Shifts between Automobile, Bus, and Bicycle Commuting in an Urban Setting

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ABSTRACT
In an urban setting, investments in bicycle and transit modes are expected to produce benefits such as reduced automobile vehicle miles traveled and reduced automobile parking demand. In reality, these benefits might be lower than expected if users simply shift between non-automobile modes. This article investigates shifts between automobile, bus, and bicycle use among students commuting to the University of Wisconsin-Milwaukee (UWM) in 2008 and 2012. We found that a significant decline in driving was associated with a significant increase in bicycle mode share, suggesting that bicycling replaced certain automobile commute trips. Analysis by distance revealed nuances in mode substitution. There were significant increases in bicycle commuting for students living between 1.0 and 9.9 miles (1.6 and 15.9 km) from campus. However, the increases in bicycling for students living between 1.0 and 1.9 miles (1.6 and 3.1 km) corresponded with decreases in bus rather than automobile commuting, suggesting bus and bicycle substitution for short commutes. There was a significant shift in long-distance commuting—greater than 10 miles (16 km)—from automobile to bus. Differentiation between primary and secondary travel modes revealed an increasing proportion of regular drivers who bicycled as their secondary commute mode between 2008 and 2012. Also, approximately two-thirds of the students who bicycled and nearly half of the students who used the bus as their primary mode used a different, secondary commute mode. Many students who already bicycled were inclined to use the bus when they were not able to bicycle, but fewer bus users tried bicycle commuting.

KEY WORDS
Bicycle, Bus, Substitution, Urban, Campus
INTRODUCTION
Public transit and bicycle modes are being promoted by many communities in the United States to reduce automobile use and increase the sustainability of local transportation systems. Shifting a portion of travel from personal automobiles to other types of transportation can have substantial transportation, environmental, social and economic benefits (1-3). However, we do not know to what extent public transit and bicycling investments can achieve these benefits, particularly if promoting one non-automobile mode reduces the use of another.

In the first decade of the 21st Century, there have been modest shifts from private automobiles to other modes of transportation in the United States. Based on Federal Highway Administration data, the proportion of trips made by automobile decreased from 86.6 percent in 2001 to 83.8 percent in 2009, while bicycle mode share increased from 0.81 percent to 1.04 percent and transit more share increased from 3.43 percent to 3.99 percent (4). Bicycle and transit journey-to-work mode shares also increased between 2006 and 2011 (5).

Still, the private automobile is the dominant mode of transportation in the United States, while public transit and bicycle mode shares are relatively small. Policies to increase bicycle and transit mode shares include infrastructure investment, economic incentives, public education, land use regulation, and social marketing programs (6-8). However, it is not yet clear which specific policies may be the most effective at shifting automobile travel to other modes in the United States (9).

One challenge to understanding the impacts of policies to promote bicycling and transit as alternatives to driving is that these modes may substitute for each other. If users shift from driving to taking transit, bicycling, or walking, automobile travel is reduced. On the other hand, if users shift from bicycling or walking to transit, the non-automobile modes merely substitute for each other without reducing automobile travel. For example, some researchers argue that investment in rail transit has increased transit ridership and reduced automobile travel (10), while others claim that rail investments tend to attract bus riders rather than automobile users and thus adversely affect bus systems (11). Policy makers and planners sometimes assume complementary effects when quantifying the benefits of non-automobile modes by counting the increasing number of users equally, regardless of previous travel modes (12). Such assumptions overlook the effects of substitution and new trip generation in the complex transportation system.

In recent decades, transit and bicycle transportation has attracted much investment as well as an increasing number of users, but mode substitution has not been researched extensively in the bicycle field. In comparison with transit, bicycling is particularly advantageous for short-distance tours because it allows travelers to go directly from door to door and provides more flexible route and schedule options. Bicycling also provides users with exercise and can be done at all hours of the day, whereas transit service may be infrequent or unavailable at night and on weekends. On the other hand, public transit has advantages over bicycling: it usually requires less physical effort, can more easily serve people with disabilities, is usually more comfortable in bad weather, is usually more convenient for traveling with heavy items, and is usually perceived to have a higher level of traffic safety especially in areas with few designated bicycle facilities. Transit may also be faster than bicycling for longer urban trips (i.e., trips with relatively infrequent bus stops) since transit vehicles can reach higher speeds between stops.

Research has not yet determined the degree to which bus and bicycle modes may substitute for each other rather than for driving. For example, employer-provided transit commuter benefits were not related to bicycle commuting in Washington, DC (13), suggesting a
complementary relationship. However, bicycle mode share decreases in Davis, CA in the 1990s have been attributed partially to free transit fares for students (14). In addition, data from Montreal suggest that many people substitute bus for bicycle travel in the winter (15, 16). With little information about shifts between bus and bicycle modes, it is difficult to determine how much increases in these modes are associated with reductions in driving.

Many studies have addressed bicycle and transit integration (e.g., bicycle parking at transit stops and stations, bicycle racks on buses, bicycle racks on rail cars), but most have described existing systems and opportunities to increase bicycle and bus use (15, 17-20). Only a few studies have attempted to account for substitution and quantify how bicycle and transit integration impacts automobile travel (15, 18).

Further complicating the analysis, there are times when regular bus or bicycle users travel by other modes. For example, commuters may choose to walk to work on a particularly relaxed day with pleasant weather. Or, if a bicyclist has a car, he/she may choose to drive on a cold, windy day or when he/she has many items to carry. Research in Vermont found that 20 percent of the days commuters reported bicycling to work they returned home by a different mode (21). In other words, secondary modes of travel also need to be considered to evaluate the impacts of mode shifts.

This article contributes to the literature by examining changes in the shares of primary and secondary modes between personal automobile, bicycle, and transit modes. Focusing on a university campus in an urban area where bicycle infrastructure has improved, this article addresses the following question: Are bicycle and transit modes substitutes, or do they complement each other by reducing personal automobile travel?

DATA AND METHOD

Study Area
To investigate the relationship between personal automobile, bicycle, and transit use, this article examines the journey-to-campus modes of students at the University of Wisconsin-Milwaukee (UWM), which is located in an urban setting where both transit and bicycle modes are feasible. UWM conducted travel surveys in 2008 and 2012 to understand the journey-to-campus travel patterns of students, faculty and staff. This article focuses on students because of their relative homogeneity in terms of age, income and education levels. While the exploratory analysis presented in this case study applies to university students at an urban campus, future research can explore bicycling and transit use among a wider range of socioeconomic groups in different built environments.

Figure 1 shows the location of the UWM campus and surrounding bus and bicycle systems. The 104-acre UWM main campus is located three miles north of Downtown Milwaukee and a few blocks west of Lake Michigan, in a moderate-density residential neighborhood with approximately eight dwelling units per acre (20 units per hectare). The university has nearly 30,000 students. Transportation demand from the large number of students on a compact campus imposes challenges to the neighborhood and the city. In particular, student automobile commuting adds traffic to local streets, creates noise, produces emissions, and increases competition for on-street parking in nearby neighborhoods.
FIGURE 1 UWM and Local Transportation Systems.

Location of UWM in Milwaukee County

Bus Routes near UWM

Bicycle Network Facilities near UWM

UWM Campus Bicycle Parking

Location of UWM in Milwaukee County

UWM Campus Boundary

Map shows bicycle facilities as of 2012
The campus is well served by all transportation modes. An extensive local roadway network grid serves this area, and Interstate Highway 43 is less than two miles west of the campus. Two parking lots on the main campus are free of charge to actively enrolled students. One of them, with 788 parking spaces, opened in April 2012, before the second campus survey took place. Additional parking is available at various fees. Moreover, the university offers free park-and-ride services one mile north of campus. Still, many students choose to park on neighborhood streets within several blocks of campus since most allow free parking for two to three hours without a residential parking permit.

The Milwaukee County Transit System (MCTS) serves the campus area with nine transit lines, including two express lines and four lines that operate during fall and spring semesters only (Figure 1). Importantly, students have free transit passes, called UPASS, to access MCTS buses during the semesters they enroll. The UPASS program was implemented in 1994, and it was successful in shifting some automobile users to commute by bus (22).

Bicycle access to the UWM campus is supported by major multi-use trails that pass within one-half mile (0.8 km) of the west side and the east side of campus (Figure 1). There are also bicycle lanes on arterial roadways on the west and south sides of campus and a grid of low-speed, low-volume residential streets in the neighborhoods surrounding campus. The campus has more than 1,200 linear feet (370 linear m) of bicycle racks, providing secure parking near most buildings (23).

Bicycle infrastructure expanded in the area around UWM between the two survey periods. The length of bicycle lanes within two miles (3.2 km) of campus increased by approximately 56 percent, from 8.7 miles (14 km) of roadway centerline with bicycle lanes in 2008 to 13.6 miles (21.9 km) in 2012. Some students also utilize bicycle racks on MCTS buses, which were first provided in fall 2009. While bicycle-on-bus ridership has increased steadily (24), student bicycle-on-bus levels are unknown.

UWM Campus Survey
The university conducted online surveys from November 17 to December 21, 2008 and October 29 to November 26, 2012 to gather information on travel patterns to and from campus (25, 26). More than 3,000 students participated in the survey in 2008, and more than 3,600 participated in 2012. Students’ travel behavior might have changed between 2008 and 2012 due to changes in economic opportunities, attitudes towards different travel modes, and changes in transportation systems, such as the supply of parking spaces on campus and improvements in bicycle facilities near campus. The difference in the dates of survey might also affect reported travel modes. The 2012 survey was done earlier in the semester (at a warmer time) than the 2008 survey, so respondents may have been traveling slightly differently at the actual time of each survey. However, we did not expect the time differences to affect responses significantly because the survey requested the typical commute modes used during the whole semester. Neither survey collected personal socioeconomic information. Therefore, it was not possible to identify potential response bias or weight responses to estimate results for the full student population. Despite this caveat, the surveys were administered similarly in 2008 and 2012, so the responses were comparable for analysis.

The analysis focused on students who were actively enrolled in the fall semesters when the survey took place, as well as those who resided in Milwaukee County (where transit and bicycling are feasible options). The final sample size was 2,007 respondents in 2008 and 2,340...
respondents in 2012. Figure 2 shows the geographic distribution of student by the zip codes of their home locations in 2012. The distribution was similar in 2008.

**FIGURE 2 Distribution of Student Home Locations (2012).**

The survey included seven modes for journey-to-campus trips: drive alone, carpool, bus, bicycle, walk, train and motorcycle/scooter. We collapsed drive alone and carpool together as the personal automobile mode and deleted train because there is no train service within Milwaukee County. The county has only one train station, which it provides interregional service to the south. Walk and motorcycle/scooter were combined as “other” modes. In this research, we focused on automobile, bus, and bicycle modes to explore commute mode shifts. For example, if the share of students who commuted by bicycle increased and the share of students who commuted by automobile decreased, while other mode shares remained constant, this is considered a complementary effect to shift travel from automobile to bicycle. In contrast, if the share of bicycle commuters increased but automobile commuters remained the same or increased, this does not represent a mode shift from automobile. In the latter case, the increase in bicycle commuting may be associated with a decrease in bus commuting.

The travel surveys included an important element that enhanced our investigation of the research question: they requested information on the secondary modes used by students to commute to campus. This information is useful for detecting if the change in the proportion of bus or bicycle users is associated with having a different mode as a secondary means of commuting. For example, if students shift their primary mode from automobile to bicycle and they use bus as the secondary mode, this shows a complementary relationship between bicycle
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and bus. If many students still use automobile as their secondary mode, the shift to bicycling has
less of an overall impact on reducing automobile commuting.

The survey also captured the frequency of primary and secondary mode use, which
allowed us to estimate the miles traveled by students using each mode, including changes in
personal automobile vehicle miles travelled (VMT) between 2008 and 2012. Six classes of
frequency were collected in the survey: daily, 2-3 times a week, once a week, 2-3 times a month,
once a month, less than once a month. We translated these categories into monthly frequencies of
20, 10, 4, 2.5, 1, and 0.5 times a month, and then calculated the weighted total miles travelled by
each mode.

Because mode share is sensitive to distance, we also broke the students into five groups
based on their self-reported, one-way commute distances to UWM. To reduce the errors of self-
reported distances, we checked them against the zip codes of residences and removed those that
did not match.

RESULTS

Primary Mode Share

Table 1 presents primary mode share based on five distance groups in 2008 and 2012. The top
section shows statistics for 2008 and the bottom for 2012. The two left columns show the
numbers and the percentages of students in each distance group. The spatial distribution is
relatively stable between 2008 and 2012.

<table>
<thead>
<tr>
<th>TABLE 1 Primary Mode Share by Distance Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2008</td>
</tr>
<tr>
<td>&lt;1 mile</td>
</tr>
<tr>
<td>1-1.9 miles</td>
</tr>
<tr>
<td>2-4.9 miles</td>
</tr>
<tr>
<td>5-9.9 miles</td>
</tr>
<tr>
<td>10+ miles</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>2012</td>
</tr>
<tr>
<td>&lt;1 mile</td>
</tr>
<tr>
<td>1-1.9 miles</td>
</tr>
<tr>
<td>2-4.9 miles</td>
</tr>
<tr>
<td>5-9.9 miles</td>
</tr>
<tr>
<td>10+ miles</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

**statistically-significant difference between the 2008 and 2012 proportions (two-tailed test; 95% confidence level)
*statistically-significant difference between the 2008 and 2012 proportions (two-tailed test; 90% confidence level)
Note: 1 mile = 1.6 km

Between 2008 and 2012, the share of all student respondents whose primary mode was
automobile declined from 37.3 percent to 32.9 percent. At the same time, student bicycle mode
share increased significantly from 6.6 to 8.5 percent. Evidently, some students shifted from
automobile to bicycle commuting. The share of student respondents whose primary mode was bus declined slightly from 34.1 to 33.2 percent, but this change was insignificant.

Exploring these results more closely by distance showed that personal automobile mode share increased with increasing distance from UWM, while bicycle mode share decreased with increasing commute distance. Bus mode share was the highest for commuters living 2.0 to 4.9 miles (3.2 to 7.9 km) from campus. Between 2008 and 2012, there were significant increases in bicycle commuting for students living between 1.0 and 9.9 miles (1.6 and 15.9 km) from campus. However, the increases in bicycling for students living between 1.0 and 1.9 miles (1.6 and 3.1 km) corresponded with decreases in bus rather than automobile commuting, suggesting bus and bicycle substitution for short-distance commutes. The significant increase in bus commuting and decrease in bicycle commuting among students living less than one mile (1.6 km) from campus provided further evidence of substitution at short distances. Significant increases in bicycle commuting were associated with decreases in both bus and automobile commuting at distances between 2.0 and 4.9 miles (3.2 and 7.9 km), and bicycle commuting substituted for automobile commuting at distances between 5.0 and 9.9 miles (8.0 and 15.9 km). Furthermore, there was a significant shift in long-distance commuting from automobile to bus.

Note that the mode shares in Table 1 are aggregate figures for all student respondents. Individual students may have actually switched in the opposite direction from the overall results (e.g., bicycle to automobile), but the total number shifting in the direction of the reported results (e.g., automobile to bicycle) was higher.

Secondary Mode Share
While the analysis of the primary commute modes provides useful information, we need to examine primary and secondary modes together to gain insights into the complex relationships between different modes. As explained in the Introduction section, people who commute by bicycle or bus often use backup modes in certain circumstances. Similarly, people who drive may use bicycle and bus as secondary commute modes.

Table 2 presents the distribution of student secondary commute modes based on the primary mode. The table has three panels representing the primary commute modes of automobile, bus, and bicycle. In each panel, the first column presents the total number of students that use the primary mode in the distance group. The following three columns show the shares of the secondary mode based on the total number in the first column. “N/A” indicates no secondary modes. Because the table does not present statistics of “other” modes, the percentage points in the three columns of secondary modes do not add up to 100.

We already found that the share of student respondents whose primary mode was automobile declined between 2008 and 2012 (Table 1). Table 2 further shows that among these students, the share of them who had no secondary mode decreased from 73 percent in 2008 to 68 percent in 2012. This significant decrease corresponded with a significant increase in primary automobile users who bicycled as a secondary mode. This suggests that a growing portion of student respondents replaced some of their automobile commute trips with bicycling. Note that the increase in bicycling as a secondary mode for automobile users was most prominent at distances between 1.0 and 4.9 miles (1.6 and 7.9 km) from campus, with a significant increases from 2 percent to 15 percent at 1.0 to 1.9 miles (1.6 to 3.1 km) distance and from 8 percent to 16 percent at 2.0 to 4.9 miles (3.2 to 7.9 km) from the campus. These distances are often viewed as being favorable for bicycle commuting (13). Further, there may be potential to shift more
automobile commuters in these distance groups to bicycle as their secondary mode, and to shift
some students from occasionally bicycling to bicycling as their primary mode.

Besides automobile users who bicycled as a secondary mode, the proportions of
secondary modes used by primary automobile, bus, and bicycle commuters changed little
between the two surveys. However, it is interesting to note that approximately two-thirds of the
students who bicycled and nearly half of the students who used the bus as their primary mode
also used a different, secondary mode to commute to and from campus. Further, while only 7
percent of primary bus commuters bicycled as a secondary mode in 2012, 32 percent of primary
bicycle commuters used the bus as a secondary mode. Therefore, many students who already
bicycled were inclined to use the bus when they were not able to bicycle, but fewer bus users
tried bicycle commuting. The results caution transportation research that relies on primary modes
alone, which might overlook the importance of secondary modes.

Effects of Mode Shift on Miles Traveled by Mode

The analysis of the primary and secondary commute modes revealed several significant changes
in student mode share between 2008 and 2012. To estimate the effects of these changes on
student respondent miles traveled, including automobile VMT, we calculated the total miles
traveled by each mode, primary and secondary, and weighted these figures by the self-reported
distance and by the frequency of using each mode (Table 3).

Table 3 gives the percentages of total distance traveled by each primary and secondary
mode. The format of Table 3 follows that of Table 2: The top section shows 2008 data, and the
bottom section shows 2012 data. The table has three panels, one for each primary mode. Each
panel now has four columns. The first column of each panel shows the percentage of all distance
traveled within each distance group using the primary mode. For example, of the total distance
traveled by all student commuter respondents in 2012, 49.7 percent of this distance was travelled
by the students who used automobile primary mode, 38.2 percent by those who used bus primary
mode, and 2.9 percent by bicycle primary mode. However, for commuters who lived less than
1.0 mile from campus, 11.7 percent of the total travel distance was covered by bicycle primary
mode, 6.1 percent by bus primary mode, and 2.5 percent by automobile. Most of the rest of the
distance was covered by students who walked to school. The next three columns of each panel
are all subsets of the first, presenting the percentages of miles travelled by each mode, including
the primary mode. If a student bicycled as his/her primary mode and does not use a secondary
mode, all of the miles traveled are counted as bicycle. If the student had a secondary mode of
bus, his/her miles travelled are split into bus and bicycle, based on the distance and the
frequency.

Table 3 quantifies the impact of the commute mode shifts identified earlier in the paper.

- There was an evident decrease in the percentage of miles travelled by students who used
  automobile as their primary mode between 2008 and 2012. These primary automobile
  commuters represented 54.4 percent of all miles traveled in 2008 but only 49.7 percent in
  2012.

- There was an increase in the percentage of students commuting by bicycle as their
  primary mode between 2008 and 2012. The share of the total miles covered by these
  primary bicycle commuters increased from 1.9 to 2.9 percent.

- The share of the total miles covered by the primary bus commuters increased from 39.3
to 41.6 percent.
### Table 2 Secondary Mode Share by Primary Mode by Distance Category

| Primary | Automobile | | | Bus | | | Bicycle | | |
|---------|------------|----|----|----|----|----|----|--------|----|----|
| Sec     | # | Percentage | # | Percentage | # | Percentage | | |
|         | N/A | Auto | Bus | Bike | N/A | Auto | Bike | N/A | Auto | Bus | |
| 2008    |     |      |     |   |     |      |     |     |      |     |     | |
| <1 mile | 5  | 20   | 0   | 0  | 8   | 88   | 0   | 13  | 32   | 41  | 13  | 6  |
| 1-1.9 miles | 53 | 64   | 17  | 2  | 171 | 44   | 26  | 9   | 65   | 34  | 11  | 35 |
| 2-4.9 miles | 126 | 63   | 25  | 8  | 224 | 51   | 25  | 10  | 32   | 38  | 13  | 38 |
| 5-9.9 miles | 172 | 68   | 21  | 1  | 97  | 48   | 42  | 6   | 3    | 33  | 67  | 0  |
| 10+ miles | 392 | 80   | 18  | 0  | 184 | 54   | 42  | 2   | 0    |     |     |     |
| Total   | 748 | 73   | 20  | 2  | 684 | 50   | 32  | 7   | 132  | 36  | 13  | 28 |
| 2012    |     |      |     |   |     |      |     |     |     |      |     |     | |
| <1 mile | 11  | 64   | 9   | 9  | 22  | 82   | 5   | 5   | 33   | 36  | 9   | 12 |
| 1-1.9 miles | 67 | 43   | 18  | 15** | 166 | 51   | 21  | 9   | 100  | 33  | 9   | 35 |
| 2-4.9 miles | 132 | 51   | 27  | 16** | 251 | 53   | 25  | 14  | 52   | 35  | 15  | 35 |
| 5-9.9 miles | 136 | 73   | 21  | 4  | 87  | 57   | 43  | 0** | 12   | 17  | 25  | 58*|
| 10+ miles | 423 | 77   | 19  | 0  | 251 | 53   | 47  | 0** | 1    | 0   | 100 | 0  |
| Total   | 769 | 68   | 20  | 5** | 777 | 54   | 33  | 7   | 198  | 33  | 12  | 32 |

2 **statistically-significant difference between the 2008 and 2012 proportions (two-tailed test; 95% confidence level)
3 *statistically-significant difference between the 2008 and 2012 proportions (two-tailed test; 90% confidence level)
4 Note: 1 mile = 1.6 km
1. **TABLE 3 Percentage of Weighted Trip Length by Mode by Distance Category**

<table>
<thead>
<tr>
<th>Primary Distance</th>
<th>Primary</th>
<th>Automobile</th>
<th>Total</th>
<th>Bus</th>
<th>Total</th>
<th>Auto</th>
<th>Bus</th>
<th>Total</th>
<th>Bicycle</th>
<th>Total</th>
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<tr>
<td></td>
<td>Secondary</td>
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<tr>
<td></td>
<td></td>
<td>&lt;1 mile</td>
<td>2.9</td>
<td>2.7</td>
<td>0.0</td>
<td>0.0</td>
<td>3.8</td>
<td>3.8</td>
<td>0.0</td>
<td>0.0</td>
<td>17.8</td>
<td>15.2</td>
<td>0.4</td>
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<td></td>
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<td>1-1.9 miles</td>
<td>8.1</td>
<td>7.4</td>
<td>0.3</td>
<td>0.0</td>
<td>39.3</td>
<td>34.3</td>
<td>2.4</td>
<td>0.9</td>
<td>14.6</td>
<td>12.2</td>
<td>0.4</td>
</tr>
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<td></td>
<td>2-4.9 miles</td>
<td>28.3</td>
<td>26.6</td>
<td>1.4</td>
<td>0.2</td>
<td>59.1</td>
<td>52.7</td>
<td>3.3</td>
<td>1.3</td>
<td>8.0</td>
<td>6.8</td>
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<td>5-9.9 miles</td>
<td>58.2</td>
<td>55.1</td>
<td>2.6</td>
<td>0.0</td>
<td>38.8</td>
<td>34.4</td>
<td>3.5</td>
<td>0.6</td>
<td>1.2</td>
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<td></td>
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<td>10+ miles</td>
<td>61.3</td>
<td>59.8</td>
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<td>0.0</td>
<td>37.3</td>
<td>34.9</td>
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<tr>
<td></td>
<td>Total</td>
<td></td>
<td>54.4</td>
<td>52.6</td>
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<td>39.3</td>
<td>36.2</td>
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<td>1.9</td>
<td>1.6</td>
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<td>&lt;1 mile</td>
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<td>2.3</td>
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<td>0.0</td>
<td>6.3</td>
<td>6.1</td>
<td>0.1</td>
<td>0.1</td>
<td>11.7</td>
<td>8.1</td>
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<td></td>
<td>1-1.9 miles</td>
<td>10.3</td>
<td>8.9</td>
<td>0.6</td>
<td>0.3</td>
<td>31.5</td>
<td>27.9</td>
<td>1.3</td>
<td>0.7</td>
<td>20.3</td>
<td>17.4</td>
<td>0.3</td>
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<td></td>
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<td>2-4.9 miles</td>
<td>25.6</td>
<td>22.8</td>
<td>1.5</td>
<td>0.9</td>
<td>55.1</td>
<td>49.6</td>
<td>2.7</td>
<td>1.7</td>
<td>11.5</td>
<td>10.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
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<td>50.3</td>
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<td>0.4</td>
<td>39.3</td>
<td>36.1</td>
<td>3.2</td>
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<td>4.8</td>
<td>4.1</td>
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<tr>
<td></td>
<td></td>
<td>10+ miles</td>
<td>55.5</td>
<td>53.9</td>
<td>1.4</td>
<td>0.0</td>
<td>41.5</td>
<td>38.3</td>
<td>3.1</td>
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<tr>
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<td></td>
<td>49.7</td>
<td>47.9</td>
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<td>41.6</td>
<td>38.2</td>
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For students who lived more than 10 miles (16 km) from campus, there was a significant shift in primary commute mode from automobile to bus. The distance traveled by primary automobile commuters decreased from 61.3 percent to 55.5 percent while the distance traveled by primary bus commuters increased from 37.3 percent to 41.5 percent.

The percentage of primary automobile commuters who used bicycle as their secondary mode increased. This shift was greater in the 1.0 to 1.9 mile (1.6 to 3.1 km), 2.0 to 4.9 mile (3.2 to 7.9 km), and 5.0 to 9.9 mile (8.0 to 15.9 km) categories. For these three categories, the distance traveled by bicycle as a secondary mode increased from 0.0 to 0.3 percent, 0.2 to 0.9 percent, and 0.0 to 0.4 percent of all miles traveled, respectively.

Comparing the percentages of miles traveled by each mode, the findings were similar to those from examining mode share. Within 2.0 miles (3.2 km), bicycle and bus were substitutes: increasing the miles traveled by one mode was associated with decreasing use of the other without a sizable reduction in primary automobile commute miles traveled. Between 2.0 and 4.9 miles (3.2 and 7.9 km), primary bicycle commuting increased while primary bus and automobile commuting decreased. Beyond 10 miles (16 km), primary bus miles traveled increased while primary automobile miles traveled decreased.

Since the data represent respondents only, it was not possible to estimate the overall changes in personal automobile VMT among all students. However, if total VMT was reduced by five percent, this would reduce traffic volumes on the main roadways surrounding campus by 300 to 700 vehicles per day, reduce the overall demand for on- and off-campus parking, and reduce other negative externalities of automobile travel. Replacing automobile commutes of more than 10 miles (16 km) with bus has a positive impact on personal automobile VMT because these commutes represent longer-distance travel. Long-distance commute shifts could even reduce traffic volumes slightly on major roadways in Milwaukee County. The small increase in bicycle miles traveled also represents more students obtaining physical activity and producing less pollution during their commutes.

CONSIDERATIONS

This study analyzes commute data reported by student respondents to the UWM Transportation Surveys, focusing specifically on mode shifts between automobile, bicycle, and bus modes. The analysis of commute distance assumes that students travel directly from home to campus and from campus to home. In reality, some students will stop at other activity locations that may not be on their direct route to or from campus. Further, the survey did not specify whether or not respondents should report the network distance or Euclidean distance between their home and campus. Therefore, actual commute distances are likely to be somewhat longer than assumed in this study. Future surveys could ask students to report locations of activity stops and actual route distances to assess commute distance. In addition, the surveys should be revised to collect socioeconomic data, making it possible to conduct a more complete analysis that can be expanded to the entire campus population.

Mode shifts also occur between walking and these other modes, so follow-up research could also explore these changes. The combined use of transit and bicycle for a commute trip was not possible to determine from the survey, so the impact of bicycle and transit integration on automobile commuting is also a topic for further study. Additional research could also stratify students into undergraduates and graduates and explore the commuting behavior of more campus
commuters, including faculty and staff. Finally, the analysis approach could be extended to other urban university campuses and other urban regions to see if similar results are produced.

**DISCUSSION**

Results revealed that the share of UWM student respondents who used automobile as their primary mode decreased between 2008 and 2012. This significant decrease in driving was associated with a significant increase in bicycle mode share, suggesting that bicycling replaced certain automobile commute trips. In addition, an increasing number of regular drivers bicycled as their secondary commute mode. These mode shifts could have been due to changes in student socioeconomic characteristics, employment opportunities, attitudes towards bicycling, or bicycle facility improvements made by UWM and the City of Milwaukee.

Analysis by distance revealed nuances in mode substitution. There were significant increases in bicycle commuting for students living between 1.0 and 9.9 miles (1.6 and 15.9 km) from campus. However, the increases in bicycling for students living between 1.0 and 1.9 miles (1.6 and 3.1 km) corresponded with decreases in bus commuting rather than automobile commuting, suggesting bus and bicycle substitution. Increases in bicycle commuting were associated with decreases in both bus and automobile commuting at distances between 2.0 and 4.9 miles (3.2 and 7.9 km), and bicycle commuting substituted for automobile commuting at distances between 5.0 and 9.9 miles (8.0 and 15.9 km). Furthermore, there was a significant shift in long-distance commuting from automobile to bus, which could have been driven by similar socioeconomic, employment, and attitudinal changes.

The study used an innovative approach to investigate commute mode choice by differentiating between the primary and second travel modes. Approximately two-thirds of the students who bicycled and nearly half of the students who used the bus as their primary mode also used a different, secondary mode to commute to and from campus. Many students who already bicycled were inclined to use the bus when they were not able to bicycle, but fewer bus users tried bicycle commuting. The results caution transportation research that relies on primary modes alone, which might overlook the importance of secondary modes. Finally, the article estimated the impacts of changes in the mode split on personal automobile VMT for student commute travel. Even the small reductions in personal automobile VMT between 2008 and 2012 suggested by the analysis would help reduce traffic volumes, parking demand, and other negative effects of automobile commuting.
ACKNOWLEDGEMENTS

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