Review Article

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Improved engineered scoring system for bicycle lane mapping development

Abstract

This paper intends to present the development of the Improved Bicycle Lane Engineered Scoring System (iBLESS). The iBLESS consists of a numerical ranking table that compares traffic volume data; speed limit; number of lanes; road width; presence of the vehicle parking; presence of night street light; road grade; overall travel length; and presence of existing bicycle lanes that is utilized to design and map the optimum achievable locations for the implementation of bicycle lanes. The City of Tyler, Texas, is utilizing the iBLESS to design a Hub-and-Spoke bicycle lane network around the city. The current map design utilizing the iBLESS is comprised of eleven bicycle spokes, and seven bicycle spoke-connections, reaching a total distance of over 55 miles (88.5km) of bicycle lanes. The presence of bicycle lanes will extend throughout the entire city, resulting in the introduction of a new mode of transportation to the City of Tyler. Results indicate that the iBLESS is a simple and useful methodology to compare and analyze roads for bicycle lane development. Since this system selects the optimal road candidates, the bicycle users feel more comfortable using bicycle lanes as opposed to riding in a roadway.

Keywords: Bicycle, Bicycle Lanes, Road Diet, Hub, Spoke, Engineered Scoring System

Volume 6 Issue 2- 2022

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Received: June 06, 2022 | **Published:** June 17, 2022

Abbreviations: AASHTO, American Association of State Highways Transportation Officials; iBLESS, Improved Bicycle Lane Engineered Scoring System

Introduction

Ubiquitously, traffic congestion has been increasing significantly, and this increase is especially pervasive in larger cities with populations reaching into the millions. This problem has also begun affecting mid-sized cities of comparable size to Baton Rouge, Stratford, and Tyler. Consequently, it is of great value to develop alternative modes of transportation to facilitate user travel and decrease the traffic flow. Bicycling is an extensively used alternative that provides a direct, safe, and consistent mode of transportation for short to medium distances. The first bicycle lane in the United States was developed in the City of Davis in 1967,[1] and since then, bicycle lanes are continuously being developed and implemented across the country. The standards set for the minimum width of a bicycle lane is 4 feet according to the American Association of State Highways Transportation Officials (AASHTO) Guide for the Development of Bicycle Facilities,[2] however, the standards also recommend using a width of 5 feet bicycle lane when possible.

Two different techniques are utilized to create the necessary width for bicycle lanes: The Road Diet and Lane Diet. Studies performed by Huang et al.[3] state that the Road Diet is a technique used to reduce the number of vehicle lanes in order to accomplish systematic enhancements. This process is used to develop the necessary width for the creation of the bicycle lanes. Road Diet benefits include crash reduction of 19% to 47%.[4] It can also make the street more attractive to people with case studies indicating high increases in the non-residential tax value of properties and liability improvement for all road users. The second technique, Lane Diet, is a technique where the width of vehicle lanes is reduced to create the space necessary for the addition of bicycle lanes, without decreasing the number of vehicle lanes.[5-7]

For this reason, it is important to include the introduction of bicycle lanes in the city's future development plans. Bicycle lanes separated with marking and appropriate signage will be an effective solution for the increasing traffic. However, the existing methods for bicycle lane development are still presenting flaws, being that there needs to be a greater concern over the design of the facilities and comforts needed to be provided for the bicyclists this in turn generates a need for a structured engineering method for road selection. With this in mind, a new numerical system for bicycle lane road selection named Improved Bicycle Lane Engineered Scoring System (iBLESS) was developed. Using the new system, roads can be accurately designed and examined with the purpose of providing the finest route choice for the implementation of a bicycle lane amongst potential candidates.

Literature review

Bicycling has gained a lot of popularity with time. The crowded streets filled with traffic jams have made the use of bicycles as an alternative mode of transportation more appealing. However, sharing the road with other vehicles can be a daunting task, due to the lack of safety. Numerous types of research have been performed at various instances to incorporate safety within the physical facilities. Hood et al.,[8] collected GPS data from bicycle users in San Francisco, and estimated a route choice model following different route preferences between users and the reason for the travel. The GPS data also indicated that cyclists preferred to ride on bicycle lanes rather than lanes designated for vehicular use. Later, Nassir et al.[9] proposed an algorithm that generates different possible routes between an origin and destination location, with the purpose of measuring the road accessibility level. Monsere et al.[10] evaluated protected bicycle lanes in five American cities according to their use, benefits, perception, and impacts. Results demonstrated an estimated increase from 21% to 171% on ridership in a year as a result of separate lanes construction for the cyclists. Residents supported the development of protected bicycle lanes, with a 75% agreement for construction in other locations.

Zhou and Ni[11] evaluated the level of satisfaction that bicyclists face when riding their bicycles in Shanghai City, China. The survey data collected indicates that high vehicle traffic flow rate, on-street vehicle parking, roads without physical separation among bicycles and vehicles, and high bicycle traffic volume on bicycle lanes (not being wider than 2 meters), have a negative impact on the satisfaction of the bicyclists while using the road. Allen et al.[12] conducted a study on operational analysis of uninterrupted bicycle facilities. The study concluded that the increasing popularity in North America is leading to the increment of bicycle related facilities. Various on-street facilities like parking and marking are considered to develop the uninterrupted bicycle flows. The methodology uses the probabilistic approach in determination.

While in Victoria, Australia, Bahrololoom et at.[13] identified different factors associated with the increase in severity of crashes with the presence of bicyclists when analyzing the city crash report. Results showed that different factors such as velocity, road quality, and age of cyclists, lighting condition, and safety equipment are important factors affecting a fatal or serious injuries crash. Lee and Moudon[14] indicated in a questionnaire survey different barriers and factors affecting cycling. The environmental barriers for cycling included: 42% of the survey group addressed traffic as a barrier for cycling; 30.5% too many hills; 20.5% no place to cycle; 29% no bicycle lanes or bicycle trails; 12.5% indicated that the distances were too long; 16% complained about the road surface quality; and 12% complained about not having interesting places to which to cycle. The same survey also indicated that having the presence of bicycle lanes and or bicycle trails facilitated the access for both active, 74%, and inactive groups, 77%. Snelson et al.[15] indentified different factors deterring people from cycling, where most people said the main reason was that they did not own a bicycle, 17% said that they did not feel safe, and 16% said that the amount of vehicle traffic put them off. In a similar study, Cleland and Walton[16] reported that 36% of women did not cycle because of the lack of bicycle facilities, while 32% of women reported the reason as the lack of on-road safety.

Tesche et al.[17] found that roads with bicycle tracks had the lowest injury risk, with the next lowest rank being roads with shared lanes by vehicles and bicyclists but without the presence of parked cars. The study also indicated that quiet streets where the total volume of vehicles is relatively low and no car parking on streets were associated with lower levels of injury risk. Hull and O'Holleran[18] highlighted coherence, directness, attractiveness, safety, and comfort as requirements for a proper cycle network design. The methodology was tested using a non-experienced and an experienced cyclists' perception to compare different cycling paths in different cities. The research concluded that the addition of factors such as wide cycle lanes, routes that are more direct, higher pavement quality, and high-quality lighting on darker cycle lanes, could encourage more cycling.

Two different methods were developed to analyze the existing road network in order to identify what roads are better for cyclists. The Bicycle Level of Service (Bicycle LOS) or quality of service stated on the Highway Capacity Manual[19] and by Landis[20] is a process that has been developed since the early 1990s to quantify the compatibility of a roadway to accommodate safe and efficient bicycle travel. The Bicycle LOS tends to assess the comfort and the perception of safety felt by the bicyclist when riding along a street with motorized vehicle traffic. In order to assess this sensation of safety, the following factors are analyzed: curb lane width, bicycle lane width, striping combination, traffic volume, pavement condition, motor vehicle speed, on-street parking and presence of heavy vehicles traffic. No correspondence between the Bicycle LOS and the user tolerance is provided, not providing a minimum prerequisite for the broad population.

Similarly, Petritsch et al.[21] also conducted a similar research on the bicycle level of service for the urban road. A model for the prediction of the bicyclist perception regarding the roadway environment. The factors that are use useful for bicyclists while moving on a road is considered in this analysis. Multiple sections of the road are graded with the score from A-F through the help of bicyclists. Similarly, Jensen[22] performed a study for developing methods to quantify pedestrians and bicyclists stated satisfaction in the road section between various intersections. Numerous variables, which influence a bicyclist's satisfaction, are also described in this study.

Mekuria et al.[23] developed a different method, a user oriented bicycling network, where the roadways level of traffic stress (LTS) are classified into four different user categories. Where LTS 1 is designed as a level that most children can tolerate; LTS 2 is for the mainstream adult population; LTS 3 is for cyclists who are confident but still prefer a dedicated space for riding; and LTS 4 is a level for only strong and fearless users. The criteria compare the street number of lanes per direction, bike lane width, speed limit, and bike lane blockage.

Meanwhile, the existing methods for bicycle lane development are still presenting flaws as the methodology is solely dependent on the bicyclist perception rather than an objective or scientific method of development, resulting in a need for a structured engineering method for road selection. For this reason, a new numerical system for bicycle lane road selection named iBLESS is being developed. Since this system uses numerous factors like number of lanes, presence of turning lanes, presence of parking, road width, grade, lighting, presence of bicycle lanes, distance difference, speed limit, and traffic volume, roads can be accurately examined and designed with the purpose of providing the finest route choice for the implementation of a bicycle lane.

Study objective

The main objective of the study is to develop a numerical engineered scoring system for bicycle lanes mapping development. This methodology will potentially assist cities with implementing a safe and efficient bicycle lane network into their transportation systems.

Data collection

Extensive data collection and followed by a data analysis of the City of Tyler road network were required to identify potential roads for the addition of bicycle lanes. The proposed bike network design required downtown (hub) accessibility. The need to generate a criterion to compare possible spokes was determined after extensive literature review. The following field data was collected: road width; number of lanes; presence of parking; presence of turning lanes; presence of bicycle lanes; street lighting; grade; traffic data; speed limit; and distance difference measured from the destinations to the start points.

Road width taken from the edge of the pavement excluding the curbs, number of lanes, presence of parking, and presence of turning lane were collected to ensure that the road had enough space for the addition of a bicycle lane. The introduction of a new bicycle lane would not interfere with present traffic, because traffic is relatively lower in mid-sized cities, allowing for strong candidates for the road diet or lane diet implementation. The street lighting is important in maintain safety during nighttime for the illumination of obstacles present on the road. Grade was considered to accommodate for the diversity of rider's present. Traffic analysis measured traffic volume at intersections where riders would have to cross, increasing the safety of the user by selecting roads with lower traffic. The speed limit was analyzed to ensure the roads used for the cyclist had vehicles at low velocities, increasing the user comfort while cycling alongside traffic.

Citation: Souliman MI, Bastola NR. Improved engineered scoring system for bicycle lane mapping development. *Material Sci & Eng.* 2022;6(2):48–55.
DOI: 10.15406/mseij.2022.06.00179

The data related to the presence and absence of bicycle lanes was analyzed to identify if the vehicle drivers were habituated towards it or not. Lastly, the distance difference between routes was considered for cyclists that are riding to reach a destination, since providing a more direct route would save the cyclists time and energy.

Before using the iBLESS

With the purpose of facilitating the design process, it was necessary to follow the subsequent bullet points gathered regarding the existing conditions of the pavement and the presence of facilities to assist the creation, of the bicycle lane known as a spoke. These qualities were developed before comparing the roads with the iBLESS:

a) Identification of spoke starting point;

b) Identification of spoke ending point;

c) Identification of points of interest to be connected with the spoke;

d) Identification of traffic light signal on the intersections so, bicyclists can safely cross major roads.

Development of the Improved Bicycle Lane Engineered Scoring System (iBLESS)

The improved Bicycle Lane Engineering Scoring System was created joining the subsequent elements in order to indicate the best choice for the implementation of bicycle lanes. The criteria consisted of two different parameters: road configuration factors, and the comfort/safety of the cyclist. The first four parameters (number of lanes, presence of turning lanes, presence of parking, and road width) are used to analyze if the road has the capacity to handle the addition of bicycle lanes, since 8 to 12 feet (2.4 to 3.6 meters) of the vehicle lane will be transferred to the bicycle lanes. Meanwhile, the remaining six elements (grade, lighting, presence of bicycle lanes, distance difference, speed limit, and traffic volume) deal directly with the comfort and safety of the user. In addition to this, the perception of a cyclist while using the road with or without bike lanes is also captured from the community input. The elements of the iBLESS and point system may be adapted and tailored for usage across different cities in the state of Texas.

Traffic volume

Traffic volume is considered one of the most important safety factors of the iBLESS affecting the selection of a bicycle spoke. The traffic analysis consisted of field measurements of traffic at intersections where riders would have to cross. Readings were taken at three key one-hour time intervals when traffic is quite high (7:00 a.m., 12:00 p.m., and 4:30 p.m.). After all traffic counts were collected, they were then separated by total number of cars entering the intersection and total number of cars using the alignment of the spoke from periphery to down-town. The average of cars using the spoke direction was then calculated. The average vehicle traffic per hour (AVG) was calculated between all the traffic counts performed. The city average vehicle traffic per hour was calculated to be 408 vehicles per hour. This way, positive points were given to roads with a lower volume of vehicles than average, while negative points where given to roads with a higher volume of vehicles. Lower traffic volume affects the safety of the road, since it is safer for bicyclists to ride their bicycles on roads with lower traffic.

Therefore, the followings are the assigned scoring points based on the traffic volume:

a) Average traffic volume -300 vehicles per hour: 3 points;

b) Average traffic volume -200 vehicles per hour: 2 points;

c) Average traffic volume -100 vehicles per hour: 1 point;

d) Average traffic volume is the same: 0 point;

e) Average traffic volume +100 vehicles per hour: -1 point;

f) Average traffic volume +200 vehicles per hour: -2 points;

g) Average traffic volume +300 vehicles per hour: -3 points.

Number of lanes per direction

More points are given to roadways with higher number of vehicle lanes per direction. For example, a 2-lane per direction roadway will offer a better opportunity to have extra width to introduce bike lanes compared to a 1-lane per direction roadway. Consequently, the following are the assigned scoring points based on the number of lanes per direction:

a) 3 or more vehicle lanes per direction: 3 points;

b) 2 vehicle lanes per direction: 1 point;

c) 1 vehicle lane per direction: -1 point.

Turning lane

The turning lane is considered as one of the factors of the iBLESS, since roads with the presence of a turning lane will suffer less from the Road Diet action, as it provides the opportunity to remove the necessary width for the bicycle lane development as turning lane can itself acts as a bicycle lane. More points are given to roads with the presence of a turning lane. Then, the following scoring points are assigned based on the presence or absence of a turning lane:

a) With turning lane: 2 points;

b) Without turning lane: -2 points.

Average lane width

Average lane width is considered one of the important factors affecting the selection of a bicycle spoke. More points are given to wider lanes compared to narrower ones. Wider lanes introduce a better chance to extract at least 4 feet (1.2m) from each side for a potential bicycle lane without affecting the road level of service. Therefore, the following are the assigned scoring points based on the lane width in feet:

a) Lane width of more than 14 feet: 3 points;

b) Lane width ranging from 13 to 14 feet: 1 point;

c) Lane width ranging from 12 to 13 feet: -1 point;

d) Lane width less than 12 feet: -3 points.

Parking

The presence or absence of parking spaces is another factor that affects the selection of a bicycle spoke. More points are given to roads with the presence of parking spaces on both sides, while roads without parking spaces receive negative points. The presence of parking spaces introduces the chance to remove parking spaces in order to implement bicycle lanes and create a safer cycle location by removing parking. The analysis of the parking spots indicated that those parking lanes were less than 1% of our total spokes. The elimination of the parking spot is itself a gradual changing process. Various studies like Toronto

Cycling have also commented on the suitability of North American demography for the increase of local business brought on by the frequent stops made by cyclists. Hence, the following are the assigned scoring points based on the presence or not of parking spaces:

a) Parking allowed on both sides: 2 points;

b) Parking allowed on one side: 0 point;

c) Parking not allowed -2 points.

Maximum road grade

Maximum road grade is considered one factor that affects the selection of a bicycle spoke. More points are given to roads with low grades compared to roads with high grades. This factor affects bikers directly, because by avoiding high grades with long durations throughout the bicycle lane design it is possible to add the smoothest option available. The grade was measured using the website http://veloroutes.org/bikemaps that uses elevation data from the United States Geological Survey (USGS). More points are awarded to the road with lower maximum grade:

a) Maximum grade is less than 2%: 3 points;

b) Maximum grade is between 2-4%: 2 points;

c) Maximum grade is between 4-6%: 1 point;

d) Maximum grade is between 6-8%%: 0 point;

e) Maximum grade is between 8-10%: -1 point;

f) Maximum grade is between 10-12%: -2 points;

g) Maximum grade is higher than 12%: -3 points.

Speed limit

Speed limit is considered a very important safety factor of the iBLESS affecting the selection of a bicycle spoke. For this criterion, more points are given to roadways with lower speed limits. For example, a road with a speed limit set at 40mph will receive 1 point, while a road with the speed limit set at 30mph will receive 3 points. Consequently, the following are the assigned scoring points based on the road speed limit:

a) Speed limit set at 30mph: 3 points;

b) Speed limit set at 35mph: 2 points;

c) Speed limit set at 40mph: 1 point;

d) Speed limit set at 45mph: 0 point;

e) Speed limit set at 50mph: -1 point;

f) Speed limit set at 55mph: -2 points;

g) Speed limit set at 60mph: -3 points.

Street lighting

Street lighting is another safety factor of the iBLESS since it directly affects nighttime bicyclists, illuminating any obstacle that might appear on the road. Roads with higher artificial lighting will receive more points, while roads without lighting will receive fewer points. The points are assigned in terms of the percentage of lighting provided for a street. For example, if the street is lightened 100% it is taken as three and if only 20 % it is taken as negative three. Consequently, the following are the assigned scoring points based on the street lighting:

a) Street lighting is perfect: 3 points;

b) Street lighting is good with some dark spots: 1 point;

c) Street lighting has a lot of dark spots: -1 point;

d) Without street lighting: -3 points.

Distance difference

Distance difference between destinations is considered a factor that affects the selection of a bicycle spoke for the commuters. More points are given to shorter options compared to longer options. Routes that are more direct will have shorter distances, saving time and energy for bikers. The direct and short routes are assigned a higher point than the longer and indirect routes. Therefore, the following are the assigned scoring points based on the distance different:

a) Shortest distance: 3 points;

b) Option is 0.1 miles longer: 2 points;

c) Option is 0.2 miles longer: 1 point;

d) Option is 0.3 miles longer: 0 point;

e) Option is 0.4 miles longer: -1 point;

f) Option is 0.5 miles longer: -2 points;

g) Option is 0.6 miles longer: -3 points.

Presence of bicycle lanes

The last factor of the iBLESS is the presence or lack of bicycle lanes in the analyzed options. This factor was added to the table in order to add extra points to the option that has bicycle lanes already present on the analyzed segment, taking into consideration the fact that drivers and bicyclists are already used to the presence of bicycle lanes on that road. Hence, the following are the assigned scoring points based on the presence of bicycle lanes:

a) Presence of Bicycle Lanes: 2 points;

b) Without Bicycle Lanes: Zero points.

Combining all the factors discussed above, the iBLESS is presented below (Table 1).

Implementation study: city of tyler hub-and-spoke bike lane network

Tyler is located in East Texas, 100 miles (160.9km) east of Dallas. Tyler is the largest city by both land and population in Smith County; it is also the region's major financial, economical, medical, cultural, and educational hub. In recent times, the city has experienced considerable expansion across the city with substantial growth in road traffic.

The recent growth in population increased the number of cyclists, and for this reason, the city is implementing a welcoming environment for bicyclists. Since 2009, the city has invested over 3 million in hiking and bicycle trail extensions alone. The city intends to keep implementing bicycle lanes into the transportation system to provide the community with an efficient mode of transportation. Based on the outcome of this research study and the developed iBLESS, in 2017, the City of Tyler received a 1 million dollar grant from the Federal Highway Administration (FHWA) through the Texas Department of Transportation (TxDOT) Transportation Alternatives Set-Aside (TA Set-Aside) Program to implement the bicycle lanes developed by the engineering team at UT Tyler utilizing the iBLESS.

Citation: Souliman MI, Bastola NR. Improved engineered scoring system for bicycle lane mapping development. *Material Sci & Eng.* 2022;6(2):48–55.
DOI: 10.15406/mseij.2022.06.00179

The City of Tyler has a system of a circular development around its main roads and for that reason, the best model for bicycle lane mapping was the hub-and-spoke design. The design mirrors the structure of the wheel of a bicycle, where the spokes of the wheel are the bicycles lanes extending radially outwards from the center hub, being downtown Tyler. Utilizing the iBLESS, the research team has developed 41.7 miles (67.1km) of bicycle lanes. Nonetheless, the design team intends to finish the design map with over 55 miles (88.5km) of bicycle lanes. The paper represents how the iBLESS tool was used to analyze one of the eleven developed spokes in the network.

Table 1 iBLESS point system

Factor	Points 3	2	1	0	-1	-2	-3	Score
Traffic Volume	AVG-300	AVG-200	AVG-100	Average (AVG)	AVG+ 100	AVG+ 200	AVG+ 300	
Lanes per Direction	3 or more lanes		2 lanes		1 lane			
Passing Lane		Yes				No		
Avg. Lane Width	> 14ft		14ft to 13ft		13ft to 12ft		< 12ft	
Parking		Both Sides		One Side		None		
Max Grade	0% to 2%	2% to 4%	4% to 6%	6% to 8%	8% to 10%	10% to 12%	> 12%	
Streets Lighting	Perfect		Good		Dark Spots		Without	
Max Velocity	30 mph	35 mph	40 mph	45 mph	50 mph	55 mph	60 mph	
Distance Difference	Shortest Distance	>0.1 Miles Longer	>0.2 Miles Longer	>0.3 Miles Longer	>0.4 Miles Longer	>0.5 Miles Longer	>0.6 Miles Longer	
Presence of Bicycle Lanes		Yes		No				
Total Result								

Spoke one

Spoke 1 was established at the southeastern side of the city. The main goal was to connect the UT Tyler campus with other commercial areas of the city due to a high concentration of students and professionals working or involved with UT Tyler, but specially to connect it with Tyler Junior College campus, a junior college with more than 9,000 students, and located 3.4 miles from the UT Tyler campus. This connection was important since many students have classes at those two locations. For this area, two different routes were created and named as Option A – McDonald Rd and Option B – Old Omen Rd (Figure 1).

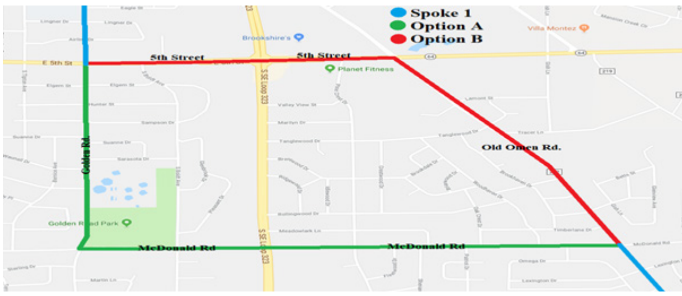

Figure 1 Spoke 1.

Spoke one option A

After analyzing the area, McDonald Rd. was selected as the best from the compared routes, since the road is wide enough to accommodate bicycle lanes. The section compared between the two options has 1.9 miles, however, the final design of the spoke has a total distance of 6.1 miles, and it is composed of six different roads. The worst section refers to the road having any of the factors having the most negative points. For matter of comparison, the worst section of the Option A is situated on McDonald Rd (Figure 2).

Figure 2 McDonald Rd.

McDonald Rd. is striped with one vehicle lane per direction, averaging 18ft lane width, and with no turning/passing lane. Vehicle parking is allowed on both sides of the road. After performing a traffic volume count, the average total cars using Option A was calculated to be 299 vehicles per hour, a quantity that reflects a lower volume of vehicles when compared to the city average traffic that was calculated to be 408 vehicles per hour. The street lighting was existent in each segment of the route, creating a good illumination during the nighttime. Bicycle lanes are found in some locations of the Option A. However, as an adverse point, the maximum grade found was 8%. For this reason, the total point received by Option A according to the iBLESS ranking is 2 points (Table 2).

Spoke one option B

After analyzing the area, the second option selected for analysis was located on Old Omen Rd. and 5th Street, since both roads were wide enough to accommodate bicycle lanes. The section compared between the two options has 1.6 miles, however, the final design of the spoke has a total distance of 5.8 miles, and it is composed of six different roads. For matter of comparison, the worst section of the Option B occurs on Old Omen Rd (Figure 3). Old Omen Rd. is striped with two vehicles lanes per direction, with the average lane width being 12ft, and without the presence of a turning lane. Vehicle parking is not allowed on either side of this road segment. After performing

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DOI: 10.15406/mseij.2022.06.00179

a traffic volume count, the average total cars using Option B was calculated to be 1403 vehicles per hour, representing a much higher quantity of vehicles than the city average that was calculated to be 408 vehicles per hour. The highest road grade found at this option was 3%, and the street lighting is present on every segment of the route, creating a good illumination during the nighttime. No bicycle lanes are present on the compared segments of the Option B. Consequently, the total points given by the iBLESS to Option B is 0 points (Table 2).

Table 2 Comparison of spoke options utilizing iBLESS

Factor	Points							Score	
	3	2	1	0	-1	-2	-3	Option A	Option B
Traffic Volume	AVG-300	AVG-200	AVG-100	Average (AVG)	AVG+ 100	AVG+ 200	AVG+ 300	-2	-3
Lanes per Direction	3 or more lanes		2 lanes		1 lane			-1	1
Turning Lane		Yes				No		-2	-2
Avg. Lane Width	> 14ft		14ft to 13ft		13ft to 12ft		< 12ft	3	-3
Parking		Both Sides		One Side		None		-1	1
								1	2
Max Grade	0% to 2%	2% to 4%	4% to 6%	6% to 8%	8% to 10%	10% to 12%	> 12%	1	1
Streets Lighting	Perfect		Good		Dark Spots		Without	1	0
Max Velocity	30 mph	35 mph	40 mph	45 mph	50 mph	55 mph	60 mph	0	3
Distance Difference	Shortest Distance	>0.1 Miles Longer	>0.2 Miles Longer	>0.3 Miles Longer	>0.4 Miles Longer	>0.5 Miles Longer	>0.6 Miles Longer	2	0
Presence of Bicycle Lanes		Yes		No				2	0
Total Result								**2**	**0**

Figure 3 Old Omen Rd.

Spoke option selection

After analyzing both options and comparing the truthful points given for options using the iBLESS, it was determined that Option A – McDonald Rd. received a total of 2 points, while Option B – Old Omen Rd. received 0 points, totaling to a difference of 2 points (Table 2). For this reason, Option A – McDonald Rd. was selected as the best option, since it will provide a much more appealing option for bicycle lanes addition.

Road implementation plan

After the selection of Option A as the optimal route for the addition of on-road bicycle lanes, the selected roads will face the road diet and lane diet process. As an example, the worst segment of the option is located at McDonald Rd. and it currently has a total width of 36ft, with non-marked parallel parking on both sides of the road. The provided solution for this part of the spoke would be to remove parking on both sides of the road, utilizing this space to implement a bike lane of 5ft width on both directions, and one 13ft wide vehicle lane per direction.

Data analysis and discussion

For every spoke originating from the periphery of the city heading towards the downtown direction, data was gathered, and two different routes were generated and compared, with the winning option being selected as the best route for the bicyclist (Table 3). It is possible to notice that all the spokes had different road configurations, and for this reason, the total points for each spoke were different. This indicates that different types of road configurations can be modified to accommodate bicycle lanes. The wider roads are good candidates to receive a lane diet, and narrow roads with multiple lanes are good candidates to receive a road diet. It is important to remember that the bicyclist safety is of vital importance, therefore, a traffic analysis is crucial, in order to award more points for roads with a lower vehicle traffic volume.

Table 3 Summary of the iBLESS point system for the developed spokes

Factors	Spokes										
	1	2	3	4	5	6	7	8	9	10	11
Traffic Volume	-1	2	-3	0	-2	2	3	3	2	3	-2
Lanes per Direction	-2	-1	-1	-1	1	-1	-1	-1	-1	-1	1
Passing Lane	3	-2	2	-2	-2	-2	-2	-2	-2	-2	-2
Avg. Lane Width	-1	1	-3	3	-3	3	3	3	3	-3	-3
Parking	-2	1	1	-1	1	-1	-1	-1	-1	-1	1
Max Grade	1	0	3	1	3	1	1	-2	0	-1	1
Streets Lighting	1	1	1	1	1	1	1	-1	1	-1	1
Max Velocity	1	3	3	3	3	3	3	3	3	3	3
Distance Difference	0	3	3	1	3	-1	3	3	3	3	3
Presence of Bicycle Lanes	2	0	0	0	2	0	0	0	0	0	0
Total Points	2	8	6	5	7	5	10	5	8	0	3

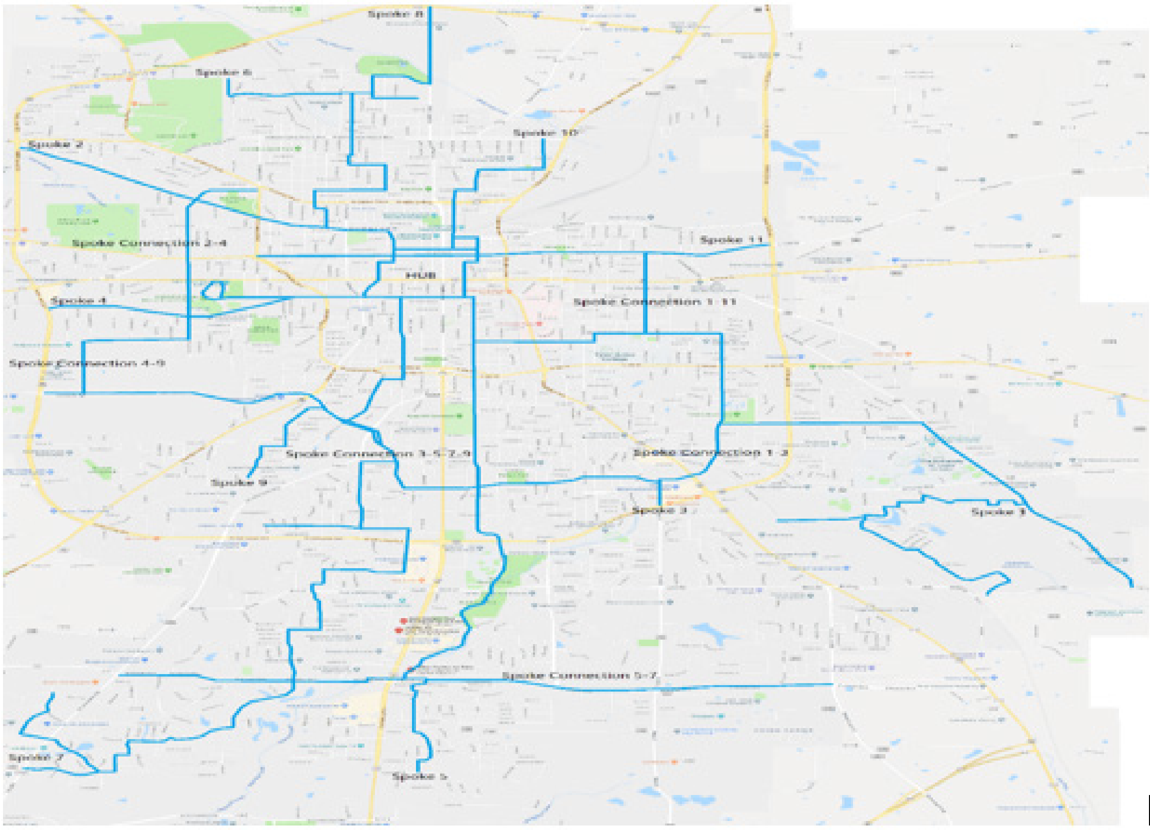

Figure 4 Hub-and-Spoke Tyler bicycle lane map.

Up-to-date bike lane map

The hub-and-spoke bike lane map reached the full development of eleven bicycle spokes and seven bicycles spoke connections that are connecting the city of Tyler and reaching a total distance of 41.7 miles (67.1km) of bicycle lanes. In Figure 4, it is possible to see the location of each spoke, indicated by the number placed at the beginning of each spoke.

Conclusion and recommendations

The presented study summarizes the progress of the development of the iBLESS and its implementation in the creation of the hub-and-spoke bicycle lane map for the City of Tyler. Every developed spoke is believed to be safe for cyclists to use, acknowledging the responsibility of utilizing the appropriate lane provided. The existence of marked bicycle lanes will aid in the city's promotion towards the attraction of the existing population towards bicycle usage, since the city will now have new and safe bicycle lane connections across all the extents of the city. An increase in the population's bicycle usage will increase user's health, while decreasing the road traffic, and consequently, the gas emissions in the air. This will provide the population with an environmentally friendly alternative mode of transportation.

To create different options for the addition of each spoke, data was gathered and compared using the iBLESS criteria. After the points were assigned, the winning option was then selected as the best route option for the bicyclist. As shown, the total points received for each road segment differed; this demonstrates that different road configurations can accommodate bicycle lanes.

After analyzing all the collected data, it was established that the iBLESS criteria is a simple way to evaluate and compare different road routes that can be used for the addition of bicycle lanes. Since the iBLESS has proven to select only the best suitable road candidates, the cyclists will feel more comfortable while using a road with a designed bicycle lane as opposed to sharing a road with motorized vehicles. With the finalized design of eleven spokes, almost completing the entire City of Tyler Hub-and-Spoke bicycle lane map, the iBLESS was confirmed as a reliable tool to identify the best streets for the addition of bicycle lanes.

Similarly, various town hall meetings, public meetings and presentations provided to various officials and students were valuable in capturing the feedback and knowing the preferences of the bicyclists. Bicyclists attending these programs claimed that the overall procedures and output presented would be very much beneficial for the riders in terms of safety and comfort. The process of data collection, which consists of road data and traffic count data, is time consuming. However, in most cases, cities already have an updated management system, where pavement data is already available, turning the mission of selecting the best routes a simple task for the iBLESS. The implementation of a bike lane in an existing road can lead to the narrowing of the road, but it can also lead to the reduction of bike related accidents. The system developed is a preliminary system where the assigned points can be easily adjusted if needed.

Acknowledgements

Authors would like to acknowledge the City of Tyler and the Texas Department of Transportation for the funding and necessary supports in completion of the research.

Conflicts of interest

The author declares that there are no conflicts of interest.

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Citation: Souliman MI, Bastola NR. Improved engineered scoring system for bicycle lane mapping development. *Material Sci & Eng.* 2022;6(2):48–55. DOI: 10.15406/mseij.2022.06.00179