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Multiple purpose tours and efficient trip chaining
An analysis of the effects of land use and transit on travel behaviour in Switzerland

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MULTIPLE PURPOSE TOURS AND EFFICIENT TRIP CHAINING: AN ANALYSIS
OF THE EFFECTS OF LAND USE AND TRANSIT ON TRAVEL BEHAVIOR IN
SWITZERLAND

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ABSTRACT

Using the 2010 Swiss Microcensus on mobility and transportation, a new approach to characterizing tours is explored. Building on recent work by Ho & Mulley (2013), we elaborate upon their typology of tours, developed based not only on tour complexity, but also on the spatial distribution of destinations within tours. Our adapted typology is then applied to investigate the relationship between land use, tour type and mode use. Our results mirror previous findings that complexity should not be seen as a deterrent to transit use overall, but rather that the distribution of destinations found within a tour must be taken into account if one seeks to better understand complexity and chaining effects on mode use. While much research focuses on land use at the home location, we find that land use at destinations is a much better predictor of chaining trips in such a way as to maximize the likelihood of transit and walking both in simple and complex tours. Finally, a more complete definition is provided for “efficient trip chaining” within tours, allowing one to better understand how low-detour or short trips can be integrated in complex tours, allowing for more sustainable travel choices.

Keywords
Tour complexity, trip chaining, land use, transit, Switzerland
INTRODUCTION

Tour complexity has often been understood to be a deterrent to transit use in the transportation modeling literature (1) (2). Recent work by Ho & Mulley (3) however, investigated this more closely. They provide evidence that complexity alone does not deter use of transit, but that complexity paired with the dispersion of destinations within a tour reduces transit use. The implications from this are many. From a mode choice modeling standpoint, this knowledge allows us to more accurately predict tour main mode. From an urban planning perspective, better understanding what particular land use properties encourage tours with less dispersed destinations in turn allows for better design of the built environment at transit stops and interchanges, and maximizes the potential for efficient chaining, or short, low-detour trips integrated into complex tours. Making use of knowledge of how best to coordinate transit provision with land use would help in maximizing the impact of investment in transit, while also increasing the likelihood of individuals combining transit with health-beneficial walking trips.

To arrive at their conclusions, Ho & Mulley (3) employ a typology of home-based tours, based not only on number of trips within a tour, as is traditionally the case (4), but also distance between trip ends. The typology employed contains: simple tours, with one trip away from home and a return journey, and by association only one trip purpose and destination (referred to in their work as single purpose, single destination tours (SPSD)); complex tours serving multiple purposes at multiple destinations (MPMD); and finally complex tours with multiple purposes at a single destination (MPSD). This last category of tours, MPSD, are complex tours characterized by: i) at least one trip made on foot; ii) following an activity not associated with a change in mode; iii) where the distance separating the trip’s origin and destination is less than 800 meters. The 800 meter cut-off value was defined as to approximate a short, walkable distance, indicating that the trip shares a common or single destination with the previous activity. By characterizing tours based not only on number of trips, but also their dispersion, the authors were able to conclude that MPSD tours are actually more likely to be made by transit, when compared to SPSD and MPMD. Moreover, while one might suspect that such tours are relatively rare, Ho & Mulley (3) find that they make up 20% of complex home-based tours in their work in Sydney – a non-insignificant portion of overall travel.

At the same time, the authors conclude that there are two aspects that deserve further attention to better understand these tours. First, a more thorough investigation of the effects of land use on the propensity to make these MPSD tours. This would be beneficial, as it would allow planners to better locate compatible services and amenities around transit facilities, as well as to understand how best to integrate future facilities in the built environment, increasing the likelihood of transit use while being paired with short walk trips. They also highlight that the endogeneity of mode and tour type needs to be accounted for.

What we seek to achieve within the following paper is to understand the effect of land-use on the likelihood of making MPSD tours. This is done by classifying tours using an approach similar to Ho & Mulley, validating their findings, while also accounting for endogeneity by separating tours by dominant tour mode.

To do this, we make use of the 2010 Swiss Microcensus on mobility and transportation, a national origin-destination survey with over 60,000 respondents and 80,000 tours. We begin by further disaggregating tours to better understand which configurations and distributions of trips increase the likelihood of efficient chaining in complex tours, as well as to better understand the role of short, simple tours in travel.
Where Ho & Mulley (3) built tour-based mode choice models to test their hypothesis of a link between trip-end proximity within complex tours and mode choice, we instead build a series of tour choice models as a function of socio-demographics, travel behavior and land-use characteristics. The primary objective of the analysis was to test the hypothesis that land use would play a considerable role in determining tour type, even after accounting for tour main mode, purpose and demographic factors.

The following will begin with a brief discussion of the tour complexity and mode use debate, as well as the benefits of planning for increased transit and walking mode use, after which the data will be described, methods of analysis explained and results presented and discussed. The paper will end with a conclusion summarizing key findings, and present ideas for future work.

LITERATURE REVIEW

As was mentioned above, there is currently debate over the direction of causality when it comes to tour complexity on mode choice (5). Some authors contend that more complex tours lead to a reduction in the use of transit (1), while others believe the opposite to be true (6) (4). Another perspective is that tour purpose determines the order in which mode and tour type decisions are made (7), while a final approach is to declare “that there is no natural sequence of component choices which lead to the travel pattern choice”, but rather that decisions regarding the number of trips, “tours, and the set of destinations to be visited, are interdependent and are compared jointly as travel pattern alternatives” (8 p. 248).

Irrespective of the direction of causality, it is clear that mode use and complexity are related however, as “much of the travel that is not home-based is constrained by modal decisions taken at the start of each tour” (9 p. 12). This is why chaining and tour type are so important, given that chains made in settings which increase the utility for non-drivers can potentially provide similar levels of accessibility without the need for a private automobile (4).

Addressing the question of these settings where the utility of non-drivers can be increased, we turn to the question of land use and its effect on tour complexity. This topic is less often explored (10), as the land use and travel demand linkages literature typically focuses on the effects of land use on VMT, mode choice (11) and trip generation (12). While Gouliaas and Kitamura for example refer to the spatial distribution of trips as a factor explaining chaining, their work incorporates neither distances between trip ends, nor land use at trip destinations as an explanatory variable (13). Where the relationship has been explored, land use is typically included as a variable measured at the home and/or work anchor (14) (10) (15), not at the various destinations found within a tour. Adler and Ben-Akiva is an exception to this, wherein the authors built a multinomial logit model of travel patterns, predicting the “number and characteristics of destinations chosen for non-work activities, the modes used to travel to those destinations, and … the number of tours used to travel to the set of destinations” jointly (8 p. 248). Treating destinations as a bundle however, the properties of all destinations are also lumped together and so it is not possible to interpret individual variables’ effects on chaining.

Finally, there is also a bias in the literature with respect to a focus on commuting tours (16), which is problematic as many have highlighted that these tours represent a shrinking share of overall travel (15) (2) (1).

To summarize, research has looked at the effect of land use on complexity of tours and chaining, but this work has either treated tours as a binary (simple or complex) or has looked at these effects using only land use properties at the home or anchor locations. Proximity between trips has also only recently begun to be explored within the tour choice literature (3).
A better understanding of individuals’ trip chaining behavior, the process whereby trips are coordinated and carried out within complex tours, would allow planners to design environments that provide residents access to the services and amenities they desire while minimizing their expenditure on mobility tools and travel time.

STUDY AREA AND DATA SOURCES

The 2010 Swiss population was approximately 7.9 million people. The country has a well-developed road network, as well as high levels of public transit and inter-city rail services. 9.8% of individuals in Switzerland have a General Abonnement (GA) pass, which gives them access to any inter or intra-city public transportation (17), while 56.5% of people have some form of transit pass, be it a local (13.7%) or a half-fare card (38.5%) (18). In 2010, Switzerland also had a gross national income considerably above its high income OECD peers, while having a per capita CO2 footprint approximately half that of its peers (19). The high rate of transit adoption combined with high incomes and low emissions would tend to indicate that its residents are choice transit users (as opposed to captive) and that as a result, lessons can be learned there that would apply in other locales seeking to increase their share of sustainable transportation use among such choice riders.

To understand the effect of the built environment on MPSD tours, we made use of 2010 Swiss Microcensus, which contains detailed information on 62,868 persons living in 59,971 households. The Microcensus contains detailed demographic and geocoded travel data.

Land use and transit data came from a variety of sources. The Bureau Fédéral de la Statistique’s (BFS) population and employment counts, from 2011 and 2008 respectively, were used to generate densities; these data were available at the hectare level for the entire study region. Land use data was also obtained from the BFS (hectare level again). The original coding for land use was very detailed, having 46 different categories. These were subsequently aggregated into functional types, namely residential, public buildings, commercial and industrial, and recreational spaces. Finally, to evaluate public transit accessibility, we used the geocoded stop locations for all forms of transit found in the HAFAS database (HACON (20)).

METHODS

As we wished to look at the relationships between land use, tour complexity and mode use, it was necessary to operationalize each component, which is described next. Afterwards, to investigate trip chaining and tour complexity - and in particular efficient chaining, or short, walked trips included within home-based complex tours- it was necessary to define what trip types constituted efficient chaining, and how we would further disaggregate simple and complex tours to better understand them.

Finally, as we use a series of logit models to predict the probability of a tour being MPSD using land use, modes of transportation and control variables, this approach and its components will also be described.

Indicator generation

In order to avoid the modifiable area unit problem (21), we chose to capture land use indicator values using a regular grid. This grid was clipped to the extent of land cover in Switzerland to better account for incomplete cells, either near the borders of the country or bodies of water; clipping allowed us to evaluate net as opposed to gross densities. The size of cells was chosen to be 500 by 500 meters, so as to approximate a 5 minute walk time across a cell, similar to what was done in (22).
Hectare population and employment counts were aggregated accordingly. In the case of employment, we used full-time equivalent jobs. Values for density in the rest of the report are expressed in persons or jobs, per hectare. For public transit accessibility, stop locations were obtained for all modes via HAFAS (20) and intersected with the grid cells to generate transit stop densities (hereafter expressed in transit stops per hectare).

We used the aggregated BFS land use classification described above to calculate land use mix. Entropy was calculated to the category-aggregated values to describe land use mix at the cell level (Values range from 0 to 1, where 0 indicates no mix and 1 indicates perfect mix, all 4 uses present in equal amounts). Finally, the Euclidian distances separating home locations from the ten largest city cores were calculated.

These indicators are commonly employed in transportation and land use research (11).

Clustering

To test the effect of both individual built environment indicators and neighbourhood types on travel behaviour, we chose to use cluster analysis. Population, employment and transit stop density, as well as land use mix were used as inputs, as elsewhere (23).

K-means cluster analysis was employed to categorize cells into neighbourhood types. The 4 indicators were standardized to avoid differences in magnitude affecting the clustering (24) and clusters were identified for all cells which had at least one non-null value. Different numbers of clusters were iteratively generated, from 2 to 10, after which Calinski-Harabasz values were used to find an optimal number - optimal in the sense of maximizing inter-cluster variability while minimizing intra-cluster variability (25). This resulted in the choice of four clusters, which for the rest of the report are numbered from 1 (combination of low density, low mix and poor transit access) to 4 (most urban, highest land use mix, transit access and densities).

Efficient travel typology

As was described above, Ho & Mulley (3) disaggregated complex tours into MPSD and MPMD to better understand the effect of dispersion on mode choice. Since there are many different ways in which short, walkable trips can be incorporated into a tour however, as well as other tour configurations that might lead to low-detour trips being made without spatial proximity between destinations, we began our investigation by drawing up a typology for efficiently chained trips within complex tours.

In this paper we apply the concept of home-based tours (tours begin when a person leaves the home and end when the person returns (26)), with three broad levels of complexity we later disaggregate. First, if a tour is comprised of only one trip where both the origin and destination are the home location, this is characterized as a stroll. Next, if an individual travels to a non-home location by one or more modes of transportation, and then returns home without engaging in another activity or trip purpose (ex: going to and from work), then this is a simple tour. Finally, any home-based tour with 2 or more intervening activities (ex: work and shopping or school, recreation and leisure, but not change of modes) is a complex tour.
In Figure 1, efficient chaining types 1-3 are shown to include short, walkable trips (indicated using thick orange arrows) integrated into complex tours. While efficient chaining is not a term Ho & Mulley use when describing their MPSD tours, our desire to better understand where a short walkable trip occurred within a complex tour led us to devise a typology and associate these short, low-detour trips with the term efficient chaining. As Ho & Mulley use the cut-off value of 800 meters from one trip end to the next to identify trips that define MPSD tours, we apply the same to obtain comparable results.

Type 1 shows a tour comprised of a trip from home to work, from work to a maintenance destination, followed by a trip home. The trip from the maintenance destination to home is less than 800 meters, and as such, one can say the tour contains trips characterized as efficiently chained – the order of the trips, as long as one of them is within 800 meters of another is unimportant. Type 2 is a short (<800 meter) trip made before or after the main purpose of a tour: here shown as a maintenance trip following an education trip, but again, the order is not important. The trip to a maintenance purpose would be the efficiently chained component of the complex tour. Finally, type 3 is a tour wherein one short trip connects a secondary purpose trip to another secondary purpose trip (discretionary and maintenance trips in close proximity in the figure above, while the main purpose, work, is not proximate to another destination). The maintenance trip would be the efficiently chained component of that tour.

Efficient chaining of types 4 and 5 is described here, but not included in later modeling. Type 4 is useful if trying to understand efficient chaining potential for active transportation, and what is shown is a trip being made more than 800 meters from either the home or work anchors (hypothetical case of which many variants are possible), where the detour required to make this maintenance trip is small. In this example, an individual could be considered to have efficiently chained trips along his or her route, as there is little to no detour involved. Type 5, finally, is the case whereby an individual makes an additional trip on the way to or from the main purpose of a tour, but makes this trip at a transit transfer point, such that the detour required is minimal.

While we believe types 4 and 5 worthy of further research, we chose to focus here on the MPSD tours comparable to those described by Ho & Mulley.
Disaggregate tour typology

A home-based tour approach was used, with tours first categorized as either strolls (both the origin and destination of the sole trip in the tour is the home), simple tours (one trip to a non-home destination and one trip back) or complex tours. If the tour was simple and the destination was within 800 meters of the home, the tour was categorized as SPSD-short (single purpose, single destination, short). If the simple tour’s destination was more than 800 meters from the home, SPSD-long. For complex tours, we looked for instances of efficient chaining as defined in Figure 1 and separated MPMD (multiple purpose multiple destination) tours from those containing an efficiently chained trip – MPSD tours of types 1 through 3.

In applying the efficient chaining typology to the trips and tours found in the Micro-census, we harmonized our categorization of trip purposes with Ho & Mulley, as well as used their hierarchy of purposes to obtain the same main purpose classification; this hierarchy had work at the top, followed by education, maintenance and finally discretionary trips.

A tour containing a short pedestrian trip (<800m) where the origin or destination is the home end, we defined as an MPSD-HomeEfficient (type 1 efficient chaining from Figure 1). A tour containing a short pedestrian trip with home at neither of its ends, but the main purpose as one of them was simply MPSD (type 2). Finally, if the short walked trip was connected to neither the home nor main purpose location, then the tour was MPSD-complex (type 3 in Figure 1). Since tours can contain multiple short walked segments, the hierarchy we employed was to classify first MPSD-HomeEfficient, then MPSD and finally MPSD-complex. This is not the same approach as Ho & Mulley, who applied the term MPSD for all tours containing a short, walked trip.

While our 3 types of MPSD tours are aggregated in the logit modeling, figures and summary statistics that follow, initially separating the 3 allowed us to capture the destination land use properties at these efficient trip chaining locations, in addition to home and tour main purpose land use, and use these as modeling inputs when predicting MPSD tours. This resulted in 1,307 MPSD-HomeEfficient, 4,191 MPSD and 1,562 MPSD-complex tours. In other words, 22% of people who integrate efficiently chained trips to their tours do so close to home, almost 60% chain activities near the main purpose destination, and 19.5% chain trips away from both the home and tour main purpose. Complex tours that contained no short pedestrian trips were identified as MPMD and account for just over two thirds of all complex tours.

Of 82,506 tours, 10,813 were strolls, 11,943 SPSD-short, 38,030 SPSD-long, 7,060 MPSD and 14,660 MPMD. While SPSD-long tours make up nearly half of all tours, a third of all complex tours contain an efficiently chained pedestrian trip component - a non-insignificant portion of overall travel in Switzerland.

The same hierarchy as Ho & Mulley was applied for mode, with the distinction that cycling and walking were differentiated to better understand their respective relationship to tour types. The hierarchy defined is based on the freedom it later affords individuals using a given type of mode (26): Train, Tram/Bus, Car, Motorbike/Moped, Bike, Foot.
Increasing the amount of MPSD tours and reducing MPMD tours, as we can see in Figure 2 above, would have beneficial effects with respect to both higher transit and walking mode use. The numbers below the column chart represent the share of each tour type made using either main mode walk, PT (public transit, either train, tram or bus), Car (including truck, motorbike, moped and scooter) or bike. When discussing a difference between 2.4 and 29.8% pedestrian mode share, or more than a doubling of transit use when converting MPMD complex tours to MPSD tours, the benefits are clear.

**Modeling**

In order to test whether land use has an effect on the likelihood of making MPSD tours, we built a series of logit models with MPSD tour-making as the dependent variable. Strolls were excluded from our model estimations, as these are tours for which travel is a not a derived demand. In addition, since our desire was to better understand everyday travel, we removed individuals who traveled by intercity modes such as plane, coach (bus), car-postal, and ship (1,276 of 210,048 trips flagged). Train trips were not excluded however because of the way the train network is integrated to everyday travel in Switzerland as result of fare integration, with the GA and other combined train/transit passes.
Since we wished to explore not only the overall effect transit or car use might have on
the propensity to make a MPSD tour, but also the varied effects explanatory variables such as
land use or travel mode might have on tours undertaken for different main purposes (work,
education, maintenance), we built main purpose-specific models where mode would be
employed as an explanatory variable, as well as main mode-specific models where we would,
instead of measuring the effect of mode on MPSD tour making, account for mode. This
approach allowed us to apply a simple logit formulation to test whether the explanatory
variables differed significantly in their estimated effect on the likelihood of MPSD tour making
both in the context of specific tour main modes and tour main purposes.

Finally, in addition to the local land use variables described above, we included
distance from nearest core city, as well as a binary variable for inner-urban area to avoid bias
related to correlation between levels of urbanity and distance from the core.

RESULTS AND DISCUSSION
### TABLE 1 Estimate results

Note: “Destination” means the tour main purpose location if there was no efficient trip component, else the location where the highest hierarchy efficient trip took place: home, work anchor, education anchor, and finally not an anchor but in order of purpose hierarchy.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TMP, Work</th>
<th>TMP, Education</th>
<th>TMP, Maintenance</th>
<th>All Purposes</th>
<th>Main mode, Transit</th>
<th>Main mode, Motorized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coeff</td>
<td>p val</td>
<td>e^β</td>
<td>coeff</td>
<td>p val</td>
<td>e^β</td>
</tr>
<tr>
<td>Home cluster 1</td>
<td>0.342</td>
<td>0.00</td>
<td>1.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home cluster 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home cluster 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home pop dens (p/ha)</td>
<td>-0.002</td>
<td>0.08</td>
<td>1.00</td>
<td>-0.004</td>
<td>0.01</td>
<td>1.00</td>
</tr>
<tr>
<td>Home PtDens</td>
<td>0.090</td>
<td>0.01</td>
<td>1.09</td>
<td>0.094</td>
<td>0.03</td>
<td>1.10</td>
</tr>
<tr>
<td>Home Land Use mix (0-1)</td>
<td>-0.444</td>
<td>0.03</td>
<td>0.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dist nearest large city (km)</td>
<td>0.005</td>
<td>0.02</td>
<td>1.00</td>
<td>0.004</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Within 8km core city</td>
<td>-0.097</td>
<td>0.08</td>
<td>0.91</td>
<td>-0.094</td>
<td>0.05</td>
<td>0.91</td>
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<tr>
<td>Destination Cluster 2</td>
<td>0.233</td>
<td>0.08</td>
<td>1.26</td>
<td>0.593</td>
<td>0.02</td>
<td>1.81</td>
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<tr>
<td>Destination Cluster 3</td>
<td>0.273</td>
<td>0.10</td>
<td>1.31</td>
<td>0.558</td>
<td>0.05</td>
<td>1.75</td>
</tr>
<tr>
<td>Destination Cluster 4</td>
<td>0.606</td>
<td>0.00</td>
<td>1.83</td>
<td>0.629</td>
<td>0.08</td>
<td>1.88</td>
</tr>
<tr>
<td>Destination Popdens (p/ha)</td>
<td>0.022</td>
<td>0.03</td>
<td>1.00</td>
<td>0.002</td>
<td>0.06</td>
<td>1.00</td>
</tr>
<tr>
<td>Destination Jobdens (j/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination Ptdens</td>
<td>0.239</td>
<td>0.00</td>
<td>1.27</td>
<td>0.148</td>
<td>0.05</td>
<td>1.16</td>
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<tr>
<td>Dest. Land Use mix (0-1)</td>
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<td>1.15</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Dist from main purp (km)</td>
<td>-0.004</td>
<td>0.03</td>
<td>1.00</td>
<td>-0.005</td>
<td>0.05</td>
<td>0.99</td>
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<tr>
<td>Work trip included</td>
<td>0.683</td>
<td>0.03</td>
<td>1.98</td>
<td>0.986</td>
<td>0.00</td>
<td>2.68</td>
</tr>
<tr>
<td>Edu travel included</td>
<td>0.623</td>
<td>0.00</td>
<td>1.87</td>
<td>0.468</td>
<td>0.05</td>
<td>1.60</td>
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<tr>
<td>Maint trip included</td>
<td>1.539</td>
<td>0.00</td>
<td>4.66</td>
<td>1.413</td>
<td>0.00</td>
<td>4.11</td>
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<tr>
<td>Discr trip included</td>
<td>1.298</td>
<td>0.00</td>
<td>3.66</td>
<td>1.328</td>
<td>0.00</td>
<td>3.78</td>
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<tr>
<td>Male</td>
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<td>0.00</td>
<td>0.74</td>
<td>-0.139</td>
<td>0.03</td>
<td>0.87</td>
</tr>
<tr>
<td>Aged 26-65</td>
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<td>0.05</td>
<td>0.91</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Aged 16-20</td>
<td>0.240</td>
<td>0.00</td>
<td>1.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student (&lt; 16 years old)</td>
<td>-0.541</td>
<td>0.00</td>
<td>0.58</td>
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<tr>
<td>Under 16</td>
<td>0.256</td>
<td>0.02</td>
<td>1.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single person</td>
<td>0.278</td>
<td>0.00</td>
<td>1.32</td>
<td>0.258</td>
<td>0.00</td>
<td>1.29</td>
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<tr>
<td>Nuclear family</td>
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<td>0.00</td>
<td>0.72</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Single parent</td>
<td>0.209</td>
<td>0.03</td>
<td>1.23</td>
<td>0.211</td>
<td>0.04</td>
<td>1.24</td>
</tr>
<tr>
<td>Low Income (&lt;24K CHF)</td>
<td>-0.163</td>
<td>0.09</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid Income (24-72K CHF)</td>
<td>-0.162</td>
<td>0.00</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Income (&gt;72K CHF)</td>
<td>0.142</td>
<td>0.03</td>
<td>1.15</td>
<td>0.182</td>
<td>0.00</td>
<td>1.20</td>
</tr>
<tr>
<td>University Ed.</td>
<td>0.128</td>
<td>0.03</td>
<td>1.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Time employed</td>
<td>-0.197</td>
<td>0.00</td>
<td>0.82</td>
<td>0.276</td>
<td>0.10</td>
<td>1.32</td>
</tr>
<tr>
<td>No parking at work</td>
<td>0.275</td>
<td>0.00</td>
<td>1.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit pass</td>
<td>0.152</td>
<td>0.01</td>
<td>1.16</td>
<td>0.186</td>
<td>0.03</td>
<td>1.20</td>
</tr>
<tr>
<td>Motorbike available</td>
<td>-0.191</td>
<td>0.03</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car available</td>
<td>-0.116</td>
<td>0.01</td>
<td>0.89</td>
<td>-0.242</td>
<td>0.03</td>
<td>0.78</td>
</tr>
<tr>
<td>Driv. License</td>
<td>-0.507</td>
<td>0.00</td>
<td>0.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible Sched</td>
<td>-0.681</td>
<td>0.05</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint car trip</td>
<td>0.480</td>
<td>0.00</td>
<td>1.62</td>
<td>-0.272</td>
<td>0.04</td>
<td>0.76</td>
</tr>
<tr>
<td>Carry goods</td>
<td>0.339</td>
<td>0.02</td>
<td>1.40</td>
<td>0.268</td>
<td>0.04</td>
<td>1.31</td>
</tr>
<tr>
<td>Number of tours</td>
<td>-0.627</td>
<td>0.00</td>
<td>0.53</td>
<td>-0.389</td>
<td>0.00</td>
<td>0.68</td>
</tr>
<tr>
<td>Tour incl transit</td>
<td>0.810</td>
<td>0.00</td>
<td>2.25</td>
<td>0.749</td>
<td>0.00</td>
<td>2.12</td>
</tr>
<tr>
<td>Tour incl car/motorbike</td>
<td>-0.361</td>
<td>0.00</td>
<td>0.70</td>
<td>-1.028</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Weekday</td>
<td>0.440</td>
<td>0.00</td>
<td>1.55</td>
<td>0.756</td>
<td>0.01</td>
<td>2.13</td>
</tr>
<tr>
<td>Saturday</td>
<td>0.246</td>
<td>0.08</td>
<td>1.28</td>
<td>0.372</td>
<td>0.02</td>
<td>1.45</td>
</tr>
<tr>
<td>Pseudo R2 / Obs.</td>
<td>0.24</td>
<td>0.19, 644</td>
<td>0.18, 6,334</td>
<td>0.15, 23,576</td>
<td>0.18, 70,272</td>
<td>0.19, 10,989</td>
</tr>
</tbody>
</table>

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Original paper submittal - not revised by author.
The first three models presented in Table 1 are estimated using tours made for a specific main purpose, while the last three include all purposes (other than stroll) with all modes, only transit main mode, and finally only motorized main mode. Coefficient estimates can thus be compared across tour main purpose types, with transit and other modes used included as explanatory variables in the first four to look at the effect they have on the likelihood of MPSD tours being made.

We will now describe specific effects highlighted by coefficient estimates related to our main research question: the influence of land use on efficiently chained trip making within complex tours, or MPSD tours. The question of magnitude is also addressed in the table through presentation of odds ratios \(e^{\beta}\), which represent the effect of a one unit increase in the independent variable on the pre-existing odds of making a MPSD tour.

To begin, higher densities, land use mix and transit access at destinations are all found to increase MPSD tour making, even after controlling for purpose and modes used. What is more, there is a build-on effect in having not only higher densities or land use mix in an area, but in combining these properties; i.e. while all statistically significant destination land use coefficient estimates are positive, destination clusters also have positive and significant coefficients, indicating that destinations where combinations of high densities, mix and transit access are found further increase likelihood of MPSD tours being made, individual variables controlled for. Magnitude of destination cluster effects generally increase from less dense (cluster 2) through more dense and urban (clusters 3 and 4) clusters. Specifically, for destination cluster 4, these odds ratios range from a 56% increase to the pre-existing odds in the context of maintenance main purpose tours, to a 187% increase in the pre-existing odds of MPSD tour-making for all-purpose motorized (car, truck, motorcycle) tours.

Worth mentioning, while statistically significant parameter estimates for individual destination land use variables, as well as clusters, are all positive, the parameter estimates are larger in magnitude in the motorized main mode model than the transit main mode model, with a larger negative constant. This makes sense as transit users are by definition more inclined to MPSD for complex tours given the constraints built in to the use of transit (no on-demand vehicle availability), echoed in the positive coefficient estimates found for transit included in tour in the purpose-specific and all purposes models. This means that by comparison, car users are more sensitive to land use at destinations. This matches findings by Manaugh and El-Geneidy, that “households with more mobility choices are more sensitive to their surroundings than those with less choice” (27 p. 309).

The effect of land use is also investigated simultaneously, both at the home and at main/efficiently-chained destinations. While home land use is often the input in research seeking to understand the effect of urban living or TOD on travel behaviour, here we employ it as a control variable, while the land use effect we seek to isolate is the effect of land use at the efficiently chained or main purpose destination location.
When looking at the summary statistics, we find that while more urban cluster residents are more likely to make MPSD tours, they are also much more likely to make SPSD-short tours than other cluster residents (from cluster 1 to 4, 13.0%, 15.7%, 18.1% and 23.5% - Figure 3 on the right). This explains the negative coefficient home clusters have when predicting MPSD tours. For home cluster 4 in particular however, residents’ increase in multiple short trips during the course of the day to access nearby amenities, or SPSD tour making, does not seem to take anything away from the increase in MPSD tours. This mirrors findings by Maat and Timmermans that compact urban designs encourage both shorter trips and complexity, as well as Krizek, who found “that households with higher levels of (neighborhood accessibility) leave home more often and make (…) more simple tours” (15 p. 388). As such, unlike home clusters 2 and 3, there is no negative coefficient estimate for home cluster 4 in the model. Cluster 4 residents are also exposed to more urban-type environments as a result of where they live, leading to a sort of spatial autocorrelation that also explains estimates; while home and destination clusters have some level of correlation across the dataset, it is with cluster 4 home and destinations cluster that this is the strongest at 0.39.

Coefficient estimates for home urban type are also generally smaller in magnitude than those for destination cluster type, indicating that, for example, if a cluster 3 resident made a tour where the main purpose was also in a cluster 3 location, the net effect would be an increase in the likelihood of a MPSD tour being made. Including both types is crucial to isolate the respective effects of both home and destination properties.

This would indicate that individuals most likely to make MPSD tours are those living in lower cluster areas traveling to higher cluster areas, which makes sense given that alternatives for short walking trips are already so much greater for high cluster residents. By association, this means sustainable travel can be made through efficient chains by individuals living in lower density areas and away from the core, as long as transit service provides access to high density, mix and transit accessible areas.

With respect to the effect of additional trip purposes satisfied during the course of the day (not necessarily the same tour), we included the variables Work trip included, Education trip included, etc. These were meant to capture the effect that certain types of complementary

---

**FIGURE 3** Distribution of tour type by Destination and Home clusters (columns add to 100%).

<table>
<thead>
<tr>
<th></th>
<th>DestClus 1</th>
<th>DestClus 2</th>
<th>DestClus 3</th>
<th>DestClus 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPSD</td>
<td>17.54%</td>
<td>20.52%</td>
<td>21.10%</td>
<td>20.68%</td>
</tr>
<tr>
<td>MPSD-D</td>
<td>2.95%</td>
<td>5.84%</td>
<td>10.84%</td>
<td>21.98%</td>
</tr>
<tr>
<td>SPSD-I</td>
<td>63.06%</td>
<td>54.47%</td>
<td>51.42%</td>
<td>46.00%</td>
</tr>
<tr>
<td>SPSD-s</td>
<td>16.45%</td>
<td>19.17%</td>
<td>16.64%</td>
<td>11.34%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>HomeClus 1</th>
<th>HomeClus 2</th>
<th>HomeClus 3</th>
<th>HomeClus 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPSD</td>
<td>23.0%</td>
<td>21.3%</td>
<td>19.5%</td>
<td>15.3%</td>
</tr>
<tr>
<td>MPSD-D</td>
<td>6.8%</td>
<td>8.0%</td>
<td>11.6%</td>
<td>18.8%</td>
</tr>
<tr>
<td>SPSD-I</td>
<td>57.3%</td>
<td>55.1%</td>
<td>50.9%</td>
<td>42.4%</td>
</tr>
<tr>
<td>SPSD-s</td>
<td>13.0%</td>
<td>15.7%</td>
<td>18.1%</td>
<td>23.5%</td>
</tr>
</tbody>
</table>

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trip necessities might have on an individuals' likelihood of making a MPSD tour without spec-
ingifying that a given tour contained both a work and maintenance trip for example. Instead what
we quantify is the effect of making a, for example, maintenance trip at some point during the
survey day, on the likelihood of MPSD tour making.

Results indicate that the trips most likely to increase the likelihood of MPSD are
maintenance, followed by discretionary, work and education trips; while 42% of all tours con-
tain a maintenance component, this increases to 73.8% in MPSD tours. These are activities
such as shopping, errands and services, and serve-passerger trips.

The fact that including distance from centers in the model does not affect cluster coef-
ficients’ significance in any meaningful way is also interesting in contrast to previous research,
which found that inclusion of distance from the center of cities greatly reduces estimated ef-
facts for local land use properties (28). While the distance parameter estimate is statistically
significant, its effect size is negligible. The only locational variable which is truly significant
is inner-metro, which we interpret in a similar way as high urbanity home cluster coefficients,
in that living within the first 5 miles of a city core increases the likelihood of SPSD-short tour
making most, ceteris paribus, because of proximity to a variety of amenities; while high ur-
banity, cluster 4 households only account for 6.3% of all tours, they account for 9.2% of all
SPSD-short tours. Related to this trade-off between MPSD and SPSD-short tours, the like-
lihood of MPSD tours decreases as number of tours increases. This speaks both to the land use
and time budget aspects of tour making, where the potential for short single purpose trips re-
duce the utility of trip chaining.

Car and motorbike access and license holding, as expected, reduce the likelihood of
MPSD tours, while transit passes and use increase their likelihood. This validates findings by
Ho & Mulley (3), in that transit use is not found to be a deterrent to complex tours, but rather
the opposite in situations where land use is conducive to trip chaining.

As for other control variables, singles are those most likely to engage in MPSD tours.
This speaks to the flexibility they have in scheduling activities, as well as an increased propen-
sity to make social and recreational trips (4). Single parents on the other hand also have high
MPSD values, but for different reasons; they likely need to more efficiently chain their trips to
save time, given the constraint of balancing responsibilities both at home and elsewhere. Hav-
ing a flexible work schedule, significant only among students, we believe must be looked at in
conjunction with part time employed, which has a similar magnitude, but opposite sign. By
definition, an individual making an education trip who is either part-time employed or has a
flexible work schedule is balancing school and work. Thus, the large coefficient estimates must
be interpreted with caution. Taken together, they indicate that being employed while also being
a student increases the likelihood of efficient chaining (as a result of additional time con-
straints), whereas having a flexible schedule decreases MPSD as it is not necessary to chain
trips as much given the flexibility of not having a 9 to 5 schedule.

The two instances where high income has a positive influence on MPSD might speak
to the possibility of spontaneous trip making and spending more disposable income. Males on
the other hand appear to be less likely to make MPSD tours, which again corresponds to the
broader literature wherein males are less likely to take transit than their female counterparts,
while also being typically responsible for less of the out-of-home household-related chores and
activities, such as shopping and serve-passenger trips (6).

Carrying goods (light case, suitcase, etc.), contrary to what is typically argued (15), is
not a deterrent to MPSD trip making, while weekday travel, and to a lesser extent Saturdays,
have a positive effect on MPSD tour-making. Sunday, the omitted category, reduces the like-
lihood of efficient trip chaining in complex tours.

One clear policy recommendation that could be made given the finding that No parking
at work site increases MPSD, would be to encourage employers to replace parking provision
with transit subsidies. As for bad weather, only once does this variable reduce chaining potential. A larger effect would have been expected given that MPSD tours are related to walking, but it appears either the legs are so short that weather does not affect them much, or that poor weather might affect trip generation directly as opposed to chaining.

Finally, as was found in previous work looking at non-home based trips with the same dataset (29), the locations where short trips were made, but not made on foot were considerably less dense, less mixed and less transit accessible. 2,854 MPMD tours contain short trips, but where the average employment density is 20 jobs/ha for these MPMD tour main purpose destinations, it is 55 for MPSD. Transit access is also almost halved and land use mix has an average of 35% in these MPMD tours compared to 44% in MPSD tours. Even when short trips are actually made, land use can be seen to greatly affect the likelihood of choosing to walk.

**CONCLUSION**

To conclude, building on Ho & Mulley’s work, a new typology of efficient trip chaining was defined and used to investigate the effect of land use on tour type, accounting for mode use. MPSD tours are found to be highly related to destination land use, with high density, mix and transit accessible locations more likely to result in efficient trip chaining. Also, SPSD-short tours are found to be an important part of sustainable travel, especially for urban type residents; both these tour types have higher combined transit and walk mode shares.

Modeling subsets by tour main purpose and mode were both found to affect the significant variables and model fit, with *work* and *education* tours having the best fit. These tours are routinely made, contain anchors, and thus their behavior is more predictable. Mode-specific models also confirmed findings by others that access to a greater variety of mobility tools makes individuals more likely to respond to differences in land use (27), as their options are less constrained at the outset.

Overall, results indicate land use can be used to encourage more sustainable travel, with awareness that different types of such travel are possible; short SPSD tours near the home location, as well as efficiently chained MPSD tours at transit and other nodes. Thinking holistically about land use, as opposed to variables in isolation, was also shown to be a more useful means of assessing potential land use and travel demand linkages.

Altogether, this would indicate that a great importance should be placed on the coordination between land use and transit. While high densities and land use mix at the home location lead to a higher prevalence of short SPSD tours (overwhelmingly made on foot), proper coordination of land use and transit provision can make complex tours sustainable also, by allowing individuals to more efficiently chain their trips. Lastly, home land use was found to be less significant than destination land use in predicting MPSD tours, a finding with considerable implications for offering viable alternatives to the automobile and providing equitable access to resources and amenities.

It would appear it is not necessarily complexity that determines mode choice, but rather the potential to feasibly chain trips that does; a potential determined in large part through land use.

Future work could build upon the ideas developed here and investigate the last two types of efficient chaining described in Figure 1. Better understanding how these low-detour and short trips can be encouraged would have benefits both in designing better environments around transit, as well as understanding what properties of a path make efficient chaining possible for active transportation users.
REFERENCES


20. HACON. (2012). HAFAS.


http://smartgrowth.umd.edu/internallyconnectedportland.html


