A Micro-Level Analysis of Bicycle Commuting and Facility Construction Using Longitudinal Data

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Abstract
A central theme in recent planning and public health policy discussions aims to spur bicycle and pedestrian travel and overall levels of physical activity. A key dimension to such discussions revolves around the role of facilities. These facilities come in the form of sidewalks, hike and bike trails, or on-street bicycle lanes. An implicit argument was that building trails would increase levels of bicycling or walking. Such an assertion is one often bantered about by planning agencies and advocacy groups. Providing research that can reliably support such an assertion is important, at least for policy officials. However, this proves to be a task that has yet to be satisfactorily tackled in much of the academic literature for a variety of reasons. This research aims to do so using longitudinal data obtained from the U.S. census focusing on commute to work rates of bicycle transportation. The setting for the research is Twin Cities of Minneapolis and St. Paul (Minnesota). The analysis is longitudinal in nature, uses relatively small units of analysis (e.g., transportation analysis zones), and, using census data, aims to control for other confounding explanations. A statistical analysis is conducted using an ordinary least square regression model to measure the effects of new facilities (off-street and on street trails) while controlling for other changes that occurred at the neighborhood level. The findings revealed that neither the on-street bicycle facilities nor the off-street ones had a statistically significant effect to induce bicycle commuting to work. This can be related back to the locations where these facilities were constructed in the city and the nature of trail users.

Introduction

A central theme in recent planning and public health policy discussions aims to spur bicycle and pedestrian travel and overall levels of physical activity. A key dimension to such discussions revolves around the role of facilities. These facilities come in the form of sidewalks, on-street bicycle lanes or off-street bicycle facilities. Several key transportation acts passed in the 1990's provided the resources to construct many such trails in urban areas. The recently passed $286.4 billion transportation bill, SAFETEA-LU, provides substantial funds devoted exclusively to the construction of bicycle facilities. An implicit argument in such legislation is that building bicycle facilities would increase levels of bicycling. Such assertions are often bantered about by planning agencies and advocacy groups.

Providing research that can reliably support such an assertion is important, at least for policy officials [1, 2]. However, this proves to be a task that has yet to be satisfactorily tackled in much of the academic literature for a variety of reasons. This research aims to do so using longitudinal data from the U.S. census focusing on bicycle commute rates in the cities of Minneapolis and St. Paul. To our knowledge, our investigation is unique because it is longitudinal in nature, uses relatively small units of analysis (e.g., transportation analysis zones), and aims to control for confounding explanations. The text that follows describes existing theory and literature related to this work, the data used in our analysis, results, and a summary of the findings.

Background

There is considerable enthusiasm about the merits of bicycle trails and paths to induce use [3, 4]. Existing studies have examined the use of particular trails [5-7] or their impact on route choice decisions [8]. Other research was among the first to explore such questions examining correlations between aggregate levels of bicycle infrastructure and commute rates [9]. This work was later updated and improved by adding additional control measures [10]. Still other work examined cycling use relative to proximity of facilities [11]. Other researchers have offered more general theories to explain induced cycling use [12] and have even tested such claims [13].

The bulk of existing work—if not all of it—answers this question using cross sectional data. The urban planning community is learning, not surprisingly, that things are not as simple as relying on findings from cross sectional research. Analyzing a single policy or environmental change without fully capturing other important influences may lead to errant conclusions and even overstate outcomes about that policy or environmental change. Such factors hold particularly true for matters related to understanding the factors leading to people's decision to cycle. Trying to unravel such decision-making web by isolating the specific role of cycling facilities is a complex endeavor.

Put another way—as any reliable textbook on statistics suggests—correlation does not mean causation. It is important to distinguish between the following: (a) documenting correlations between bicycle facilities, versus (b) claiming that bicycle facilities will induce use. It is increasingly being realized that the majority of previous work on the subject has not adequately differentiated between the two.

For example, residents (or families) often select locations to match their desires for certain behaviors, such as cycling. This is an option they prioritize in their home location. This suggests that differences in rates of cycling between households in different areas of the city with different access to cycling facilities should *not* be credited to facility alone; the differences should be attributed to self-selection. In other words, people who are likely to cycle, choose to locate in a given neighborhood where they have a better chance of cycling.

The above considerations are particularly vexing matters for researchers aiming to shed light on debates and discussions around causality. Proving statistical association is not the same as proving causality; in fact, one can never prove causality. Two phenomena can move together due to chance, or there could be bi-directional causality. However, there is no statistical test for causality. What is the researcher of cycling behavior left to do? How can one reliably say that cycling facilities will increase levels of cycling?

While one can never prove causality, social scientists provide several guidelines that help move us several steps further in inferring causality. Some of the most relied on guidelines were reportedly first provided by John Stuart Mills who suggested that at least three conditions need to be met:

1. Concomitant variation is the extent to which a cause, *X*, and an effect, *Y*, occur together or vary together in the way predicted by the hypothesis under consideration (i.e., rates of cycling and the presence of a cycling facility)
2. The time order of occurrence condition states that the causing event must occur either before or simultaneously with the effect; it cannot occur afterwards (i.e., the cycling facility came before heightened levels of cycling)
3. The absence of other possible causal factors means that the factor or variable being investigated should be the only possible causal explanation. This is the one most difficult to satisfy (i.e., heightened levels of cycling are not due to the "Lance Armstrong" factor. This is in reference to the fact that the U.S. experienced an overall cycling boom in the 1999 and 2000 possibly because of the increased popularity American Lance Armstrong brought to the sport—and the activity of cycling—after winning his first of seven races of the Tour de France).

The methodological approach described in this paper is based on the premises outlined by these conditions. Our paper employs a longitudinal method to determine the effect of bicycle facility construction in Minneapolis-St. Paul, MN, on journey to work bicycle mode share. During the 1990s a number of new facilities were constructed in the two central cities; many of them focused on the bicycle commuting hotspots of the University of Minnesota and nearby downtown Minneapolis, and on connection to existing facilities. As such, the central question in our research is: did constructing new bicycle facilities lead to an increase in bicycle commute rates to work between 1990 and 2000?

Methods

Our research is based in the Twin Cities of Minneapolis and St. Paul, Minnesota which border one another and are roughly the same geographic size (approximately 57 square miles each (148 square km)). The separate central businesses districts for each city are less than ten miles (16 km) from one another. According to the 2000 Census, Minneapolis has roughly 100,000 more residents than St. Paul (382,618 versus 287,151). The setting of these cities proves to be almost ideal for several reasons. Both Minneapolis and St. Paul are well equipped with both on-street and off-street bicycle paths. The cities have a combined 60 miles (97 km) of on-street bicycle lanes and 123 miles (198 km) of off-street bicycle paths. Furthermore, residents comprise a population who appear to cherish such trails, particularly in the summer months. Minneapolis ranks among the top in the country in percentage of workers commuting by bicycle [10].

Ten new bicycle facilities in the cities of Minneapolis and St. Paul were selected for this analysis: three are on-street bicycle lanes, the remaining seven are off-street bicycle trails and bridges. Figure 1 presents a representative photograph of each type of facility. All facilities were built in the 1990s, though these facilities do not necessarily represent a comprehensive list of all new facilities constructed during this period. The ones selected are of particular interest for this study because they all are located in areas where they could reasonably be expected to impact the rate of bicycle commuting through providing improved access to the major employment centers of downtown Minneapolis and the University of Minnesota (which are about one mile apart (1.61 km)). These ten facilities are described in Table 1 and examples are shown in Figure 1. Table 1 includes the total length of the facility studied, it is important to note that not all the reported values are within the study region.

Our knowledge of who cycled to work is derived from the U.S. Census. A key feature of this investigation is that it applies to two entire central cities, rather than precise study areas or specific corridors of interest. Overall, the Twin Cities metropolitan area experienced a relatively small increase in bicycle mode share during the 1990s: it increased from a mere 0.442% to 0.462% over the ten years. Focusing on the central cities of Minneapolis and St.Paul, however, reveals a different story; rates increased from 1.153% to 1.386% of commute trips. Minneapolis has a much higher bicycle mode share than St. Paul, probably due to a large extent to the presence of the bulk of the University of Minnesota campus.

Census data is obtained from the U.S. Census Bureau website at the Census Tract level of analysis. The data was mapped to correspond with transportation analysis zones (TAZs) because TAZs are more widely used and understood by transportation planners and engineers. This transformation is done through area ratio using a geographic information system method. The transformation is conducted after removing lakes, parks, and non-residential areas from both TAZs and Census Tracts.

Variables that were measured include differences between 2000 and 1990 for each of the following phenomena for each TAZ:

- population density,
- median household income,
- percentage of workers,
- percentage of people with a commute time less than 30 minutes, and
- number of people who reported using bicycle as their transportation mode to work.

All variables are normalized either through percentages or densities to control for the variances in TAZ sizes. Figure 2 show the absolute change in bicycle commuters to work between 1990 and 2000 in the study region. At first glance, it is difficult to discern a strong relationship between positive changes in the number of cyclists and the spatial distribution of the new facilities. However, several TAZs adjacent to the new facilities seem to have experienced a slight increase in the number of people commuting to work by bicycles, while others have experienced a slight change or a decrease. TAZs with high levels of positive change in bicycle commuters to work are not directly adjacent to any of the new facilities. To examine this phenomenon in more detail, we employ GIS buffer techniques in concert with multivariate statistical analysis.

The supposed effects of new bicycle facilities are likely not limited to the immediate TAZs they pass through; facilities are hypothesized to affect adjacent areas as well (i.e., there is a spill-over effect). Two sets of buffers are developed using a geographic information system (GIS) to control for such. A set of buffers is constructed for each type of facility (on-street facilities and off-street facilities and bridges). Each set contains four buffers or service areas measured from access points to the trail along the network. Determining the buffer size based on access points to the trail and measuring the distance from these points along the network is a relatively robust strategy. Previous research used Euclidean distances, which do not necessarily represent the reality of how users access such facilities.

The buffers are constructed to define areas within one quarter mile, half mile, three quarters of a mile, and one mile of network distance from the facility access point (respectively, 400m, 800m, 1200m, and 1600m). These buffers are shown in Figure 3. The buffers are intersected with the TAZ to determine the percentage of area covered by each buffer in each TAZ for both types of facilities. The percentage is also used to control for the variance in the TAZ areas. In the interest of parsimony, overlapping service areas were assigned the lower buffer value. For example, imagine a scenario where a TAZ has 10 percent of its area is within a quarter mile from a trail (trail A) access point, while 20 percent of the same TAZ is within half mile from access point along another trail (trail B). If the two service areas do not overlap, this TAZ will be assigned 10 percent within one quarter mile and 20 percent within half mile. On the other hand if an overlap existed between the two service areas and such overlap is around 5 percent of the total TAZ area. Accordingly the value assigned to such TAZ will be 10 percent within onequarter mile (400 m) from a facility and 15 percent within half mile of a facility. This method simplifies the analysis and accounts for the overlap in service areas.

The difference between our research and previous efforts is that this research analyzes the *change* in the number bicycle commuters relative to the *change* in construction of bicycle facilities, adjusting for rival explanations. The change in the number of people who commuted to work in other areas (that did not experience additional bicycle facilities) is provided as a control for overall changes that might have occurred in the city level. A linear regression model is estimated of the sort:

$$\Delta BU = f\left\{\Delta POPDEN, \Delta PWORK, \Delta INC, \Delta PCOM30, \Delta TRL\frac{1}{4}, \Delta TRL\frac{1}{2}, \Delta TRL\frac{3}{4}, \Delta TRL1, \Delta TRLS\frac{1}{4}, \Delta TRLS\frac{1}{2}, \Delta TRLS\frac{3}{4}, \Delta TRLS1\right\}$$

Each of the variables is defined in Table 2, while Table 3 includes the summary statistics for each variable. It is clear from Table 3 that the average change in cyclist who commutes to work by bicycle is around 4 cyclists per TAZ, while some TAZs have faced a decline in the number cyclists to work and others were subjected to an increase. The standard deviation of cyclists who commute to work by bicycle compared to the mean indicates a high level of variation in term of the changes in the number of bicycle commuters between the two time periods. All service area variables has a minimum value of zero, this is due to including TAZs that were not subjected to any increase in bicycle facilities in their vicinity. These TAZs are used in the model to control for the changes that occurred in cyclists' behavior over time. The change in income was around $13,000 with a standard variation of $5,000 between the two time periods, which indicates a low level of variation in term of changes in income along the TAZs. It is also noticed form Table 3 all socioeconomic and demographic characteristics have faced an increase except for the number of people whom their commute time is less than 30 minutes. Accordingly correlating the increase in the number of bicycle commuters to work to being in the vicinity of a bicycle facility is not expected.

Results and Discussion

The results of the model are provided in Table 4. Only 11% of the variance in the dependent variable can be explained by the independent variables used in the model. A low R-square can be related to the omitted variables that have not been included in the analysis and cause such variation. An example of such variables is self selection criteria. Interpreting of each variable and the regression output is included in this section. The change in population density shows a statistically significant relationship in relation to the change in the number of bicycle commuters to work. As expected, the positive sign indicates that the number of bicycle commuters increased with the increase in population density. For each increase in the number of people living in the TAZ by one person per km living the number of cyclists is expected to increase by 0.006 persons. A statistically significant and positive relationship exists between the change in the percentage of people working in TAZ and the number of people who commute to work by bicycle. For each additional worker the number of cyclists is expected to increase by 0.46 commuters. This suggests that the higher the number of workers in a TAZ the higher the probability of bicycle commuters. A positive increase in median household income between 1990 and 2000 did not show a statistically significant relationship with a decrease in the number of bicycle commuters. The number of cyclists is expected to decrease by 0.92 for each $1,000 increase in median house hold income in the TAZ. It is also expected that bicycle commuters to work will increase if the travel time to jobs is less than 30 minutes by 0.7 cyclist; correspondingly, it is expected the more dispersed jobs are in a region (distance between homes and work is more than 30 minutes) the less likely people will use bicycle as their mode of transportation to work. Table 3 did show a decline in the number of people working within a travel time that is less than 30 minutes. Both variables appear statistically significant. Most of the other control variables had the hypothesized signs that follow the theoretical expectations, thereby increasing our confidence in the model. It is also important to note that various models were tested and the control variables maintained their sign and statistical significance, which increase our confidence in the findings too.

Turning to the policy relevant variables, we first examine the impact of on-street facilities. The results find that the percentage of TAZ area that is within one quarter mile, one half mile, three quarters of a mile, or one mile of an on-street facility did not have a statistically significant effect on the number of bicycle commuters. Yet the expected positive sign was present for the one half mile, three quarters of a mile, or one mile of an on-street effect on bicycle commuters to work. A negative sign was present for the one quarter mile effect, observing the location where new on-street facilities were added in the region can explain the reasons of such findings. The facilities were located along major arterials with commercial and mixed use zones. Areas around and near commercials and mixed use zones have a higher rent values compared to other areas in the region. This indicates a consistency in the findings of the model where the income effect had a negative impact on the number of bicycle commuters to work. Accordingly land values around these major corridors are an obstacle for bicyclers as they tend to live beyond the quarter mile from the facility access point or even more.

Examining the effects of off-street facilities on bicycle commute to work presented a different story. Neither of the percentages of area that is within one quarter mile, one half mile, three quarters of a mile, nor the one mile travel distance did show a statistically significant relationship with the number of bicycle commuters to work. Meanwhile, negative signs were present in terms of the effects on bicycle commuters to work except for the three quarters of a mile. Interpreting these four off-street facility variables in the model can raise more questions than answers regarding the effects of bicycle facilities on the commute to work using bicycles. In other words, if a new facility is present around a TAZ within one quarter of a mile or one half of a mile or one mile from the facility access point workers tend not to use their bicycles to commute to work. While if the improvement is within a three quarters of a mile the opposite effect might be present with the increase in the area covered. Observing Figure 2 helps explain such findings. Most of the new off-street facilities were built adjacent to existing bicycle facilities. In addition, most are relied on for recreational use as they do not connect primary residential areas to work destinations as it is the case for on-street facilities.

Conclusions

The novelty of this research is that it examines the effects of building cycling facilities on rates of bicycle commuting before and after building the facilities. Previous research does not offer such an in-depth approach to measure these effects. The relationship between the off-street facilities did not necessarily follow the expected theory, at least for commute travel. On-street facilities, however, did not show a statistically significant effect on the change in the number of bicycle commuters to work in areas, yet the expected sign was present. Such findings need to be considered in light of the level of analysis, the research question, and available data. For example, the average change in mode share in the studied area was around four commuters per TAZ. This small change raises the question of how effective such facilities in diverting people from their modes to new ones. Off-street bicycle facilities might have an effect on leisure commutes more than the effects on commute to work, which requires an additional research in this field.

Additional research is needed to more reliably define service areas around trails and more in depth analysis is recommended to understand the recreational use of bicycle facilities. Constructing a facility will lead to an increase in the number of cyclists using it. However, several issues questions deserve further attention, such as who is using such facilities, why they are using them, where the facilities lead to, and how far common destinations are from such facilities. The model provides a significant increase in the number of people commuting by bicycle to work if their employment is within a 30 minutes commute time. This finding is essential for policy makers who are trying to promote bicycling and walking as main mode for transportation to work. The research succeeds in employing a new approach to examine census data in a longitudinal manner using control variables. However, additional work is needed to fully understand such relationships for other type of travel.

Authors' contributions

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Figure 1: Representative photographs of off-street trail and on-street bicycle lane (respectively)

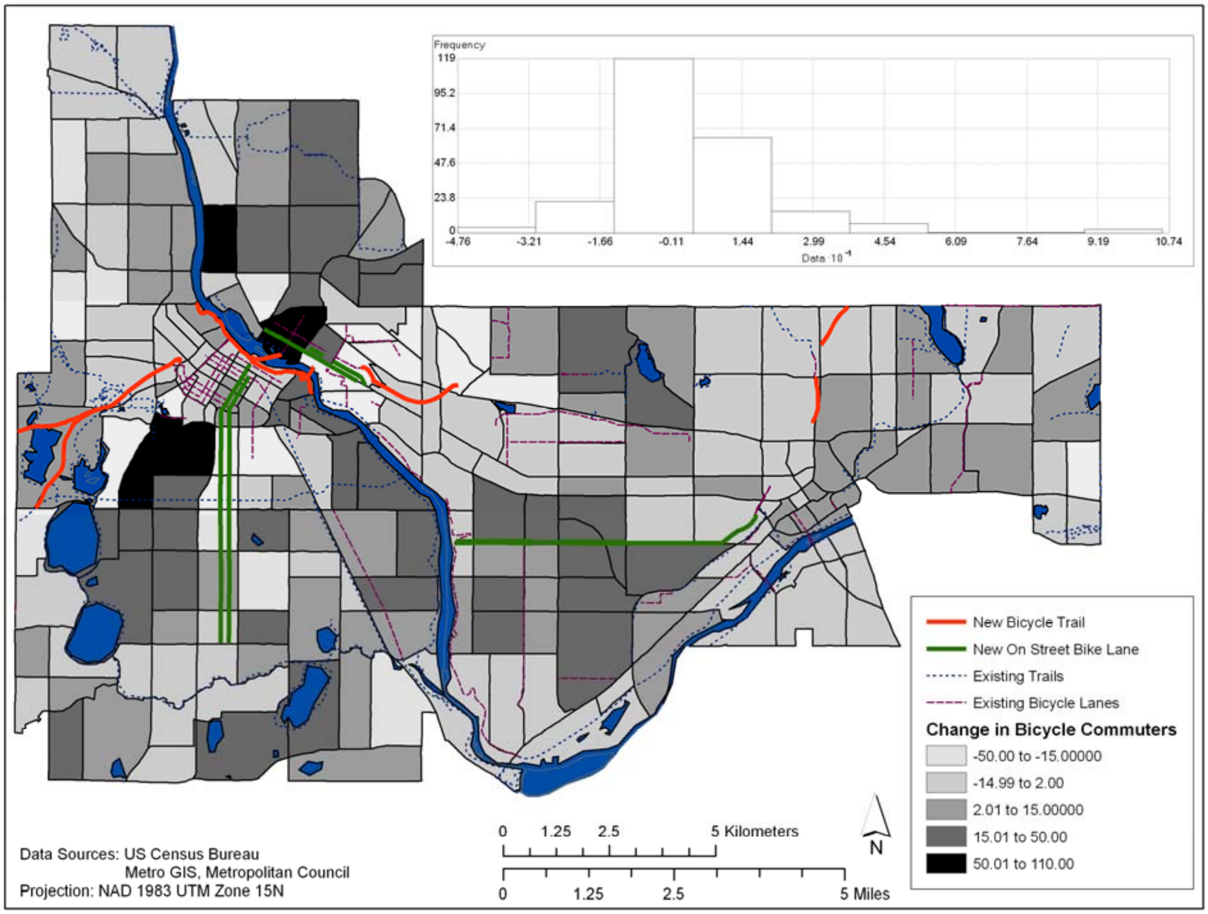

Figure 2: Absolute change in bicycle commuters to work between 1990 and 2000

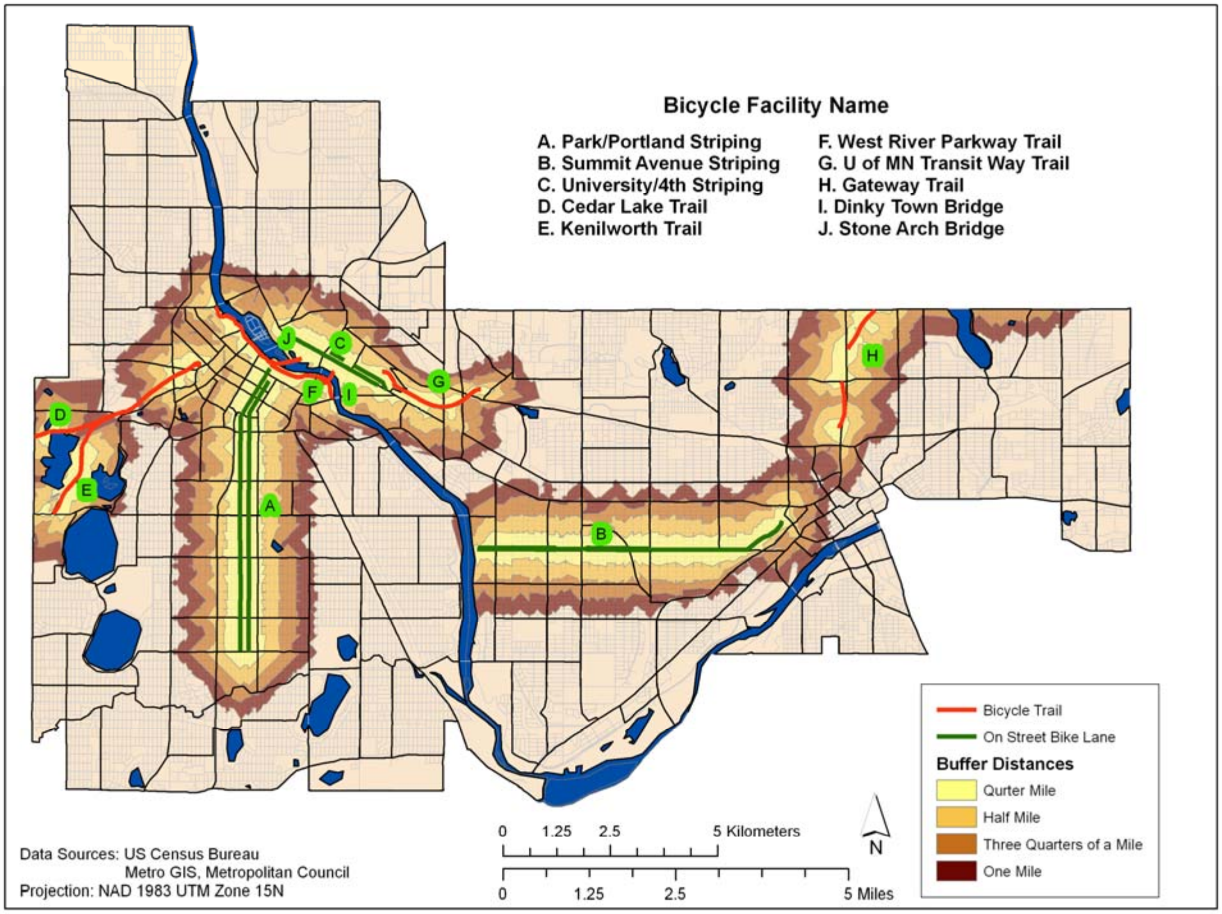

Figure 3: Map depicting locations of the ten facilities examined.

Table 1: Characteristics of Bicycle Facilities Examined

Name	Type	Length*
Park/Portland Stripping	On Street Bicycle Lane	27.02
Summit Stripping	On Street Bicycle Lane	21.95
University/4th Stripping	On Street Bicycle Lane	7.88
Cedar lake Trail	Off Street Bicycle Path	25.55
Kenilworth Trail	Off Street Bicycle Path	5.85
West River Parkway	Off Street Bicycle Path	7.93
U of MN Transitway	Off Street Bicycle Path	5.55
Gateway Trail	Off Street Bicycle Path	57.13
Dinky Town Bridge	Off Street Bicycle Bridge	1.32
Stone Arch Bridge	Off Street Bicycle Bridge	1.57

* Total Length of facility in Miles

Table 2: Definitions of variables used in analysis

Variable	Description
ΔBU	Change in the number of people commuting to work by bicycle in the TAZ (actual)
$\Delta POPDEN$	Change in the population density in the TAZ (person/Km^2)
$\Delta PWORK$	Change in the percentage of working people who live in the TAZ (percentage)
ΔINC	Change in the median household income in the TAZ (per \$1,000)
$\Delta WPCOM30$	Change in the percentage of people whom their commute to work is less than 30 minutes (actual)
$\Delta TRL\frac{1}{4}$	Percentage of TAZ area that is within one quarter mile from an off-street bicycle trail measured along network (percentage)
$\Delta TRL\frac{1}{2}$	Percentage of TAZ area that is within one half mile from an off-street bicycle trail measured along network (percentage)
$\Delta TRL\frac{3}{4}$	Percentage of TAZ area that is within three quarters of a mile from an off-street bicycle trail measured along network (percentage)
$\Delta TRL1$	Percentage of TAZ area that is within one mile from an off-street bicycle trail measured along network (percentage)
$\Delta TRLS\frac{1}{4}$	Percentage of TAZ area that is within one quarter mile from an on-street bicycle facility measured along network (percentage)
$\Delta TRLS\frac{1}{2}$	Percentage of TAZ area that is within one half mile from an on-street bicycle facility measured along network (percentage)
$\Delta TRLS\frac{3}{4}$	Percentage of TAZ area that is within three quarters of a mile from an on-street bicycle facility measured along network (percentage)
$\Delta TRLS1$	Percentage of TAZ area that is within one mile from an on-street bicycle facility measured along network (percentage)

Table 3: Summary statistics

Variable	***Mean***	***St. Dev***	***Minimum***	***Maximum***
ΔBU	4.52	19.63	-47.59	105.96
$\Delta POPDEN$	189.38	673.85	-2020.80	5190.20
$\Delta PWORK$	2.08	6.96	-32.67	28.84
ΔINC	13.14	5.95	-1.09	36.95
$\Delta WPCOM30$	-4.02	5.21	-20.65	12.77
$\Delta TRL\frac{1}{4}$	3.77	13.27	0.00	86.06
$\Delta TRL\frac{1}{2}$	7.12	17.19	0.00	91.11
$\Delta TRL\frac{3}{4}$	7.17	15.63	0.00	85.85
$\Delta TRL1$	6.96	14.32	0.00	72.72
$\Delta TRLS\frac{1}{4}$	7.48	20.85	0.00	100.00
$\Delta TRLS\frac{1}{2}$	7.57	16.05	0.00	75.15
$\Delta TRLS\frac{3}{4}$	8.75	16.41	0.00	97.57
$\Delta TRLS1$	9.30	16.83	0.00	71.51

Table 4: Results of regression model

Variable	***Coefficient***	***t-statistic***
$\Delta POPDEN$	0.006	2.747*
$\Delta PWORK$	0.477	2.253**
ΔINC	-0.192	-0.795
$\Delta WPCOM30$	0.767	2.869*
$\Delta TRL\frac{1}{4}$	-0.043	-0.388
$\Delta TRL\frac{1}{2}$	-0.059	-0.583
$\Delta TRL\frac{3}{4}$	0.028	0.261
$\Delta TRL1$	-0.112	-1.093
$\Delta TRLS\frac{1}{4}$	-0.027	-0.410
$\Delta TRLS\frac{1}{2}$	0.088	0.973
$\Delta TRLS\frac{3}{4}$	0.036	0.464
$\Delta TRLS1$	0.027	0.354
CONSTANT	8.194	1.977**
R Square	0.11	
Number of observations	237	

* indicates statistical significance at the 99%
** indicates statistical significance at the 95%