Much-Anticipated Marriage of Cycling and Transit

How Will It Work?

Julie Bachand-Marleau, Jacob Larsen, and Ahmed M. El-Geneidy

In response to the environmental, economic, and social costs associated with overreliance on the automobile, planners and transportation professionals are promoting sustainable alternatives such as walking, cycling, and public transit, either as single modes or in combination. It has been argued that the marriage between cycling and transit presents opportunities for synergy by enlarging catchment areas of transit stations while drawing in new users to both of these green modes. However, because of the marginality of combining cycling and transit in North America, there is a shortage of reliable empirical studies in this area. The present study addressed this gap through an analysis of travel behavior and preferences related to cycle–transit (C-T) integration. An online survey was conducted in the region of Montreal, Canada, during the summer of 2010. The questionnaire included a section on Montreal's public bicycle sharing system, Bixi (bicycle taxi), and its potential for integration with transit. Three current or potential C-T user groups were identified through a factor–cluster analysis: current parking bike-and-riders, Bixi users, and car drivers. Bringing a bicycle on transit was the preferred form of integration; however, scenarios involving bicycle parking (or using a public bicycle) were likely to be used more regularly. To accommodate the greatest number of bicycle–transit trips, measures that facilitated parking at transit stops and those that enabled the bringing of bicycles on board transit vehicles were recommended in tandem.

In response to concerns over congestion, air pollution, and sedentary lifestyles related to automobile dependency, transportation professionals and researchers are seeking new solutions. Many cities have adopted strategies to increase the attractiveness of walking, cycling, and public transit usage. Among the measures implemented, some have been aimed at facilitating the combination of two or more of these transportation modes under the moniker "bike-and-ride," cycle–transit integration (C-T), or simply the transportation cocktail. Combining modes allows for more flexibility, making multimodal transport more appealing, and increases travel options. Similarly, integration can be beneficial for transit agencies as they expand transit stations' service area at both ends of the transit trip (*1*). Some researchers claim that C-T will increase the mode share of cycling and public transit at the expense of the use of private vehicle and help in decreasing congestion, but others debate this claim (*2*). Up until this point, there has not been any study in the North American context that uses empirical data to measure the actual needs for such integration among cyclists and transit users.

Past literature has identified general measures that can facilitate bicycle and transit integration (*3*); however, details on how this union can work have been in short supply. Recognizing the need for elementary information on the subject for researchers and practitioners alike, this paper seeks to answer two basic questions related to bicycle–transit integration: (*a*) who are the potential users of this type of intermodal transport?, and (*b*) what are their current needs and priorities? This research draws on a detailed online survey conducted in Montreal, Quebec, Canada, specifically for this purpose. The survey included demographic, travel behavior, and spatial questions to explore the factors affecting the use of and opportunities for C-T integration. In addition, given the presence in Montreal of Bixi (bicycle taxi), North America's first large-scale public bicycle sharing system, a set of questions was included to measure the potential of this new system to augment the existing public transit service.

LITERATURE REVIEW

The body of knowledge on C-T is relatively small; however, as evidenced by the growing literature and transportation initiatives, interest in this form of multimodal transportation is growing. Researchers have identified four areas for C-T implementation: (*a*) enabling bicycles to be brought on transit vehicles, (*b*) improving the availability of parking near transit stops, (*c*) connecting transit stations to an existing network of bicycle paths and lanes, and (*d*) providing bicycle sharing systems near transit stations and major destinations (*3*). However, beyond this general roadmap, little is known about demand for various integration measures. Developing a more detailed understanding of this market, the priorities of potential users, and the specific benefits of integration is an essential next step.

Not surprisingly given the reliance on buses as the main mode of public transit in North America, bicycles on buses (BOB) is by far the most common type of C-T. For example, of the C-T measures of 83 North American transit authorities listed in an online database, 63 involve BOB (*4*). Although no systematic method exists for monitoring usage of bus racks, reports from transit agencies range from 575,600 to less than 20 bicycle boardings per year, with an overall year-to-year growth documented in the share of BOB trips to total boardings (*5*). Moreover, it appears that opportunities for BOB are growing; the provision of bicycle racks on buses has almost tripled in the United States in only 8 years, from 27% in 2000 to 71% in 2008 (*3*). Nonetheless, various criticisms have been raised about

School of Urban Planning, McGill University, Suite 400, 815 Sherbrooke Street, West, Montreal, Quebec H3A 2K6, Canada. Corresponding author: A. M. El-Geneidy, ahmed.elgeneidy@mcgill.ca.

Transportation Research Record: Journal of the Transportation Research Board, No. 2247, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 109–117.
DOI: 10.3141/2247-13

BOB, including delays to transit service and underuse (*2*). More substantial, however, are the critiques that BOB will remain a marginal service, because of limited rack capacity and smaller bus stop catchment areas, in part because of stop spacing (*6, 7*).

The question of catchment or service areas is central to the branch of C-T research concerned with cycling to transit or bike-and-ride. In one study, in which survey respondents were presented with bike-and-ride scenarios containing hypothetical access distances, researchers found that the majority of people willing to bike and ride were within 2.4 km of the transit station, whereas those between 3.2 and 4.8 km demonstrated equal preference for car and bicycle as an access mode to transit (*8*). A study from Mumbai revealed that whereas only 1% of commuters traveling 1.2 km or less used a bicycle to access transit, that figure climbed to 11% beyond that distance (*9*). Overall, the mean access distance by bicycle was found to be 2.7 km. A Dutch study found that cycling was the predominant train access mode between 1.2 and 3.7 km; compared with cases in the United States and India, this similarity suggests that access distances may traverse across cultures (*10*). Further analysis from the Netherlands revealed that access and egress time are not stable for all trip purposes, but increase proportionately with in-vehicle time, then decline as total trip extends beyond 60 min (*11*).

Although C-T is related to the growing body of work on bicycle infrastructure use generally, there has been only cursory study of the effect of bicycle lanes on increasing the attractiveness of C-T. One such study indicated that the presence of bicycle facilities at the census tract level had a positive effect on demand for C-T (*6*). However, the effect of bicycle infrastructure has been shown to vary depending on cycling experience; among Texas cyclists, the presence of bicycle lanes had four times the effect on encouraging bike-and-ride among inexperienced riders relative to those with more experience (*8*). It is logical to conclude that in other locations as well, the presence of infrastructure will have a greater effect attracting new and inexperienced cyclists to the C-T option than among veteran cyclists.

Some research has been directed toward understanding the sociodemographic factors characteristic to current and potential C-T users, although conclusions have been mixed. Although preliminary research in the United States suggests that household income levels and vehicle ownership are negatively correlated to C-T usage (*6, 7*), studies from the Netherlands reveal the opposite (*12*). This may indicate that C-T usage in the United States is higher among people with fewer travel options. Another explanation for these mixed results may be that C-T usage is in part determined by attitudinal factors that cut across sociodemographic lines, as demonstrated in related research on opportunities for mode shifting (*13*).

DATA AND METHODOLOGY

To better understand current and potential users of bike and ride, an online survey on C-T was undertaken in the region of Montreal, Canada. The official mode share of cycling for Montreal is 1.3% of all trips (*14*), which is around the national average; however, central areas are between 6% and 7% (*15*). Currently, bicycle and transit integration in Montreal is possible in some circumstances, but it is restricted at certain times and on certain transit vehicles. Bicycles are prohibited on the city's metro during peak hours, on weekends, and during special events, largely because of capacity limitations. Although most stations are not equipped with aids for bringing bicycles to boarding platforms, newer and some downtown stations include elevators. Bicycles are allowed outside peak hours on two of the five commuter train lines. Buses operated by the Société de transport de Montréal, the transit provider on the island of Montreal, are not equipped with bicycle racks; however, several other transit agencies in the region have installed such racks on their bus fleets. Regular outdoor bicycle parking can be found at most metro, bus, and train stations; longer-term and covered parking is rare.

Given the limitations of online surveys, particularly for overrepresentation of certain groups, a variety of methods were used to ensure that a broad cross section of the public was reached. The survey was publicized through a combination of e-mail newsletters, mailing lists, several newspaper articles in English and French, a radio interview, and various social networking media. Flyers advertising the survey were distributed at the major transit stations of the region. These measures allowed for broader exposure than would be possible with only e-mail distribution, as recommended by Dillman et al. (*16*). The total sample of the survey was 1,787 individuals. Incomplete and outlier observations were excluded from the analysis leading to a sample size of 1,432 individuals. This sample is approximately equivalent to the number of cycling trips recorded in the regional travel survey, which covers 5% of the region's population and is considered a representative sample (*17*). This number is also larger than most of the samples used in previous cycling travel behavior research (*18–22*). However, because the region's morning peak transit mode share is more than 20%, a larger sampling of transit users will be required to understand the preferences for C-T integration among existing transit users.

The analysis section commences with an explanation of the state of C-T in Montréal followed by descriptive statistics obtained from the survey. Descriptive statistics concentrate on the demographics and travel habits of the surveyed population. Understanding the characteristics of C-T potential users is the next step. This is done through a market segmentation analysis. Market segmentation is a common practice in the travel behavior research field and has been used to develop a clearer portrait for new transit projects before major investments and to attract new patrons (*23–25*). Essential to this type of analysis is the concept that the market for any given product or service consists of several segments, rather than one homogenous whole. Studies have used market segmentation to identify perceived types of cyclists by users and nonusers (*26*); however, this technique has not yet been used to identify opportunities for C-T. Factor–cluster market segmentation analysis, a two-step analytical procedure, was used to classify large data sets into meaningful groups [see Shiftan et al. (*23*), Outwater et al. (*24*), and Krizek and El-Geneidy (*25*) for examples of factor–cluster market segmentation analysis]. A principal component factor analysis was used to learn how each of the variables relates to one another. Factor analysis extracts a small number of fundamental dimensions (factors) from a larger set of intercorrelated variables measuring various aspects of those dimensions. The second step in the analysis was to perform a cluster analysis, using the newly generated factors as a reduced-form data set, using the *K*-means statistical routine. Cluster analysis is used to sort different objects (in this case, a reduced form version of the responses to the survey questions) into groups wherein the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. The purpose of the cluster analysis is to determine how each of the factors combines to represent different groups of bicycle and transit integrators and nonintegrators.

After identifying the main factors affecting potential C-T users, these factors are described in detail in the following sections concentrating on priorities for integration, acceptable access and egress distances, and, finally, the role of bicycle sharing systems in promoting

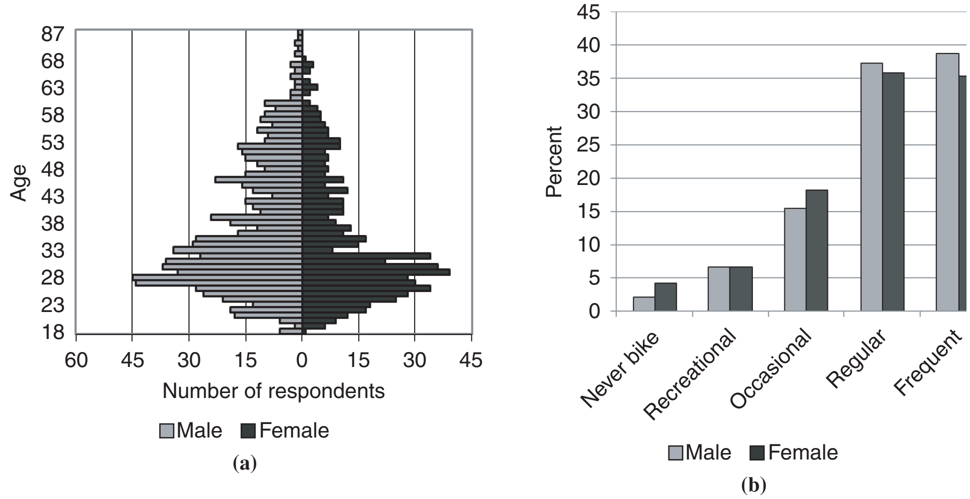


FIGURE 1 Sociodemographic characteristics and travel habits.

C-T. This is done through a series of cross tabulations of the relevant survey questions.

ANALYSIS

Descriptive Statistics

Respondents were aged from 18 to 87; however, the majority fell between the ages of 25 and 35 (Figure 1*a*). Men were slightly overrepresented, constituting 58% of the sample, and represented a larger portion of regular and frequent cyclists (Figure 1*b*). Annual household income was evenly distributed among respondents, and the majority reported living in small households of one or two people, indicating that young people with no families are overrepresented in the sample. In terms of transportation options, 94% of the respondents own a bicycle, 87% have a valid driver's license, and 52% own at least one car per household. Although respondents reported driving and walking evenly throughout the year, cycling and transit usage have considerable variation; predictably, cycling decreases in winter months and transit usage increases, suggesting that people substitute one of these modes for another depending on weather conditions.

Overall, 63% of respondents indicated they would be willing to combine bicycle and public transit for a trip that they conduct. However, certain transit users reported a greater interest in C-T than others; more than 80% of respondents using the metro and train equally or metro, train, and bus equally are likely C-T users (Figure 2*a*). Commuter train users, especially those connecting between multiple transit vehicles, represent the prime set of candidates for such measures. On the basis of respondents' reported cycling habits, recreational cyclists and noncyclists were least likely to integrate their cycling with transit (Figure 2*b*), whereas 68% of occasional cyclists reported that they would do so.

In addition, the highest values among potential transit users come from users who are using more than one mode of transit to reach their destination. This finding is consistent with Mees's observation that C-T users will mainly be existing transit users who would like to replace an inconvenient portion of their trip (*27*).

Factor–Cluster Analysis

With 28 variables derived from responses to survey questions, 13 factors were obtained with eigenvalues above 1. The factors were

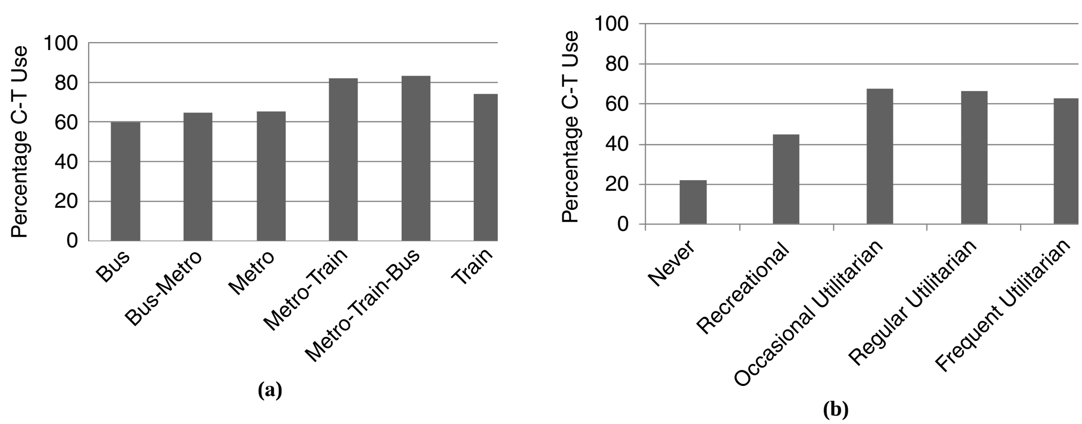


FIGURE 2 Travel habits of potential cycling and transit users.

TABLE 1 Factors with Values of Constituent Variables

Variable	Factor 1	2	3	4	5	6	7	8	9	10	11	12	13
Commitment to cycling													
Metro per year	**−0.61**	0.01	0.05	−0.4	0.07	0.11	−0.07	−0.14	0.19	0.17	−0.06	0.05	0.09
Bus per year	**−0.57**	0.10	0.03	−0.34	0.03	0.11	−0.03	−0.05	0.24	0.21	0.07	0.01	0.14
Seasons cycling	**0.81**	0.08	0.07	−0.15	0.01	0.06	−0.08	−0.04	0.11	0.13	0.00	0.05	0.05
Cyclist type	**0.84**	0.05	0.00	−0.25	0.05	0.05	−0.10	−0.01	0.12	0.08	0.03	0.02	0.05
Household size													
People per household	0.04	**0.92**	−0.02	0.06	−0.03	0.01	0.01	−0.03	0.01	−0.01	0.03	0.01	0.03
Children per household	0.08	**0.86**	0.09	0.01	−0.05	0.01	0.06	0.09	−0.03	0.01	0.00	0.03	−0.03
Occupation and income													
Full-time worker	0.03	0.04	**0.90**	0.04	0.03	0.01	0.04	0.00	−0.01	−0.03	−0.01	−0.01	0.03
Income	−0.04	0.48	**0.56**	0.21	0.11	−0.08	0.01	0.12	−0.08	−0.11	0.02	−0.06	−0.01
Full-time student	−0.01	0.00	**−0.86**	−0.05	0.01	−0.02	−0.05	−0.2	0.01	−0.04	0.02	−0.02	0.02
Car potential													
Replace car by bike-and-ride	0.13	0.01	0.15	**0.73**	−0.05	0.04	−0.07	−0.03	0.18	0.07	0.10	0.05	0.10
Seasons driving	−0.21	0.10	0.02	**0.67**	−0.01	−0.01	0.19	0.13	−0.13	0.01	−0.07	0.00	−0.01
Cars per household	−0.17	0.50	0.09	**0.56**	0.00	0.03	0.17	0.08	−0.09	−0.05	−0.09	−0.09	0.02
Bixi using													
Bixi yearly membership	−0.01	0.00	0.06	−0.04	**0.91**	−0.02	−0.05	−0.03	0.06	0.01	0.01	0.02	0.02
Bixi uses per month (2010)	0.01	−0.05	0.00	−0.02	**0.91**	0.00	−0.02	−0.03	0.07	0.01	0.00	−0.01	0.03
Currently bringing bicycle													
Bringing on bus per year	−0.01	0.04	0.01	0.01	0.00	**0.91**	0.01	0.02	−0.04	−0.03	0.03	−0.01	−0.02
Bringing on metro per year	0.00	−0.03	−0.02	0.01	−0.02	**0.91**	−0.01	0.02	0.08	0.04	−0.03	0.02	0.03
Poor transit service													
Home to bus station	0.00	−0.01	0.03	0.01	0.00	−0.01	**0.88**	−0.02	0.00	0.01	−0.03	0.05	0.01
Home to metro station	−0.11	0.11	0.06	0.14	−0.07	0.01	**0.85**	0.05	0.02	−0.01	0.02	−0.04	0.04
Experience													
Years cycling	0.03	0.05	0.00	0.01	−0.01	0.02	−0.01	**0.90**	−0.02	0.03	−0.03	0.00	0.00
Age	0.02	0.08	0.33	0.15	−0.08	0.02	0.05	**0.77**	−0.07	−0.03	0.00	0.00	−0.07
Transit potential													
Willing to combine	0.10	−0.06	−0.01	0.25	0.09	0.09	−0.01	−0.03	**0.84**	0.15	0.09	0.06	0.06
Replace transit by bike-and-ride	−0.07	−0.02	−0.05	−0.24	0.07	−0.05	0.04	−0.06	**0.76**	−0.10	−0.07	−0.02	−0.08
Currently parking													
Parking at bus stop	0.03	−0.04	0.01	0.11	0.01	−0.01	0.02	−0.07	−0.13	**0.77**	0.00	0.07	−0.02
Parking at metro station	−0.01	0.01	−0.04	−0.08	0.02	0.01	−0.02	0.07	0.16	**0.73**	−0.03	−0.08	0.00
Priority of bringing racks inside transit vehicles	0.06	0.01	−0.02	0.00	−0.03	0.01	0.02	−0.02	0.03	−0.05	**0.90**	0.17	0.15
Priority of bringing time													
Priority: extend hours	0.17	0.00	0.00	0.02	−0.12	0.01	0.10	0.05	0.06	−0.05	−0.57	**0.55**	0.39
Priority not indoor parking	0.00	0.00	0.02	−0.01	−0.04	−0.02	0.01	0.00	−0.02	−0.01	−0.16	**−0.91**	0.15
Priority not access to platform	0.03	0.00	0.00	−0.07	−0.06	−0.01	−0.04	0.05	0.02	0.02	−0.08	0.10	**−0.92**

NOTE: Values of >0.5 for each factor are represented in bold.

used to define categories of current and potential users (Table 1). More questions were tested for this analysis, yet they were dropped because of absence of statistical significance. The high values (>0.5, indicated in bold) are all in a single column, each column representing one of the 13 factors. Cumulatively, these factors explain more than 75% of overall variation in the data. Using these newly generated factors, a cluster analysis was performed. In this type of analysis, it is important to determine the most appropriate number of clusters. The hypothesis was that there are at least two, and possibly three, clusters representing general profiles: current cycling and transit users, potential cycling and transit users, and noncycling and transit users. A variety of cluster numbers was tested to obtained the best result with five groups.

The cluster average for each of the previously defined 13 factors is represented by the height and direction of each bar, as shown in Figure 3. Current bicycle and transit integrators account for 23% of the sample, nonintegrators represent 47% of the sample, and the remaining 30% are potential integrators. In addition to presenting the cycling and transit integration potential for each group, the analysis shows that respondents are clustered according to their current transportation habits.

The first cluster is characterized by a high value for the transit potential factor, a higher-than-average value for the occupation and income factor, and a positive value for the currently parking factor; respondents in this cluster have a positive perception of C-T and already park and ride. The second cluster is characterized by a high value in the Bixi using factor, a positive value in the transit potential factor, and a positive value for the two factors indicating interest in bringing bicycles on transit (priority bringing racks and priority bringing time). These Bixi users are willing C-T users and prioritize

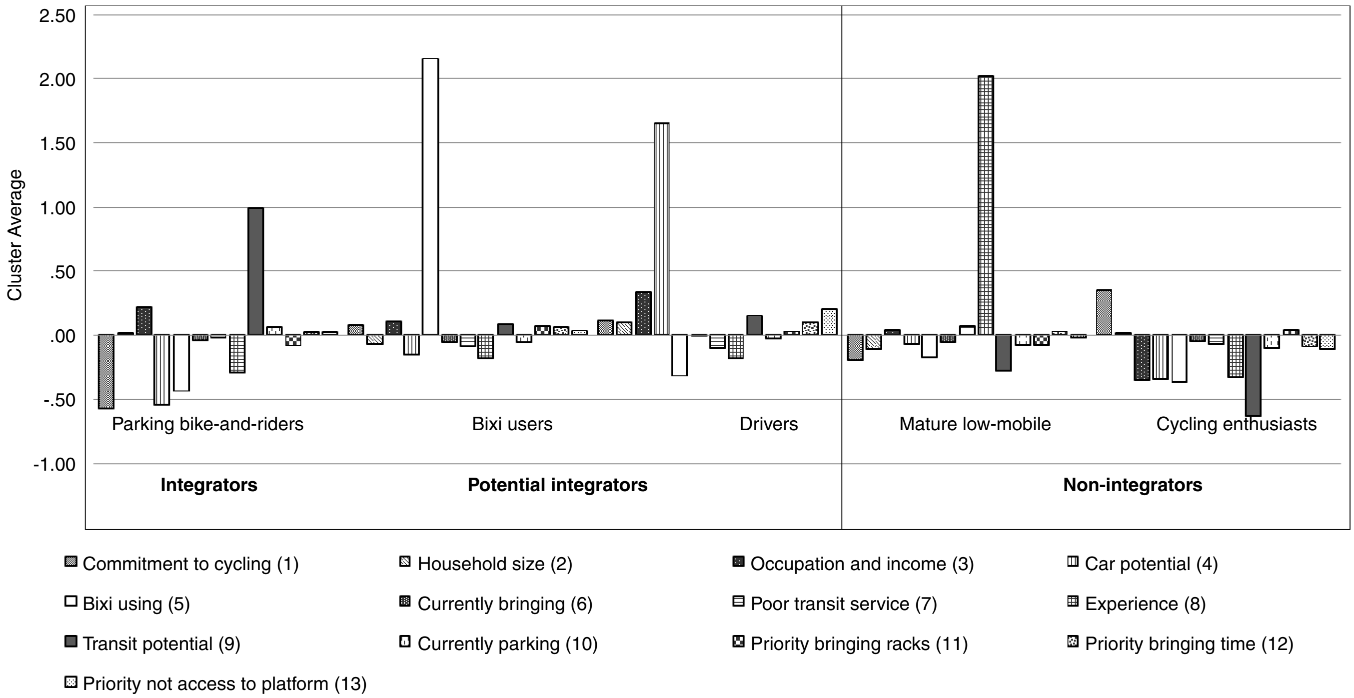


FIGURE 3 Current and potential cycling and transit users according to factor–cluster analysis.

measures to bring bicycles on transit vehicles. The third cluster shows a high value for the car potential factor; a higher-than-average value for household size, occupation, and income; and a positive value for the factors related to bringing bicycles on transit. This group represents respondents with children, currently driving and willing C-T users, particularly if it involves bringing their bicycle on board. The fourth cluster is mostly characterized by a high value in the experience factor and negative or low values for the other factors, indicating that these respondents are older and have been cycling for longer. They are poorly served by public transit and are not likely C-T users. The last and largest of the clusters is composed of committed cyclists that have a lower value in the occupation and income factors and are relatively young; this group is considered nonpotential C-T users.

The factor and cluster analysis identified three willing groups of current and potential C-T users: the current parking bike-and-riders, and two groups of potential C-T users, the Bixi users and the drivers. Both Bixi users and drivers selected priorities related to bringing bicycle on transit vehicles; other priorities were selected by current parking bike-and-riders, indicating that different population groups have distinct needs and preferences for C-T integration. Awareness of these different groups, and a better understanding of their priorities, will enable transit authorities to provide appropriate services and facilities to satisfy existing demand and attract new users.

Identifying Priorities

Despite growing interest in bicycle C-T schemes, little study has been directed at the travel circumstances in which individuals are most likely to desire and choose this option. Four possible scenarios were identified in which bicycles could be incorporated into a transit trip, and survey respondents were asked to select the one they were most like to use (Figure 4). Fifty-six percent of all respondents indicated a preference for one of the scenarios. Overall, 60% of respondents selected Option C, bringing their bicycle with them on transit, followed by Option A, accessing transit by bicycle and walking to one's final destination (21%). Because each different C-T option entails different costs for transportation agencies and may appeal to different segments of the population, these scenarios were explored in greater detail.

Of those respondents expressing interest in combined C-T trips, 40% reported they would do so for regular trips (e.g., to work or school),

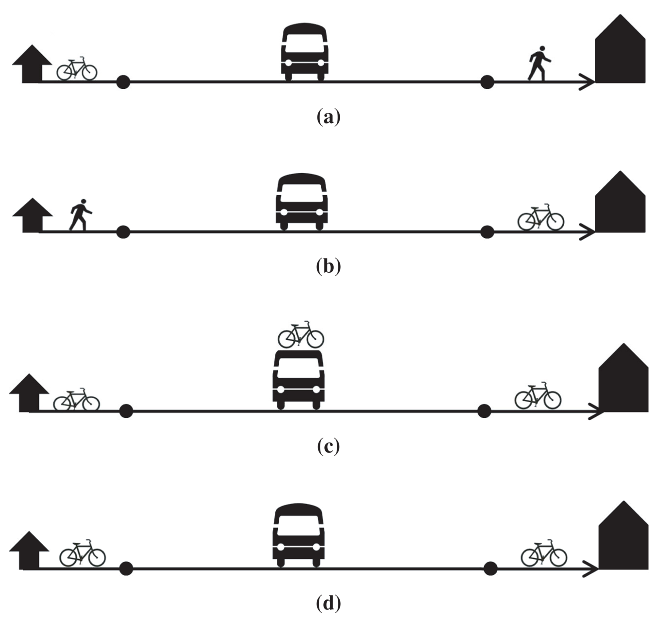


FIGURE 4 Four possible C-T scenarios: (*a*) cycle–transit–walk, (*b*) walk–transit–cycle, (*c*) cycle–bring on transit–cycle, and (*d*) cycle–transit–cycle.

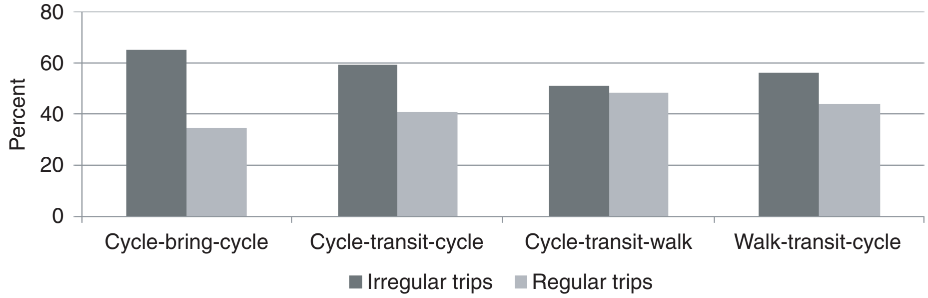


FIGURE 5 Preferred scenario by likely frequency of C-T usage.

whereas 60% would use this option primarily for irregular trips (e.g., shopping, social visit). This finding contrasts with past research, which has observed C-T users to be primarily commuters (*7, 28, 29*). The current research shows that the ratio of regular to irregular C-T potential users varies according to the scenario selected (Figure 5); whereas only 34% of respondents who prefer to bring their bicycle on transit (Option C) would be regular C-T users, 48% of respondents who would cycle to transit (Option A) would be regular C-T users. These findings suggest that good-quality bicycle parking facilities will be most useful to regular commuters, whereas racks on vehicles will appeal more to those irregularly using C-T.

Respondents were asked what type of a trip they were most likely to replace with a C-T trip. Overall, trips made by one public transit vehicle accounted for 34% of potential C-T trips, followed by car (25%), existing multimodal trips (24%), bicycle (9%), walking (5%), and taxi (3%). To better understand how opportunities for C-T vary by location, respondents' distance from a central point in downtown is cross tabulated with the mode most likely replaced by a C-T trip (Figure 6). Not surprisingly, respondents living at central locations where private automobile ownership is lowest are more likely to replace trips involving transit as one of two or more modes. These are the parking bike-and-riders and Bixi users identified in the factor–cluster analysis. Beyond 15 km from downtown, drivers are the group most likely to constitute the greatest share of replaced trips.

Every respondent was asked to provide his or her priority for a better integration of cycling and transit in Montreal. Of all priorities indicated, the preference for bringing bicycles on transit vehicles was dominant, particularly for extending the time in which the bicycles would be allowed on board. More generally, measures facilitating bringing bicycles on transit account for 45% of the identified priorities, whereas various measures facilitating bicycle parking at transit stations represent 34% of the priorities. Another 13% identified bicycle network connectivity with transit stop as the top priority. That no single integration measure was clearly identified as the number one priority by a majority of respondents also reveals that a host of different interventions are needed to promote C-T.

Respondents who said that they would not integrate cycling and transit indicated why they would not do so. The reason most commonly given was unwillingness to forego a bicycle trip, which speaks to the dedication of Montreal cyclists and the many short distance trips made. More than half of the reasons given were related to convenience (e.g., no time savings; impractical), whereas 20% indicated lack of appropriate parking facilities or fears about theft. This question underscores the difficulty of quantifying preference for a currently little-used practice; in particular, it is unclear whether the overwhelming preference for bringing bicycles on transit is the expression of a fundamental need or whether it reflects a lack of other viable options, such as secure and convenient parking.

Acceptable Distances

Those respondents who selected a C-T integration scenario were then asked to indicate acceptable travel times for each portion of the trip: access, egress, and on board transit. Using distance decay functions, these acceptable access and egress times by both walking and cycling were graphed. Respondents show markedly higher acceptable travel times by bicycle than by walking. When access and egress distances were compared (Figure 7), a steeper egress curve by both walking and cycling was noted, indicating that a greater proportion of C-T users were willing to accept longer access than egress times. This finding

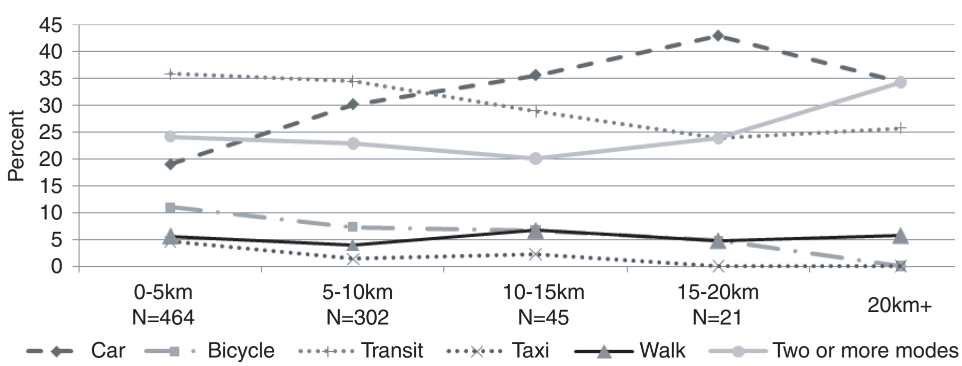
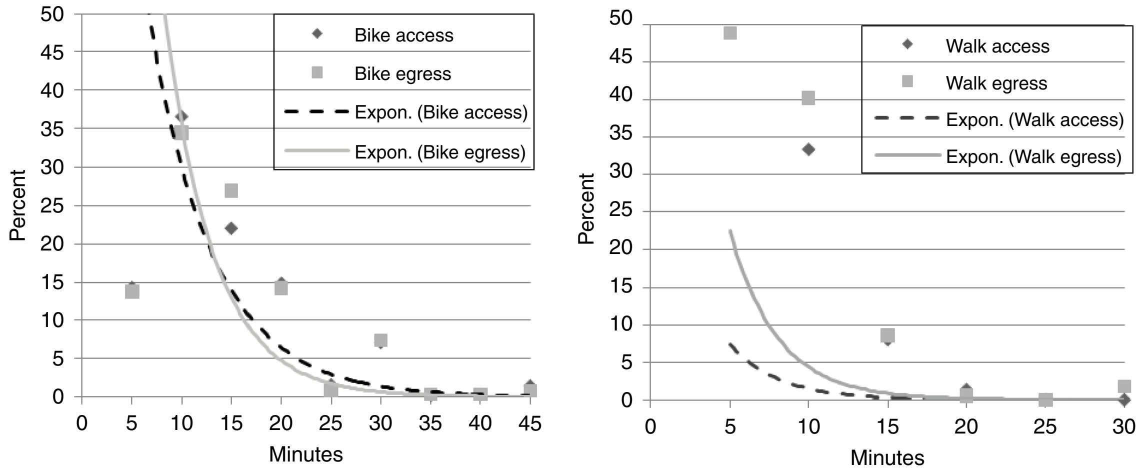


FIGURE 6 Stated mode replaced with C-T by home–downtown distance.



	Min	Max	Mean	Std	R^2		Min	Max	Mean	Std	R^2
Access	1	60	14.51	9.27	0.4701	Access	1	20	7.16	3.59	0.6986
Egress	2	90	14.97	10.16	0.4880	Egress	1	30	8	4.58	0.7071

(a) (b)

FIGURE 7 Distance decay of reported acceptable times for (*a*) cycling and (*b*) walking (expon. = exponential; std = standard deviation).

appears to confirm respondents' preference for using a bicycle at the home end rather than the destination end of a journey.

Bicycle Sharing

Given the recent implementation of Bixi, the public bicycle system in Montreal, a section was included in the survey to examine the role bicycle sharing systems can play in C-T. Users can take a Bixi from 1 of 400 docking stations located in the city center, cycle to their destination, and leave the bicycle at another station. There are three possible membership types: pay per use, monthly, or yearly enrollment. Thirty-seven percent of respondents were Bixi users, traveling by Bixi on average 12 times per month when the service is available between May and November. Among the sample, memberships were split almost evenly between pay per use and yearly, with only 1% of the Bixi users indicating they use a monthly membership; these users were not considered in the remainder of the analysis. More than half of the Bixi users lived less than 0.8 km from a metro station; pay-per-use users tended to live farther from metro stations. As indicated by the factor–cluster analysis, yearly Bixi members were more likely than pay-per-use users to integrate cycling and transit (Figure 8*a*).

In most cases, bicycle sharing usage replaces trips previously made by other "green" modes, namely public transit, bicycle, or walking. Approximately 8% of Bixi users replaced taxi trips, whereas only 2% of the respondents used a Bixi instead of driving, revealing that official estimates of CO_2 reduction because of the implementation of the program are exaggerated (*30*). The availability of bicycle sharing incited 3% of the respondents to add an extra trip they would

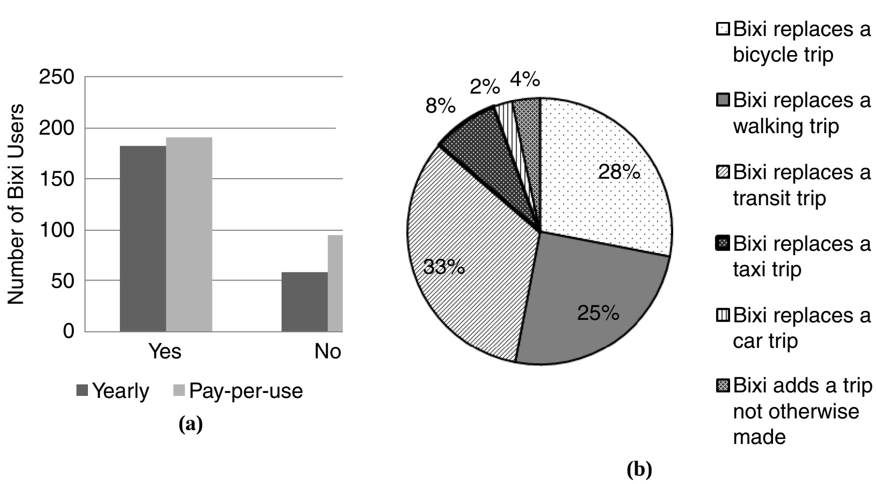


FIGURE 8 (*a*) Willingness to integrate by Bixi membership type and (*b*) trip types replaced by Bixi.

not otherwise have made. Among the different reasons for using Bixi, the most popular was the usefulness for one-way trips, which is followed by their practicality to use in conjunction with public transit; nonetheless, the majority of Bixi trips involved no other transportation mode. This may be because Bixi stations are spatially concentrated, resulting in short-distance trips that can be made easily. Finally, many respondents expressed the need for Bixi stations outside the central neighborhoods, where transit stops cannot always be accessed by foot.

DISCUSSION OF RESULTS AND CONCLUSIONS

As municipalities and transit providers aim to provide better options for "green" transport, cycle-transit integration offers significant opportunities for synergy between these modes. Existing knowledge has identified several factors affecting the C-T usage, including transit mode, urban form, access and egress catchment areas, and trip purpose. Given the variety of options for increasing C-T integration and the significant costs associated with certain measures, the results in this paper may help to guide municipalities in selecting the most cost-effective solutions based on their goals and types of users they are trying to attract. However, the needs and preferences in terms of bicycle and transit integration may differ from one city to another; it is thus important to use locally obtained data when determining the most appropriate measures.

Through market segmentation using factor–cluster analysis, three of five distinct groups were found to be current or potential C-T users: (*a*) parking bike and riders, (*b*) Bixi users, and (*c*) drivers. Descriptive statistics confirmed this finding: self-described occasional cyclists are more likely to choose C-T than those who cycle recreationally, regularly, or almost always. Understanding the dynamics and preferences of these groups can significantly aid in providing C-T integration services. A better knowledge of these groups' characteristics can also help transit agencies to effectively match resources to their potential users' preferences as part of a competitive positioning strategy to increase their market share (*23*).

The current research revealed that transit users who primarily use Montreal's commuter rail train, or make train-based multimodal trips, are the most likely C-T users, mirroring findings from locations where the practice is more common (*10, 11, 31*). To replace car trips with C-T trips, a major preoccupation within this field, this research suggests that opportunities are greatest for people living farther than 15 km from the city center. Thus, improving the integration of cycling and rail transit, particularly if combined with suburban cycling infrastructure improvements, is expected to result in the greatest increase in C-T rates. By contrast, given the greater ridership of the city's metro system and its higher overall share of current C-T trips, improvements focused on this transport mode will likely yield a greater gain in absolute terms, although more likely at the expense of other green modes. Specific policy objectives and the availability of resources will thus determine whether efforts are best directed toward replacing car trips, improving overall accessibility and mobility, or working toward both of these goals.

The preference expressed by more than 60% of respondents for the option to bring their bicycle on board transit presents serious challenges to promoting more widespread usage. Capacity limitations and capital costs associated with this option will necessitate more aggressive promotion of short- and longer-term parking options and public bicycle programs to significantly increase C-T integration. This research makes several promising contributions to this dilemma: trips involving access or egress by bicycle at only one end of the trip accounted for the greatest proportion of respondents who stated they would be regular C-T users. In other words, although the option to bring a bicycle on transit remain the most popular, scenarios involving parking a bicycle (or using a public bicycle) at one end are likely to be used more regularly. To the extent possible, measures facilitating both bicycle parking at transit and those enabling bringing bicycles on board transit are recommended.

Given the absence of research on public bicycle sharing systems, and their planned adoption in other North American cities, a section on Montreal's Bixi system was included. More than one-third of survey respondents reported having used Bixi. As shown through factor–cluster analysis, Bixi users, especially those with a yearly membership, are most likely to integrate cycling and transit. However, despite the claims of reducing transportation emissions, this service appears to mostly replace trips made by green modes. Although the popularity of bicycle sharing suggests that there are significant benefits to users in terms of convenience and overall mobility, its environmental benefits have been grossly exaggerated. Further research into bicycle sharing systems will be needed.

After thoroughly reviewing the state of the knowledge from a small but growing subset of transportation research, this paper included a wide-ranging analysis into how and for whom to promote C-T integration. The current study has several limitations, including risks for sample bias and the difficulty of analyzing a marginal transportation practice. The former is addressed by using multiple dissemination tools; the latter is a shortcoming that can only be overcome as this practice becomes more widespread.

Nonetheless, using the preferences and practices of current and potential C-T users in Montreal, concrete conclusions can be made that can guide transportation professionals in implementing cost-effective solutions for better bicycle–transit integration. Although caution should be taken to avoid generalizations, it is believed that the results will be of use to transportation researchers and professionals as they seek to understand and promote this promising form of multimodal transportation.

ACKNOWLEDGMENTS

The authors thank Robert Stafford of the Société de Transport de Montréal for his support in advertising the survey. The authors are grateful for funding from the Natural Science and Engineering Research Council of Canada and Fonds Québécois de la Recherche sur la Nature et les Technologies. The authors also thank Lise Gauvin and Daniel Fuller of the University of Montreal for their feedback to the survey, and the dedicated Montreal cyclists and transit users whose thoughtful responses form the basis of the analysis. The authors thank the six anonymous reviewers for their feedback during the review process.

REFERENCES

1. Doolittle, J. T., Jr. and E. R. Porter. *TCRP Synthesis of Transit Practice 4: Integration of Bicycles and Transit.* TRB, National Research Council, Washington, D.C., 1994.
2. Mees, P. *Transport for Suburbia.* Earthscan, London, 2010.
3. Pucher, J., and R. Buehler. Integrating Bicycling and Public Transport in North America. *Journal of Public Transportation,* Vol. 12, No. 3, 2009, pp. 79–104.
4. Spindler, S., and J. Boyle. *Bikes on Transit Database: Bikes on Transit Ridership Statistics,* 2009. http://www.bikemap.com/trans.html. Accessed July 25, 2010.

5. Schneider, R. *TCRP Synthesis of Practice 62: Integration of Bicycles and Transit.* Transportation Research Board of the National Academies, Washington, D.C., 2005.
6. Krizek, K. J., and E. W. Stonebraker. Bicycling and Transit: A Marriage Unrealized. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2144,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 161–167.
7. Hagelin, C. *A Return on Investment Analysis of Bicycles-on-Bus Programs.* Publication NCTR 576-05. FDOT BD549-04. National Center for Transit Research, Center for Urban Transportation Research, University of South Florida, Tallahassee, 2005.
8. Taylor, D., and H. Mahmassani. Analysis of Stated Preferences for Intermodal Bicycle-Transit Interfaces. In *Transportation Research Record 1556,* TRB, National Research Council, Washington, D.C., 1996, pp. 86–95.
9. Rastogi, R., and K. Rao. Travel Characteristics of Commuters Accessing Transit: Case Study. *Journal of Transportation Engineering,* Vol. 129, No. 6, 2003, pp. 684–693.
10. Rietveld, P. The Accessibility of Railway Stations: The Role of the Bicycle in the Netherlands. *Transportation Research Part D,* Vol. 5, 2000, pp. 71–75.
11. Krygsman, S., M. Dijst, and T. Arentze. Multimodal Public Transport: An Analysis of Travel Time Elements and the Interconnectivity Ratio. *Transport Policy,* Vol. 11, No. 3, 2004, pp. 265–275.
12. Krygsman, S., and M. Dijst. Multimodal Trips in the Netherlands: Microlevel Individual Attributes and Residential Context. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1753,* TRB, National Research Council, Washington, D.C., 2001, pp. 11–19.
13. Anable, J. "Complacent Car Addicts" or "Aspiring Environmentalists"? Identifying Travel Behaviour Segments Using Attitude Theory. *Transport Policy,* Vol. 12, 2004, pp. 65–78.
14. Pucher, J., and R. Buehler. Why Canadians Cycle More Than Americans: A Comparative Analysis of Bicycling Trends and Policies. *Transport Policy,* Vol. 13, No. 3, 2006, pp. 265–279.
15. Vélo-Québec. *L'état Du Vélo Au Québec En 2005.* Publication Montréal, Montreal Quebec, Canada, 2005.
16. Dillman, D., J. Smyth, and L. Christian. *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method,* 3rd ed. John Wiley & Sons, Inc., Hoboken, N.J., 2009.
17. Agence métropolitaine de transport. *Enquête Origine-Destination 2003.* Publication Montréal, Montreal Québec, 2003.
18. Dill, J., and J. Gliebe. *Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice.* Oregon Transportation Research and Education Consortium, Portland, 2008.
19. Hyodo, T., N. Suzuki, and K. Takahashi. Modeling of Bicycle Route and Destination Choice Behavior for Bicycle Road Network Plan. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1705,* TRB, National Research Council, Washington, D.C., 2000, pp. 70–76.
20. Krizek, K., A. El-Geneidy, and K. Thompson. A Detailed Analysis of How an Urban Trail System Affects Cyclists' Travel. *Transportation,* Vol. 34, No. 5, 2007, pp. 611–634.
21. Moudon, A., C. Lee, A. Cheadle, C. Collier, D. Johnson, T. Schmid, and R. Weather. Cycling and the Built Environment, a US Perspective. *Transportation Research Part D,* Vol. 10, No. 3, 2005, pp. 245–261.
22. Tilahun, N., D. Levinson, and K. Krizek. Trails, Lanes, or Traffic: Valuing Bicycle Facilities with an Adaptive Stated Preference Survey. *Transportation Research Part A,* Vol. 41, No. 4, 2007, pp. 287–301.
23. Shiftan, Y., M. Outwater, and Y. Zhou. Transit Market Research Using Structural Equation Modeling and Attitudinal Market Segmentation. *Transport Policy,* Vol. 15, 2008, pp. 186–195.
24. Outwater, M. L., S. Castleberry, Y. Shiftan, M. Ben-Akiva, Y. S. Zhou, and A. Kuppam. Attitudinal Market Segmentation Approach to Mode Choice and Ridership Forecasting: Structural Equation Modeling. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1854,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 32–42.
25. Krizek, K. J., and A. El-Geneidy. Segmenting Preferences and Habits of Transit Users and Non-Users. *Journal of Public Transportation,* Vol. 10, No. 3, 2007, pp. 71–94.
26. Gatersleben, B., and H. Haddad. Who Is the Typical Bicyclist? *Transportation Research Part F,* Vol. 13, 2010, pp. 41–48.
27. Mees, P. *Transport for Suburbia: Beyond the Automobile Age.* Earthscan, London, 2010.
28. Givoni, M., and P. Rietveld. The Access Journey to the Railway Station and Its Role in Passengers' Satisfaction with Rail Travel. *Transport Policy,* Vol. 14, 2007, pp. 357–365.
29. Van Goeverden, C. *Gecombineerd Gebruik van Fiets en Openbaar Vervoer: Verwachte Effecten op de Vervoerwijzekeuze van Optimale Fietsbeschikbaarheid in Voor.* Publication TU Delft, Faculteit der Civiele Techniek, Delft, Netherlands, 1993.
30. *BIXI by the Numbers.* BIXI, Montreal, Quebec, Canada, 2009. http://montreal.bixi.com/news/category/BIXI%20en%20chiffres. Accessed July 25, 2010.
31. Replogle, M. Bicycle Access to Public Transportation: Learning from Abroad. In *Transportation Research Record 1396,* TRB, National Research Council, Washington, D.C., 1992, pp. 75–80.

The Bicycle Transportation Committee peer-reviewed this paper.