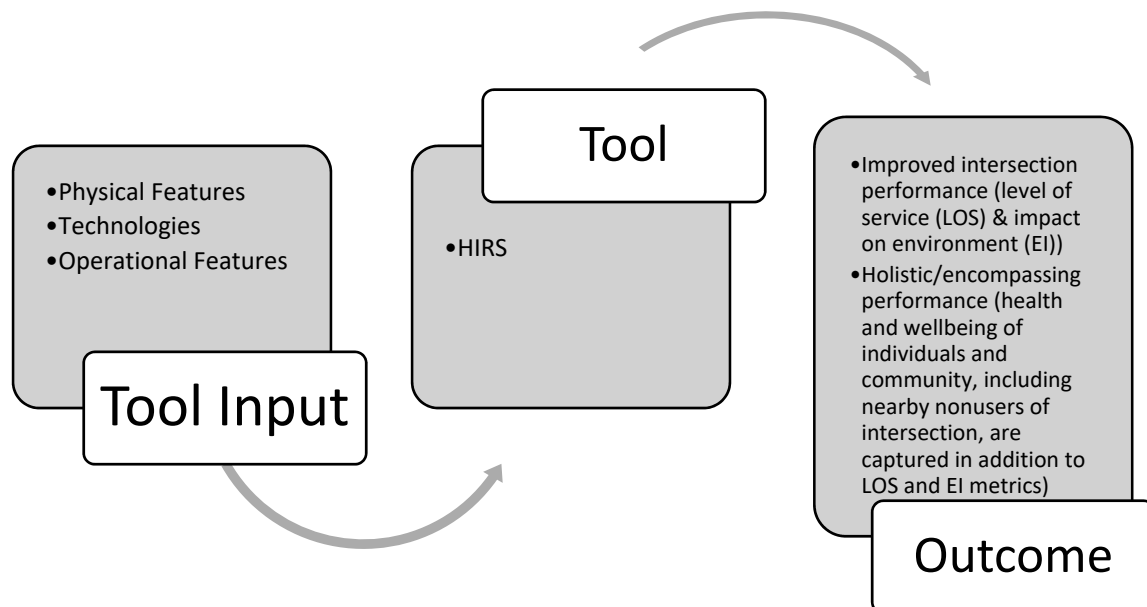

Figure 1. HIRS conceptual implementation framework.

2.2. Research Methodology

This research uses both qualitative and quantitative means to answer the following research question: At what holistic level do signalized urban intersections perform? Or, from a detailed outcome-oriented view, what is the level of integration of sustainability measures and public health- and community wellbeing-supporting features in the physical and operational designs of signalized intersections?

The qualitative means involve evaluating existing rating systems previously used for different components of a highway. The weaknesses and gaps in those rating systems were identified to inform the development of the new rating system. Another extensive literature review was carried out to identify all pertinent enabling technologies, both hard and soft, physical design features, and operational design practices and protocols that are currently available and/or are actually in use. All technologies and design features/protocols identified in this search were then used in the HIRS theoretical framework. A quantitative approach was used where all HIRS's features were validated through a panel of experts in the fields of transportation and public health. Members of the expert panel were tasked with assessing the significance of each feature through an importance score. Based on the data collected from the panel and using the Relative Importance Index (RII) formula, more weightage of each item was given accordingly under the respective subsection established (so that it is clear, HIRS has 44 features or entries: the 44 features are divided into, or belong to, a total of nine subsections. The nine subsections are grouped into two main sections). Later on, HIRS was then validated (or tested) using data from 20 existing signalized urban intersections from different cities in the UAE. The final score, out of 100, for each of the 20 signalized urban intersections reflects the degree to which the operations at the intersection in question are holistic (as holistic is defined in this research). Later on, results based on data from the 20 signalized urban intersections were analyzed using statistical measures to gain a deeper insight into the spread and the central tendency of the results, as well as the features that fed the relative strengths and weaknesses of the respective intersections. Last, based on the analysis of the results, recommendations were given to improve the weaknesses in some areas.

2.3. Brief Description of HIRS

HIRS is a tool that is to be used to rate the level of integration of enabling technologies and physical and operational design features into the design of signalized urban intersections which together give rise to a more holistic operational performance of those intersections. Technologies in the context of HIRS cover electronic and mechanical devices and protocols that improve the safety and operational performance of the signalized urban intersection, such as vehicle and pedestrian detection hardware that enables signal coordination and preemption. Physical design covers designs that can be applied to the intersection area to improve the performance of the intersection, such as road diet/narrowing and pedestrian and cyclist detection. Operational design/features include new/innovative operational practices or protocols that improve the performance of signalized urban intersections, such as adaptive timing schemes, flashing warning green lights, and signal count-down features.

HIRS rates a signalized urban intersection based on the level of integration and/or presence of enabling technologies and physical and operational designs/features that are the building blocks of holistic performance of the intersection. A holistic operation, as explained in the introduction, is one that engenders fitting traffic functionalities, sustainability, and public health and community wellbeing. HIRS has two main sections: one pertains to servicing of motorized traffic, and the other pertains to actively fostering public health and community wellbeing. Under those two sections fall nine subsections (that are not strictly non-overlapping). They are traffic signal management, special features for 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 for cyclists, and physical and psychological health effects of transportation systems. In those nine subsections fall 44 features (or entries) on technologies and physical and operational designs. Figure 2 shows a simplified structure of HIRS. More information on the specifics of the technologies and physical and operational design features of HIRS is presented in the following three sections. Section 2.3.4 presents how HIRS assesses the level of usage of technologies and physical design and operational features for this survey.
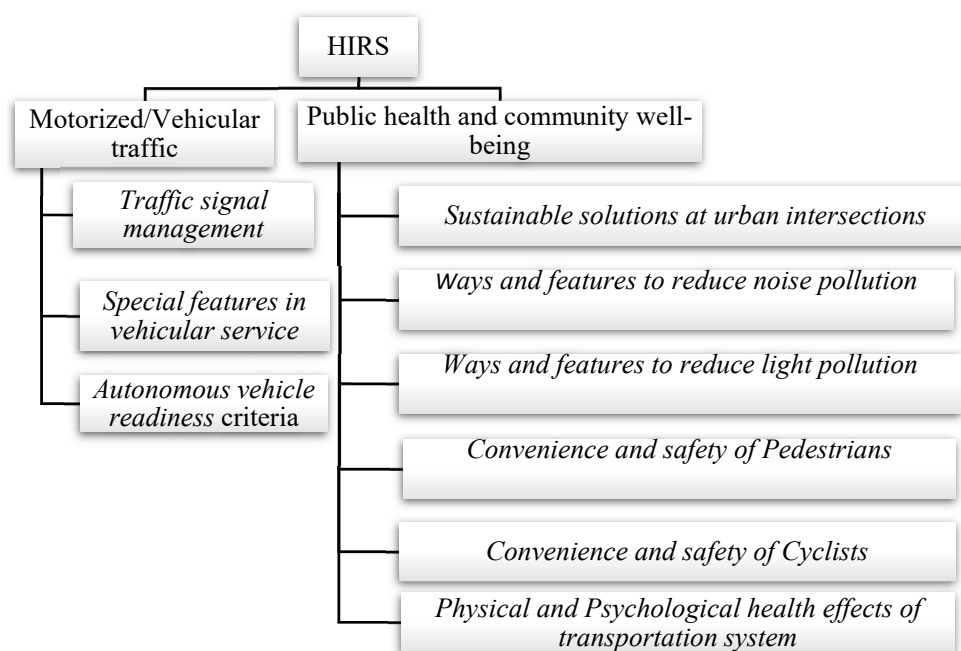

Figure 2. HIRS structure.

HIRS is a rating system designed for appraising signalized intersections from a more inclusive viewpoint. HIRS rates the signalized intersections based on the presence or absence of the technologies and operational and physical design features that lead to improvement in traffic functionality, sustainability, and public health and community wellbeing. This is in order to achieve a better service for the direct and indirect users of the intersections, such as motorized vehicle users, pedestrians, cyclists, and people living in households near the intersections.

HIRS is composed of 44 items (a brief overview is shown in Appendix A), and the 44 items are weighted accordingly based on their importance using the RII method, in order to give important items more weight than the less important ones.

2.3.1. Enabling Technologies

The following enabling technologies are used in the HIRS rating system for signalized urban intersections. These include both proven protocols or programs, and hardware or physical elements. More details on those technologies can be found in topical specialized literature. **Signal coordination:** when the traffic signals are closely spaced, optimum green time intervals would be staged through specific time offsets so that vehicles pass through a set of signals over a section of the road with minimum interruptions. Good signal coordination saves time, conserves fuel consumption, and reduces pollution [24]. An intersection that is part of a coordinated system would likely experience fewer stops, less noise, lower levels of pollution, and likely lower than typical crash exposure. **Dynamic signal optimization:** here, optimum green intervals are updated in real time for every cycle based on prevailing traffic conditions. Dynamic signal control systems have an edge with higher throughput, reduced delays and emissions, and improvement of travel times [25]. **Traffic signal priority** is a system that prioritizes the movement of approaching transit (or emergency response) vehicles using a signal receiver and a transmitter-equipped vehicle. The signal controller then preempts the signal operation by either prolonging the green or shortening the red interval to ensure minimum flow disruption of subject vehicles [26]. **Red light running camera (RLR)** is a system to capture red-signal crossing violations. Use of RLR cameras leads to a significant reduction in all types of RLR crashes [27]. **Traveler information system** is an information system that provides three main types of real-time data, namely emergency advisories, traffic conditions, and road conditions, through dynamic message signs, phone messages, internet websites, and radio transmissions. This system requires the presence of sensors on the road to detect relevant conditions and conveys real-time data to a central traffic control center. Advisories are then delivered to the drivers either using dynamic message signs or phone messages or internet websites and radio. This system helps in optimizing the utilization of road capacity and congestion [28]. **Incident detection system** is a system that uses sensors to detect incidents and traffic roadway data. Once an incident occurs, an emergency response is broadcast from the traveler information system. This system leads to a reduction in fuel consumption (less CO, NO, and hydrocarbon emissions). In addition, it reduces the average delay time caused by incidents [29]. **Turn off street lighting:** streetlights are equipped with motion sensors that turn off the lights when there is no need for light. Such practices reduce the light pollution caused by streetlights [30]. **Warning light:** flashing amber lights placed on the pavement in front of the pedestrian sidewalk increases the safety of pedestrians [31]. **Crossing audio-tactile:** provides audio-tactile indications to notify pedestrians with visual disabilities on when and when not to cross, which increases the safety of visually impaired pedestrians [32]. **Signal detection and actuation:** bicycle detection devices are used to detect the presence of bicycles and alert the signal controller. There are four types of bicycle detectors that could be installed in the signalized intersection: microwave radar, loop induction, video detection, and push button. This system reduces the delay time of cyclists at the traffic signal intersection [33].

2.3.2. Physical Design Features

The physical design features that could be utilized in HIRS to be rated for signalized urban intersections are as follows: **Median refuge island:** a raised area designed to allow pedestrians to cross one direction of the street at a time, which increases the safety of the pedestrians [31,33]. **Raised crosswalk:** an elevated crosswalk above adjacent driving lanes. It serves a dual purpose of making pedestrian and cyclist crossings smoother and continuous, and it acts as a traffic calming feature [31]. **Bike parking:** there are two types of bicycle parking: bicycle racks (fixed objects made of metal to which the bicycles are secured) and bicycle lockers (they vary in design) [33]. Both increase the convenience for cyclists. **Bike boxes:** a designated area located at the head of travel lanes at the intersection. This area provides cyclists with a safe and visible way to get ahead of queuing vehicles during signals' red phase [33]. **Intersection crossing marking:** these are pavement markings that designate paths for cyclists to cross the adjacent lane, thus increasing the safety of cyclists [33]. **Bicycle lanes:** lanes that are marked by solid white boundary lines and a bicycle symbol to indicate exclusive use for bicycles [33]. **Context-sensitive design:** this is a set of standards and practices aimed at maintaining harmony with the intersection's surrounding environment. The dictates of these practices vary widely but all aim at minimizing disturbances and thus ensuring the intersection fits harmoniously in its surrounding physical, ecological, and social environment [34]. Deliberate use of natural native material, colors, plants, architecture, and visual effects are all specific examples. Context sensitivity is known to contribute positively to quality of life for the community as the natural environment is a critical component of the community itself [34]. Biophilia (love of nature), a related notion to context-sensitive design, is also accounted for in HIRS.

HIRS also accounts for the use/presence of biophilic design elements. The components of a biophilic design that have been included in HIRS as advanced physical design features are as follows: **Green street:** a stormwater management technique that involves using permeable pavement vegetation to capture rainwater instead of directing into sewer systems [35]. **Urban trees:** planting trees on the side of the streets [36]. **Edible landscaping:** planting edible plants on the side of the streets [36]. **Light color pavement:** pavements that have a lighter color (lighter than black) are more reflective than a black pavement [36]. Studies have proven that contact with nature, which comes in different forms in the built environment such as biophilic design and green space, helps in reducing stress levels, leads to faster recovery rates from illness, reduces mental fatigue, and increases concentration levels [37,38].

2.3.3. Operational Design Features

The HIRS rating scheme accounts for the following intersection operational features: **Flashing green light:** traffic signals that are equipped with a flashing green light. A flashing green light notifies drivers that the pedestrian signal has been activated and the vehicles' signal will turn red soon [39]. **Traffic signals with countdown timer: this feature helps drivers be more precisely informed of different control intervals, thus enhancing drivers' response** to control as it lets the drivers know when the traffic signal will turn from green to red, which causes a safer response from the drivers [40]. **Yellow box junction: this is** a yellow framed box with crisscross lines inside the box painted in the center of the intersection. A yellow box indicates that vehicles are not allowed to enter the box unless they can exit the box. The use of yellow boxes helps guard against traffic blockages at the center of intersections and thus ensures the continued flow of traffic in all directions [41]. **Traffic signal equipped with battery backup system:** traffic signal equipped with battery backup system allows the traffic signal to function smoothly for a limited number of hours even after a power failure. This minimizes disruption of flow and occurrence of crashes during power downtime [42]. **Use of clean modes of power generation (for traffic lights and traffic signals):** powering traffic signals and smart message boards by sustainable energy sources such as wind turbines and solar panels reduces air pollution [43]. **Planting vegetation on the side of the road:** this helps in absorbing noise generated by

vehicles [44]. **Planting dense vegetation** such as hedges, medium-height green barriers, trees, and integration of vegetation in walls of nearby buildings serve the purpose of noise reduction [45]. **Placement of sound barriers:** this can be in the form of boxes made of different materials to absorb energy waves (sound waves). Materials such as wood, stucco, masonry, metal, or any material that absorbs vehicle-generated noise may also be used [44]. **Use of full cutoff fixtures to eliminate light above the horizontal level:** this fixture reduces light pollution from streetlights as it focuses the light downwards, thus preventing light "leaks" at or above 90 degrees [30]. **Advance stop line and sign:** a stop line and a sign marked/placed in advance of crosswalks to improve the safety and visibility of pedestrians [31]. **Advanced signing:** a sign that is placed to warn the drivers of an impending pedestrian crossing [31]. **Marking and crossing signs:** these are used to alert drivers of pedestrians crossing at specific points [31]. **Street pedestrian crossing signs:** these are "redundant" signs placed on lane edges or road centerlines to augment the basic must-have signs, thus further enhancing pedestrian safety [31]. **Signs and high-visibility markings** are similar to conventional signs and markings but have higher retroreflectivity and high conspicuity (higher visibility characteristics) to grab the drivers' attention [31]. **Road diet/narrowing:** this narrowing of the roadway can be achieved by reducing lane width and using excess space to increase the widths of bicycle lanes or sidewalks. Such narrowing induces speed reduction, thus further enhancing pedestrian and cyclist safety by way of reducing drivers' reaction distance and lessening the severity of injuries when crashes occur [31]. **Traffic signal with pedestrian countdown signal** displays the time left for the pedestrian to cross the roadway. Precise information enables better informed decisions and crossing speed selection, thus enhancing safety [46]. **Warning tactile ground surface indicators** are raised (protruded) studs on the ground surface to assist users, especially the visually challenged, with directions/orientation and locations of decision points or nearby hazards (for example, ahead of train/tram platform or a warning of the presence of stairs) [47]. **Directional warning tactile ground surface indicators:** raised studs oriented in parallel lines to indicate the direction of travel for pedestrians and the visual challenged [47]. **Bicycle signal heads:** three-lens electronic traffic control devices used with the conventional traffic signal/hybrid beacons to enhance cyclists' safety. These heads are installed at heights and with orientations fit for cyclists [33]. **Colored bicycle facility:** colored pavement sections within the bicycle lanes enhance cyclists' safety [48]. **Use of creative signs that have humor/emotions/emojis content:** the presence of humor/emotions/emojis on lenses of traffic signal heads aims to evoke positive emotions among users. Signs with facial expressions were found to positively affect drivers psychologically [49,50].

HIRS also accounts for the requirements of autonomous vehicles or AVs (these are vehicles that drive autonomously and navigate and perform necessary maneuvers by detecting obstacles, traffic lanes and road edge boundaries/markings, and surrounding vehicles [51]). While those vehicles will operate within existing infrastructure, they necessitate that specific elements of existing infrastructure be maintained to higher standards than for conventional (human-operated) vehicles. **Quality of lane markings and clear signs:** presence of clear traffic signs and highly retroreflective lane markings are necessary to enable AVs to recognize surrounding environments and perform critical operations such as lane keeping, lane departure, left turn assists, stopping, and yielding [52]. **Traffic signal detection:** this refers to the installation of multiple traffic signal heads at different angles to help AVs detect traffic signals in challenging ambient light and climatic conditions, such as low-angle bright sunlight [53].

2.3.4. How to Use HIRS

As inputs to assessing how holistic an intersection operation is, HIRS uses the level of adoption of enabling technologies and the physical and operational features noted in the previous section and assigns a weighted score as shown in the five-level scale in Table 1. The relative weights of different features were developed with input from the panel of

experts. For instance, if a given signalized urban intersection has a final score of 30 (about 96%), this denotes that the subject signalized intersection has a very high level adoption of the technologies and physical and operational features that are the ingredients of holistic operational performance. Similarly, a final score of 5 points means the intersection has a very low level of use of the same features. A perfect score is 31.25, which means the intersection has all 44 features. In this case, each feature gets a score of 1, and each is multiplied by its weight of relative importance. For example, if an item is present at the intersection, the intersection is awarded 1 point for it and the weight of the item is 0.66, then this item's contribution to the total intersection score is $1 \times 0.66 = 0.66$ (if it is not present, then the intersection is awarded 0 points, and thus its contribution is $0 \times 0.66 = 0.0$). The points awarded for each item follow a binary scale, either a 0 or a 1. The 0 to 31.25 range is divided into five categories, or levels of usage of the features (i.e., the technologies and operational and physical features) that make the intersection's operations holistic. The categories ranged from "very low" to "very high" as shown in Table 1. A score of 80% or higher means the intersection is "very highly" equipped for a holistic operation. The list of technologies and features that make intersection's operations holistic on which those scores are based is a dynamic one; as more of those technologies and features come online and become usable at intersections they will be added to the number of features, which will grow beyond the 44 presented at this stage.

Table 1. Level of usage of enabling technologies and physical design and operational feature breakdown for HIRS survey.

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

2.4. Establishing the Relative Importance of HIRS Features (Items)

HIRS was validated using a panel of experts in the fields of transportation and public health. The experts were separately asked to rate the importance of each of the 44 features under the subsections. Table 2 shows the experts' inputs for a sample of the features in HIRS. The weightage of every feature of each subsection was established using the experts and using the RII formula. A brief overview of HIRS's structure is shown in Appendix A.

Table 2. Sample of experts' inputs.

HIRS 44 Items	Extremely Important	Very Important	Important	Somewhat Important	Not at All Important
Item 1: Signal coordination	2	4	1		
Item 2: Dynamic signal optimization	4	2	1		
Item 43: Use of creative signs that have humor/emotions/emojis		2	2	3	
Item 44: Context sensitivity		2	4	1	

3. A Case Application of HIRS

To demonstrate how HIRS works in the real world, data were collected from 20 signalized urban intersections. Data collectors and field crews verified the presence or absence of each of the 44 items/features that make up HIRS at each of the subject intersections. For example, if the tested intersection is equipped with a signal coordination system, 1 point will be awarded to that intersection; otherwise, 0 is awarded. The points awarded for each

feature are then multiplied by the weightage factor (that was calculated using RII based on experts' input) to obtain the score for that feature. At the end, the sum of the scores from all 44 features will make up the final score for the intersection at hand. The final score that each of the 20 tested signalized urban intersections accumulated (out of the perfect score of 31.25) is the relative holistic operational level the intersection is currently operating at.

4. Analysis of Results and Discussion

Table 3 and Figure 3 summarize the final scores and level of adoption of the holistic features for the 20 intersections in the study sample. While there is no such thing as a passing score per se, all 20 intersections did not fare well; all fell in the middle and lower tiers, none were in the lowest tier, and none were in the two high tiers. None of the three intersections in the table are particularly holistic. Even for the best one, 50% of the holistic operations-enabling technologies and features are missing. In short, the results point to a serious lack of relevant holistic operations-enabling features (HOeFs) and, thus, a lack of promising potential to augment operations at those intersections and make them the holistic urban facilities they can be.

Table 3. Intersections' final scores.

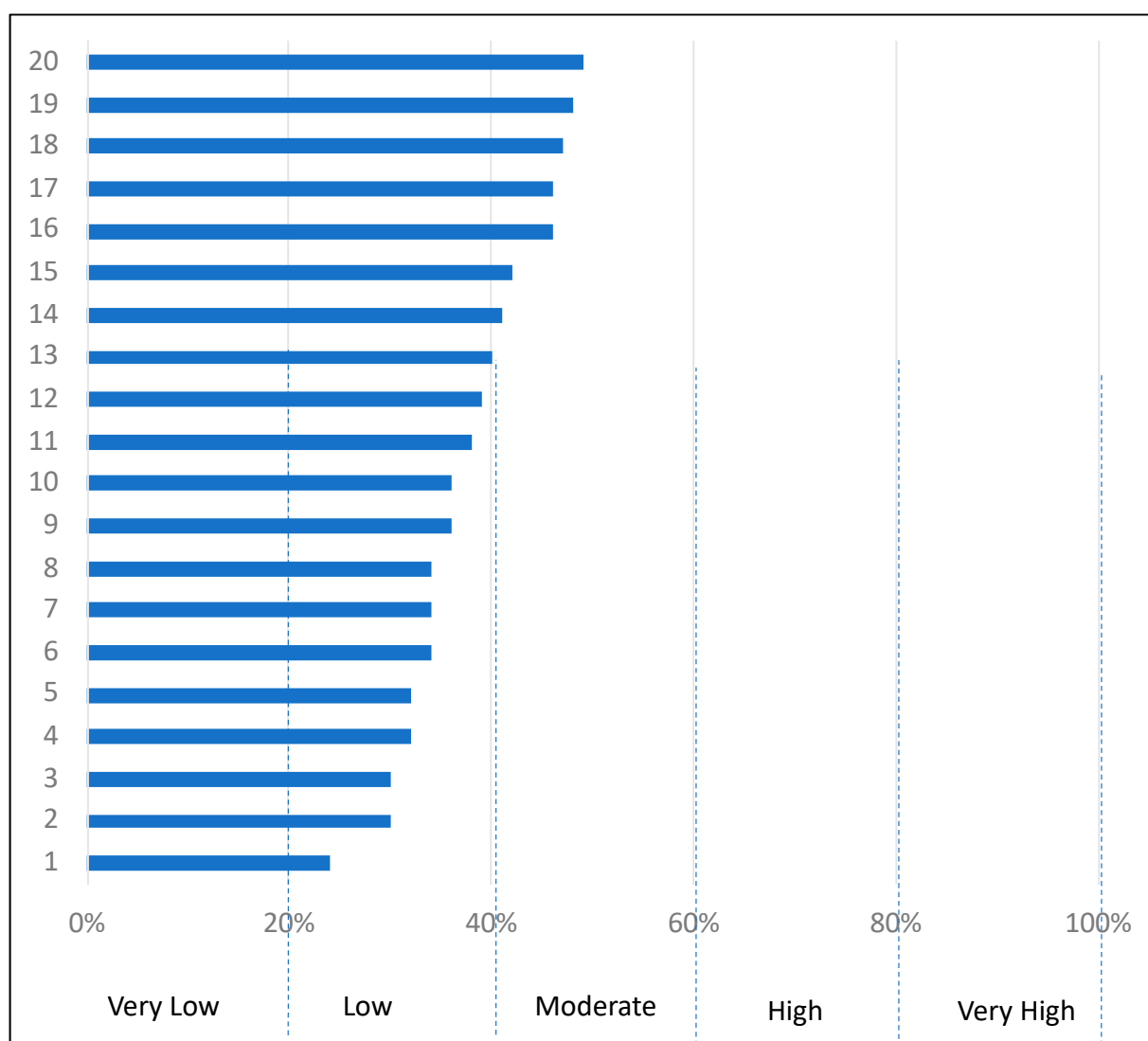| Signalized Urban Intersection No.	Final Score out of 31.2 Points	Final Score, Percent	Level of Usage of Technologies and Physical Design and Operational Features
1	15.35	49%	Moderate
2	14.38	46%	Moderate
3	14.56	47%	Moderate
4	14.42	46%	Moderate
5	15.07	48%	Moderate
6	12.47	40%	Moderate
7	12.12	39%	Low
8	11.81	38%	Low
9	12.67	41%	Moderate
10	10.03	32%	Low
11	11.32	36%	Low
12	10.51	34%	Low
13	7.57	24%	Low
14	11.32	36%	Low
15	13.16	42%	Moderate
16	10.64	34%	Low
17	10.52	34%	Low
18	10.09	32%	Low
19	9.36	30%	Low
20	9.49	30%	Low

Figure 3. Percent final scores and level of holistic features.

A statistical analysis was conducted to quantitatively assess the central tendency and spread of the results. The mean score for all 20 signalized urban intersections was 11.84 (out of 31.25), or 38%. This low score indicates a low usage of the holistic operations-enabling features (HOeFs). Moreover, the maximum score among the 20 intersections was 15.35 (out of 31.25), or 49%; the minimum score was 7.57 (out of 31.25), or 24%. That is, even the best of intersections in the sample does not fare well; it is using just about half of the HOeFs needed to enable a holistic operation. The mean and maximum values point to a clear deficiency among the study intersections. If we are to assume that the sample is a good representation of all signalized intersections in their home city (and country), that points to a significant potential to further enhance their operations through targeted additions of missing HOeFs. Intersections with more HOeFs, thus higher scores, are enablers of sustainable and healthier urban living of the tested signalized urban intersections, based on the items that this study tackles. Moreover, analysis of specific sections within HIRS reveals existing biases.

The detailed analysis for different sections in HIRS that was performed for the tested 20 signalized urban intersections indicated that the tested intersections scored a mean of 53% on the "motorized/vehicular traffic" section (items/features geared towards vehicular traffic and drivers). This analysis indicates that the intersections are equipped with half of the technologies and physical design and operational features needed for holistic operations

(and rated by HIRS). While this is good in that it results in an improved service to vehicle drivers, the section on public health and community wellbeing is not as positive.

The mean score on public health and community wellbeing is 32%. This part of HIRS focuses on the service for pedestrians, cyclists, and people living nearby. A grade of 32% is a failing one; it indicates that the tested signalized urban intersections are missing most of the enabling technologies, physical designs, and operational designs or features that enable or support positive outcomes on the physical and mental health of the pedestrians, cyclists, and people living nearby. While things are changing in some parts of the world, nonmotorized modes, particularly the active ones (pedestrians and cyclists), are still not getting sufficient attention from road design and traffic engineers. A staggering 270,000 pedestrians lose their lives every year around the world, many at signalized intersections [31]. In 2015, more than two cyclists in the United States lost their lives every day due to bicycle–vehicle collisions [54]. However, improvements can be made easily by integrating the enabling technologies, physical design, and operational features that are listed under the "public health and community wellbeing" section.

The standard deviation (SD) of the final score of the 20 tested signalized intersections using HIRS was equal to 2.15. This indicates that the final scores of the signalized urban intersections' operation performance are close to the low mean calculated earlier, which is not an encouraging result. Finally, all the values (mean, max, min, range, SD) indicate that there is a serious problem with the tested signalized urban intersections in that there is much to be desired—and integrated—in their physical design and operations to make them holistic. A summary of the mean, maximum, minimum, and SD of the final scores of the 20 signalized urban intersections can be seen in Table 4.

Table 4. UAE signalized urban intersections' score on HIRS.

Tested Signalized Urban Intersections' Holistic Operational Performance		
Statistical Measures	**Final Score (out of 31.25)**	**Percent Final Scores**
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	—

While these results may be interpreted to point to a missed opportunity and thus a potential to improve operations at those intersections, this is true only if we are to assume that all urban signalized intersections are of similar functionality and equal importance. However, this is not exactly accurate since, based on the class of roads, some intersections are serving roadways that emphasize vehicular mobility while others are part of accessibility roads, and this necessarily means that the nonvehicular traffic and community needs are not the same. This implies that only one set of feature/technology importance scores or scoring system may not be exactly equitable; a varying scoring scheme, one that is roadway class-sensitive, might be a more suitable scheme.

5. Conclusions

Signalized intersections in urban areas are critical elements for the functioning of the transportation network. Those intersections are integral to the good functioning of the bigger urban system. Intersections, signalized or not (but more so signalized ones), are dynamic nodes through which pathways to public health and community wellbeing pass and, therefore, can be optimized for maximum positive (minimum negative) impacts. Those nodes can be designed (physically and operationally) to modulate the impacts on traffic, community character and feel, health, and the environment to meet desired ends. Multiple criteria are combined to determine the level of effectiveness and sustainability of operation of such facilities.

The evaluation and ranking of the operations of those intersections with respect to their intended functionalities and the consequences of those functionalities on the surrounding community and the users of the intersection is a complex undertaking, as multiple interrelated criteria must all be weighed, considered, and given their due importance. The complexity and multitude of the operations of those sections and the factors involved in the operation, however, do not preclude the necessity of scoring and comprehending the holistic view of the operations at the core of transportation planning. Multiple technical techniques and considerations can all be combined to produce a relatively easy-to-comprehend yet encompassing score scheme that speaks to how well an intersection is operating, however "well" is defined.

A combination of extensive literature research, a survey of relevant technologies and operational concepts, and the judgment of experts on the relevance of the relevant technologies and design considerations were all combined in a purposeful way to enable HIRS to be a convenient tool to rate intersections with respect to how holistic their functionality and operations are. The system presented in this paper to rank intersections with respect to how holistic their operations are is a manifestation of the need for, and the possibility of, a convenient one-stop approach to an overview of how well intersections are operating.

On the other hand, it is also necessary to build flexibility and robustness with respect to how realistic transit operations are progressing. Signalized intersections in urban areas, by virtue of their functionality and purpose, are subject to standards, policies, political pressures, efficiencies, and redundancies of technologies. A system with robustness built therein to accommodate those restrictions, demands, and necessities is critical. HIRS has in it the robustness needed to make the proposed system usable in different places and in different settings based on the level and nature or functionality expected from such intersections and/or the links it connects. HIRS has flexibility built into it to accommodate new practices and technologies as they come online. These can be incorporated into the system relatively easily. The validation process and, thus, the relative weights established in this paper are not fixed, nor are the scores presented in this paper final; input from additional experts in the fields of transportation and public health will continue to be incorporated. Slight changes in the relative weights are expected. In addition, more items/features will likely emerge that will have to be incorporated in HIRS.

HIRS is a user-friendly and easy-to-use tool. It can be adapted to different localities and different network conditions and constraints. Specific local, climatic, and cultural conditions may impose limitations and/or dictate special considerations and/or weighting schemes. HIRS's structure is modular and flexible; such additions (or customization) can be readily incorporated. Both HIRS's depth and breadth can be improved where views and ratings from additional experts in transportation and public health, as well as those from other relevant professions such as policy and planning, can be incorporated.

The binary award point scale used in this work may, as applicable, have to be converted to a linear (or not) continuum between 0 and 1. Even though the spirit of HIRS is at the heart of the sustainability debate, specific sustainability metrics may need to be incorporated. The concepts of HIRS can be extended to other transportation network components such as urban arterials and roundabouts. Some of this work is currently underway and will be reported in future publications. These and other features/improvements will be incorporated in the HIRS software (e-HIRS) currently under development.

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Appendix A

Table A1. A Partial Overview of HIRS's Structure.

Holistic Intersection Rating System (HIRS)				
Section A: Motorized/vehicular traffic				
Subsection 1: Traffic signal management				
Subsection 1 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Signal coordination	The three main parameters of traffic signal coordination, namely cycle length, split, and offset, are designed to allow the vehicle to cross multiple traffic signals on a section of the road [25].	1 point: The platoon of vehicles are able to cross multiple traffic signals on a section of a road in one go. 0 points: The platoon of vehicles are not able to cross multiple traffic signals on a section of a road in one go.	0.83	

Subsection 2: Special features				
Subsection 2 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Flashing green light or a countdown timer	Flashing of a green light alerts the drivers that the pedestrian signal is activated; this procedure notifies the driver that the green light will end soon.	1 point: Traffic signal has flashing green light. 0 points: Traffic signal does not have flashing green light.	0.51	

Section B: Public health and community wellbeing				
Subsection 1: Sustainable solutions at signalized urban intersections				
Subsection 1 Items	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)*
Item 1: Usage of clean mode of power generation (for traffic lights and traffic signals)	Powering the traffic signals, electronic boards, and traffic lights with eco-friendly energy sources such as wind turbines and solar panels [44].	1 point: Usage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 points: Nonusage of ecofriendly energy sources to power the traffic lights, traffic signals, and electronic boards. 0 points: Absence of Item 1.	0.66	

Subsection 2: Ways and features to reduce noise pollution				
Subsection 2 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)* *Score (1)*(2)*

Table A1. *Cont*.

Holistic Intersection Rating System (HIRS)				
Item 1: Absorption of the sound wave	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 points: Energy dissipater not available on the side of the road (made up of wood, stucco, masonry, metal).	0.54	

Subsection 3: Ways and features to reduce light pollution				
Subsection 3 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)* *Score (1)*(2)*
Item 1: Turn off the lights when not needed	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 points: Traffic lights are not equipped with motion sensors.	0.51	

Subsection 4: Pedestrian service				
Subsection 4 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)* *Score (1)*(2)*
Item 1: Median refuge island is wide enough to accommodate pedestrians and cyclists	The median refuge island is wide enough to accommodate pedestrians and cyclists.	1 point: If the median refuge island is wide enough to accommodate the pedestrians. 0 points: If the median refuge island is not wide enough to accommodate the pedestrians.	0.94	

Subsection 5: Cyclist service				
Subsection 5 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)* *Score (1)*(2)*
Item 1: Bicycle lanes	Lanes that are designated by solid white lines and a bicycle symbol that indicates that this lane is exclusively for bicycles.	1 point: Presence of bicycle lane at the intersection. 0 points: Absence of bicycle lane at the intersection.	0.94	

Subsection 6: Psychological effect of transportation

Table A1. *Cont.*

Holistic Intersection Rating System (HIRS)				
Subsection 6 Items:	Subsection description:	Points awarded based on: (1)	*Weighted factor (2)*	*Score (1)*(2)* *Score (1)*(2)*
Item 1: Components of biophilic design green street	The sides of the street of the intersection are planted.	1 point: If the sides of the street of the intersection are planted. 0 points: If the sides of the street of the intersection are not planted.	0.63	

Total score =	

References

1. Leibowicz, B.D. Urban land use and transportation planning for climate change mitigation: A theoretical framework. *Eur. J. Oper. Res.* **2020**, *284*, 604–616. [CrossRef]
2. May, A.D. *Traffic Flow Fundamentals*; Prentice Hall: Englewood Cliffs, NJ, USA, 1990. (In English)
3. Federal Highway Administration. Signalized Intersections: Informational Guide. In *Federal Highway Administration Research and Technology*; Federal Highway Administration: Washington, DC, USA. Available online: https://www.fhwa.dot.gov/publications/research/safety/04091/03.cfm (accessed on 12 October 2019).
4. Yue, Z.Q.; Wong, S.C. Performance evaluation of signalized urban intersections under mixed traffic conditions by gray system theory. *J. Transp. Eng.* **2004**, *130*, 113–121.
5. Office, G.B.N.A. *Improving Road Safety for Pedestrians and Cyclists in Great Britain: Department for Transport*; Stationery Office: London, UK, 2009; (HC. 2008-09; 437). (In English)
6. American Society of Civil Engineers. *Code of Ethics*; American Society of Civil Engineers: Washington, DC, USA, 2019. Available online: https://www.asce.org/code-of-ethics/ (accessed on 16 May 2019).
7. Ghassan, A.-L. Urban transport and impacts on public health. In *Low Carbon Mobility for Future Cities: Principles and Applications*; The Institution of Engineering and Technology: London, UK, 2017. [CrossRef]
8. Meyer, M.D.; Elrahman, O.A. *Transportation and Public Health: An Integrated Approach to Policy, Planning, and Implementation*; Elsevier: Amsterdam, The Netherlands, 2019. (In English)
9. Simpson, S.; Ozbek, M.; Clevenger, C.; Atadero, R. *A Framework for Assessing Transportation Sustainability Rating Systems for Implementation in US State Departments of Transportation*; Mountain Plains Consortium: Fargo, ND, USA, 2014.
10. Clark, C.P.M.H.; Tetreault, Z.; Thomas, J. *Green Guide for Roads Rating System*; Worcester Polytechnical Institute: Worcester, UK, 2009. Available online: https://web.wpi.edu/Images/CMS/CEE/Green_Guide_for_Roads_Rating_System.pdf (accessed on 12 October 2019).
11. Illinois State Department of Transportation. American Council of Engineering Companies of, A. Illinois Road and Transportation Builders, and G. Illinois Joint Sustainability. In *I-LAST: Illinois-Livable and Sustainable Transportation Rating System and Guide*; Illinois State Department of Transportation, Division of highways: Springfield, IL, USA, 2012. (In English)
12. Weinstein, N. An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes. In Proceedings of the Green Streets and Highways 2010, Denver, CO, USA, 14–17 November 2010; American Society of Civil Engineers: Denver, CO, USA, 2011. (In English).
13. Foundation, G. *What Is Greenroads*; Greenroads Foundation: Seattle, WA, USA, 2020. Available online: http://www.greenroads.org/howitworks (accessed on 6 May 2019).
14. Lee, J.C.; Edil, T.B.; Benson, C.H.; Tinjum, J.M. Evaluation of variables affecting sustainable highway design with BE2ST-in-Highways system. *Transp. Res. Rec.* **2011**, *2233*, 178–186. [CrossRef]
15. Lee, J.; Tinjum, J.M.; Edil, T.B.; Benson, C.H. Building Environmentally and Economically Sustainable Transportation Infrastructure: Green Highway Rating System. *J. Constr. Eng. Manag.* **2013**, *139*. [CrossRef]
16. McVoy, G.; Nelson, D.A.; Krekeler, P.; Kolb, E.; Gritsavage, J.S. Moving towards Sustainability: New York State Department of Transportation's GreenLITES Story. In Proceedings of the Green Streets and Highways 2010: An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes, Denver, CO, USA, 14–17 November 2010; American Society of Civil Engineers: Denver, CO, USA, 2010.
17. FHWA. *About Invest*; Federal Highway Administration: Washington, DC, USA, 2018. Available online: https://www.sustainablehighways.org/100/about.html (accessed on 3 May 2019).
18. CEEQUAL. *An Introduction to CEEQUAL*; CEEQUAL: Watford, UK, 2010. Available online: http://www.ceequal.com/about/ (accessed on 12 October 2019).

19. Santa Cruz County Regional Transportation Commission. *Sustainable Transportation Access Rating System (STARS)*; Santa Cruz County Regional Transportation Commission: Santa Cruz, CA, USA, 2020. Available online: https://sccrtc.org/projects/multi-modal/stars/ (accessed on 14 May 2019).

20. Institution for Sustainable Infrastructure. *Envision's Critical Role in Infrastructure Sustainability*; Institution for Sustainable Infrastructure: Washington, DC, USA. Available online: https://sustainableinfrastructure.org/envision/use-envision/ (accessed on 15 May 2019).

21. Kazmierowski, T.; Navarra, M. Sustainability Metrics of Two Pavement Rating Systems Developed in Canada. *Green Technol.* **2014**, *1*, 1–17. Available online: http://conf.tac-atc.ca/english/annualconference/tac2014/s-22/kazmierowski.pdf (accessed on 23 May 2019).

22. Pratt, D.; Santi, P.; Mountain, G.-C.R. A landslide hazard rating system for Colorado highways. *Geotech. Pract. Publ.* **2014**, *2014*, 120–138.

23. Strickland, J.A.; Wiltshire, R.L.; Goss, C.M. Front Matter. In Proceedings of the Rocky Mountain Geo-Conference 2014, Lakewood, CO, USA, 7 November 2014.

24. Yun, I.; Park, B. Stochastic Optimization for Coordinated Actuated Traffic Signal Systems. *J. Transp. Eng.* **2012**, *138*, 819. [CrossRef]

25. Köhler, E.; Strehler, M. Traffic Signal Optimization: Combining Static and Dynamic Models. *Transp. Sci.* **2019**, *53*, 21. [CrossRef]

26. Truong, L.T.; Currie, G.; Sarvi, M. Analytical and simulation approaches to understand combined effects of transit signal priority and road-space priority measures. *Transp. Res. Part C* **2017**, *74*, 275–294. [CrossRef]

27. Ko, M.; Geedipally, S.R.; Walden, T.D.; Wunderlich, R.C. Effects of red light running camera systems installation and then deactivation on intersection safety. *J. Saf. Res.* **2017**, *62*, 117. [CrossRef]

28. Gandy, R.; Meitner, M.J. Advanced traveler information systems: Bringing environmental information to recreational driving. *Landsc. Urban Plan.* **2008**, *85*, 185–194. [CrossRef]

29. Ma, J.; Lochrane, T.; Jodoin, P. Traffic Incident Management Programs AND Benefit-Cost Analysis. *Inst. Transp. Eng. ITE J.* **2016**, *86*, 30–36.

30. Ziou, D.; Kerouh, F. Estimation of light source colours for light pollution assessment. *Environ. Pollut.* **2018**, *236*, 844–849. [CrossRef] [PubMed]

31. World Health Organization; Foundation for the Automobile and Society; Global Road Safety Partnership; World Bank. *Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners*; World Health Organization: Geneva, Switzerland, 2013. (In English)

32. Council, B.C. *Guidelines for Audio-Tactile Pedestrian Facilities*; Brisbane City Council: Brisbane, QLD, Australia, 2019. Available online: https://www.brisbane.qld.gov.au/traffic-transport/traffic-management/audio-tactile-pedestrian-facilities (accessed on 23 May 2019).

33. National Association of City Transportation Officials. *Urban Bikeway Design Guide*; National Association of City Transportation Officials: New York, NY, USA, 2014. (In English)

34. Stamatiadis, N.; Kirk, A.; Hartman, D.; Pigman, J. A Process for Measuring Context Sensitive Solutions Benefits. In Proceedings of the Green Streets and Highways 2010: An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes, Denver, CO, USA, 14–17 November 2010; American Society of Civil Engineers: Denver, CO, USA, 2010.

35. Afrad, A.; Kawazoe, Y. Can interaction with informal urban green space reduce depression levels? An analysis of potted street gardens in Tangier, Morocco. *Public Health* **2020**, *186*, 83–86. [CrossRef] [PubMed]

36. Beatley, T. Biophilic Cities and Healthy Societies. *Urban Plan.* **2017**, *2*, 1–4. [CrossRef]

37. Frumkin, H.; Fox, J. Contact with Nature. In *Making Healthy Places: Designing and Building for Health, Well-Being, and Sustainability*; Island Press/Center for Resource Economics: Washington, DC, USA, 2011; pp. 229–243.

38. Silvestre, B.S.; Țîrcă, D.M. Innovations for sustainable development: Moving toward a sustainable future. *J. Clean. Prod.* **2019**, *208*, 325–332. [CrossRef]

39. Factor, R.; Prashker, J.N.; Mahalel, D. The flashing green light paradox. *Transp. Res. Part F Psychol. Behav.* **2012**, *15*, 279–288. [CrossRef]

40. Yu, S.; Shi, Z. Analysis of car-following behaviors considering the green signal countdown device. *Nonlinear Dyn.* **2015**, *82*, 731–740. [CrossRef]

41. Transport of London. *Yellow Box Junctions*; Transport of London: London, UK. Available online: https://tfl.gov.uk/modes/driving/red-routes/rules-of-red-routes/yellow-box-junctions (accessed on 25 June 2019).

42. Zhao, M.; Sharma, A.; Smaglik, E.; Overman, T. Traffic Signal Battery Backup Systems: Use of Event-Based Traffic Controller Logs in Performance-Based Investment Programming. *Transp. Res. Rec.* **2015**, *2488*, 53–61. [CrossRef]

43. Bai, X.F.; Cai, H.N.; Qiu, S.; Li, P.; Na Song, X. Solar Energy Traffic Control Box Design. *Appl. Mech. Mater.* **2014**, *538*, 398–401. [CrossRef]

44. World Health Organization Regional Office for Europe. *Night Noise Guidelines for Europe*; World Health Organization: Geneva, Switzerland, 2009. (In English)

45. Lacasta, A.M.; Peñaranda, A.; Cantalapiedra, I.R. Green Streets for Noise Reduction. In *Nature Based Strategies for Urban and Building Sustainability*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 181–190.

46. Thomas, L.; Thirsk, N.J.; Zegeer, C.V. *Application of Pedestrian Crossing Treatments for Streets and Highways*; Transportation Research Board: Washington, DC, USA, 2016; (NCHRP synthesis, 0547-5570; no. 498). (In English)

47. Tomomi, M. Installation errors and corrections in tactile ground surface indicators in Europe, America, Oceania and Asia. *IATSS Res.* **2008**, *32*, 68–80. [CrossRef]

48. Kim, M.; Hong, S.-h. Relationship between the reflected brightness of artificial lighting and land-use types: A case study of the University of Arizona campus. *Landsc. Ecol. Eng.* **2015**, *11*, 39–45. [CrossRef]

49. Downes, S. Look Out for Smiley Faces when You're Driving on This UAE Road. Available online: http://whatson.ae/dubai/2017/08/look-smiley-faces-uae-roads/ (accessed on 6 June 2019).

50. New Dubai Traffic Signs Use Emojis. Gulf News: Dubai, United Arab Emirates, 2017. Available online: https://gulfnews.com/uae/transport/new-dubai-traffic-signs-use-emojis-1.2090806 (accessed on 3 May 2019).

51. Sun, B.; Deng, W.; Wu, J.; Li, Y.; Wang, J. An Intention-aware and Online Driving Style Estimation Based Personalized Autonomous Driving Strategy. *Int. J. Automot. Technol.* **2020**, *21*, 1431–1446. [CrossRef]

52. Kockelman, K. *An Assessment of Autonomous Vehicles: Traffic Impacts and Infrastructure Needs—Final Report*; CTR Technical Report; 0-6847-1; Center for Transportation Research, The University of Texas at Austin: Austin, TX, USA, 2017. (In English)

53. Meng, X.; Roberts, S.; Cui, Y.; Gao, Y.; Chen, Q.; Xu, C.; He, Q.; Sharples, S.; Bhatia, P. Required navigation performance for connected and autonomous vehicles: Where are we now and where are we going? *Transp. Plan. Technol.* **2018**, *41*, 104–118. [CrossRef]

54. Pedestrian Bicycle Information Center. *Pedestrian and Bicyclist Crash Statistics*; U.S. Department of Transportation Federal Highway Administration: Raleigh, NC, USA, 2018. Available online: http://www.pedbikeinfo.org/data/factsheet_crash.cfm#No1 (accessed on 20 May 2019).