

Bicycle Facility Planning Using GIS and Multi-Criteria Decision Analysis

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In this paper, a multi-criteria evaluation (MCE) analysis was utilized to determine optimal bicycle facilities in the City of Milwaukee, Wisconsin based on a bicycle level of service (BLOS) and other state mandated planning criteria. While supply-based models, e.g. BLOS, have been typically relied on to plan for bicycle facilities, the methodology utilized in this paper incorporates the traditional BLOS and other common planning criteria together in one model. Both positive criteria (population coverage, parks, recreation areas, businesses, and schools) and negative criteria (bicycle crashes and crime) were utilized to derive an attractiveness value for each road link through a maximizing and minimizing linear value function. The BLOS and planning criteria were weighted and combined to determine the trade-offs between criteria among several weighting scenarios within one neighborhood. It was found that when BLOS was used alone for planning, the selected routes were associated with a high number of crimes, although the population coverage was also high. As more weight was assigned to the attractiveness criteria, the BLOS remained reasonably good (with a score of A) while the number of crimes dropped significantly. The existing bicycle facility was associated with a relatively high number of crime and bicycle crashes, and had an average BLOS (with a score of C). These results suggest that a combination of GIS and MCE analysis can serve as a better alternative to plan for optimal bicycle facilities that meet the objectives of government agencies, planners and bicyclists.

1.0 INTRODUCTION

Sustainable transport, defined as “satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs” (1), has become an important goal in transportation planning and research recently. One major reason is that the current auto-dependent urban transportation systems in U.S. cities are considered not sustainable (2). In particular, current auto-dependent city has contributed to the degradation of natural environments (e.g. water, air, vegetation, and soils) and depletion of finite natural resources (e.g. petroleum) (3, 4, 5). Moreover, congestion is becoming a critical problem which has cost 12 trillion dollars per year globally and has exasperated air pollution due to “stop and go” traffic (6). Newman and Kenworthy (2) have stated that an ideal sustainable postmodern city should include a prominence of walking and cycling transit, cars as supplementary, and air for global transit. Moreover, to achieve a sustainable transportation network, alternative modes of transportation must be accessible, perceived as safe, and desirable. In response to the negative externalities associated with the automobile culture, the U.S. Federal Government has recognized the need for developing a heterogeneous transportation system.

Federal regulations have mandated local governments to comprehensively assess multi-modal transportation planning. The passage of the Clean Air Act Amendments in 1990 has attempted to promote sustainability by curtailing auto emissions, especially in urban areas (5). Moreover, the Intermodal Surface Transportation Efficiency Act (ISTEA) was passed by U.S. Congress in 1991, and is intended to allocate funds towards non-highway projects such as: walking, bicycling, and public transit (7). The act requires that metropolitan areas with a population greater than 200,000 have their transportation plans approved by the federal government every 3 years, with a clear motive to reduce congestion and improve air quality. More importantly, the ISTEA has served as the impetus to seriously plan for sustainable transportation by incorporating measures which promote alternative modes of transport, such as public transit, bicycling, and walking facilities. Another asset to bicyclists is that the ISTEA has allotted money to implement bicycling transportation facilities and each state is required to have a bicycle and pedestrian coordinator (5, 8). States such as Wisconsin have mandated that a bicycle role be in place during all transportation planning. Furthermore, according to Wisconsin State Statute 85.023, the Wisconsin Department of Transportation (WIDOT) is to provide assistance in the development of bicycle facilities (9).

This paper proposes a comprehensive bicycle planning methodology, using GIS and a Multi-Criteria decision analysis to determine optimal bicycle routes with multiple objectives. The remaining of this paper is organized as follows: current bicycle planning methods are detailed in section 2; and section 3 developed a new comprehensive planning method, which extends the traditional methods by incorporating environmental and socio-economic factors. The application of this newly developed method in a neighborhood of Milwaukee, WI is detailed in section 4; and finally section 5 concludes this paper.

2.0 CURRENT BICYCLE FACILITY PLANNING

Typical bicycle facility planning relies on two overarching theories; all major arterials and collectors should have bike facilities regardless of physical road conditions, or, a quantitative model, such as a bicycle level of service (BLOS) or bicycle compatibility index should be calculated and reviewed prior to bicycle route planning (Huber, Unpublished Data). In other

words, bicycle facility planning is either ad-hoc, or utilizes a quantitative model to assess roadway conditions that measures the perceived safety of a road segment to the bicyclist. A level of service analysis measures the supply of potential bicycle infrastructure by strictly incorporating roadway variables in bicycle facility design and attempts to quantify the level of roadway comfort for bicyclists. While such a supply-based analysis indirectly addresses the “safety” factor—the greatest inhibitor of bicycling, it alone does not produce the most “desired” pathway, nor does it acknowledge associated bicycle travel demand.

To address the issues with travel demand, many researchers have attempted to incorporate facets from the four-step automobile travel demand model into bicycle related planning. According to the Federal Highway Administration (FHWA) publication, “Guidebook on Methods to Estimate Non-Motorized Travel: Overview of Methods” (10), various methods have been developed to predict non-motorized travel and they include: aggregate behavior studies, sketch plan methods, discrete choice models, market analysis, and facility demand potential. In particular, Landis (11) proposed the Latent Demand Score (LDS) model to estimate travel demand with bicycle trip generators and attractors, such as employments, shopping centers, parks, and schools. While these demand-based models provide an indication of a possible bicycle facility implementation or corridor improvement, they fail to include other variables imperative to bicycle facility planning. Especially, safety is one of the primary inhibitors to bicycling that cannot be integrated into the demand models. Additionally, bicycle demand models do not indicate site specific facility improvements or represent actual increase in usage from a bicycle facility improvement (12, 10).

According to the Wisconsin Bicycle Planning Guidance Handbook (9), planning of bicycle facilities should follow three steps and include factors such as: directness, accessibility, continuity, barriers, security, and aesthetics. By including this comprehensive set of criteria, a potential bicycle facility will be effective and desirable. While both supply- and demand-based models have partially incorporated these criteria, they fail to acknowledge many others, including environmental, social, cultural, and commercial needs. Therefore, the development of a multiple criteria decision analysis model that can address the needs of all riders and satisfy explicit bicycle route planning criteria as stated in the Wisconsin Bicycle Planning Guidance Handbook (WBPG), shows great promise in non-motorized transportation planning. Therefore, the model proposed in this paper incorporates the traditional BLOS suitability analysis, and a multiple criteria decision analysis.

3.0 COMPREHENSIVE BICYCLING FACILITY PLANNING USING MULTI-CRITERIA DECISION ANALYSIS

A multi-criteria evaluation (MCE) methodology was utilized in this paper to produce a benefit maximizing (least cost) bicycle surface network. MCE is an intuitive methodology, whereas criteria are mentally ranked and optimized to reach the best compromise solution among dominated and non-dominated alternatives. A multi-criteria analysis is able to solve for complex set of problems involving multiple, with often conflicting attributes (6). Specifically, the method consists of analyzing problems in which a linear function of a number of variables is either maximized or minimized (13). The transformation of a multi-criteria problem to a single criterion problem can be solved through linear programming or the weighting method (14). In this paper, the weighting method is utilized to convert the multi-criteria problem into a single criterion. Subsequently, through parametric variation of weights, the best and most efficient

solution, based on decision makers' goals, can be determined (15). In particular, the MCE method utilized in this paper can be divided into three steps: 1) bicycle level of service measurement, 2) Attractiveness (ATTR) measurement through simple additive weighting (SAW), and 3) tradeoff analysis.

3.1. Bicycle Level of Service (BLOS) Measurement

The perception of safety is a major determinant in a cyclist's choice of routes, and is one of the commonly used measures to plan for bicycle facilities in most metropolitan planning organizations (MPO) (16). With the objective of quantifying the perception of safety, Landis et al. (17) developed the bicycle level of service (BLOS) measurement. The BLOS is a function of per-lane motor vehicle traffic volume, speed of motor vehicles, traffic mix, potential cross-street traffic generation, pavement surface condition, and pavement width for bicycling (11, 17). BLOS is similar to an automobile level of service and is therefore, recognized by transportation engineers and has subsequently made it a popular measure for bicycle route planning. This supply side quantitative measurement, while has become the most popular tool for bicycle planning, does not meet all bicycle planning criteria. For example, the BLOS does not incorporate traffic generators or attractors. In this study, the purpose of determining a BLOS was to incorporate this widely accepted measurement into a holistic bicycle planning analysis, visualizing and evaluating the trade-offs between BLOS and other criteria.

3.2. Attractiveness Measurement through Simple Additive Weighting (SAW)

3.2.1. Criteria Selection and Ranking

The performance objectives and criteria selected by the authors were based on the WBPG, relevant literature, interviews with personnel from the Bicycle Federation of Wisconsin and the Wisconsin Department of Transportation. In particular, the criteria utilized in this project to achieve the performance objectives entailed: bicycle crashes, crimes, desirable businesses (coffee shops, bike stores, and restaurants), schools, recreation areas, parks, and population (see table 1).

[INSERT TABLE 1 HERE]

Personal safety is a vital component in siting bicycle facilities. Bicycle crashes are indicative of hotspots where dangerous sections of roadway or traffic conditions are present. As a result, bicycle crashes may have the highest potential to deter bicycle facility usage. In addition to bicycle crashes, the fear of crime on-street or on sidepaths can also significantly discourage many potential bicyclists. Therefore, crashes and crimes are considered as negative criteria and selected with the highest ranks.

The WBPG handbook (9) states that commercial and retail centers should be incorporated in bicycle planning. Commercial business data was limited to four types of establishments: restaurants, taverns, bicycle stores, and coffee shops. Based on personal experience and interviews with bicyclists, these are the most frequented establishments that may enhance the bicyclist's experience. Schools are inherently important to a wide range of bicyclists and potential bicyclists. Education institutions are a vital component in bicycle facility planning because they generate a large amount of bicycle trips. It has been estimated that bicycling

involves approximately 15-30% trips to schools and remains at 10% year round near college campuses (9). Recreation areas include playgrounds and places where the public has open access to open space and public events. Therefore, recreation areas and parks, although ranked separately, were considered generators and magnets and integral to bicycle facility planning as stated in WBPG. In addition, parks can be desirable origins, enhance the aesthetics of the facility, and also provide weather relief. As a result, the percent of park space is positively associated to the amount of bicycling or walking (18). Parks, recreation areas, scenic trails etc., attract a higher amount of bicycle trips than the community average, and therefore, parks were incorporated into this analysis (9).

The last criterion utilized in this paper is population. Population provides a general index of access and demand. If a bicycle facility is present, it is useless if people cannot access it, or the immediate population does not support it. Access and demand are critical in measuring present and future performance of transportation networks (6, 19). Therefore, population in terms of a bicycle network will provide an estimate of potential demand for and access to bicycle facilities. According to the WBPG and the Bicycle Federation of Wisconsin (BFW), bicyclists will not deviate further than 2 blocks (e.g. 660 feet in Midwestern cities) away from a direct route. Therefore, in this study, all off-network criteria within 2 blocks of each road segment were summarized using an ESRI ArcGIS 3.3 Avenue script. Parks, schools, census block population, and recreation areas were summarized within a 660 ft of every road link and then joined to each road link. In addition, population data from census blocks within the 660 ft threshold was also summarized and attached to each road link. On-street criteria (crime, bicycle crashes, businesses) were summarized for each road link and attached via a point-on-polyline geoprocessing function in ESRI's ArcGIS 9.0.

3.2.2. *Simple Additive Weighting*

With all these selected criteria, it is necessary to generate a single measurement representing the attractiveness (ATTR) of bicycle facilities. To generate this ATTR measurement, a modified simple additive weighting (SAW) method was used in this research. With the SAW, criterion weights for all the criteria were approximated using a normalizing weighting function. More specifically, a rank-sum approach was used to convert the ranking order to normalized weight values w_j between 0-1 for each criterion.

$$w_j = \frac{n - r_j + 1}{\sum (n - r_k + 1)} \quad (1)$$

where

w_j is the normalized weight for the j th criterion

n is the number of criteria under consideration ($k=1,2,\dots,n$)

r_j is the rank position of the criterion

The normalized weights can then be interpreted as the change in the overall value for a criterion that results from a unit change in the criterion value function. The linear value function was utilized in order to maximize the positive criteria and minimize the negative criteria. During the shortest path analysis the lowest value per road segment produced the most benefit (i.e. lowest cost pathway). Therefore, a minimizing and maximizing function was used to account for both negative and positive criteria, and to highlight the most beneficial and potential bicycle facility location. The linear value function approach normalizes the criterion to values between 0-1 (20). Linear value functions are given as follows:

$$\begin{aligned} v_j(x_{ij}) &= (x_{ij} - x_{j^*}) \div (x^*_j - x_{j^*}), j \in C - \\ v_j(x_{ij}) &= (x^*_j - x_{ij}) \div (x^*_j - x_{j^*}), j \in C + \end{aligned} \quad (2)$$

where

C is the set of Criteria

$C +$ is the set of positive Criteria

$C -$ is the set of negative Criteria

v_j = value of criterion at road segment j

x_{ij} = attribute value at location i to j

$$x^*_j = \max_i \{x_{ij}\} \text{ and } x_{j^*} = \min_i \{x_{ij}\}$$

Once the normalized weights and criterion values were obtained, they were then summarized to produce a total ATTR value for each road segment for all criteria. Based on the work of Smith and Taylor (20), the normalized weights and criteria can be multiplied by a linear value function and then summarized across all the attributes for each standardized criterion value at each road segment. The total ATTR value represents both the negative and positive criteria to achieve a maximum attractiveness for each road segment as criterion values increase or decrease. The total ATTR value at each road segment for each j th criterion is given as follows:

$$\begin{aligned} \text{ATTR}_i &= \sum_{j=1}^J w_j v_j(x_{ij}) \\ (i &= 1 \dots\dots I) \end{aligned}$$

where

ATTR_i = Total attractiveness value for each road segment

w_j = Normalized weight for the j th criterion (obtained from equation 1)

$v_j(x_{ij})$ = Linear value function result for each criterion from i to j (obtained from equation 2)

3.3. Trade-off Analysis

Trade-off analysis is used to determine the relationships between criteria as one criterion changes in respect to other criteria. It is not the intention to display the best route in this research, but to depict trade-offs in performance criteria based on differing weighting scenarios as indicated in table 2. Weights that ranged from 0 to 1 were applied to the BLOS and ATTR and then summed together to represent the robustness of the multi-criteria decision analysis and to test the performance of the criteria in its achievement towards maximizing the performance of each alternative. A least cost (shortest path) path algorithm was used in a GIS environment to determine the optimal route selection based on the BLOS and ATTR for each road link.

[INSERT TABLE 2 HERE]

4.0 APPLICATIONS

4.1. Study area and data

The Bayview neighborhood (Figure 1), located in a medium density residential area southeast of the CBD of the City of Milwaukee, WI, was utilized to determine criterion trade-offs between BLOS and ATTR. The Bayview and its adjacent neighborhoods have many desirable bicycle amenities that justify an in-depth analysis of the characteristics of the existing bicycle facility and possible improvements in bicycle facility selection. This neighborhood is characterized by having dispersed bicycle crashes, predominant parks, relatively low crime, and a moderate level of schools and recreation areas. As evidenced in Figure 1, a bicycle route traverses this neighborhood connecting neighborhoods to the north and south.

The current bicycle network for the Bayview neighborhood was derived from the Wisconsin Bicycle Federation's database and represents current conditions up to 2004. The road network consists of the Fire DIME road network developed by the City of Milwaukee and is currently the most precise road network available. For the purposes of this research, only current on-street bicycle facilities were assessed. Highway engineering road variables for all roads in southeastern Wisconsin were obtained from the Wisconsin Department of Transportation. The engineering road data, coupled with the Fire DIME network, contains traffic counts, heavy truck volume, parking width, travel lanes, and travel lane width. Demographic variables were obtained from the United States Census Bureau. Population data at the block level was used in this analysis. Bicycle accident point data from the year 2003 was obtained from the Wisconsin Department of Transportation (WDOT) and the City of Milwaukee. In addition, crime data from the City of Milwaukee for the year 2003 was also incorporated in this study. Businesses, parks, schools, and recreational area data was utilized in this study in order to account for desirable origin-destinations and aesthetics. Business data was obtained from the City of Milwaukee and selected via the federal Standard Industrial Classification (SCI) code. Park, recreation, and school data was obtained from the Milwaukee County Parks Department.

[INSERT FIGURE 1 HERE]

4.2. Analysis of results

A shortest path analysis using 11 weighting schemes was used to calculate the least cost routes through Bayview. Although 11 different weighting schemes were utilized in this study area, only 3 different potential bicycle facilities were produced from the shortest path analysis and only these will be assessed in this paper (see Figure 2). We can infer that the majority of the shortest path routes have homogenous levels of criteria. Figure 2 also indicates when ATTR criteria are introduced into the weighting scheme the shortest path route moves from the area consisting of a higher density crime to the east where a higher proportion of parks are located. The spatial pattern of the shortest path routes clearly indicates that when BLOS is used alone, the potential route is circuitous. As ATTR criteria are included in the weighting scheme, the highest benefit route moves towards Lake Michigan and away from higher crime areas. We can infer that crime may be one factor in discriminating between different network derived shortest paths. Figure 2 more importantly depicts the less than direct pathways selected by the GIS software when compared to the existing bike route. Although neither of the routes produced is the most direct, it does reveal how the influence of social and cultural activities re-directs the potential bicycle facility towards positive criteria.

Figure 3 lends more information to the specific conditions and criteria levels surrounding the Bayview neighborhood. When BLOS is used exclusively in the shortest path analysis, it is evident that the BLOS 1.0 route contains the best average BLOS score, and the highest proportion of crime. While only considering the traditional supply-side planning methodology (BLOS), it is apparent that the level of service scores an “A”, but in reality, crime and bike crashes negate this score. Furthermore, it can be inferred that the trade-off from an increase in positive criteria results in an increase in crime along this traditionally planned route. As ATTR is introduced at the .1 level it is observed that crime is reduced greater than 56% and businesses increase 17% compared to when BLOS is used exclusively. In addition, population decreases 54% when ATTR is used at the .1 level. The average BLOS score when ATTR is at the .1 level is “A”, but the total number of parks, schools, and recreation decrease, while the number of crashes remains unchanged. When ATTR is used exclusively it is observed that the BLOS score is “A” and crime decreases 4% from the ATTR .1 level. In addition, businesses increase almost 2% from the ATTR .1 level while the number of schools, parks, and recreation areas remain the same as in the ATTR .1 level. The existing route has an average BLOS score of “C” and also relatively high proportions of negative and positive criteria. As evidenced in Figure 3 the existing bicycle facility has an elevated amount of crime and bicycle crashes when compared to the GIS shortest path selected routes. It can be inferred that the existing bicycle route contains elevated bicycle crashes and crime due to the correlation between existing cyclist activity, arterial automobile traffic, and land-use conditions. In addition, the existing route is also the most direct relative to the other shortest path analysis routes and contains the 2nd highest population.

[INSERT FIGURE 2 HERE]

[INSERT FIGURE 3 HERE]

[INSERT FIGURE 4 HERE]

5.0 CONCLUSIONS

The model used in this study is based on a simple additive weighting and ranking methodology to combine aspects from both supply-side and demand side bicycle planning. Through the use of MCE and GIS it was evidenced that a multi-criteria analysis can be used towards bicycle facility planning. Although in typical MCE planning scenarios, participatory surveys and decision makers are incorporated into the planning and final ranking process, the sole purpose of this paper was to address the potential improvement over traditional bicycle planning methodology at the model development stage. Moreover, this paper established an approach that validates the benefits of incorporating several, conflicting and/or competing variables into decisions regarding bicycle facility planning and implementation via a neighborhood application.

An inverse ranking of criteria was used in this study to maximize the benefits for each road segment for bicycling. The ranking used in this method were based on goals and planning criteria stated in the WBP (9), personal experience, and interviews with personnel from the Bicycle Federation of Wisconsin. In this paper, the weighting technique used represented the change in overall value as a result of a unit change in attribute value of each criterion. The normalized weighting and linear value function rewarded the line segment with a lower cost (higher benefit) as positive criterion values increased, while the increase in negative criterion values added cost to the line segment. The minimization and maximization value range function decision rule summarized and standardized the entire criterion to 0-1 values, where values close to 0 produced the most beneficial roadway segment in this study and through a GIS shortest path analysis, the lowest cost bike routes were found. Once the shortest paths were selected by the GIS application, the trade-offs among criteria using the traditional bicycle planning methodology (BLOS) and/or combination of MCE methods could be viewed for further analysis.

The application of the aforementioned methodology to a neighborhood revealed that it is possible to account for both positive and negative criteria for bicycle facility selection while incorporating a BLOS at the linear segment level. Specifically, the neighborhood criteria trade-off analysis revealed the influence of different weighting schemes of ATTR and BLOS towards an actual neighborhood. While the BLOS shortest path analysis indicated many suitable bicycle facility route options within neighborhood study area, the trade-offs for a route score of "A" without accounting for ATTR included prominent increases in all negative criteria. At the same time, the existing bicycle facility also contained elevated levels of negative criteria and exhibited a BLOS score of "C". When the MCE methodology was utilized and ATTR was weighted along with BLOS, the selected route resulted in a BLOS score of "A" and acceptable levels of both negative and positive criteria. We can infer from this that it is possible to utilize both traditional supply side and demand methods together for bicycle facility route selection resulting in acceptable levels of positive criteria and BLOS scores. Furthermore, the trade-off analysis has exposed the faults in simple ad-hoc bicycle facility planning, as well as the traditional BLOS measurement. When mandated bicycle planning criteria is not incorporated in the planning process, there is an apparent disconnection between bicycle facility planning results and goals as evidenced in this analysis. The traditional method of BLOS quantification resulted in possible roadway segments that did not meet bicycle facility planning goals. Furthermore, the existing bicycle facility trade-off analysis revealed elevated levels of negative criteria and only an average BLOS scores. Conversely, when BLOS and ATTR are used together, negative criteria are significantly reduced.

The MCE methodology applied in this research has highlighted the results of incorporating data that meets bicycle facility planning goals through an applied neighborhood approach in Milwaukee, Wisconsin. This paper progresses current bicycle facility planning by incorporating an intuitive MCE methodology to address state mandating bicycle planning goals. Specifically, this paper has alluded to the possibilities towards real-world planning. For example, a decision maker can use this methodology towards planning in various ways: to highlight routes with elevated levels of positive criteria for implementation of bicycle facilities, or expose routes with superior positive criteria and low BLOS scores for spot improvements to raise the BLOS grade and induce ridership. Overall, this methodology has introduced a new approach towards bicycle facility planning and provides a reasonable estimation of bicycle facility improvement, implementation, or elimination. The analysis has proven that a MCE system involving multiple criteria, supply-side, and travel demand methods should be considered in the bicycle facility planning process that meets most, if not all, bicycle planning criteria.

Further research into the refinement of weighting between ATTR and BLOS or the weighted aggregation technique will reveal more insight into the threshold limits of the criteria quantities. Due to the extensive data range differences between criteria, another normalization rank summation could be used to minimize influence of criteria with excessively high or low quantities. As with any MCE approach, decision makers and public participation is critical to the success of the stated goals. Therefore, this approach highlighted the need to comprehensive plan for bicycle facilities and move away from single handedly planning for bicycle facilities using ad-hoc, BLOS, or demand methods. The approach presented in this paper is essentially the beginning, and further solicitation of responses from the public and decision makers regarding criteria, ranking, and decision rules will only vindicate this methodology and warrant further adjustments such as: inclusion of route length, directness, land-use, public participation, and decision maker's recommendations.

REFERENCES

1. Black, W.R. Sustainable Transportation: A U.S. Perspective. *Journal of Transport Geography*, Vol. 4, 1996, pp. 151-159.
2. Newman, P. and J. Kenworthy. *Sustainability and Cities*. Island Press: Washington D.C. 1999.
3. Black, W.R. North American Transportation: Perspectives on Research Needs and Sustainable Transportation. *Journal of Transport Geography*, Vol. 5, 1997, pp.12-19.
4. Greene, D.L., and M. Wegener. Sustainable Transport. *Journal of Transport Geography*, Vol. 5/3, 1997, pp.177-90.
5. Hanson, S. *The Geography of Urban Transportation*. Guilford, New York. 1995.
6. Miller, J.H., and S.L. Shaw. *Geographic Information Systems for Transportation*, Oxford University Press Inc. Oxford, 2001.

7. Garder, P. Bicycle Accidents in Maine: An Analysis. In *Transportation Research Record: Journal of the Transportation Research Board, No 1438*, TRB, National Research Council, Washington, D.C., 1994, pp. 34-41.
8. Feske, D. Life in the Bike Lane. *American City and County*, Vol. 109, 1994, pp. 64-77.
9. Huber, T. Wisconsin Bicycle Planning Guidance, Guidelines for Metropolitan Planning Organizations & Communities in Planning & Developing Bicycle Facilities Wisconsin Department of Transportation, 2003.
10. *Guidebook on Methods to Estimate Non-Motorized Travel: Overview of Methods*. FHWA-RD-98-165, <http://www.tfhrc.gov/safety/pedbike/vol1/title.htm>. Retrieved July 11, 2006
11. Landis, B.W. Bicycle System Performance Measures: The Interaction Hazard and Latent Demand Score Models. *ITE Journal*, Vol. 66, No. 2, 1996, pp. 18-26.
12. Hyodo, T., N. Suzuki, and K. Takahashi. Modeling of Bicycle Route and Destination Choice Behavior for Bicycle Road Network Plan. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1705*, TRB, National Research Council, Washington D.C., 2000, pp. 70-76.
13. Black, W.R. *Transportation: A Geographical Analysis*, Guilford, New York, 2003.
14. Malczewski, J. *GIS and MultiCriteria Decision Analysis*. John Wiley & Sons, Inc., New York, 1999.
15. Malczewski, J. and W. Ogryczak. The Multiple Criteria Location Problem: 1. A Generalized Network Model and the Set of Efficient Solutions. *Environment and Planning A.*, Vol. 27, 1995, pp. 1931-1960.
16. Allen-Munley, C., J. Daniel, and S. Dhar. Logistic Model for Rating Urban Bicycle Route Safety. In *Transportation Research Record: Journal of the Transportation Research Board No. 1878*, TRB, National Research Council, Washington D.C., 2004, pp. 107-115.
17. Landis, B., V.R. Vattikuti, and M.T. Brannick. Real-Time Human Perceptions Toward a Bicycle Level of Service. In *Transportation Research Record, No. 1578* TRB, National Research Council, Washington D.C., 1997, pp. 119-126.
18. Allen, I. R. Urban Green Space Linked to Walking, Cycling Levels. *Medical News Today*, 2005, <http://www.medicalnewstoday.com/printerfriendlynews.php?newsid=20455.htm>. Accessed July 30, 2005.

19. Mescher, P.J. Utilization of a Geographic Information System to Facilitate the Bikeway Planning Process. Master's Thesis, Iowa State University, 1996, pp. 1-86.
20. Smith, P.N., and C.J. Taylor. A Method For the Rationalization of a Suburban Railway Network *Transportation Research A*, Vol. 2, 1994, pp. 93-107.

TABLE 1 Criteria Selection, Ranking, Normalized Weighting

TABLE 2 Trade-Off Scenarios Between BLOS and Attractiveness

FIGURE 1 Bayview Neighborhood in Milwaukee, WI

FIGURE 2 Shortest Path Routes and Comparisons to Existing Bicycle Route: (a) existing route vs. BLOS 1.0 only; (b) existing route vs. BLOS .9 ATTR .1; (c) existing route vs. ATTR 1.0 only

FIGURE 3 Summarized Criteria and BLOS

FIGURE 4 Summarized Population

TABLE 1 Criteria Selection, Ranking, Normalized Weighting

<u>Criterion</u>	<u>Rank</u>	<u>Normalized Weight</u>
Crashes	1	0.250000
Crime	2	0.214286
Businesses	3	0.178571
Schools	4	0.142857
Recreation Areas	5	0.107143
Parks	6	0.071429
Population	7	0.035714

**TABLE 2 Trade-Off Scenarios Between
BLOS and Attractiveness**

Weighting Scheme

BLOS x 1.0
BLOS x .9 + ATTR x .1
BLOS x .8 + ATTR x .2
BLOS x .7 + ATTR x .3
BLOS x .6 + ATTR x .4
BLOS x .5 + ATTR x .5
BLOS x .4 + ATTR x .6
BLOS x .3 + ATTR x .7
BLOS x .2 + ATTR x .8
BLOS x .1 + ATTR x .9
ATTR x 1.0

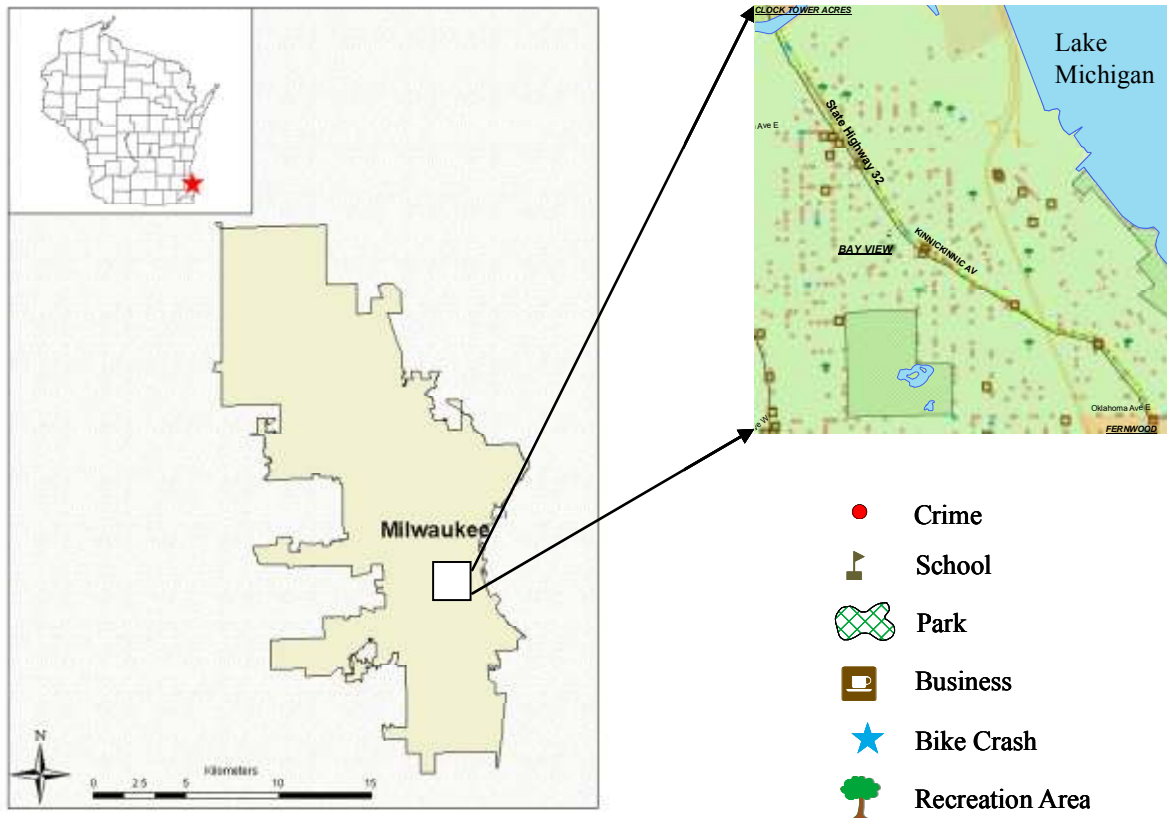


Figure 1 Bayview Neighborhood in Milwaukee, WI

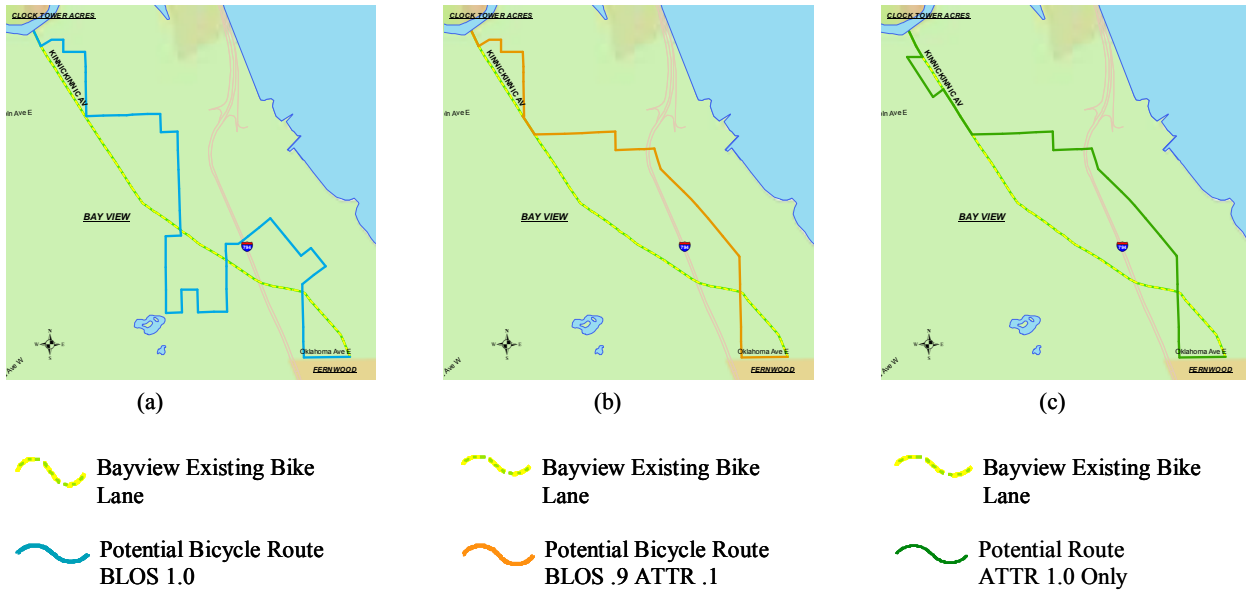


FIGURE 2 Shortest Path Routes and Comparisons to Existing Bicycle Route: (a) existing route vs. BLOS 1.0 only; (b) existing route vs. BLOS .9 ATTR .1; (c) existing route vs. ATTR 1.0 only

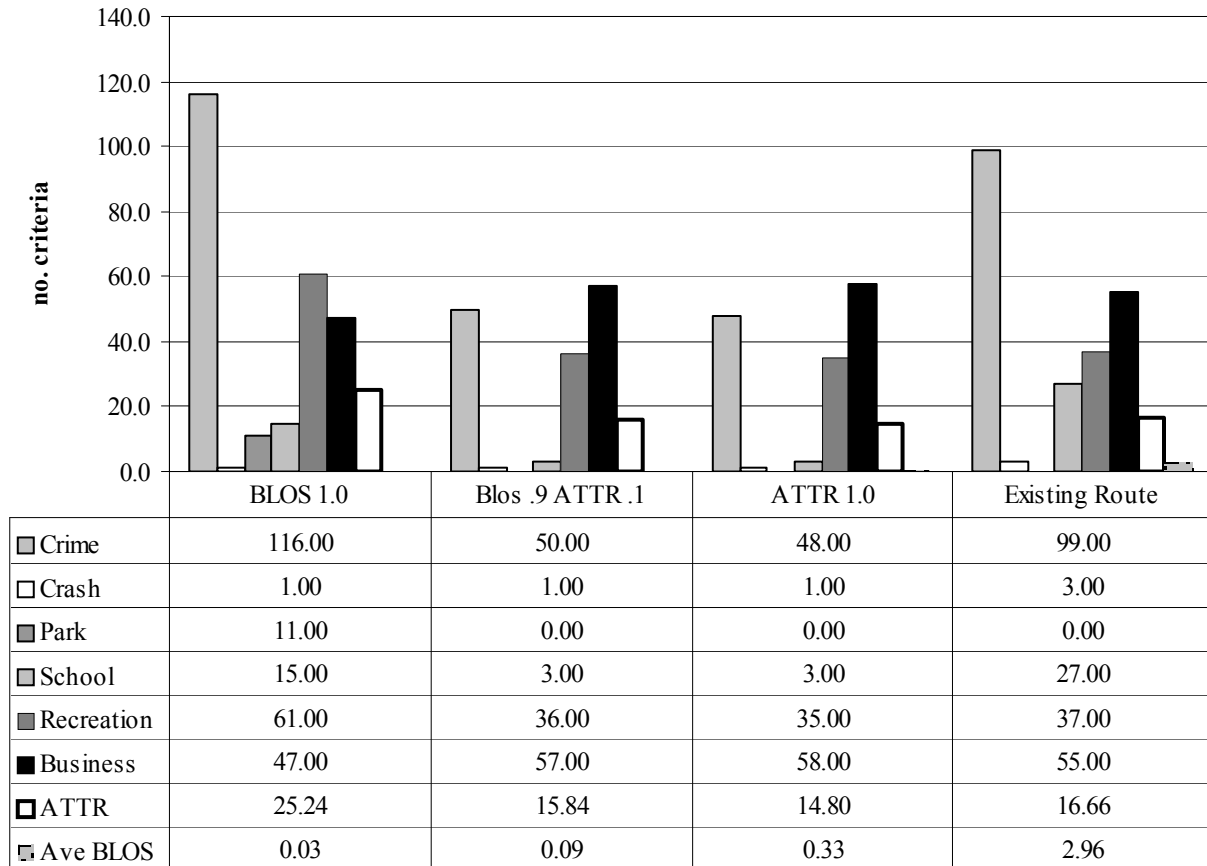


Figure 3 Summarized Criteria and BLOS

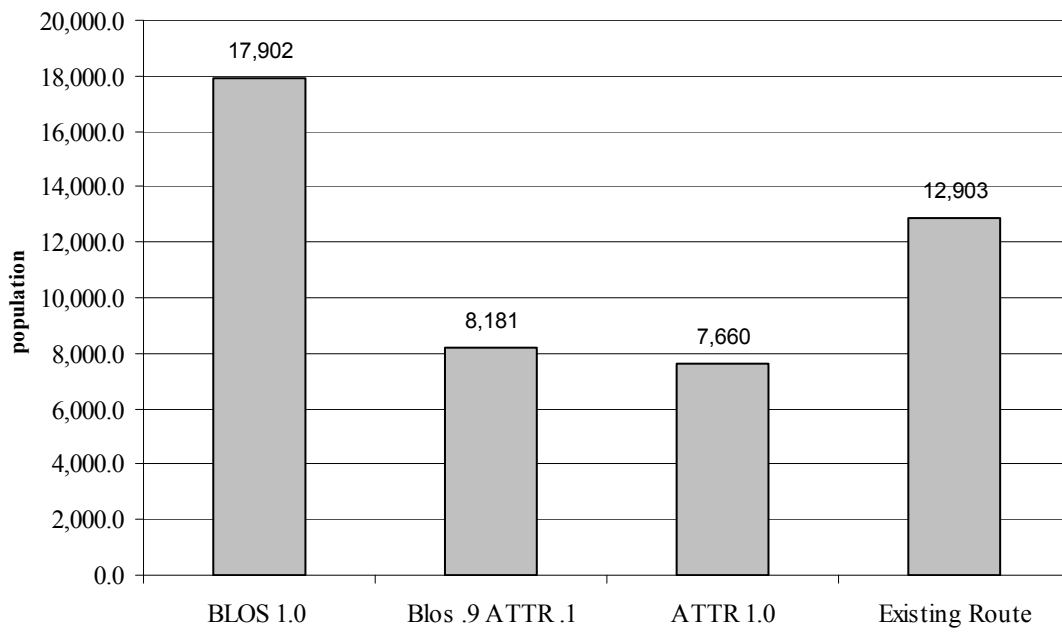


Figure 4 Summarized Population