Travel time competitiveness of cycling in Sydney

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Abstract

A key issue for both sustainable transport and public health is the viability of cycling as a genuine alternative transport mode to the car, particularly for short trips. This paper considers this issue by assessing hypothetically the travel time implications of substituting actual car trips with cycling. The car trips are captured over several weeks for 100 Sydney motorists using GPS technology, while the cycling trips are generated using reverse geocoding processes in GIS software, taking into account the impacts of terrain in particular on cycling travel times. Both individual trips and (arguably more importantly) trip chains are considered. Results suggest that for car trips up to five kilometres in length (which comprised 58 percent of trips), over 90 percent of these trips could be cycled within 10 minutes of the time taken by car while around 30 percent of trips up to two kilometres in length could be cycled either in the same amount of time or faster than by car. Furthermore, it is shown that cycling is generally more competitive than public transport on the basis of time and that this applies equally to individual trips and trip chains for short distances.

1. Introduction

Fuelled by ever-worsening traffic congestion coupled with environmental and growing public health concerns, Australia (like many other countries) has been seeking to increase the use of active transport modes, particularly cycling and walking. Currently, cycling accounts for around one percent of daily trips across Australia (Bauman et al., 2008) although this disguises the fact there are quite marked differences between and within cities (Pucher et al. 2010). While similar to the UK, USA and Canada, it is much lower than countries such as the Netherlands (27% bicycle mode share), Denmark (16%) and Germany (10%) (Pucher and Buehler, 2008).

The reasons why cycling rates are much lower in Australia compared to (in particular) Europe are largely attributed to land use and transport policies that are much more supportive of cycling and discouraging of car use in Europe (Pucher et al. 2010). This is evidenced by significant investment in cycling infrastructure, greater integration with public transport, increased education/training of both cyclists and motorists, lower urban speed limits, extensive traffic-calming programs, more expensive parking and fuel prices, and land-use policies that favour high density and mixed-use development leading to trips that are shorter and more ‘bikeable’ than in Australia.

Implicit to the question of how to increase cycling rates is assessing (and ultimately improving) the *competitiveness* of cycling versus other modes of transport, particularly the car. This competitiveness constitutes a range of metrics including travel time, accident risk, health benefits, pollution and financial costs. Evidence suggests that bicycles come out more favourably than the car on health benefits, pollution and financial costs (Newman 2003) and less favourably on accident risk (Garrard et al., 2010). In terms of travel time competitiveness, evidence suggests that bicycles are competitive with cars up to a distance of approximately five km (Dekoster and Schollaert 1999). Given a substantial proportion of car trips are less than five kilometres in length – for instance latest evidence from Sydney shows that 43 percent of trips made by car are less than five kilometres in length, with 17 percent less than two kilometres in length (NSW Government 2005) – arguably these should be substitutable by bicycle. In reality, the situation is much more complex than that because the relative competitiveness depends on a host of additional factors in addition to distance, including terrain, weather, levels of congestion, cycling facilities (or lack of them), trip purpose, the capabilities of the cyclist, and whether a trip is part of a longer chain/tour.

With this in mind, this paper considers the question of how many trips made by car as part of regular travel routines are genuinely substitutable by bicycle based on travel time alone. Unlike other studies, which have focused on particular routes or origin-destination pairs (Clement 2008) this paper considers the issue by assessing (hypothetically) the implications of substituting actual (car) trips captured during a five-week investigation of driving behaviour in Sydney, with cycling. This enables an exploration of both individual trips and trips made as part of longer chains as well as other pertinent characteristics of trips (purpose, passengers etc). The next section of the paper reviews the literature on cycling competitiveness with a primary focus on travel time. We then detail the methods and data used for the analysis together with appropriate caveats before presenting results comparing cycling travel times with corresponding trips and trip chains made by both cars and public transport. Finally, we draw conclusions on overall competitiveness of cycling on the basis of travel time and its suitability as a substitute for cars.

2. Literature review

2.1. Travel time budgets

An individual’s travel time budget is the amount of time they are able or willing to travel per day. Although the average travel time budget differs by location, it has generally been shown to be around one hour per day (Schafer 2000). Latest evidence from Sydney, suggests travel time budgets average around 80 minutes per day, but the high variance suggests many people are spending significantly longer than this travelling (Transport Data Centre 2009). Travel time budgets vary by personal characteristics and age, but appear to be stable by population density (Schafer 2000) although there is some debate on if this is still true or if they have recently increased in some locations (Levinson and Wu 2005). Crucially for the competitiveness of public transport in particular, Levinson and Wu (2005) found that travel time for public transport appears to have increased by a larger proportion than travel times by car. Regardless of the mode, any increase in travel time should still be within an individual’s travel time budget as this is likely to have a significant impact on the mode that is ultimately chosen. Levinson and Wu (2005) also report that the average daily travel time is higher for public transport than for car travel. This may suggest that users of public transport have a higher travel time budget.

2.2. Travel time competitiveness of cycling

While there are many documented barriers to increasing cycling rates, the focus of this review is specifically on travel time. Investigations into the travel time competitiveness of bicycles have taken both an empirical and hypothetical approach. A European study comparing travel time by different modes showed that cycling was generally faster than driving for trips up to approximately five kilometres (Figure 1) in length in urban areas (Dekoster and Schollaert 1999). The same study also showed that public transport (both buses and trains) were slower than cycling up to a distance of approximately eight kilometres.

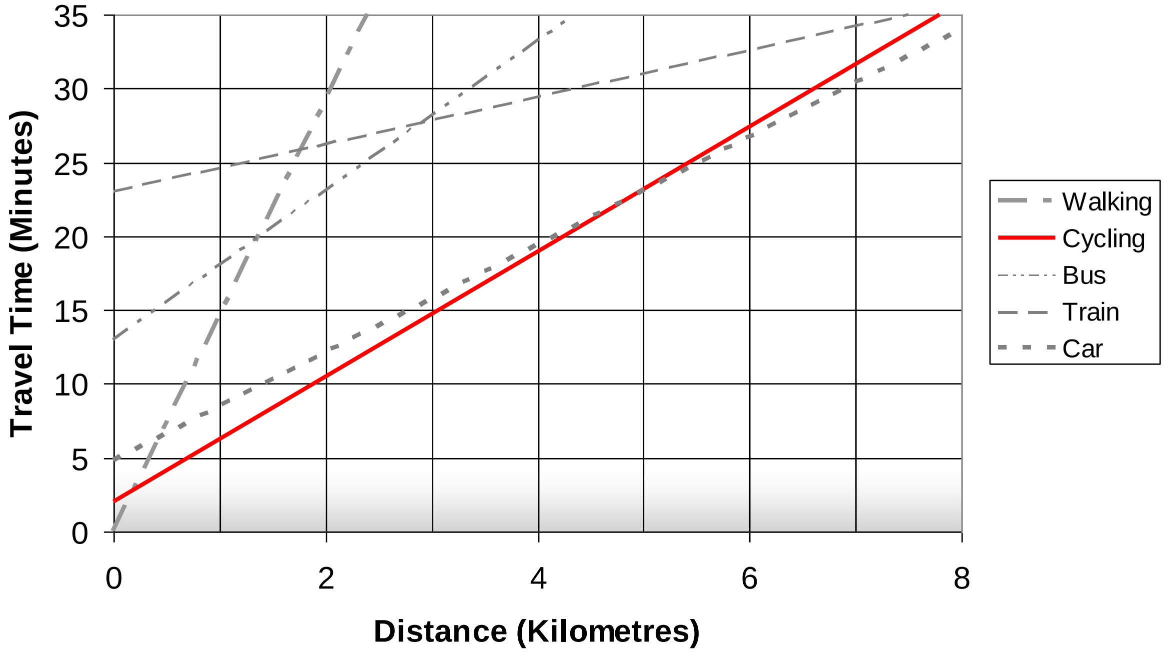


Figure 1: Travel time by distance for different transport modes (Source: Adapted from Dekoster and Schollaert 1999)

In terms of the more specific issue of the impacts of modal switching for actual trips made, research conducted in Oxfordshire identified a group of people considered most likely to change modes from using a car to using alternative modes (Curtis and Headicar, 2007). For one third of this group, changing mode to cycling for the trip to work would increase their travel time by less than ten minutes. A further 40 percent of people would see an increase in travel time of less than 30 minutes. The study also concluded that these figures were evidently seen as too much of a barrier for many people to change.

An important, yet often overlooked issue affecting the travel time-related competitiveness of bicycles relates to trip chaining. The issue here is that with the exception of trips where the sole purpose is to drop-off or pick-up a passenger, all trips are made as a sequence of trips which together make up a “trip chain” or “trip tour”. At the most basic level a chain consists of an outbound trip (from the origin to the destination) and an inbound trip (from the destination back to the origin). However, many chains consist of trips to multiple destinations, which may have different purposes (Hensher and Reyes 2000). There is some debate if trip chains are a result of mode choice or a determinant of mode choice. Ye, et al. (2007) argue trip chains (particularly complex chains) are a strong determinant of mode choice with more complex chains being more likely to be done by car. This is supported by Mackett (2003) who showed that among the most common reasons given for using a car for short trips was the car being needed for a subsequent trip. In Sydney, approximately 24 percent of people who use a car to commute to work do so because the car is required for either work-related trips or for other non-work trips (Transport Data Centre 2009). Similarly, Hensher and Reyes (2000) argue that the complexity of trip chains is likely to increase as a result of an increase in the number of children and other changes in family characteristics. This in turn is likely to result in a decrease in the use of public transport by the family as a whole. While this makes it clear that the use of alternative modes is likely to decrease as the complexity of trip chains increases, it is not clear that this is the result of alternative modes becoming less competitive for more complex chains rather than a *perception* that this is the case. The authors acknowledge that the requirements of some trip purposes are likely to make alternative modes either infeasible or inconvenient for some trip chains, but this is not thought to be an issue for most trip chains.

3. Data and methodology

3.1. Data overview

The trip data used in this paper were collected during a before-and-after study on driver behaviour in Sydney for which trips were recorded using a Global Positioning System (GPS) device placed in participants' cars for a period of several months (Greaves et al., 2010). In addition, supplementary data sources were used to provide data on possible travel times by public transport, "suggested" walking routes (which were also used as cycling routes) as well as terrain data used for accounting for the impact of topography on cycling speeds.

3.1.1. Data sources and collection

Including the pre-testing of devices, pilot testing, and main data collection phase, the GPS study on which this study was based ran from March-December, 2009 involving a total of 178 participants from a number of suburban hubs and surrounding suburbs in Sydney. Specifically these were Parramatta (33 percent), Strathfield (20 percent), Chatswood (11 percent), Sutherland (16 percent), Blacktown (13 percent) and Randwick (5 percent). Participants were selected from a market research panel who had indicated they were interested in participating in the study according to quotas based on age and gender. Approximately 36 percent of participants were males aged between 31 and 65 years, 37 percent were females aged between 31 and 65 years, 11 percent were males aged 18 to 30 and 16 percent were females aged 18 to 30. Recruitment of younger drivers proved difficult resulting in the larger proportion of drivers being in the older age group. During the study participants were asked to use a web-based prompted recall interface to provide additional information on their trips including who was driving, the main purpose of each trip and the number of passengers (Greaves, et al. 2010).

The New South Wales Government's Transport Info website[1] was used to provide public transport route and timetable data for each trip. Although it is acknowledged that using timetable data is not likely to match the travel time had the original trip been taken using public transport, the timetables were considered to be adequate for comparison purposes. In addition, the information available from the timetables are likely to be those used by individuals when deciding if (and when) to take public transport as well as deciding which services to use. The timetables and routes used were those in use at the beginning of May 2010. The data available from the Transport Info website included the service(s) required to travel between the origin and destination and the estimated travel time as well as the time required to access and egress from public transport.

Following a similar logic of using publicly available information, Google Maps[2] was used to generate possible cycling routes for each trip. Google Maps does have the ability to generate cycling routes in some areas but this is not yet available for Sydney and as a result walking routes were used. This was because in contrast to the GPS-recorded trips and standard driving routes generated by Google Maps, the use of walking routes ignores direction on one-way streets and avoids motorways. Given terrain is considered to be one of the possible reasons cycling is less common in Sydney than in less hilly areas (Pucher et al. 2010) terrain must also be included. This was done by using an elevation model from Geoscience Australia (Geoscience Australia 2003) and matching this data to the routes in Google Maps. It should be noted that due to the limits of the data the routes and elevation data were accurate to a distance of about 100 metres. This was considered to provide sufficient accuracy to give an indication of the impact on terrain for cycling and an estimated

[1] http://www.131500.com.au
[2] http://www.google.com/maps

cycling time. The estimation of cycling time used a base speed of 16km/h, identified by the UK Department of Transport as a standard speed for “inexperienced adult” cyclists (Parkin and Rotheram 2010). Clearly, there is considerable heterogeneity in cycling abilities and speeds across the population and this is considered a conservative estimate. To take into account the impact of elevation changes, this base speed was adjusted using values found by Parkin and Rotheram (2010). This increased the speed by 0.86km/h for each one percent of downhill gradient and decreased the speed by 1.44km/h for each one percent downhill gradient. The use of the routes from Google Maps was limited to the use of its measure of distance to estimate travel time.

3.1.2. Data quality

While the data were generally of a high quality, invariably there were issues that needed to be addressed prior to use for this application. Trips shorter than 100 metres in length, other obvious anomalies and those for which participants did not provide the required trip details through the prompted-recall interface were removed. An important consideration for the current application was the ‘cold start’ issue. This refers to the delay between the start of a trip and when the GPS starts recording and can last anywhere from a few seconds to a couple of minutes. Typically, cold-starts are ignored or dealt with by imputation of missing attributes (distance, travel time, speed etc). Distance is relatively simple to deal with, but travel time requires imputation of start-time, which in turn requires an assumption to be made about travel speed. Given the main objective of the study was to compare bicycle times with car times, the beginning of the bicycle trip was taken as where the GPS data started and finished.

The final sample of trips used in the study was 64,089 trips. The distribution of these trips is shown in Table 1 and Table 2. In terms of distance, around 58 percent of trips were less than five kilometres in length, with almost 30 percent less than two kilometres. Focusing on travel time, almost one-third of trips were less than five minutes while over two-thirds of trips were less than 15 minutes in duration. This supports evidence elsewhere that a substantial number of car trips are for short distance travel, on the face of it at least, the most amenable to potential modal substitution by bicycle.

Table 1: Frequency of sample trips by distance

	Frequency	Percent	Cumulative Percent
Shorter than 1km	8255	12.9%	12.9%
1–2km	10240	16.0%	28.9%
2-5km	18363	28.7%	57.5%
5-10km	11395	17.8%	75.3%
10-20km	10085	15.7%	91.0%
More than 20km	5751	9.0%	100.0%
Total	64089	100%	
Mean	8.07 kilometres		
Median	4.01 kilometres		

Table 2: Frequency of sample trips by travel time

	Frequency	Percent	Cumulative Percent
0 to 5 minutes	20498	32.0%	32.0%
5 to 10 minutes	15118	23.6%	55.6%
10 to 15 minutes	8167	12.7%	68.3%
15 to 20 minutes	5567	8.7%	77.0%
20 to 30 minutes	6949	10.8%	87.8%
30 to 60 minutes	6602	10.3%	98.1%
More than 60 minutes	1188	1.9%	100.0%

Total	64089	32.0%	32.0%
Mean	14.9 minutes		
Median	9.0 minutes		

3.2. Integration of data sources

To assist in the integration of the various data sources a PHP: Hypertext Preprocessor (PHP) script was developed that would select the data from each source before calculating the estimated travel time and distance between each pair of origins and destinations originally recorded using the GPS device. For public transport the day of the week and time of day of the original trip was taken was used to select the appropriate services. For cycling the time of day was not taken into account when estimating travel time. However, the potential for cycling to be more competitive during periods of peak congestion on major roads (when average speed is lower) was included by using the travel time originally recorded by the GPS device.

Another PHP script was developed to first define each trip chain starting from when the participant left home and including all trips until they returned home. This may have been a trip to a single destination followed by the trip returning home or trips to multiple destinations before returning home (Ellison, et al. 2010). This script also aggregated the trip information calculated for each individual trip to find the total distance and travel time for the trip as a whole. If public transport was not available for any trips within a chain the chain was considered to be infeasible by public transport. It should be noted that the time spent at each destination was not considered in this analysis.

A further point of note is it was implicitly assumed all participants were capable of cycling and were of average ability for “inexperienced adults” (Parkin and Rotheram 2010), resulting in an assumed average speed on the flat of 16 km/h. Clearly, this assumption would need to be verified within the physical abilities of participants.

4. Competitiveness of cycling

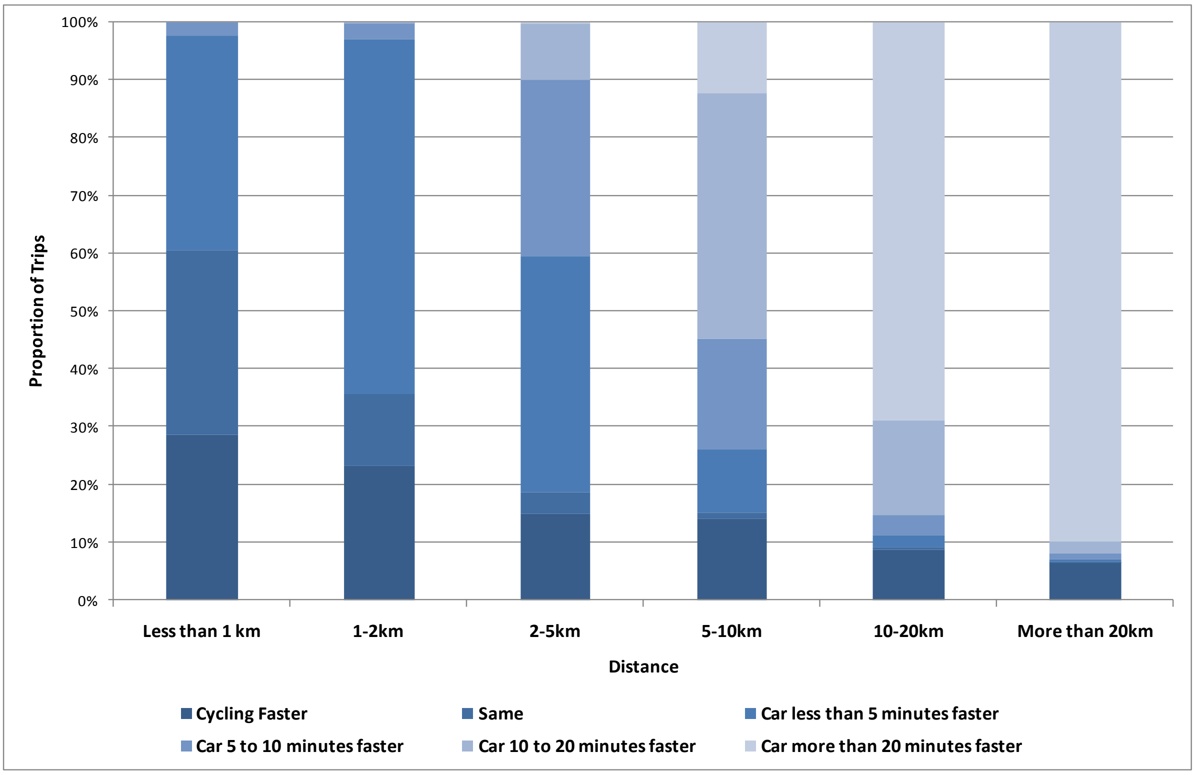
This evaluation of the travel time competitiveness of cycling in Sydney considered both individual trips in isolation and several trips taken together as part of a larger trip chain. This distinction is important because if cycling is uncompetitive for one trip in a chain it is unlikely to be used for any other trip in the chain. Furthermore, it must be emphasised (again) that the results discussed in this section are based on a standard speed of 16km/h and travel times for most cyclists are likely to be faster, particularly for experienced cyclists.

4.1. Individual trips

Much of the focus for increasing the proportion of trips cycled has been on short trips where evidence in Sydney suggests many of these trips are still done by car (Transport Data Centre, 2009). The results show that for trips of 2-5 kilometres, approximately 60 percent could be cycled within five minutes and 90 percent within 10 minutes of the time taken by car (Figure 2). Furthermore, for trips with a distance of less than two kilometres, around one third could be done in the same amount of time or quicker than the same trip done by car. Furthermore, since this analysis is based on the travel time (and distance) of recorded car trips it does not include the time required to walk to and from where the car is parked. Were this to be included cycling would likely be seen to be even more competitive for short distances (Rietveld 2000).

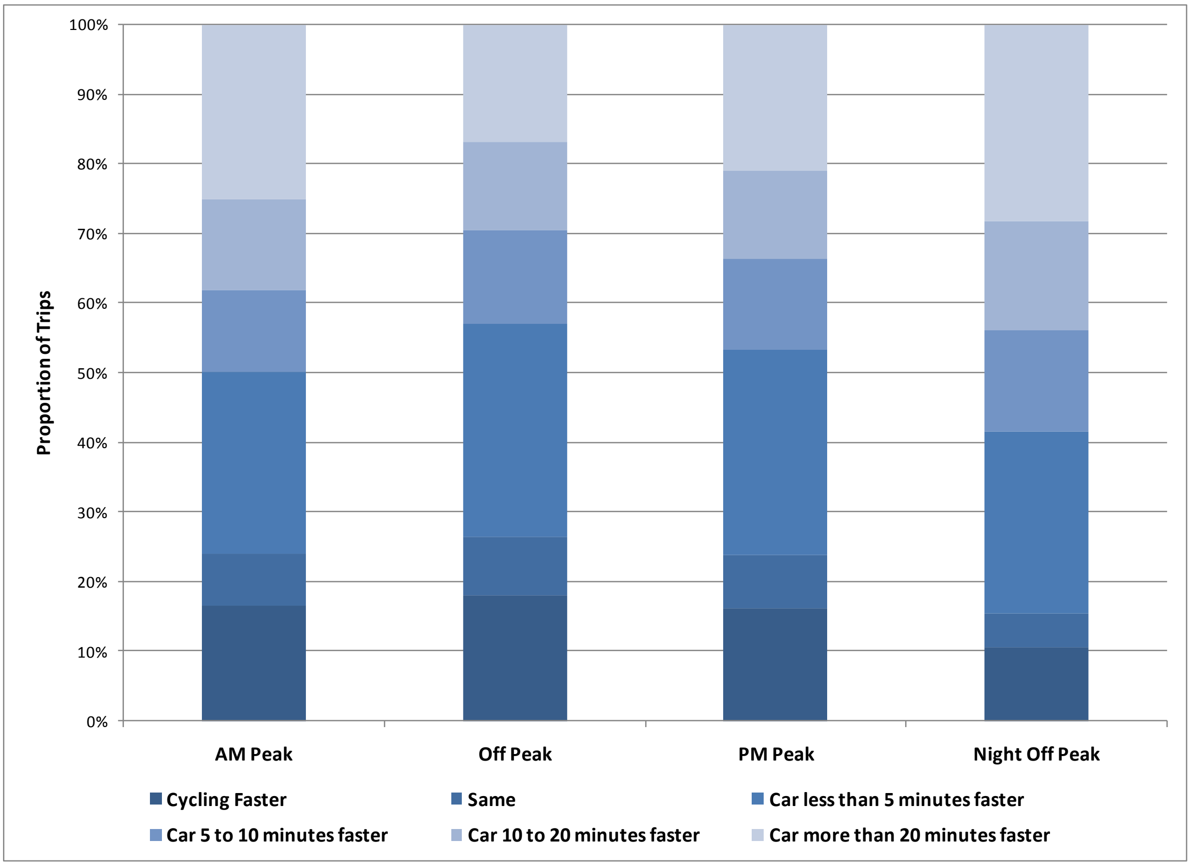
As expected, cycling travel time competitiveness decreases substantially for longer trips, although it remains competitive for a small number of longer trips. For trips 5-10 km in length, around 45 percent can be cycled within 10 minutes of the time taken by car, while for trips longer than 10 kilometres in length around 10 percent can be cycled within 10 minutes fo the time taken by car.

Figure 2: Comparison of cycling and car travel times by trip distance



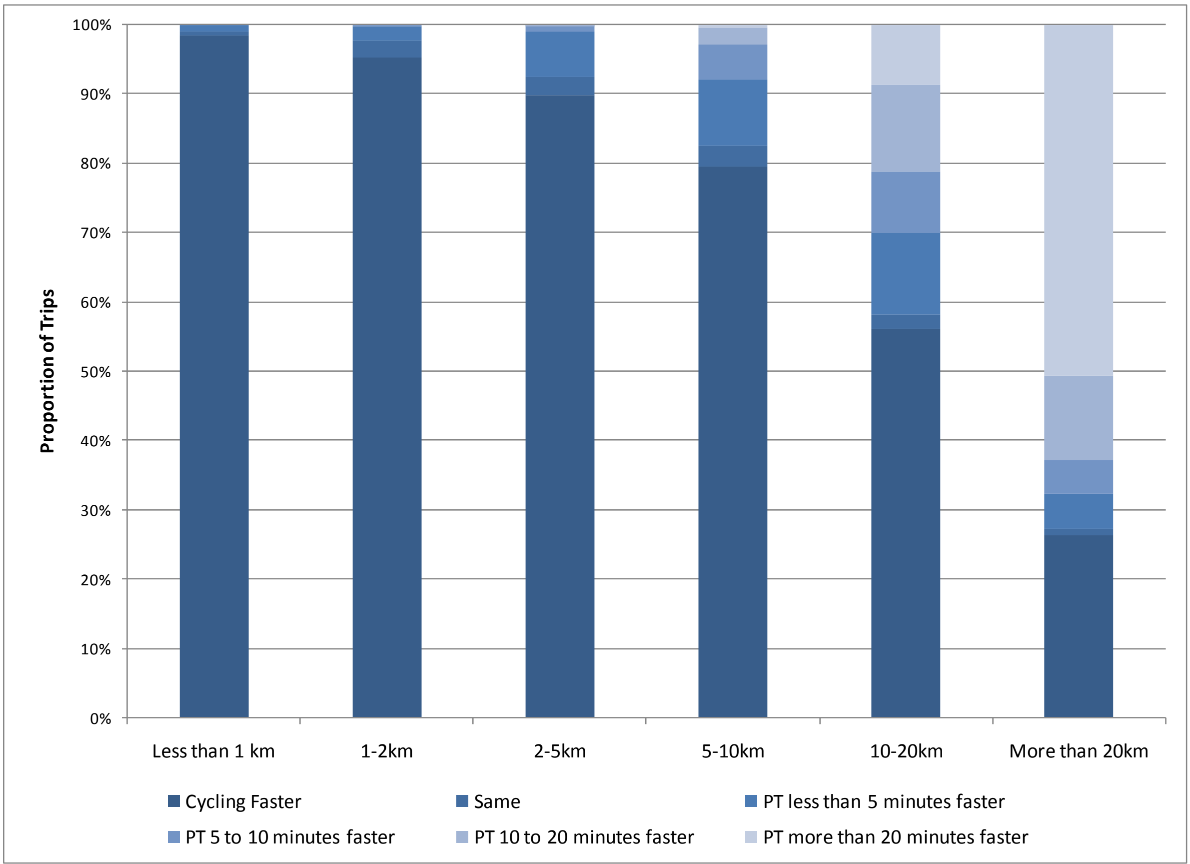
One of the key advantages of cycling over cars is the ability for cyclists to more easily avoid congestion and in the case of Sydney, take cut-throughs unavailable to cars, particularly in the inner areas. The increasing number of bicycle lanes and cycling-only contraflows on one-way streets is further improving the ability of cyclists to avoid congestion. This combined with the lower average speeds of cars during peak periods would suggest that cycling should be more competitive during these periods than it is during other times of the day. This is particularly important if cycling is to be used more for trips to and from work. Surprisingly this does not appear to be the case in Sydney. Comparing the competitiveness of cycling by time of day for weekdays (for all distances), shows that temporal differences appear to be marginal with differences more likely to reflect trip distances than time effects per se (Figure 3). This is supported by there being an even smaller difference between time periods when only trips up to five kilometres in length are included. However, while congestion does not appear to have an impact on the competitiveness of cycling during the peak periods, congestion is still a barrier to expanding the use of cycling in that it may also reduce the willingness of people to cycle due to the perceived decrease in levels of safety (Pucher et al. 2010). The expansion in the number of dedicated bicycle lanes may mitigate this risk and by extension increase the willingness of people to cycle when roads are congested.

Figure 3: Comparison of cycling and car travel times by time of day on weekdays



Public transport can in some ways be considered a substitute for cycling because it can be considered both environmentally sustainable and in many of Sydney's population centres, widely available. However, cycling appears to be very competitive with public transport on the basis of time with more than 90 percent of trips shorter than five kilometres being faster by bicycle than public transport (Figure 4). Similarly to the reduction in the time competitiveness of cycling compared to cars, competitiveness decreases for longer trips. Perhaps surprisingly, approximately 25 percent of trips longer than 20 kilometres in length can still be done faster by bicycle than public transport. In many cases this is because public transport is simply unavailable or less frequent between the origin and the destination whilst in others it would require a number of changes between different services which would increase waiting time and ultimately total travel time. Cycling could be particularly useful as a complementary mode to public transport with cycling used for shorter links within trip chains. However, in contrast to cities elsewhere (such as Christchurch) which provide bicycle racks on a number of bus routes, bicycles are not currently allowed on Sydney buses making this use of cycling somewhat problematic.

Figure 4: Cycling and public transport by distance



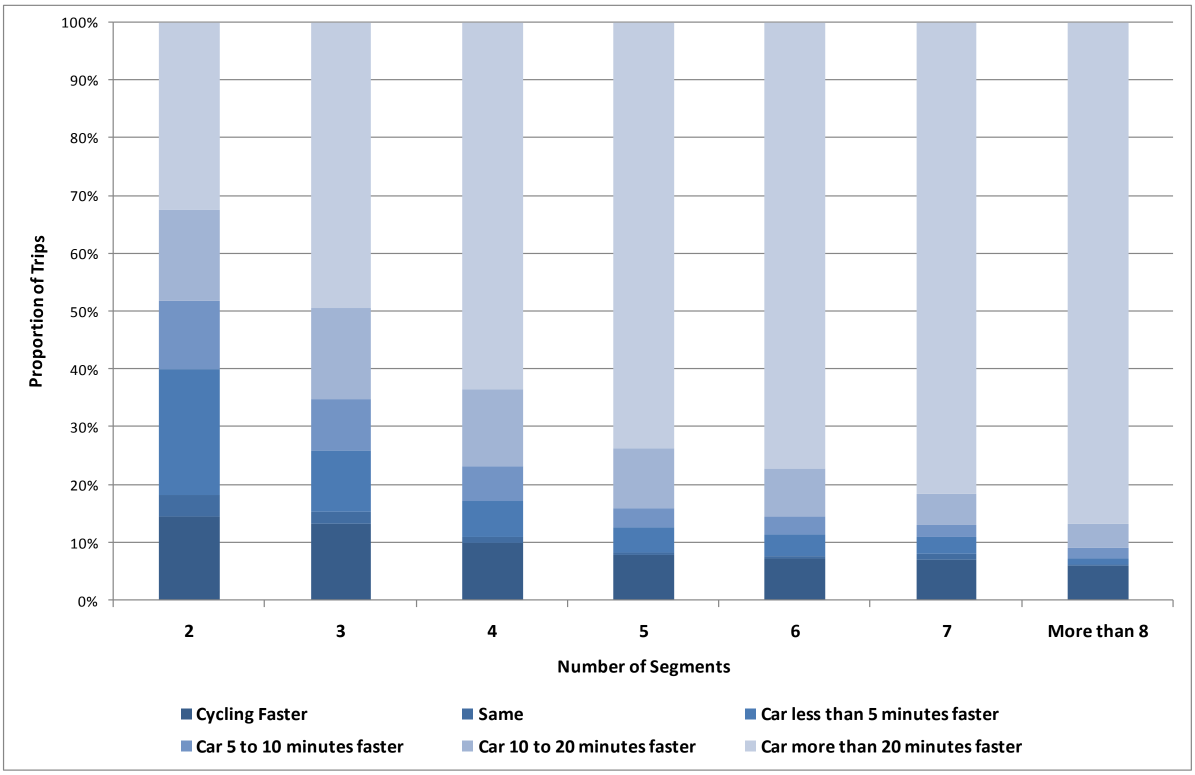
4.2. Trip Chains

One of the limitations of looking at individual trips in isolation is that this is not an accurate reflection of how people travel. This means that despite cycling being competitive with cars for short trips in isolation, short trips may in reality be part of a chain of trips comprising other short and/or long trips. A long trip within a trip chain may make all other trips (however short) in the chain uncompetitive. This analysis looks at the competitiveness of cycling of current trip chains although it is acknowledged that changing modes may also result in a change to how trips are chained.

Using the method described in Section 3.2, 22,299 trip chains were found although some of these consisted of only a single trip due to being a trip where the sole purpose was to drop-off or pick-up a passenger. These chains were excluded from further analysis resulting in a total number of trip chains of 19,889.

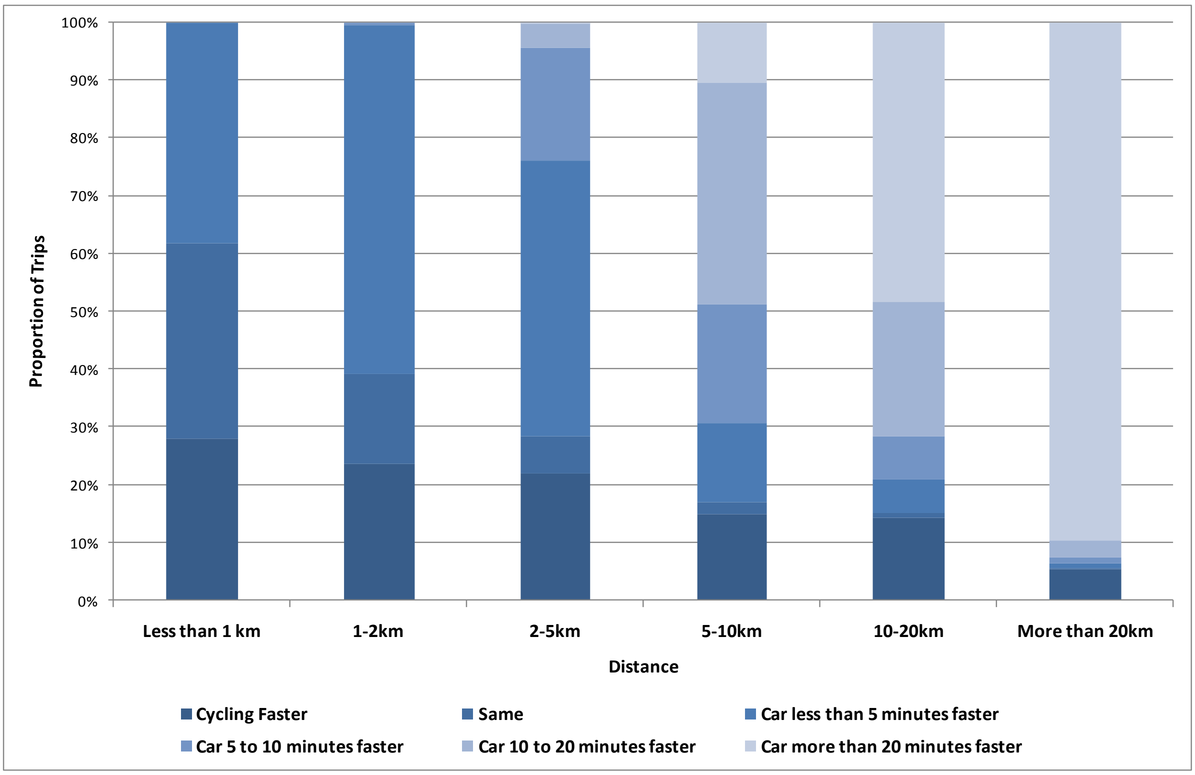
The complexity of trip chains varied significantly with some chains consisting of only two trips and others consisting of more than eight. Cycling was most competitive for trip chains consisting of only two segments (trips), one to the destination and one returning home (Figure 5). For these trip chains, approximately 50 percent of chains could be completed with a total travel time of less than 10 minutes more than the same chain done by car. This decreased for trip chains with a larger number of segments. However, because these trips include only the routes driven by cars, this likely underestimates the competitiveness of cycling for more complex trip chains by ignoring the time taken to walk to and from where the car is parked to the final destination.

Figure 5: Cycling and cars for trip chains by number of segments



Approximately 40 percent of trip chains had a total distance of less than 10 kilometres. Unsurprisingly this is a significantly smaller proportion than for individual trips. However, it appears that for trip chains shorter than 10 kilometres in length, cycling is equally as competitive as for individual trips shorter than 10 kilometres (Figure 6). Despite the correlation between competitiveness and the number of segments, this is an indication that the competitiveness of cycling for trip chains is more dependent on the total distance rather than the complexity. For the shortest trip chains, cycling is even more competitive than for individual trips of the same distance although these comprise a much smaller proportion of trip chains.

Figure 6: Cycling and cars for trip chains by total distance

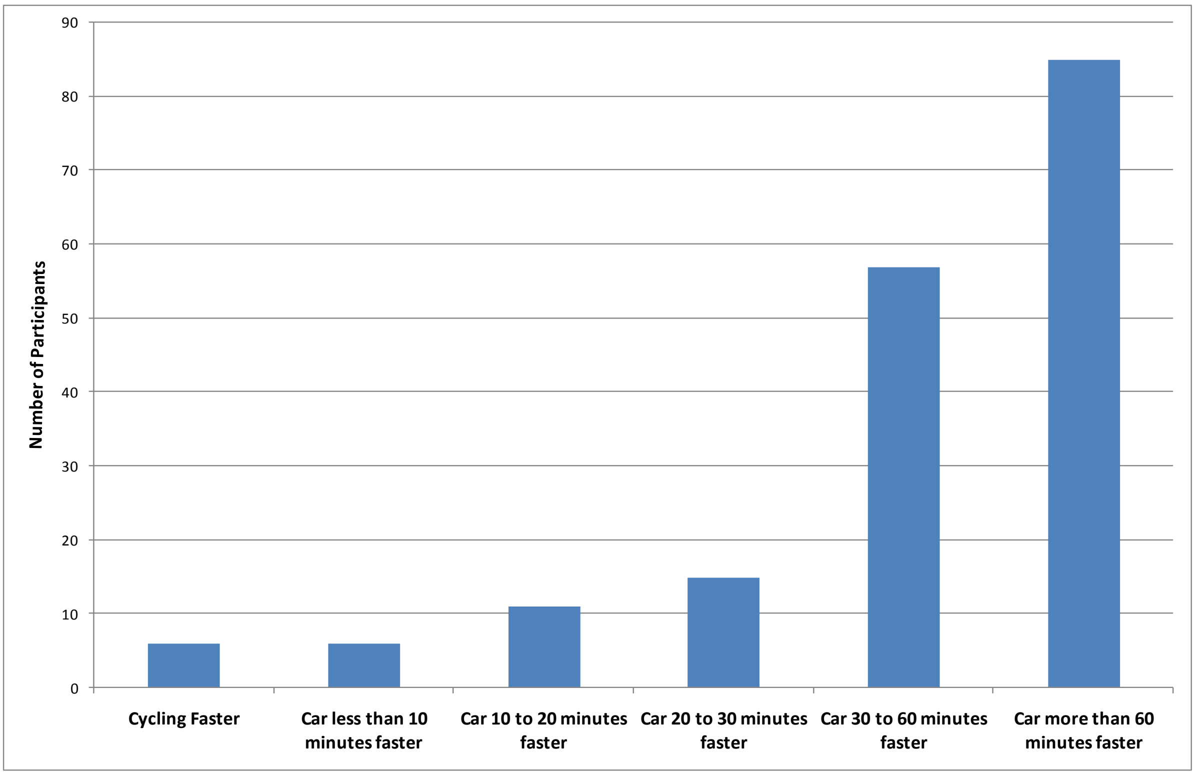


4.3. Travel time budgets

One crucial factor of the overall travel time competitiveness of cycling is the potential for all trips an individual makes in a day to be done within that person's travel time budget. For cycling to be completely substitutable for cars, it must be possible to cycle the required trips but stay within (or as close as possible) to the person's travel time budget. In this analysis, each individuals travel budget was considered to be the average travel time per day for their original trips. For the study participants, the average travel budget was approximately 69 minutes per day which is comparable to the travel budget of 80 minutes reported earlier given this 69 minutes is only the time spent in the car (Transport Data Centre, 2009).

Figure 7 shows the increase in average daily travel time for the participants in the GPS study, if they were to complete all trips by bicycle. The average time which would be required to complete all trips by bicycle would be an average of 133 minutes per day, almost double the original time. The large increase in travel time is largely the result of the uncompetitiveness of cycling for longer distances. Such a large increase would most likely be unacceptable to a large proportion of people for substituting all trips with bicycle. Around ten percent of the sample would see either a decrease in their average daily travel time or an increase of less than 10 minutes if they were to cycle rather than drive. A further 10 percent of participants would see an increase of less than 20 minutes. It is (arguably) this group of people who could be considered most likely to change their primary mode to cycling.

Figure 7: Increase in average daily travel time



5. Discussion and Conclusions

Accepting the many caveats to this analysis, there are several important insights that can be drawn. First, when viewed on an individual trip basis, it does indeed appear that the majority of trips deemed to be of a distance that is 'bikeable' (i.e., up to 5 kilometres) can be made without significant time penalty by bicycle in comparison to a car. Second, while cycling is marginally more competitive during the day (when it is more congested), the impact of congestion does not appear large enough to make up for the lower competitiveness over long distances. Third, cycling is substantially faster than public transport over 'bikeable' trips, with 90 percent of trips under five kilometres being quicker by bicycle than public transport. Fourth, when injecting more reality into the comparison by considering trip chains, it is clear the competitiveness of cycling goes down in comparison to the car with the more legs in the chain. However, it appears the total distance of the chain, may be a more crucial issue, with cycling being equally competitive for trip chains shorter than 10 kilometres as for individual trips shorter than 10 kilometres. Fifth, when considered in the context of the daily travel time budgets for the study participants, the analysis suggests around 20 percent of people could switch totally to cycling without incurring more than a 20 minute additional increase in travel time.

The analysis presented here suggests that based on travel time alone, cycling is a feasible option for replacing a small but significant number of car trips in Sydney. The travel time budget analysis suggests that it is unlikely to replace the car totally for the majority of people, primarily because it is uncompetitive for longer distances. However, the trip chain analysis, suggests it could become a more viable option for making a larger proportion of trips by bicycle. Furthermore, the competitiveness of cycling compared to public transport in Sydney shows that cycling should be considered as an important mode within Sydney's transport system despite the relatively low current levels of cycling compared to other countries. While

Sydney's hilly terrain does reduce the competitiveness of cycling to some extent, this does not appear to be significant (although the specific impact is likely to differ for each person).

The differences in transport systems, congestion and other factors which influences travel time between different cities means that were this study to be replicated in another city, the results could be somewhat different to those of this study. However, two results of this study are likely to be similar in other urban areas. Specifically these are that cycling is largely competitive with cars over short distances and that the travel-time competitiveness of cycling for trip chains is related more to distance than to complexity.

This study has a number of acknowledged limitations when it comes to accessing the overall competitiveness of cycling in Sydney (rather than travel time competitiveness) which offer an opportunity for further research. Specifically, the focus on travel time overlooks other important factors which may reduce the attractiveness of cycling, including the impact of environmental factors (weather primarily), continuing safety concerns and passenger requirements (particularly for the very young and elderly). These issues may mean a trip that is travel time competitive cannot (or is unlikely) to be cycled. A further limitation of this study is that it does not account for the varying levels of cycling experience and equipment among cyclists. The relatively slow base speed of 16 km/h used in this analysis was chosen with this in mind. Were these factors to have been included in the analysis, trips by experienced cyclists and younger age groups are likely to have been more competitive, even for longer distances. In particular, cycling to work is likely substantially more competitive than this analysis suggests. Combined with the recent expansion of bicycle lanes in and around Sydney's Central Business District (CBD) a more detailed study on the competitiveness of cycling to work appears particularly topical. In addition, further research on how cycling can be combined with public transport both as a mode for access to and egress from public transport and as a mode within a multi-modal trip chain could help assess the benefits of the introduction and expansion of bicycle facilities on public transport in Sydney.

Despite the travel time competitiveness of cycling for short distances, a number of obstacles remain before the numbers of trips made by bicycle are likely to increase significantly. These include the continuing problems of safety for cyclists and the long distances of trip chains. Some of these problems can be mitigated through an increase in infrastructure for bicycles while others require a change in travel behaviour which may not be possible in the short-term. However, in the short-term it appears that for many short trips taken to a local shop or to visit friends, cycling could replace the car while a car continues to be used for longer trips. In addition, given that cycling does appear to be travel time competitive for a significant portion of trips, increasing cycling infrastructure may bring significant benefits by increasing the number of cyclists while reducing congestion during peak periods and the number of cars on the road.

References

Bauman, A, Rissel, C, Garrard, J, Ker, I and Speidel, R 2008, "Cycling - Getting Australia Moving: barriers, facilitators and interventions to get more Australians physically active through cycling." Melbourne.

Clement, SJ 2008, “An environmental cost model for travel time differences between bicycles and cars” in Papers of the Thinking on two wheels cycling conferences 2005-2007.

Curtis, C and Headicar, P 1997, "Targeting travel awareness campaigns: Which individuals are more likely to switch from car to other transport for the journey to work?" Transport Policy, vol. 4, no. 1, pp. 57-65.

Dekoster, J and Schollaert, U 1999, “Cycling: the way ahread for towns and cities”, Office for Official Publications of the European Communities, Luxembourg. Retrieved from http://ec.europa.eu/environment/archives/cycling/cycling_en.pdf

Ellison, RB, Fifer, S and Greaves, SP 2010, "A comparison of methods to reclassify trip purpose within trip chains," in 33rd Australasian Transport Research Forum, Canberra.

Garrard, J, Greaves, SP, Ellison, AB 2010, “Cycling injuries in Australia: Road safety’s blind spot?” Journal of the Australasian College of Road Safety, special issue on Cycling Safety.

Geoscience Australia 2003, "3 & 18 Second DEM: Digital Elevation Model of Australia."

Greaves, SP, Fifer, S, Ellison, R and Familar, R 2010, "Development and Implementation of a GPS/Internet-based Design for Longitudinal Before-and-After Travel Behaviour Studies," in 12th World Conference on Transport Research WCTR Conference 2010, Lisbon, Portugal.

Hensher, D and Reyes, A 2000, "Trip chaining as a barrier to the propensity to use public transport." Transportation, vol. 27, no. 4, p. 341–361.

Levinson, D and Wu, Y 2005, "The rational locator reexamined: Are travel times still stable?." Transportation, vol. 32, no. 2, p. 187–202.

Mackett, R 2003, "Why do people use their cars for short trips?." Transportation, vol. 30, no. 3, p. 329–349.

NSW Government 2005, "Sydney Metropolitan Strategy: City of Cities." Handbook of Business Strategy, vol. 5, no. 1, pp. 155-197.

Newman, P 2003, "Sustainability, Urban Design and Transport," in In Search of Sustainability online conference, Canberra, pp. 1-14.

Parkin, J & Rotheram, J 2010, "Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal." Transport Policy, vol. 17, no. 5, pp. 335-341.

Pucher, J and Buehler, R 2008, "Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany." Transport Reviews, vol. 28, no. 4, pp. 495-528.

Pucher, J, Garrard, J and Greaves, S 2010, "Cycling Down Under : A Comparative Analysis of Bicycling Trends and Policies in Sydney and Melbourne." Journal of Transport Geography, vol. 18, pp. 1-46.

Rietveld, P 2000, "Non-motorised modes in transport systems: a multimodal chain perspective for The Netherlands." Transportation Research Part D, vol. 5, p. 31–36.

Schafer, A 2000, "Regularities in travel demand: an international perspective." Journal of transportation and Statistics, vol. 3, no. 3, p. 1–31.

Transport Data Centre 2009, "2007 Household Travel Survey: 2009 Release. Summary Report.” Transport and Infrastructure, Sydney.

Ye, X, Pendyala, R and Gottardi, G 2007, "An exploration of the relationship between mode choice and complexity of trip chaining patterns." Transportation Research Part B, vol. 41, no. 1, p. 96–113.