The Efficacy of TDM Measures in Managing Parking Demand:

Evidence from McMaster University, Canada

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ABSTRACT

Although travel demand management (TDM) has featured more prominently in transportation planning and programs, its role in a university context is still emerging. University TDM efforts hold much potential to meaningfully shape the travel patterns of major regional trip generators, but there are also unique implementation challenges. Given the frequently progressive and sustainability-oriented values of millennials and their educators, universities appear to be ripe markets for changing travel behavior by improving non-auto alternatives. But can supplying better walking, bicycling, and transit services meaningfully shift a university mode share? Or are blunter instruments, such as raising the price of parking, reducing transit fares, and constraining parking supply necessary?

This study explores whether available TDM tools can meaningfully lead to auto travel reductions by analyzing data from a 2015 travel survey of student, faculty, and staff from McMaster University in Hamilton, Ontario. McMaster University is a large (approximately 30,000 students and 6,000 faculty and staff) public research university approximately 70 kilometers west of Toronto. This study focuses on the extent to which a) transit service improvements (travel times, transfers, and prices), b) walking and biking service improvements (travel time equivalents), or c) auto convenience (parking capacity, parking prices, and congestion) can deliver sufficiently meaningful reductions in auto mode shares to avoid needing additional on-campus parking capacity. Results from scenarios developed using mode choice models suggest that although improving non-auto travel services is important (perhaps most important for building public support of actions), the most meaningful shifts in mode shares are unattainable without constraining parking supply (i.e. increasing the price of monthly on-campus parking) and reducing the monthly price of transit for faculty and staff.

Keywords: mode choice, parking demand, scenario planning, travel demand management, university travel

INTRODUCTION

Travel demand management (TDM) has become a core competency in most transportation programs and provides a bundle of potential alternatives to road or transit investment. The TDM approach seeks to shift transportation system users away from cars and into alternate travel modes such as public transit, walking, or bicycling modes by either improving the quality of alternatives or providing better information (*pull factors*), or by making auto use less convenient or more costly (*push factors*). But while pull factors are frequently more palatable to decision-makers, this approach is often not enough on its own to change behavior (1).

Reducing auto use has become a core prescriptive policy approach of many sustainability-oriented urban planning efforts (2; 3). Auto use has long been underpriced relative to its external costs to others (4; 5), its excess use has contributed to urban sprawl (6) and traffic congestion (7), and its service advantage over other modes has degraded the market share of public transit (8). But despite efforts to shift from auto-oriented towards other travel choices, the influence of policy on user behavior, while significant, often pales in comparison with broader social, economic, and urbanization-related influences (9).

TDM has featured more prominently in transportation planning and programs over time (10; 11), but the role of TDM in a university context is still emerging (12; 13). Universities are significant regional trip generators and university TDM efforts could influence the behavior of tens of thousands of commuters - many of whom are still developing lifelong commuting habits. Nevertheless, university TDM efforts also have unique challenges despite the sustainability-oriented values of many students and their educators (14). Notably, university facility operations reinforce seniority within the university systems - for example in allocating parking permits (14). University TDM efforts have emphasized the importance of providing reasonable alternatives to driving if TDM is to be a policy priority (15). But the efficacy of TDM efforts to induce changes in travel behavior is often elusive and depends on many characteristics of the university population, social environment, and available services (16).

This study explores the conditions under which available TDM tools can lead to auto travel and parking demand reductions at McMaster University, a large (approximately 30,000 students and 6,000 faculty and staff) public research university approximately 70 kilometers west of Toronto, Ontario. The existing literature on TDM as a normative approach is discussed in the university context and the relative efficacy of different TDM measures are explored. Then the outlook for TDM success at McMaster University is estimated using data from an individual travel survey representing a 5% student sample (N=1,480) and a 15% faculty/staff survey sample (N=676) at McMaster University during the spring of 2015. Using mode choice models, parking demand is forecasted for 2025 given expected university growth under a range of alternative future transportation policy scenarios based on the estimated behavioral sensitivity to potential TDM measures.

LITERATURE REVIEW

Managing travel demand has become the focus of many transportation programs and represents an approach towards transportation service provision which emphasizes infrastructure management, encouraging non-auto travel modes, and discouraging auto use (17). TDM represents an alternate policy approach to the era of "predict and provide," through which auto travel demand is forecasted and accommodated through road and parking construction (18). While the merits of TDM and its associated efforts to reduce vehicle travel remain contested (19), it represents a shift in thinking: from building infrastructure for long-term growth to effectively managing existing infrastructure and investing in new services while focusing on encouraging use of more environmentally sustainable transportation options (20; 15). It focuses both on disincentivizing auto use and encouraging alternatives. TDM represents an approach rather than a single policy intervention, so TDM can feature many elements: a plan, an institutionalized program, specific projects, marketing and information provision (21), a minimalist approach towards new infrastructure (1), and evaluation (22).

TDM, a prescriptive approach

Travel demand management, as a prescriptive approach, is linked with multiple social objectives, including individual health, environmental sustainability, and efficient public service provision. These reasons broadly reflect the objectives of efficient public service provision (1) and reduction of social and environmental externalities from auto travel (20). Each is discussed in turn.

First, TDM is often justified on the basis of efficient public service provision, frequently for transportation system users without access to cars(23; 24). There are limits in the capacity to increase transportation service supply due to budgetary constraints, land scarcity, and political will (1). Focusing exclusively on capacity expansion leads planners to largely ignore the opportunity costs of using scarce resources for more productive uses. Increasing the supply of roads and parking spaces in congested areas is not always a viable approach (8). Instead, transportation planners have begun pursuing strategies to decrease the demand for single occupancy vehicle use, make better use of the valuable auto-oriented services available, and by encouraging commuters to use alternate modes (25). Auto travel remains an important part of urban life, but remedying both its direct consequences and potential inefficiencies due to its subsidization over other uses has been a focus of many corrective policy actions in university settings (26; 27; 28).

Second, TDM represents a means of mitigating the negative social and environmental consequences of automobility (29; 30). Automobility has resulted in significant social benefits to users, enabling complex daily activity patterns, fast mobility, and freedom (19). Despite these social benefits, public policy contexts which have historically favored automobility have led to auto dependence and traffic congestion, as well as environmental, social and economic consequences which are now being managed in efforts to holistically improve the transportation system (20). Auto use generates significant environmental consequences and dependence can be linked with less physical activity among users (31; 15), though not in all circumstances (32).

Insofar that TDM is consistent with efficiency, environmental sustainability, and health and that these are broad social objectives which reflect democratic values, TDM may have a role in university contexts as a matter of moral responsibility (33). According to Harkavy (34), Universities may have a moral obligation as models in educating the public to not only study society through basic research, but to engage society in promoting good outcomes such as environmental stewardship. Universities' social responsibilities may therefore extend to encouraging environmental sustainability both through education and by promoting positive environmental stewardship (33). Principles of environmental sustainability have been developed and institutionalized through efforts such as the Stockholm Declaration (35; 36). The Tbilisi Declaration of 1977, likewise, strengthened the principles of environmental sustainability for the purposes of university contexts, highlighting both environmental action and equal access to environmental education using different modes as keys to improving environmental sustainability (37). These objectives imply that Universities' obligations to develop basic research and educate in the classroom should be augmented by university-centered practical sustainability agendas. As such, universities' TDM priorities align with short-term interest to manage travel demand and align with broader moral grounds for universities to lead in environmental sustainability efforts and education.

TDM Efficacy and Implementation

As means to implement TDM, research has focused on the effectiveness and political palatability of both *push measures*, those which discourage overreliance on cars, and *pull measures*, those which make alternatives to auto travel relatively more attractive (1). Findings indicate that pull measures are more politically palatable (11; 4), but push measures may be most effective (38; 1). Pull measures may be more politically palatable because they directly reduce the price or improve a service, push measures are politically more challenging because they directly increase a price or decrease a service level for auto use. The relative efficacy of each approach rests on whether sufficient alternatives to driving already exist, the relative service and price differences between auto use and other options, and the conditions under which the full range of daily travel needs can be accommodated using alternate approaches.

Others highlight that bundling push and pull factors is critical to yield the largest behavioral shifts from TDM(15). According to Eriksson et al. (17) push measures (e.g. increasing the price of gasoline) and pull measures (e.g. improving public transit services) are not enough on their own; instead, packages of joint push and pull measures are necessary to achieve meaningful behavioral changes. Alternately, providing system users with information on the relative balance of travel incentives and disincentives has more commonly featured as a TDM technique which seeks to better align user decision-making with existing price signal changes of which users may not be aware (21).

Regardless of the technical merits of push and pull factors, considering the institutional and political circumstances which can lead to TDM is important. For example, research indicates that employers' approaches towards encouraging commuting significantly impacts the likelihood of using a car (39). Research by Zhou et al. (10) suggests that the potential success of TDM programs (e.g. carpool matching) depends significantly on the wage profile of employees (higher incomes are associated with access to more choice) and that larger employers generated returns to scale which improved the efficacy of TDM programs. This suggests that larger employers can play important regional TDM roles and that consolidating programs for smaller employers can yield benefits (10).

TDM in Universities

Several themes are common among studies of TDM in universities. First, student populations are already much more likely to commute by non-auto means - and enjoy doing so (40), as they live closer to the university than faculty (13). Second, public transit quality and capacity serve as barriers to behavioral shift (13). Third, based on students' location choices, students are less likely to use auto modes and more likely to walk or bike to campus, leading active transport to be a potentially attractive TDM alternative(13). Despite the less auto-oriented travel patterns of university commuters (and especially students), it remains unclear whether the market for additional non-auto travel is already saturated or not.

While some studies have found optimism for changing students' travel behavior (13), others have found that students have already embraced more sustainable travel alternatives and there is only modest hope in additional travel behavior adjustments. For example, Rose (41) finds that by simply providing students with better information on public transit options in the context of a Melbourne university, significant uptake in public transit is expected. Likewise, Shannon et al. (12) find that by reducing actual and perceived travel times by public transit and bus could induce up to 30% of university students, faculty, and staff to switch from automobile use.

Others suggest that the opportunities for transportation or facility interventions to induce travel behavior change among university students, faculty, and staff is poor. Akar and Clifton (16) find that students' latent preferences are more important than any transportation services or land use patterns in shaping the likelihood of using non-auto travel modes. Similarly Nikurunziza et al. (42) support the weakness of physical interventions and the relative strength of mental states and preferences in shaping travel behavior. Bonham and Koth (43) likewise highlight that campus culture can often be counter-productive to the type of pro-cycling culture needed for cycling commuting to be socially validated. Miralles-Guasch and Domene (44) similarly suggest that behavioral shifts can be highly challenging to achieve even in university contexts - particularly in suburban contexts in which the market in non-auto alternatives is very poor. Davison et al. (45) highlight regional attitudinal differences, gender-related differences, and residential location (at home vs. near campus) choices as critical barriers to switching from auto use. These findings imply that the role for policy may be strongest in providing information and actively shaping preferences - insofar that this is feasible (46; 47).

RESEARCH DESIGN

Three research stages were employed to explore the conditions under which parking demand reductions can best be accomplished through TDM at McMaster University. First, a survey was developed and administered to McMaster students, faculty, and staff. Participants were asked about their current travel behavior, locations of residence, individual and household characteristics, and travel preferences. A subset of survey participants who regularly commute to work by car were also administered a stated preference survey designed to identify parking price sensitivity with respect to mode choice. Second, using these data, discrete choice models were estimated to explore the predictors of mode choice. These models were calibrated to estimate mode choice responses to alternate transportation service, demand management, and price interventions which could be undertaken. Finally, models calibrated using the survey data are employed to forecast eight alternate parking utilization scenarios under which future demand can be accommodated by the existing system. To estimate the extent to which TDM measures can enable the university to accommodate expected growth without constructing new parking capacity, several scenarios are developed based both on push (parking prices and travel costs) and pull (non-auto travel costs) factors. Scenarios are developed using a sequential modeling system - in which revealed and stated preference choice models are used in sequence to forecast changes in future mode shares and parking demand. Each of these three steps are discussed below.

Travel Survey

The travel survey was administered to McMaster students (undergraduate and graduate), faculty, and staff through the McMaster University Faculty Association, Human Resources, and the Office of the Registrar during the spring of 2015. Following cleaning, the survey data represented 5% of students (1,550/30,117) and 15% faculty and staff (892/5,895). Survey participants were recruited by email through authorized student, faculty, and staff list-servers on campus and it is believed that the underlying sample frame represents the university population of interest.

The survey included questions relating to how individuals traveled to and from McMaster University, the characteristics of the survey participants, attitudes towards travel, and (for a sub-set of survey participants) a series of stated preference questions asking respondents to select from among alternative hypothetical travel choices. The latter part of the survey is known as *stated preferences*, as opposed to the former part which is usually referred to as *revealed preferences*. The survey was administered between March 11, 2015 and April 17, 2015. As list-serves were employed for recruitment, each potential participant received the survey four times: on initial recruitment letter and three subsequent reminders. Participants' comments about the survey were submitted both to the research team and to members of the McMaster University Ethics team and questions and identified problems were addressed.

Model Calibration

Multinomial logistic regression models were employed to estimate predictors of mode choice. Two types of data are employed: revealed preference data and stated preference data. While revealed preferences reflect survey participants' stated behavior in reality, stated preferences reflect survey participants stated choices in response to a hypothetical situation. The stated preference approach is needed in this case to estimate participants' behavioral sensitivity to the monthly costs of parking and transit prices. As such, all future-oriented scenarios are developed using models in which behavioral sensitivity to alternate policy environments are calibrated to the underlying population of interest.

Revealed Preferences

First, multinomial logistic regression models of mode choice are estimated for McMaster University faculty, staff, and students. Models are estimated separately for students than from faculty and staff. The underlying population is estimated to be approximately 30,117 students and 5,895 faculty and staff, of which 1,550 students (5%) and 892 faculty and staff (15%) sufficiently completed the online survey following cleaning and pre-processing. Mode choice models are estimated using multinomial logistic regression models, according to which the probability of driving alone - the reference case, is estimated in comparison with walking, taking public transit, carpooling, or bicycling to campus. Common predictors of mode choice include socioeconomic characteristics (e.g. age, number of days typically spent on campus in a week, household size,), characteristics common to all potential choice alternatives (e.g. travel times), transportation option access (e.g. vehicle ownership, parking permit ownership, bicycle ownership), land use characteristics (e.g. job density), and mode-specific characteristics (e.g. number of public transit transfers necessary).

Stated Preferences

Using a stated preference experimental design, those faculty, staff, and students who indicated that they had access to a vehicle and parked on campus were administered eight stated preference choice experiments in which survey participants were asked to make hypothetical choices about their mode to work in the event that they faced different service levels. In total, 176 students and 172 faculty and staff participated in the stated preference survey components and each responded to eight choice sets each (a total of 1,408 student choice experiments and 1,376 faculty and staff choice sets). Survey participants were given choice alternatives constrained to the following four (students) or five (faculty/staff): two (students) or three (faculty/staff) auto travel options each with a different parking location and price alternative, walking or biking, and public transit. Each of these alternatives were assigned choice attributes consisting of the following: a travel time in minutes, a monthly price (0 for active travel and alternate monthly prices for driving and public transit – each of which are comparable to existing prices), whether there was a shuttle or not (specific to select auto alternatives), and which a lot could be used for parking (specific to some auto alternatives). Parking lots mirrored current prices and ranged from $40 to $118, while public transit passes (free for students) for faculty and staff were assigned prices between $0 and $86 per month. An orthogonal survey design was employed.

Projections and Forecasting

The efficacy of potential TDM policy levers are estimated and tested using forecasts of plausible alternate TDM scenarios. Accommodating future vehicular travel demand within the existing parking capacity was used as an objective through which the efficacy of alternate policy actions are estimated. Existing parking utilization is estimated as a basis of comparison and the estimated mode choice models and background university growth projections are employed to estimate changes in scenario-specific mode choice and parking utilization. Future growth (to 2025) in faculty and staff are projected to be 30% and growth in students is projected to be 15% using data from McMaster University on recent growth trends.

Mode share and parking utilization forecasts are estimated using eight alternate future scenarios. Four fundamental scenarios (listed below) are explored and each of these four scenarios are further assessed based on an unpriced alternative (in which transit and parking prices remain the same in the future) and based on a priced alternative (in which the cost of faculty/staff transit passes decreases by 30% and the price of all parking passes increases by 30%). This leads to eight alternate scenarios in total (see Table 1).

Table 1. Differences Between Eight Modeled Scenarios

<table>
<tr><th rowspan="3">Treatment</th><th colspan="8">Scenario Type (8 in total)</th></tr>
<tr><th colspan="2">Build Parking</th><th colspan="2">Minimalist Approach</th><th colspan="2">Transit Improves</th><th colspan="2">Broader TDM</th></tr>
<tr><th>Unpriced</th><th>Priced</th><th>Unpriced</th><th>Priced</th><th>Unpriced</th><th>Priced</th><th>Unpriced</th><th>Priced</th></tr>
<tr><td>All Parking Prices</td><td rowspan="2">No real change.</td><td>+30%</td><td rowspan="2">No real change.</td><td>+30%</td><td rowspan="2">No real change.</td><td>+30%</td><td rowspan="2">No real change.</td><td>+30%</td></tr>
<tr><td>Faculty/Staff Transit Prices</td><td>-30%</td><td>-30%</td><td>-30%</td><td>-30%</td></tr>
<tr><td>Parking capacity</td><td colspan="2">Increases with background growth</td><td colspan="6">No change, implying a decline in per-person parking permits proportional to background growth.</td></tr>
<tr><td>When parking demand exceeds capacity</td><td colspan="2">n/a. By definition, capacity exceeds demand.</td><td colspan="6">When demand exceeds capacity, auto travel times are increased by five minutes due to additional searching time for parking or walking from further-lying locations. This occurs in one iteration.</td></tr>
<tr><td>Congestion growth</td><td colspan="2">None; traffic flow improves at the rate of growth.</td><td colspan="6">Otherwise, auto travel times increase by 1% by 2025 due to background increases in traffic congestion.</td></tr>
<tr><td>New parking lot locations</td><td colspan="2">Reflect current lot distributions.</td><td colspan="6">None.</td></tr>
<tr><td>Transit travel times</td><td colspan="4">No change.</td><td colspan="4">10% decrease in travel times</td></tr>
<tr><td>Transit transfers</td><td colspan="2">No change.</td><td colspan="2">No change.</td><td colspan="4">10% potential trips have one less transfer</td></tr>
<tr><td>Walking and bicycling services</td><td colspan="6">No change.</td><td colspan="2">Services improve proportionally to a 10% travel time decrease.</td></tr>
</table>

The expected mode-specific travel times, availability of parking permits, and presence of transfers for the underlying sample were adjusted based on each of the scenarios to simulate alternate mode shares and develop parking demand relative to existing conditions. Changes in parking demand are estimated as follows.

First, parking mode shares are independently estimated for students and for faculty/staff in each of the scenarios. Mode shares are independently estimated as the mean probabilities in each of the two groups of choosing from among the five modes (drive alone, public transit, walking, bicycling, and carpooling) given changes in covariates which are adjusted according to the scenario specification. As such, mode shares are estimated for each scenario using the estimated revealed preference mode choice models characterizing the links between policy-specific actions and the probabilities of using each of the modes. For example, in scenarios in which no new parking capacity or permits are made available, the probability of students having a parking pass is reduced by 12% (the inverse of the growth rate), while the probability of faculty and staff having a parking pass is reduced by 23%.

Then to construct the four scenarios in which the price of parking is increased by 30% and the price of faculty/staff transit use is reduced by 30%, projected mode shares are re-estimated using stated preference model results for current users who drive and park on campus alone. The difference between the forecasted mode splits among these auto commuters was estimated for both active modes and for public transit. Thus, the expected share of users switching to public transit was estimated for each scenario and the share of those switching to active transportation modes was estimated (and allocated equally to walking and bicycling modes). As stated preference models did not account for the potential impacts of price on carpooling, the carpooling mode share was expected to remain the same in the future.

Second, using forecasted mode shares for each of the scenarios, parking demand is estimated and in the cases of scenarios in which parking demand exceeded absolute capacity, mode shares were re-estimated once (assuming five-minute longer auto travel and parking search times) to estimate final change in demand. To estimate change in parking demand relative to existing conditions, first scenario specific parking demand is estimated for each group (faculty/staff or students) in either the initial (2015) or future (2025) years:

$$M_{sgy} = \left(D_{sg} * P_{gy} * K_g * A_g / 5 * O_g\right) + \left(L_{sg} / C * P_{gy} * K_g * A_g / 5 * O_g\right) \qquad (1) \quad ,$$

where M_{sgy} represents the parking demand for scenario s (described in Table 1) for group g (faculty/staff or students) in year y (2015 or 2025); D_{sg} represents the drive alone mode share; P_{gy} represents the population (34,100 students and 4,300 faculty and staff in 2025 and 30,100 students and 3,300 faculty and staff in 2015); K_g represents the share of group g parking during the peak parking hour in the midday (0.67 for students and 0.96 for faculty and staff); A_g represents the number of days on campus by group g (4 for students of 4.7 for faculty and staff); and O_g represents one minus the share of parkers in group g parking off campus (29.9% for students and 12.0% for faculty and staff); L_{sg} represents the carpool mode share in scenario s and group g; and C is 2.1 (the assumed occupancy of the mean carpool).

$$G_s = \frac{M_{sg_1y_2} + M_{sg_2y_2}}{M_{sg_1y_1} + M_{sg_2y_1}} \qquad (2) \quad ,$$

where G represents the parking demand growth in scenario s; M_s represents the parking demand for scenario s; $g1$ and $g2$ respectively represent the faculty/staff and student groups; and $y1$ and $y2$ respectively represent 2015 and 2025.

When the very first estimate of G_s is expected to be greater than 1.05, auto travel times are expected to grow by five minutes due to searching and parking further from campus. This would mean that travel demand is expected to grow by 5% and would leave the on-campus parking at capacity, given that the two highest demand days are approximately 95% of capacity. These higher search and egress times are very bluntly re-introduced to the mode share model by increasing auto travel times by five minutes in a one-time iteration.

RESULTS

The strength and outlook of potential interventions to reduce parking demand is estimated by describing existing parking utilization, estimating future parking demand using mode choice models, forecast parking utilization based on alternate scenarios, estimate parking price sensitivity, and further refining parking utilization estimates based on alternate scenarios. The efficacy of TDM options are interpreted with respect to accommodating future peak period parking demand relative to existing parking supply.

Revealed Preference Model Results

First, the predictors of typical mode choice to work are estimated using multinomial logistic regression. Results are shown in Table 2 and illustrate the strength of key correlates in predicting student and faculty/staff mode choice to campus. In student models, results indicate that having a university parking permit, being a female, having many public transit transfers, not owning a bicycle, and residing in a large household are associated with a higher likelihood of driving alone.

Other correlates reveal interesting nuances in utility for different modes among students. For example, models in which travel time is specified both as a logged and a squared logged term are preferred and these indicate a positive utility to travel time for some modes up to a mode-specific threshold, above which mode-specific utility declines. This is broadly consistent with previous findings by Paez and Whalen on commuting satisfaction among McMaster University students (40). Those thresholds are estimated (e.g. for public transit: exp(7.468/abs(-1.247)/2) = 20.0 minutes) as follows: 4 minutes (drive alone), 10 minutes (walking), 20 minutes (public transit), 3 minutes (carpooling), and 3 minutes (bicycling). Thus, both walking and public transit exhibit the highest positive utilities of travel time. Student age is eliminated as a covariate, as there is very little variation in age among students and the variable was not significant in models.

Results from the faculty and staff model are broadly consistent with the findings on students (see Table 2). But in contrast to student models, neither bicycle ownership nor sex were linked with mode choice (which is different from students), while being older is associated with a lower likelihood of using alternate modes. Similarly to students, travel times are non-linearly associated with choosing alternatives to driving alone. A positive utility from travel time was estimated for four of the five modes, while walking travel times are a net disutility at diminishing rates. The inflection points at which higher travel times for the other four modes become a disutility are estimated similarly to above: 21 minutes (drive alone), 29 minutes (public transit), 11 minutes (carpooling), and 28 minutes (bicycling). The non-linear relationship between travel times and utility - particularly given the high thresholds at which faculty appear to enjoy a positive utility from travel - suggest that reducing travel times sometimes may achieve counter-intuitive results in achieving mode shifts. For example, if someone's 29-minute transit trip were shortened while the their alternative drive-alone trip were lengthened (perhaps due to congestion) from 15 to 18 minutes, all else being equal, one might expect the user to gain even more utility from driving alone rather than taking public transit.

Table 2. Revealed Preference Mode Choice Results: Multinomial Logit (Drive Alone is Reference)

	Students (N = 1,480, McFadden R-Squared = 0.419)					Faculty and Staff (N = 676, McFadden R-Squared = 0.420)				
Explanatory Variable	Drive Alone	Walk	Public Transit	Carpool	Bicycling	Drive Alone	Walk	Public Transit	Carpool	Bicycling
Intercept	n/a	-0.940	-6.261	-4.607	1.997	n/a	-10.61	4.378*	2.207	-8.363
Number of Transfers	n/a	0.079	-0.460*	0.036	-0.353	n/a	-0.358**	-0.247**	0.074	-0.807*
Sex: Female Status	n/a	-1.138**	-0.967**	0.211	-2.03***	n/a	n/a	n/a	n/a	n/a
Respondent Age (ln)	n/a	n/a	n/a	n/a	n/a	n/a	-0.065**	-0.05***	-0.031*	-0.112**
Mode-Specific Travel Time (ln)	1.750**	8.303***	7.468***	1.456	1.346	2.721***	-1.353**	2.189***	2.225***	1.748**
Mode-Specific Travel Time Squared (ln)	-0.66***	-1.79***	-1.25***	-0.61***	-0.56**	-0.45***	0.071	-0.33***	-0.46***	-0.263*
Parking Permit (binary)	n/a	-2.98***	-5.03***	-1.34***	-2.983	n/a	-2.94***	-3.71***	-0.86***	-2.940
Vehicle Ownership (binary)	n/a	1.496	-1.84***	0.607	-1.694**	n/a	-2.34***	-2.65***	-1.44***	-2.97***
Bike Ownership (binary)	n/a	-0.174	-0.273	-0.225	4.038***	n/a	n/a	n/a	n/a	n/a
Days on Campus	n/a	-0.049	0.604**	0.255	-0.218	n/a	0.674***	0.391***	0.195*	0.298
Job Density (ln)	n/a	-1.414	-1.873**	0.535	0.319	n/a	5.994**	-0.699	-0.226	3.018
Job Density Squared (ln)	n/a	0.120	0.174***	-0.027	0.009	n/a	-0.437**	0.076*	0.018	-0.215
Household Size (ln)	n/a	-0.224	0.100	0.089	0.382***	n/a	-0.470**	0.170**	0.174**	-0.893**

Significance denoted at 0.10-level (*), 0.05-level (**), and 0.01-level (***)

Stated Preference Model Results

Second, stated preference models are estimated both for students and faculty/staff (see Table 3). These models are designed to estimate the price sensitivity of parking demand, while other covariates are specified partially for comparison with revealed preference results.

Table 3. SP Mode Choice Results: Multinomial Logit (Active Transport is Reference)

	Students N = 176; 8 questions each; 5 potential alternatives each McFadden R-Squared: 0.167					Faculty and Staff N = 172; 8 questions each; 4 potential alternatives each McFadden R-Squared: 0.130			
	Active Transport	Drive & Park West Campus	Drive & Park at Stadium	Drive & Park at Ward	Public Transit	Active Transport	Drive & Park West Campus	Drive & Park at Main Campus	Public Transit
Intercept		25.90	20.67	20.38	15.34		5.89	13.46***	-8.58
Price (ln)		-3.37***	-3.37***	-3.37***	-3.37***		-0.31***	-0.31***	-0.31***
Age (ln)		2.00	1.76	3.65*	0.67		-0.22***	-0.22***	-0.22***
Travel time (ln)	-3.34	1.98***	3.11***	-1.20	-3.77**		-3.35***	-3.81***	-4.02***
Travel time (ln) squared	0.28	-0.28*	-0.64***	0.41**	0.38*	-2.07	3.52	0.08	12.61***
Household members <15		-1.92**	-1.19	0.16	-1.41	-0.02	-0.98*	-0.37	-2.05***
On Main Campus (dummy)		-1.72***	-1.65**	-0.37	-1.35*				
On Main Campus, South (dummy)							-0.19	-0.15	1.08
On Main Campus, North (dummy)							-0.55	-1.22***	-0.37
Days on Campus		0.52**	0.46	0.97***	1.61***		-0.78***	-0.75**	-1.20***
Residential Density (ln)		-4.98	-2.78	-5.79*	-8.75***		n/a		
Residential Density (ln) squared		0.43	0.26	0.51*	0.75***		n/a		
Household Size		0.27	-0.18	-0.24	0.48		1.37***	1.33**	1.88***

Significance denoted at 0.10-level (*), 0.05-level (**), and 0.01-level (***)

Based on alternate specifications, active transportation is chosen as the reference group - against which the relative utility of alternate choices are compared. There are three driving alternatives within each choice set: parking on West Campus, parking at the stadium parking structure, or parking at the outer-lying Ward Lot. Finally, public transit is employed as a final alternative. Overall, model results find that there are non-linear relationships between travel times and the utility of various alternatives. Linear and squared travel time coefficients are used to estimate thresholds above or below which the links between travel times and utility changes directions: 34 minutes (driving to west campus), 11 minutes (drive and park at stadium), and 4 minutes (drive and park at Ward). As such, these thresholds imply that given the relative costs and convenience of these parking lots (Stadium is most convenient but Ward is most challenging to access to due to its low-frequency shuttle), students are most willing to travel further distances to West Campus and least far to Ward. Based on alternate specifications, the monthly price of travel is assumed to be equally sensitive across alternate all alternate modes.

Next, faculty and staff stated preference results are estimated. Results for faculty and staff are generally similar to those of students, but the sensitivity to the price of parking is somewhat different. While models in which the natural-log of price is inserted were preferred for students, faculty and staff models included both the natural log and the squared natural-logged terms. Given the negative signs on both coefficients, this indicates that faculty and staff are sensitive to price at an increasing rate.

Scenario Assessment

Using parking utilization data collected from the McMaster Parking Services department, typical parking utilization levels are estimated for the current conditions. Parking capacity is 3,543 stalls, while utilization data indicates that fall use is higher than that in other months. Typical in-session parking demand ranges from 1,500 to 3,000 spaces, while on two days in the year utilization was more than 95% of capacity.

First, mode shares are estimated using the unpriced scenarios. Expected mode shares are estimated using the mean RP mode choice probabilities, while adjusting the covariates in line with each of the scenarios. Mode shares in the unpriced Build Parking Scenario are equivalent to current mode shares, as the availability of all services and parking are assumed to simply maintain current rates. Expected mode shares for alternate scenarios are shown in Table 4 and are estimated using assumptions in Table 1. Results indicate that of the scenarios, Build Parking drive alone mode shares are highest (particularly for faculty and staff), while Broader TDM drive alone mode shares are lowest. Student mode shares change very little between each of the scenarios (ranging from 16.5% to 19.0%), but faculty and staff mode shares change most (ranging from 58.1% to 40.7%).

Expected growth in parking demand (Table 4) is estimated using Equation 2 and represents a combination of the growth in faculty/staff (30% growth to 2025), and students (15% growth to 2025), and the relative change in mode choice among the five modes. The most impactful actions in managing future parking demand are constraining parking supply, increasing the monthly price of on-campus parking (+30%) and reducing the monthly price of public transit for faculty and staff (-30%). The impact of not building additional parking capacity can be seen in the difference between the Build Parking and Minimalist Approach: this single action is expected to decrease parking demand by more than eight percent (20.2% to 11.3% in unpriced scenarios and 13.5% to 5.2% in priced scenarios).

Table 4. Forecasted Mode Shares and Parking Demand Growth in Eight Future Scenarios (2025)

Scenario	*Minimal Action*		*Build Parking*		*Improve Transit*		*Broader TDM*	
	Unpriced	*Priced**	*Unpriced*	*Priced**	*Unpriced*	*Priced**	*Unpriced*	*Priced**
Students								
Drive Alone	18.4	17.1	19.0	17.7	18.0	16.8	17.8	16.5
Walk	26.8	27.3	26.9	27.4	27.3	27.8	28.1	28.6
Transit	44.7	45	44.1	44.5	44.8	45.1	44.4	44.7
Carpool	6.9	6.9	6.9	6.9	6.7	6.7	6.7	6.7
Bike	3.2	3.6	3.1	3.6	3.2	3.6	2.9	3.4
Faculty/Staff								
Drive Alone	48.0	45.2	58.1	54.7	46.8	44.1	43.2	40.7
Walk	7.7	8.5	7.0	8	7.9	8.6	8.9	9.7
Transit	18.4	19.6	12.9	14.3	18.9	20	18.9	20
Carpool	16.3	16.3	13.8	13.8	16.3	16.3	18.1	18.1
Bike	9.6	10.4	8.2	9.2	10.2	11	10.8	11.5
Total Change in Parking Demand Relative to Existing								
Percent Change	+11.3%	+5.2%	+20.2%	+13.5%	+8.8%	+2.8%	+6.0%	+0.2%

Significance denoted at 0.10-level (*), 0.05-level (**), and 0.01-level (***)
** Priced scenarios represent 30% increases in the monthly price of parking for all users and a 30% decrease in the monthly price of a faculty/staff transit pass. Students currently can use transit for free during the school year.*

CONCLUSION

The opportunities for TDM in universities have gathered increased attention both because universities represent significant trip-generating anchor institutions and because of the moral responsibilities of universities as social and environmental stewards in defining a normative future. While many, including this study, have identified the relative merits of various interventions in affecting mode shift, rectifying the balance of winners and losers (those most impacted) is likely to remain a critical consideration independent of efficiency concerns which will influence the potential for implementation.

This study of McMaster University students, faculty, and staff in Hamilton, Ontario highlights the opportunities for university service providers to affect mode shifts and manage parking demand. While these opportunities hinge on both employing push factors (constraining parking capacity and increasing the price of parking) and on pull factors (reducing the price of transit while improving alternate services), push factors appear to be more critical. Beyond parking capacity and price interventions, the roles of public transit improvements and walking and biking interventions are relatively modest (see Table 4). By deploying more comprehensive TDM actions from the Minimalist Approach to the Transit Improves to Broader TDM, no other mode shifts are expected which are higher than 3% in total. This partly reflects the strength of pricing and parking capacity policy levers, but also highlights the complex relationships between transportation services and system utility. For example, mode choice models indicate that travelers actually gain utility from higher travel times up to certain thresholds, above which mode-specific utilities are negative; so reducing travel times across the system does not always create a net user benefit, as one might have expected. Likewise, results indicate that the potential for planners to meaningfully shift mode share is significantly reduced when constraining TDM efforts strictly to improving alternatives to driving without effectively managing parking capacity and the generalized price framework.

Nevertheless, in light of the unequal implications of policy actions on different users, improving alternatives to driving will remain an important ingredient to enabling public buy-in to affect mode shifts. For example, this study suggests that faculty and staff have more leeway to switch to non-auto alternatives. But without pull factors (improving walking, bicycling, and transit services while reducing public transit fares), TDM measures may be more challenging to implement.

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