Utilizing Bicycle Level of Service and Latent Demand Score for Small City Bicycle Route Planning

*Tonjanika Robinson
Graduate Student
Department of Civil Engineering
Tennessee State University
3500 John A Merritt Blvd
Nashville, TN 37209
(678) 469-2325
Email: tanzrob@gmail.com

Emmanuel Kidando
Graduate Student
Department of Civil Engineering
Tennessee State University

Deo Chimba, Ph.D., P.E., PTOE.
Assistant Professor
Department of Civil Engineering
Tennessee State University

*Corresponding Author

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Abstract = 168 Words
This paper evaluated small city bicycle route planning using both Bicycle Level of Service (BLOS) and Latent Demand Score (LDS) models. Using the city of Pleasant View, TN as the case study, it was found that the two methodologies are relevant for small city planning but with some limitations. The BLOS model was challenged with the availability of daily traffic volume data, which is scarce for non-state roadways in a small city. BLOS scores were grade C or better meaning that those roadways are suitable for bicycle travel. The challenge for the LDS model was the availability of trip purpose data within the city, so nationwide values based on urban areas, were used. Another limitation of LDS, whose results are given as the relative demand, was choosing the most appropriate bike facility considering the magnitude of the demand when compared to that of a metropolitan area. The bike facilities chosen to be most appropriate for the bicycle network design are bike lane, paved shoulder, and shared roadway.
INTRODUCTION
The objective of this paper is to evaluate and compare methodologies for small cities bicycle routes planning. Using bicycling as a mode of transportation has a significant impact on air pollution control and is beneficial to people’s health and physical fitness. Neighborhood network planning and design have a great impact on the transportation network to encourage people to use bicycle as mode of transportation (1, 20). As most bicycle route designs have come from metropolitan areas, a small city may want to use what have been successful in these areas to influence their design. When designing, it is important to consider how a small city environment is different from that of a metropolitan area such as having less traffic volume, lower speed limits, and being less economically developed. Low traffic volume and speed limit can have an effect on how comfortable a bicyclist may feel riding on a shared roadway and a city being less economically developed can affect the type of bike facilities used due to funding. With this in mind, it is considered whether bike facilities incorporated in metropolitan areas can be used with different characteristics for small cities. It may be more practical that not all roads be immediately improved or designed with the best or most appropriate bike facility (2). As majority of the population is comprised of casual bicycle riders, a well-designed visible bicycle network incorporating multiple bicycle facilities is needed to encourage bicycling (2, 21). This study focuses on small cities bicycle routes planning with the city of Pleasant View in Tennessee as a case study, Figure 1. The city has population of approximately 4000 and is comprised of mostly residential communities but also has a small shopping center, two elementary schools, and two recreational parks (3).

FIGURE 1 The City of Pleasant View in Tennessee with Land Use Distribution (3)

This study followed the city long-range transportation plan that proposed recreational and work based bike routes on some of its roadways. The city council therefore asked for the appropriate
bike route planning methodology. Two approaches, the Latent Demand Score (LDS) and Bicycle Level of Service (BLOS), were therefore tested for appropriation. These two methodologies have been cited to work successfully in the bicycle route design of metropolitan areas. BLOS is an evaluation of a bicyclist perceived safety with respect to motor vehicle traffic while traveling on a roadway focusing on whether the roadway is bicycle friendly and whether the bicyclist feels comfortable on the roadway. The LDS is a GIS based model that estimates the number of potential non-motorized trips on the road network and then determines the probabilistic values using the gravity model which is based on the proximity, frequency (rate) use, and magnitude of population along each roadway segment. The American Association of State Highway and Transportation Officials (AASHTO) Guide for the Planning, Design, and Operation of Bicycle Facilities provides information on general considerations for selecting an appropriate bikeway facility (2). Majority of bicycle networks in urban areas consist of bike lanes and shared roadways, whereas bicycle networks in rural areas mainly consist of only shared roadways. For this study, the bikeway facilities found to be most appropriate for use in the network design are bike lanes, paved shoulder, and different types of shared roadway. It is found that bike lanes provide bicyclists the most comfortable riding experience allowing one to ride at their own speed and are used in rural and suburban areas where there is a high demand for bicycle use (2). On the other hand, the use of each shared roadway depends on a variety of road characteristics such as speed limit, traffic volume, and space constraints.

LITERATURE REVIEW

According to the Wisconsin Bicycle Planning Handbook, planning of bicycle facilities should include supply and demand based models in order to offer that bicycle facilities will be both safe and desirable (4). The supply (quantitative) based model used in this study is Bicycle Level of Service (BLOS) and the demand based model used is the Latent Demand Score (LDS). The BLOS was developed based on proven research documented in Transportation Research Record where over 200,000 miles of roadway in North America was evaluated (5, 6). Since BLOS is evaluated on shared roadways, the equation uses some of the same measurable traffic and roadway factors, including motor vehicle speed and traffic volume, that are used for evaluating the level of service of roadways for other transportation modes. BLOS is adopted by many states and metropolitan areas for evaluating existing roadway conditions for bicyclists (6). For example, after two of Tennessee’s largest urban areas used BLOS successfully, Tennessee selected this as its preferred methodology for accessing roadway conditions for bicycle use (8). Furthermore, due to its engineering similarities, BLOS has made great advances in bicycle planning amongst transportation engineers and planners (7).

On the other end, LDS was developed by Landis, B. to estimate the potential demand of bicyclists. It uses the probabilistic gravity model to assess facilities based upon the proximity, frequency, and magnitude of adjacent bicycle trip generators and/or attractors (9). It analyzes four basic trip purposes, home based work, home based shopping, home based recreational and home based school trips using geographic information system (GIS) to locate both the trip attractors and generators on a roadway segment for analysis (11). However, the model does not quantify non-destination trips, for example recreational trips, with no specific destination. Furthermore, LDS results quantitatively prioritize roadways in a network for bicycle planning and implementation (9).
Across the country, BLOS and LDS are used conjointly to develop bicycle networks in metropolitan areas. For example, the city of Atlanta Plan for Bicycle and Pedestrians Walkways used both of them to propose routes and prioritize roadways. BLOS analysis included data collection to determine a level of service grade. In the GIS environment, roads were broke down into segments which run between intersections and population data was calculated for four trip purposes and inputted into the LDS formula. Results from both analyses were used to propose the desired routes for bicyclists (6). In 2001, North Central Florida Regional Planning Council analyzed existing roadway conditions using BLOS and the demand for bicyclists using LDS for the Alachua County bicycle master plan. BLOS analysis results of existing conditions on arterial, collector, and local roads showed an average level of service grade C constituting 32% of the roadway mileage studied in the network. BLOS analysis was also performed for 2020 traffic volumes with an average level of service grade D. In addition, LDS analysis was performed for key attractors and generators that were identified in a GIS environment using 2020 demographic and employment data. LDS results were sorted in descending order to view roads with high demand and proposed bicycle routes accordingly (10).

The city of Richmond, VA also used BLOS and LDS to develop its bicycle and pedestrian plan. In Richmond, there were approximately 2,300 miles of roadway analyzed for which 63% of the mileage was included in the proposed pedestrian and bicycle plan. BLOS analysis results concluded that 20% of the proposed network mileage had a level of service grade C or better and the remaining 80% had a level of service grade D or lower. Generally, roadways with BLOS grade C or better were characterized as having low speed limits, wider lanes, and low traffic volumes (10, 11). Also, LDS analysis was performed using a separate ranking scale for each jurisdiction. Each scale was divided evenly, highest 20% segments, next highest 20% segments, and so forth, in order to allow planners to account for the substantial difference in population and trip destination characteristics between urban areas and towns. Furthermore, this approach allowed for the prioritization of demand within each district (11).

Another relevant example was for Orlando Metropolitan in preparation for its 2030 Long Range Transportation Plan. Along with BLOS and LDS analysis, six public involvement exercises were performed which were targeted to an audience that represented active bicycle facility users who voted on desired locations of future bicycle facilities; the average of the sum of BLOS, LDS, and public involvement scores were used to prioritize bike facilities. LDS results showed that a higher LDS was generally located in areas with high population and employment densities. In addition, the proposed bicycle projects were separated into two groups based on whether they were urban cross-sections, which are more suitable for restriping, or rural cross-sections, which are more suitable for new bike lanes (12).

Apart from metropolitan areas, BLOS and LDS have scarcely been used to design bicycle networks for small towns. An example of BLOS and LDS being used for bicycle network design in a small town is the city of Decatur in Georgia. For its Community Transportation Plan, BLOS results ranged from bike paths having a score of A to multi-lane roads with high traffic volume and speed limit having a score of E. Furthermore, LDS results for each road segment were based on relative demand with the highest demand located within approximately a 2800 foot radius from the center of town. Using BLOS and LDS results in conjunction with street typology classifications, recommendations were made for proposing bicycle and pedestrian routes (13).
DATA

The data was gathered in different ways because BLOS uses roadway characteristics for statistical analysis while LDS uses, for example census block data and land use, for statistical analysis and spatial analysis in GIS. In relation to BLOS, the Tennessee Department of Transportation website provided AADT for the year 2012 at five locations within the study area as point data. A shortcoming of this was that the point data assumed continuous along some roadways. Although considered, performing a manual traffic count for some collector roadways was concluded not feasible due to cost. Subsequently, the BLOSs of two arterial streets and two collector roadways were not analyzed, but based on their road type, they are predicted to have a LOS of C or lower (7). Furthermore, in order to determine speed limits and pavement conditions for BLOS analysis, it was necessary to visit the study area. Based on engineering judgment by a three-person consensus, the pavement condition was determined using the pavement condition descriptions provided in the Highway Performance Monitoring System-Field Manual. Other data needed for BLOS analysis was determined using Google Earth and the Highway Capacity Manual.

The city of Pleasant View and Cheatham County, the county in which the study area is located, provided data needed for the LDS analysis of three trip purposes, school, shopping, and recreational and social trips. Although work is usually identified as a trip purpose, it was not considered because majority of Pleasant View residents commute to Nashville (the nearest largest city) or other surrounding cities to work (3). To calculate the LDS, steps were taken in GIS and excel spreadsheet to prepare the data for statistical analysis. First, population, the generator, was provided in GIS as census block layers but needed to be converted to single values according to the buffer distances. The buffered distances created around each destination were in distances of 0.5 mile, 1.0 mile, 1.5 mile, and 2.0 miles since studies show that most people consider two miles as reasonable distance for bicycling (1, 14, 15). Next, using the geoprocessing tools in GIS, the buffered areas were dissolved to remove overlapping buffers and then clipped with the census block layer. As a result, some buffered areas now contained partial areas of census blocks. Therefore, normalized buffered blocks were created by dividing the area inscribed in the buffer area by the total area of the census block (16). Furthermore, each roadway in the city was divided into segments, which run between intersections. The segments were then overlaid in the buffered area and the trip probability of a bicyclist based on distance for each segment was identified using the approach in Figure 2. Other data needed for LDS analysis included trip generation rates that were obtained from the 2009 National Household Travel Survey and the bicycling trip by purpose statistics which show that of all transportation modes, biking represent 19.7% of personal, 24.8% of social/recreational, and 14.1% of school trips (10, 17).
FIGURE 2 Typical trip making probability due to distance (6)

METHODOLOGY AND RESULTS

As seen in the literature review, bicycle level of service and latent demand have been used together to create bicycle routes for metropolitan areas. Although this study focuses on a small city, these two methods will be used in analysis and the characteristics of bike facilities modified to consider a bicycle route network on a smaller scale. The following are the methodology and analysis results of BLOS and LDS.

Bicycle Level of Service (BLOS)

Safety is an important factor in determining a bicyclist route of choice and is one the most commonly used measures to plan for bicycle networks in many metropolitan areas (7). BLOS quantifies the perceived safety and comfort level of bicyclists on a shared roadway with respect to motor vehicle traffic. In other words, BLOS yields answers to the questions (a) is a roadway “bicycle-friendly?” and (b) are bicyclists comfortable cycling on the roadway? The following statistically calibrated mathematical equation is one of most accurate methods of evaluating the bicycling conditions of shared roadway environments. Widespread use of BLOS has led to refinements creating Version 2.0 of the BLOS Model that was used in this study. The following is Version 2.0 of the BLOS Model (7):

\[ BLOS = a_1 \ln \left( \frac{Vol_{t}}{L_{n}} \right) + a_2 SP_t(1 + 10.38HV)^2 + a_3 \left( \frac{1}{PR_s} \right)^2 + a_4 (W_e)^2 + C \]  

Where:

\( a_1 : 0.507 \quad a_2 : 0.199 \quad a_3 : 7.066 \quad a_4 : -0.005 \quad C : 0.760 \)
(a_1 - a_4) are coefficients established by the multivariate regression analysis

$L_n$ = total number of directional through lanes

HV = percentage of heavy vehicles

$PR_5$ = FHWA’s five point pavement surface condition rating (1 to 5)

$Vol_{15}$ = directional motorized vehicle count in 15 minute time period

$$Vol_{15} = \frac{(ADT \times D \times K_d)}{(4 \times PHF)}$$

ADT = Average Daily Traffic on the segment or link (19)

D = directional factor

$K_d$ = peak to daily factor

PHF = Peak Hour Factor

$SP_t = \text{effective speed factor, } SP_t = 1.1199 \ln(SP_p - 20) + 0.8103$

$SP_p$ = posted speed limit (a surrogate for average running speed) (mph)

$W_e = \text{average effective width of outside through lane (ft.) where: }$

$W_e = W_e - (10f_1 \times %OSPA)$ and $W_l = 0$

$W_e = W_e + (1 - 2 \times %OSPA)$ and $W_l > 0 \& W_{ps} = 0$

$W_e = W_e + W_l - 2(10 \times %OSPA)$ and $W_l > 0 \& W_{ps} > 0$ and a bike lane exists

$W_t = \text{total width of outside lane (and shoulder) pavement}$

$OSPA = \text{percentage of segment with occupied on-street parking}$

$W_l = \text{width of paving between the outside lane stripe and the edge of the pavement}$

$W_{ps} = \text{width of pavement striped for on-street parking}$

$W_e = \text{effective width as a function of traffic volume}$

$W_v = W_t$ if ADT > 4,000 veh/day

$W_v = W_t (2-0.00025 \times ADT)$ if ADT ≤ 4,000 veh/day, if the street is undivided and unstriped

The resultant BLOS score represents the perceived safety or comfort of a bicyclist. It is divided into six categories from A to F, with A being the best conditions and F being the worst. The range of BLOS scores are A for ≤1.5, B for >1.5 and ≤2.5, C for >2.5 and ≤3.5, D for >3.5 and ≤4.5, E for >4.5 and ≤5.5 and F for >5.5. A poor score does not necessarily mean that bicycles should be prohibited on a roadway, but instead suggests that the roadway may need other improvements (in addition to adding shoulders) to help a bicyclist to feel comfortable cycling on it (18). For the study area, eight roadway segments BLOS score ranged from A to C. Table 1 displays the input values and BLOS score for the streets and highways analyzed. Along the highways, segments were determined based on cross-street intersections. BLOS results show that two roads with the same speed limit have different BLOS scores due to the existence of a shoulder, which can be used, as an alternative area for bicyclists to ride on a shared roadway. Also, BLOS results where color coded on a GIS map (Figure 3) where it can be seen that the segment of roadway containing the attractors of an elementary school and park had a BLOS score B; the segment of roadway that contained only a park had a BLOS score C. The network bike routes design section of this paper explains how BLOS analysis will be used together with LDS to propose bicycle facilities for roadway segments.
<table>
<thead>
<tr>
<th>Roadway</th>
<th>AADT</th>
<th>L_n</th>
<th>V_{15}</th>
<th>Cnfg</th>
<th>SP_p</th>
<th>SP_l</th>
<th>% HV</th>
<th>Pavement Condition</th>
<th>Lane Width</th>
<th>W_1</th>
<th>W_t</th>
<th>W_v</th>
<th>W_e</th>
<th>Score</th>
<th>BLOS</th>
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<td>3283</td>
<td>2</td>
<td>49</td>
<td>U</td>
<td>15</td>
<td>0</td>
<td>0.01</td>
<td>4</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>12.97</td>
<td>12.97</td>
<td>1.98</td>
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<td>3.39</td>
<td>0.01</td>
<td>4</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>12.97</td>
<td>12.97</td>
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</tr>
<tr>
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<td>3</td>
<td>48</td>
<td>U</td>
<td>45</td>
<td>4.42</td>
<td>0.01</td>
<td>4</td>
<td>12</td>
<td>2</td>
<td>14</td>
<td>16.87</td>
<td>18.87</td>
<td>1.89</td>
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<td>79</td>
<td>U</td>
<td>45</td>
<td>4.42</td>
<td>0.01</td>
<td>4</td>
<td>12</td>
<td>2</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>2.85</td>
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<td>79</td>
<td>U</td>
<td>45</td>
<td>4.42</td>
<td>0.01</td>
<td>4</td>
<td>12</td>
<td>5</td>
<td>17</td>
<td>17</td>
<td>22</td>
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<td>3.39</td>
<td>0.01</td>
<td>4</td>
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<td>4</td>
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<td>194</td>
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<td>0.01</td>
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<td>13</td>
<td>15</td>
<td>3.17</td>
<td>C</td>
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<td>124</td>
<td>U</td>
<td>35</td>
<td>3.84</td>
<td>0.01</td>
<td>5</td>
<td>11</td>
<td>2</td>
<td>13</td>
<td>13</td>
<td>15</td>
<td>2.94</td>
<td>C</td>
</tr>
</tbody>
</table>
Although a roadway may have an acceptable BLOS, there may not be a need for a cyclist to use that roadway or a cyclist may prefer to use a more direct route even though it may have a lower...
BLOS rating. LDS predicts whether there is a demand for a cyclist to use a roadway. The Latent Demand Model is a theory based on Newton’s law of universal gravitation, which well describes travel patterns in a metropolitan area. The model quantifies the demand for existing and potential bicycling trips in a study area including both ends of the bicycling trip as well as considering all key generators and attractors. The number of trips a bicyclist makes is directly related to the number of trip productions and trip attractions. Examples of trip productions include population and residences, whereas examples of trip attractions include schools, parks, workplaces, and shopping centers. Impedances to the bicycling mode, such as travel distance and condition of the environment, play a greater role in determining the latent demand than that of the automobile mode. (6) The LDS quantifies the demand for bicycling trips according to four trip purposes identified in the National Personal Transportation Survey (17). Some parameters of LDS include the proximity, the frequency (rate) use, and the magnitude of population along each of roadway segment (8). Moreover, how far a typical bicyclist is willing to travel based distance between generators and attractors, the trip probability, varies according to three trip purposes, school, and social-recreational (5). The following is the LDS algorithm (6):

\[
LDS = \sum_{n=1}^{4} TTS_n \times \frac{\sum_{n=1}^{4} (GA_n \times T_n)}{(GA_n \times T_n)} \times (\bar{TG}_n \times \sum_{d=0.5}^{P_{nd}} ga \times g_n) \tag{4}
\]

- **LDS** = Latent Demand Score
- **n** = bicycle trip purpose
- **TTS** = trip purpose share of all bicycle trips
- **GA** = number of generators or attractors per trip purpose
- **\(\bar{TG}\)** = Average trip generation of attractor or generator
- **ga** = number of generators or attractors within specified travel distance range
- **d** = travel distance range from generator or attractor

Figure 4 displays the LDS of most roadways within the city. The relative LDS values are categorized as low (0-3), medium-low (4-12), medium (13-18), medium-high (19-37), and high (38-74), with a higher value meaning that bicycle facilities on that roadway will have a greater chance of being used. Since the results were skewed towards lower values, categories were determined using the natural breaks method to maximize the difference between classes. Furthermore, it can be seen in Figure 4 that there is an average (demand per mile) medium-high demand for bicyclists to use from Pleasant View Rd. to Keystone Dr. Furthermore, it is noted that on this roadway segment is the location of the city’s two parks, one opposite of an elementary school, which area less than one mile from each other. The next section of this paper discusses the utilization of latent demand results with that from BLOS to propose the bike facilities used in the bicycle network.
FIGURE 4 Latent Demand Score (LDS) for each Roadway Segment
BIKE NETWORK ROUTE DESIGN

Results from BLOS and LDS were analyzed together to propose a bicycle network. The LDS was determined for all roadways within the city, but BLOS was only calculated for some roadways. Since a drawback of designing a bicycle network for a small city is the availability of data, and under the assumption that a bicyclist would take the most direct route, the bicycle network design used local roads that were predicted to have a LOS of A or B (7). Also, the design characteristics and considerations for different bicycle facilities were studied to conclude that bike lanes, paved shoulder, shared roadways (lane markings), shared roadways (signed), and shared roadways (no special provision) were the most appropriate for the study area. Table 2 shows the BLOS each roadway segment along with the LDS(s) and bicycle facility chosen. The bike facility paved shoulder was used when there was a low demand and adequate space \((W_i \geq 4)\) to accommodate bicycle travel. On one roadway segment, Hicks Edgen Rd. to Substation Rd., it is proposed to use paved shoulder although two feet of paved shoulder will need to be added. Shared roadway was found to be suitable for a variety of LDS and BLOS scores with "signed" being used to provide continuity along the street. Furthermore, it was noticed that a bike lane may have been more suitable in some areas, but considering cost and the magnitude of the relative demand of a small city compared to that of a metropolitan area, it was only implemented in one location. Figure 5 is a map of the bicycle network. This design did not consider the BLOS and therefore a bike facility at the intersection due to its complexity.

<table>
<thead>
<tr>
<th>Roadway</th>
<th>BLOS Score</th>
<th>LDS</th>
<th>Bicycle Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Church St - Pleasant View Rd.</td>
<td>B</td>
<td>Low &amp; Medium</td>
<td>Shared Roadway (lane markings)</td>
</tr>
<tr>
<td>Pleasant View Rd. - Keystone Dr.</td>
<td>C</td>
<td>Medium &amp; Medium-High</td>
<td>Shared Roadway (lane markings)</td>
</tr>
<tr>
<td>Hwy 41A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hicks Edgen Rd. - Substation Rd.</td>
<td>B</td>
<td>Low &amp; Medium</td>
<td>Paved Shoulder</td>
</tr>
<tr>
<td>Substation Rd. - Ren Mar Dr.</td>
<td>C</td>
<td>High</td>
<td>Bike Lane</td>
</tr>
<tr>
<td>Christopher Dr. - Main St.</td>
<td>B</td>
<td>Low</td>
<td>Paved Shoulder</td>
</tr>
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<td>Hwy 49 Main St. - Boat Factory Rd.</td>
<td>A</td>
<td>Low</td>
<td>Paved Shoulder</td>
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<tr>
<td>Church St. - Main St.</td>
<td>C</td>
<td>Low</td>
<td>Shared Roadway (signed)</td>
</tr>
<tr>
<td>Main St. - Ellis Dr.</td>
<td>C</td>
<td>Low</td>
<td>Shared Roadway (signed)</td>
</tr>
<tr>
<td>Ellis Dr. - Main St.</td>
<td>C</td>
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<td>Shared Roadway (lane markings)</td>
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<tr>
<td>Main St. - Triangle Rd.</td>
<td>C</td>
<td>Medium</td>
<td>Shared Roadway (lane markings)</td>
</tr>
</tbody>
</table>
FIGURE 5 Final Planned Bike Route based on BLOS and LDS
CONCLUSION

This paper used Bicycle Level of Service (BLOS) and Latent Demand Score (LDS) models for small city bike route planning. BLOS evaluates a roadway based on a bicyclist perceived safety with respect to motor vehicle traffic and its analysis consists of inputting of road characteristic values into an equation. The LDS is a GIS based model which estimates the number of potential non-motorized trips on a roadway. Since BLOS and LDS are mostly used for metropolitan bike route planning, there were some limitations of using it for small city bike route planning such as, for BLOS, the availability traffic volumes. BLOS scores of roadways in the study area ranged from LOS A to LOS C meaning that they are suitable for bicycle travel. LDS, whose results are given as the relative demand, was seen to have a limitation in relation to the magnitude of the demand when compared to that of a metropolitan area. This was important to consider when combining BLOS and LDS results to choose the most appropriate bicycle facility. The combined BLOS and LDS methodologies led to a bicycle network design that composed of 10% bike lanes, 30% paved shoulders, and 60% shared roadways design facilities based on those roadways with a BLOS score.

Future research should approximate future conditions for level of service and latent demand to account for city growth including recreational biking routes connecting nearby small and large cities. Moreover, since walking accounts for 10.5% of all trips, the pedestrian level of service could be added to determine if a roadway is suitable for walking (J7). Pedestrian level of service and LDS can be analyzed together to propose whether sidewalks should be added.

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